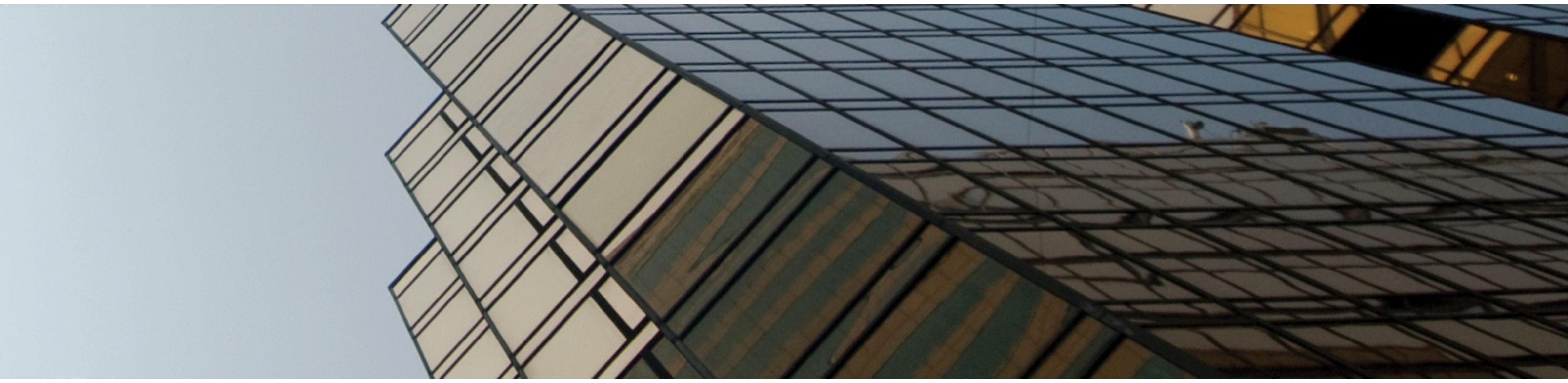

STUDY REPORT SR 277/3 [ 2012 ]

# BEES INTERIM REPORT

## Building Energy End-Use Study – Year 5

# ENERGY USE OUTLIERS

Rob Bishop and Nigel Isaacs

Funded by BRANZ from the Building Research Levy

Ministry of Business, Innovation & Employment

Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao



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# BEES (BUILDING ENERGY END-USE STUDY) YEAR 5: ENERGY USE OUTLIERS

## BRANZ Study Report SR 277/3

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## Reference

Bishop, R., and Isaacs, N. (2012). Building Energy End-Use Study (BEES) Year 5 Interim Report: Energy Use Outliers, BRANZ Study Report 277/3, Judgeford.

energy solutions

## Reviewers

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# PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. More efficient buildings will help reduce greenhouse gas emissions and enhance business competitiveness. The Building Energy End-use Study (BEES) is taking the first step towards this by establishing where and how energy and water resources are used in non-residential buildings and what factors drive the use of these resources.

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

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

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

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

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

The high level survey initially involved collecting data about a large number of buildings. From this large sample, a smaller survey of businesses within buildings was carried out which included a phone survey, and collecting records of energy and water use and data on floor areas. The information will enable a picture to be built up of the total and average energy and water use in non-residential buildings, the intensity of this use and resources used by different categories of building use, answering research questions one to four.

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

This report is one of a series of BEES year 5 report completed by the multidisciplinary BEES team. It presents data and analysis drawn from detailed monitoring of specific premises that have shown anomalously high or low Energy Use Intensity (EUIs). It looks at the specific site energy load patterns and analyses them to show what causes the high or low energy use index for each site.

This is of value, as it shows the causes of the high or low EUIs are due to the premise use. None of the high or low EUI premises were well-conditioned, regularly-occupied offices that make up the bulk of local experience. However, there were several instances of refrigeration systems in retail premises operating at apparently very low efficiency.

The data and analysis in this report contributes to answering research questions two (average $kWh/m^2$), three (identification of largest end-use categories), five (energy and water end-use patterns), six (determinants of end-use patterns) and seven (critical intervention points to improve resource use efficiency).

Further analysis (on this topic) that will be done for the final BEES report includes a similar analysis for larger office buildings with anomalously high or low EUIs.

# SUMMARY

- Energy Use Intensity (EUI) normalises the energy use of the premise by floor area to allow comparisons between different sized premises
- The premise operation was found to have the greatest influence on EUI
- None of the high or low EUI premises in BEES were offices, they were retail
- Low EUI premises tended to have poor space conditions, however many of the high EUI premises also had poor space conditions

Comparing the energy use of different buildings is often done by the use of the EUI, defined as the annual total energy purchased by that site, divided by the assigned floor area. The EUI allows comparisons of premises of different sizes, which is usually the largest determinant of the differences in energy use between premises.

Historical information, based on experience with larger New Zealand buildings has indicated a typical range of 100-300 kWh/m$^2$ for a typical New Zealand commercial building. This is consistent with NZS 4220:1982, which specifies an energy consumption target of 100 kWh/m$^2$/yr for new office buildings and 200 kWh/m$^2$/yr for existing office buildings. However, the randomly-selected buildings chosen for BEES show a much wider distribution of EUIs, with some much lower and some much higher than previously measured.

This report analyses some of the highest and lowest EUI premises to determine what characteristics of these buildings causes such low or high energy use (per square metre). Six premises with anomalously low EUIs (under 50 kWh/m$^2$) and five premises with anomalously high EUIs (over 300 kWh/m$^2$) were analysed.

The result is that virtually all differences in energy use can be explained by the differences in operation of the premises. While previous experience (showing EUIs generally in the range 100-250 kWh/m$^2$) entailed relatively large offices, operated consistent number of hours each week and with relatively well-controlled space conditions (temperature, illuminance and air quality), the BEES buildings showing anomalously low EUIs were smaller, occupied by less people for less hours and were poorly space conditioned.

**Table A: Summary of EUI by Premise**

| Name | Use | EUI (kWh/m$^2$) |
|---|---|---|
| High 5 | Butcher Shop | 777 |
| High 4 | Fish and Chips | 723 |
| High 3 | Supermarket | 459 |
| High 2 | Liquor Store | 401 |
| High 1 | Restaurant | 303 |
| Low 6 | Retail/Factory | 45 |
| Low 5 | Activity Centre | 43 |
| Low 4 | Building Supplies | 39 |
| Low 3 | Garden Shop | 25 |
| Low 2 | Office/Warehouse | 25 |
| Low 1 | Hardware Store | 14 |

The premises with anomalously high EUIs were invariably associated with food handling (cooking and/or refrigeration), so their high process loads caused the high energy use.

Even some of the high EUI premises had poor space conditions. Several of them also had refrigeration systems that were operating for long hours to achieve the desired conditions. Poor control, poorly insulated storage areas or some other cause may be the reason for this. Refrigeration looks to offer opportunities for significant energy and cost savings.

**Table B: Summary of Refrigeration Loads**

| Name | Use | Refrigeration EUI ($kWh/m^2$) | Number of Hours Operating per Year (FLH/Yr) | Number of Hours Operating per Day (FLH/Day) |
|---|---|---|---|---|
| High 2 | Liquor Store | 334 | 4,673 | 12.8 |
| High 5 | Butcher Shop | 285 | 4,632 | 12.7 |
| High 3 | Supermarket | 228 | 5,819 | 15.9 |
| High 4 | Fish and Chips | 145 | 6,264 | 17.2 |
| High 1 | Restaurant | 42 | 5,310 | 14.5 |
| Low 5 | Activity Centre | 10 | 2,917 | 8.0 |

Overnight energy use also appeared to be higher than required, suggesting there may also be opportunities for improved energy efficiency, whether by improved controls or by replacement with more efficient equipment.

It is interesting to note there was an absence of offices from the very low or very high EUI BEES premises.

# GLOSSARY/ABBREVIATIONS

**Energy Use Intensity (EUI)**

A term for benchmarking the comparative energy use of buildings, the EUI is generated by dividing the annual energy use (from individual or combined energy sources) by the floor area of the space, in square metres. EUI normally has units of $kWh/m^2$. The EUI can be used for comparing individual energy end-uses (such as plug/other loads, refrigeration, or heating for example), as well as total energy use.

**Parts per million (ppm)**

A measure of concentration of one gas in another, in the context of this report, it refers to the concentration of carbon dioxide ($CO_2$) in air. Carbon dioxide levels measured at Baring Head, Wellington are about 390 ppm, though this varies by location and time of day (MfE, 2012). The maximum target indoor $CO_2$ concentration is 1,000 ppm, as per NZS 4303:1990.

**Full Load Hours (FLH)**

The equivalent full load hours are a measure of the operation time of equipment. A piece of equipment operating at 100% load for 1,000 hours/year would give 1,000 FLH/yr of use, the same as a piece of equipment operating for 2,000 hours per year at 50% load, or 4,000 hours per year at 25% load.

**Peak Load**

The peak measured load of the energy assessed as contributing to that end-use. Note: this may be different than the installed load, as some equipment may never be observed to have operated during the monitoring period.

**Peak Load Density**

This peak load was divided by the recorded floor area of the premise, to yield the observed peak load density, in watts per square metre.

**Heating Ventilation and Air-Conditioning (HVAC)**

Includes both central systems and heating done by plug-in heaters for this work.

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# TABLES

# 1. INTRODUCTION

The energy use of non-residential buildings is usually characterised by Energy Use Intensity (EUI), which is the amount of energy consumed annually, divided by the floor area of the space. The EUI is normally expressed in kWh/$m^2$.

Historical information, based on experience with larger New Zealand buildings has indicated a typical range of 100-300 kWh/$m^2$ for typical New Zealand commercial buildings. This is consistent with NZS 4220:1982, which specifies an energy consumption target of 100 kWh/$m^2$/yr for new office buildings and 200 kWh/$m^2$/yr for existing office buildings.

However, the randomly-selected buildings chosen for BEES inclusion show a much wider distribution of EUIs, with some much lower and some much higher than previously measured.

Figure 1 is a histogram showing the range of EUIs seen for New Zealand office buildings that had energy audits done in the 1990s. It also shows the range of simulated EUIs for typical New Zealand offices.

As can be seen, most offices at this time ranged between about 100 and 200 kWh/$m^2$, with a significant tail to over 300 kWh/$m^2$, and a few occurrences over 400 kWh/$m^2$.

By contrast, Figure 2 shows the range of EUIs measured in BEES, available when work on this report commenced (albeit from smaller buildings and not necessarily offices) as a histogram. As can be seen, most of the buildings are showing EUIs below 100 kWh/$m^2$, with a significant number of very high cases.

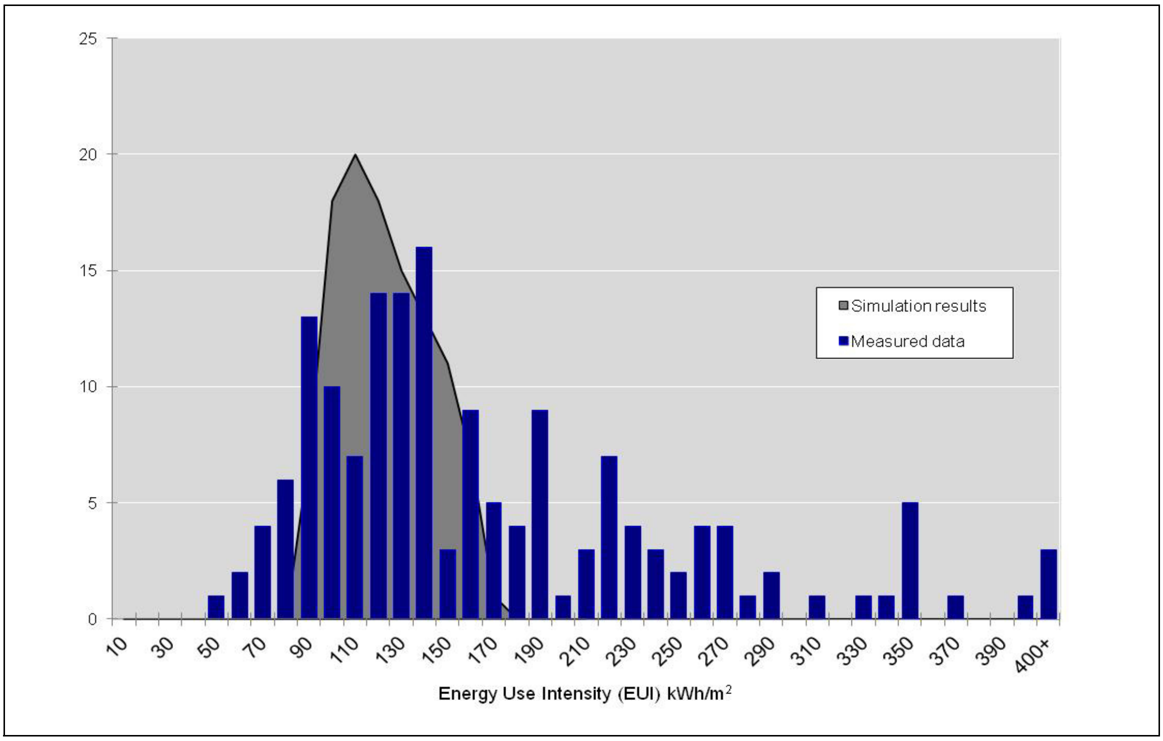


**Figure 1: 1990s NZ Office EUI Distribution**

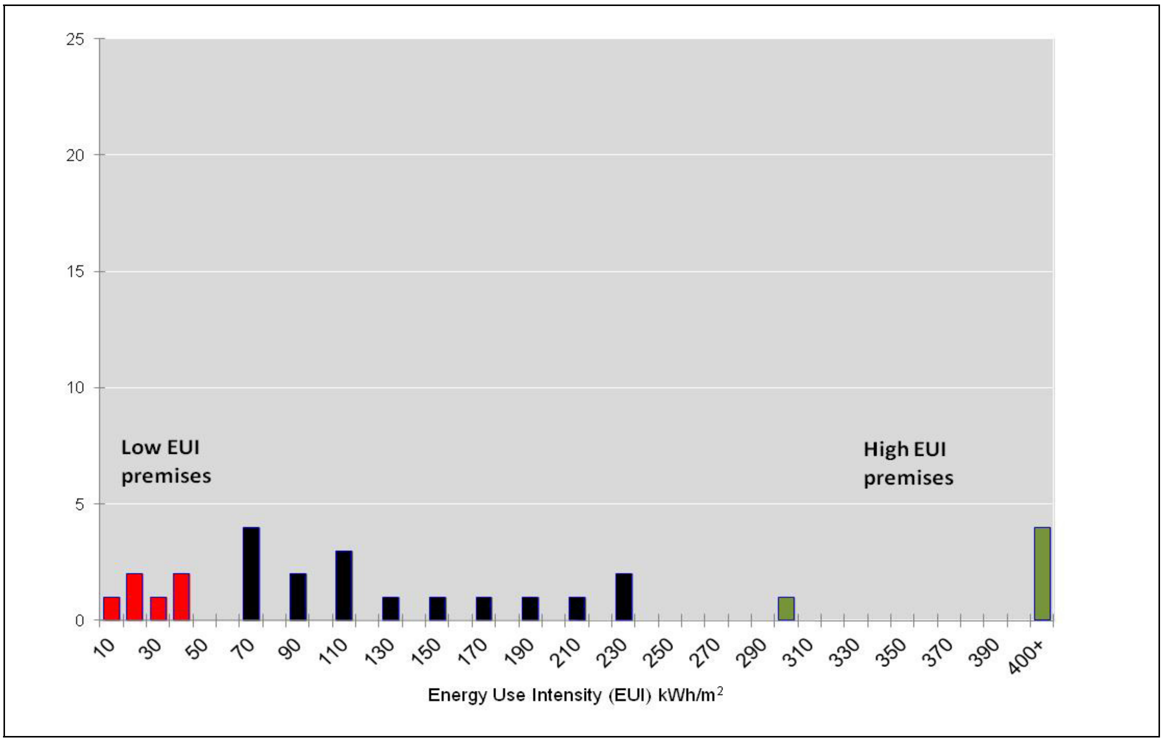


**Figure 2: EUI Distribution Measured for BEES Buildings**

This report examines the characteristics of some of these premises with high or low EUIs (outliers from the typical distribution) to determine why their use is so high (or low).

Six premises with anomalously low EUIs (under 50 kWh/m$^2$) were analysed and five premises with anomalously high (over 300 kWh/m$^2$). For each premise, the detailed monitoring records were analysed to determine the amount of energy for each end-use. With the exception of two premises with gas, all-electric premises were chosen, allowing the end-use loads to be resolved in detail.

The analysis was done with the detailed monitored data (Camilleri and Babylon, 2011) and the revenue data from power companies. Detailed monitoring for each premise was typically for two-four weeks. Individual circuits were monitored allowing analysis of end-uses. Available revenue data varied between premises, sometimes circuits had separate meters allowing analysis of end-uses, whereas others had only a total for the premise.

The total amount of energy used by each end-use during the period of the monitoring was calculated and extrapolated to an entire year's energy use. This assumed that the non-temperature-dependent loads were effectively constant through the year and gave an extrapolated total annual energy use (in kWh/yr) for each end-use.

The month-to-month revenue energy data (e.g. electricity readings from the power company) was examined to determine how much of the load, if any, was temperature dependent, and if this was noticeable, then the annual usage for HVAC was adjusted[1] to take this into account (HVAC is the most temperature-dependent of energy loads and accounts for both space heating and cooling).

The annual energy consumed by each end-use was divided by the premise's floor area to yield the EUI for each end-use and these end-use EUIs were summed to give the total EUI for the premise.

Then the peak load was determined for each major end-use (lighting, HVAC, other loads, etc), as the highest recorded electrical demand during the period of the monitoring. This was done by observing the coincident demands of all data channels referring to each end-use, so the effect of diversity of loads through all the circuits was included.

This peak load was divided by the recorded floor area of the premise, to yield the observed peak load density in watts per square metre.

Finally, the power density and EUI were related by calculating the equivalent full load hours that each load operated at. The EUI in kWh/m$^2$ was divided by the measured power density in kW/m$^2$ to give the number of (equivalent full load) hours/year, to show how constant each end-use load was.

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[1] Due to each premise being monitored for a period of two-four weeks, seasonal differences were identified in the revenue data (often only for the total building) and adjustments made when appropriate to the calculated annual energy use for different end-uses.

# 2. OVERVIEW OF RESULTS

The premises with anomalously high or low EUIs which are analysed in this report are listed in Table 1 below. For anonymity, they are only designated as "High" or "Low" (EUI) and a number based on their EUI order (the higher EUI, the higher the number). The table also gives a brief description of the type of commercial operation, the floor area in square metres, the EUI in kWh/m$^2$ and the peak power density in W/m$^2$.

**Table 1: Summaries of Analysed Premises**

| Name | Use | Floor Area (m$^2$) | People* | Space per Person (m$^2$/Person) | EUI (kWh/m$^2$) | Peak Load Density (W/m$^2$) |
|---|---|---|---|---|---|---|
| High 5 | Butcher Shop | 216 | 18 | 12 | 777 | 225 |
| High 4 | Fish and Chips | 69 | 10 | 7 | 723 | 693 |
| High 3 | Supermarket | 3,621 | 210 | 17 | 459 | 83 |
| High 2 | Liquor Store | 298 | 20 | 15 | 401 | 86 |
| High 1 | Restaurant | 165 | 39 | 4 | 303 | 101 |
| Low 6 | Retail/Factory | 405 | 16 | 25 | 45 | 28 |
| Low 5 | Activity Centre | 85 | 48 | 2 | 43 | 55 |
| Low 4 | Building Supplies | 1,680 | 29 | 58 | 39 | 15 |
| Low 3 | Garden Shop | 303 | 22 | 14 | 25 | 13 |
| Low 2 | Office/Warehouse | 1,543 | 15 | 103 | 25 | 8 |
| Low 1 | Hardware Store | 384 | 4 | 96 | 14 | 11 |

*People counts are approximate average occupancy during the hours of operation.

Unsurprisingly, all of the high EUI premises were involved with handling of food and drink, with consequent refrigeration and cooking loads. The following tables explore the different aspects of energy use in the 11 premises. The "Name" allocated in Table 1 is used consistently in the following tables, illustrating that the ranking may differ in the individual energy uses compared to the overall EUI.

The refrigeration loads for each of these premises that had refrigeration monitored are listed in Table 2, along with the EUI for this specific end-use, the maximum recorded load in kW, the recorded peak power density for this end-use in W/m$^2$ and the equivalent full load hours per year and day that the load was seen to operate at.

**Table 2: Refrigeration Loads**

| Name | Use | Refrigeration EUI (kWh/m$^2$) | Peak Load (kW) | Peak Load Density (W/m$^2$) | Full Load Hours per Year (FLH/Yr) | Full Load Hours per Day (FLH/Day) |
|---|---|---|---|---|---|---|
| High 2 | Liquor Store | 334 | 21.3 | 72 | 4,673 | 12.8 |
| High 5 | Butcher Shop | 285 | 13.3 | 61 | 4,632 | 12.7 |
| High 3 | Supermarket | 228 | 142.0 | 39 | 5,819 | 15.9 |
| High 4 | Fish and Chips | 145 | 1.6 | 23 | 6,264 | 17.2 |
| High 1 | Restaurant | 42 | 1.3 | 8 | 5,310 | 14.5 |
| Low 5 | Activity Centre | 10 | 0.3 | 3 | 2,917 | 8.0 |

As can be seen, the refrigeration systems are often quite large (in terms of power density, W/m$^2$) and operate very long hours – one at 17.2 hours or 72% of all hours in the day. There may have been some additional refrigeration systems that could not be separated and were attributed to other loads, but these are believed to be rare.

Some of the refrigeration systems did not appear to be well controlled and running almost constantly (except for periods of defrosting). These appear to be a good area for potential energy savings.

Most of the high EUI premises also had some load due to cooking or food preparation on site (Table 3). This data is listed in the same format as Table 2, the refrigeration full load hours per day (FLH/day) has been included to allow comparisons to be made.

**Table 3: Cooking Loads**

| **Name** | **Use** | **Cooking EUI** (kWh/m$^2$) | **Peak Load** (kW) | **Peak Load Density** (W/m$^2$) | **Full Load Hours per Year** (FLH/Yr) | **Full Load Hours per Day** (FLH/Day) | **Refrigeration** (FLH/Day) |
|---|---|---|---|---|---|---|---|
| High 4 – Electricity | Fish and Chips | 195 | 35.9 | 520 | 375 | 1.0 | 17.2 |
| High 4 – Gas | Fish and Chips | 176 | | | | | |
| High 1 | Restaurant | 64 | 9 | 55 | 1,167 | 3.2 | 14.5 |
| High 5 | Butcher Shop | 44 | 11.6 | 54 | 819 | 2.2 | 12.7 |
| High 3 | Supermarket | 33 | 64.2 | 18 | 1,887 | 5.2 | 15.9 |

As can be seen, premise "High 1", providing fast-food, had an extremely high cooking peak power density, though it only operated a few hours per week at this level (think of a fish and chips shop at 6pm on a Friday night). This peak load was almost ten times higher than any of the other premises! Premise "High 3" had an on-site bakery which started early in the morning and finished mid-morning.

The equivalent full load hours per year of these cooking loads are all much lower than the equivalent refrigeration loads (shown in the rightmost column). For example, in premise "High 1", a restaurant, cooking was at full load for 3.2 hours a day, compared to the refrigeration which was at full load for 14.5 hours per day. Although this could be expected, the high refrigeration load suggests either an undersized refrigeration plant (working excessive hours to maintain the required temperature) or poor control.

In contrast to these high "process" loads for premises where food handling and preparation were done, lighting loads were generally reasonable for all premises. The recorded lighting loads for all premises are presented in Table 4, following, in the same format as the previous tables.

**Table 4: Lighting Loads**

| Name | Use | Lighting EUI (kWh/m²) | Peak Load (kW) | Peak Load Density (W/m²) | Full Load Hours per Year (FLH/Yr) | Full Load Hours per Day (FLH/Day) |
|---|---|---|---|---|---|---|
| High 5 | Butcher Shop | 49 | 2.4 | 11 | 4,333 | 11.9 |
| High 1 | Restaurant | 47 | 2.2 | 13 | 3,519 | 9.6 |
| High 3 | Supermarket | 34 | 23.4 | 6 | 5,238 | 14.4 |
| Low 4 | Building Supplies | 28 | 18.1 | 11 | 2,572 | 7.0 |
| High 4 | Fish and Chips | 23 | 1.6 | 24 | 971 | 2.7 |
| High 2 | Liquor Store | 23 | 2.0 | 7 | 3,322 | 9.1 |
| Low 6 | Retail/Factory | 13 | 1.7 | 4 | 3,270 | 9.0 |
| Low 3 | Garden Shop | 12 | 1.5 | 5 | 2,412 | 6.6 |
| Low 2 | Office/Warehouse | 11 | 5.7 | 4 | 3,061 | 8.4 |
| Low 1 | Hardware Store | 0 | 0.3 | 1 | 233 | 0.6 |
| Low 5 | Activity Centre | 0 | 0.1 | 1 | 255 | 0.7 |

All lighting loads in these high EUI premises are in the ranges expected from prior experience in offices, ranging from 23 to 49 kWh/m$^2$. The highest lighting power density was 24 W/m$^2$ and the lowest 6 W/m$^2$. Only the supermarket, which had essentially 24-hour (partial) operation, had high equivalent full load hours' operation of their lights.

The building supplies premise showed lighting performance similar to the high EUI premises, both in terms of EUI and power density.

However, the other low EUI premises had significantly lower lighting EUIs, ranging from less than 1 to 13 kWh/m$^2$. Their power densities were also much lower, from about 1 to 5 W/m$^2$. These premises were generally at least partially daylit and used mostly during the daytime. The extremely low lighting EUI premises rarely used electric lights.

The Heating, Ventilation and Air-Conditioning (HVAC) loads for each premise where these could be identified are listed in Table 5. Note that the level of HVAC provided varied considerably and in the low EUI premises might be no more than a portable electric heater, which would be recorded as part of the other load. In the restaurant, fish and chips shop, garden shop and retail/factory shop, there was no observed HVAC equipment in place. In the case of the hardware store and the activity centre premises, the annual HVAC energy use was estimated from the annual energy purchase data.

**Table 5: HVAC Loads**

| Name | Use | HVAC EUI (kWh/m²) | Peak Load (kW) | Peak Load Density (W/m²) | Full Load Hours per Year (FLH/Yr) | Full Load Hours per Day (FLH/Day) |
|---|---|---|---|---|---|---|
| High 5 | Butcher Shop | 149 | 5.8 | 27 | 5,533 | 15.2 |
| High 3 | Supermarket | 30 | 37.3 | 10 | 2,891 | 7.9 |
| Low 5 | Activity Centre | 28 | - | - | - | |
| High 2 | Liquor Store | 17 | 1.8 | 6 | 2,849 | 7.8 |
| Low 1 | Hardware Store | 5 | - | - | - | |
| Low 4 | Building Supplies | 2 | 2.5 | 2 | 1,461 | 4.0 |
| Low 2 | Office/Warehouse | 1 | 1.8 | 1 | 830 | 2.3 |

As can be seen, only the butcher shop had an unusually high HVAC load.

The service water heating loads are listed in Table 6 for the premises where these could be identified and separated from other energy use. Only two premises had significant service water heating loads: the restaurant and the butcher shop. The water heating loads for the supermarket and fish and chips shop could not be discerned from the monitoring and circuit identification. The water heating load for the restaurant was from its commercial dishwasher. In all cases, the full load hour per day appear reasonable for the type of premise.

**Table 6: Service Water Heating Loads**

| **Name** | **Use** | **Water Heating EUI** ($kWh/m^2$) | **Peak Load** (kW) | **Peak Load Density** ($W/m^2$) | **Full Load Hours per Year** (FLH/Yr) | **Full Load Hours per Day** (FLH/Day) |
|---|---|---|---|---|---|---|
| High 1 | Restaurant | 46 | 6.8 | 41 | 1,121 | 3.1 |
| High 5 | Butcher Shop | 42 | 5.7 | 26 | 1,594 | 4.4 |
| Low 6 | Retail/Factory | 6 | 4.8 | 12 | 513 | 1.4 |
| High 2 | Liquor Store | 2 | 1.3 | 4 | 373 | 1.0 |
| Low 2 | Office/Warehouse | 1 | 2.0 | 1 | 1,084 | 3.0 |
| Low 5 | Activity Centre | 1 | 2.5 | 29 | 46 | 0.1 |

Finally, the miscellaneous, "plug" or "other" loads for the premises are listed in Table 7, below. These contained the office equipment and all other loads that were plugged into the wall power points.

**Table 7: Miscellaneous "Plug" or "Other" Loads**

| **Name** | **Use** | **Other Loads EUI** ($kWh/m^2$) | **Peak Load** (kW) | **Peak Load Density** ($W/m^2$) | **Full Load Hours per Year** (FLH/Yr) | **Full Load Hours per Day** (FLH/Day) |
|---|---|---|---|---|---|---|
| High 4 | Fish and Chips | 184 | 10.5 | 152 | 1,213 | 3.3 |
| High 1 | Restaurant | 104 | 6.0 | 36 | 2,860 | 7.8 |
| High 3 | Supermarket | 134 | 90.4 | 25 | 5,372 | 14.7 |
| High 2 | Liquor Store | 25 | 3.9 | 13 | 1,945 | 5.3 |
| High 5 | Butcher Shop | 128 | 8.9 | 41 | 3,092 | 8.5 |
| Low 4 | Building Supplies | 9 | 5.2 | 3 | 2,992 | 8.2 |
| Low 1 | Hardware Store | 9 | 3.9 | 10 | 855 | 2.3 |
| Low 3 | Garden Shop | 0 | 0.3 | 1 | 323 | 0.9 |
| Low 2 | Office/Warehouse | 7 | 4.9 | 3 | 2,241 | 6.1 |
| Low 6 | Retail/Factory | 9 | 4.0 | 10 | 889 | 2.4 |
| Low 5 | Activity Centre | 4 | 4.6 | 54 | 67 | 0.2 |

As can be seen, the other loads were invariably much higher for the high EUI premises than the low ones. Of the high EUI premises, only the liquor store, which also had anomalously high refrigeration loads, had an other load EUI under 100 kWh/m.

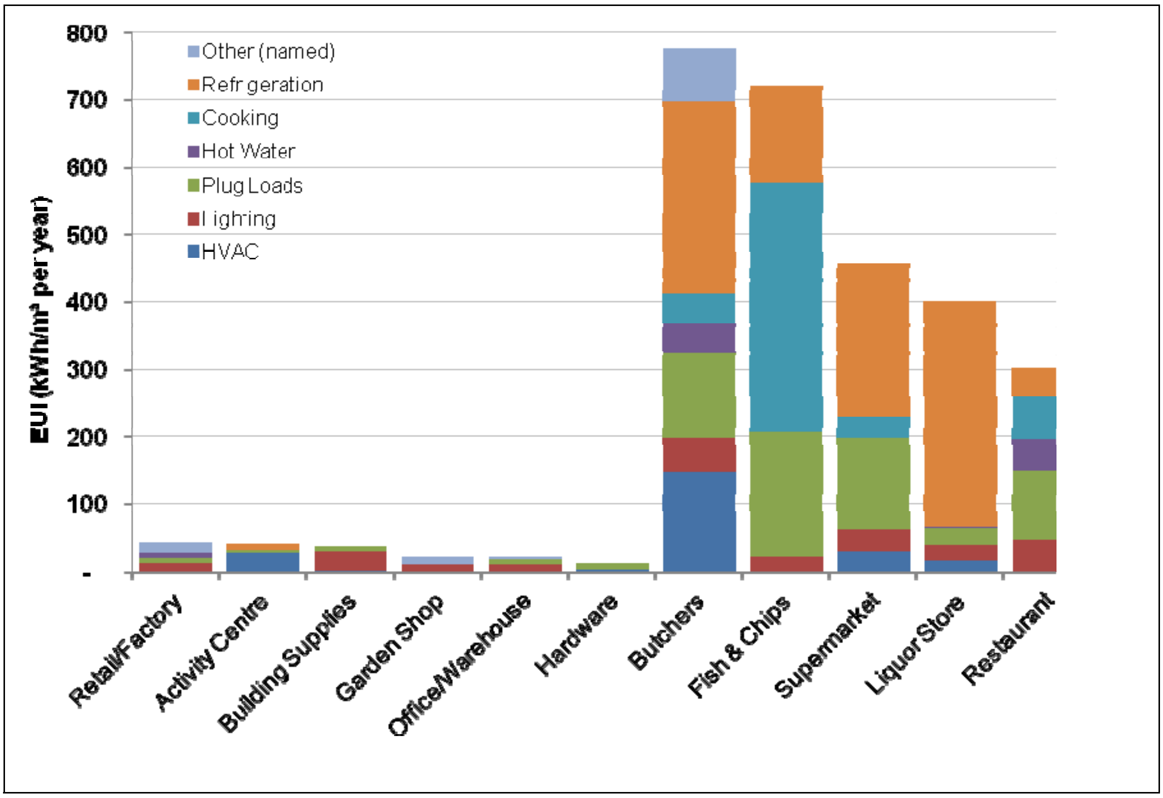


**Figure 3: Energy by Load Type**

# 3. LOW EUI PREMISES

## 3.1 Building Supplies – 39 kWh/m$^2$ (EUI)

This premise was a large hardware/timber retailer. Although there was a yard full of materials on the site, only the energy use of the building was analysed. The floor area of the premise was 1,680 m$^2$.

During a normal working day there were 29 people occupying the premise, which is equivalent to an average of 58 m$^2$/person. The space was not well space-conditioned, with temperatures recorded below 10°C and above 30°C, but it was very well ventilated! The maximum space $CO_2$ levels were just over 500 ppm, with averages about 400 ppm. As noted in Study Report SR 260/4 (Bishop, et al. 2011), spaces with $CO_2$ less than 600 ppm have air exchange rates higher than required to maintain good air quality. This can cause higher heating and cooling loads than necessary.

The electrical load pattern was very constant day-to-day, as shown in Figure 4, below. The grey lines are the loads for individual days, the solid black line is the average for weekdays and the solid red line is the average for all weekend days.

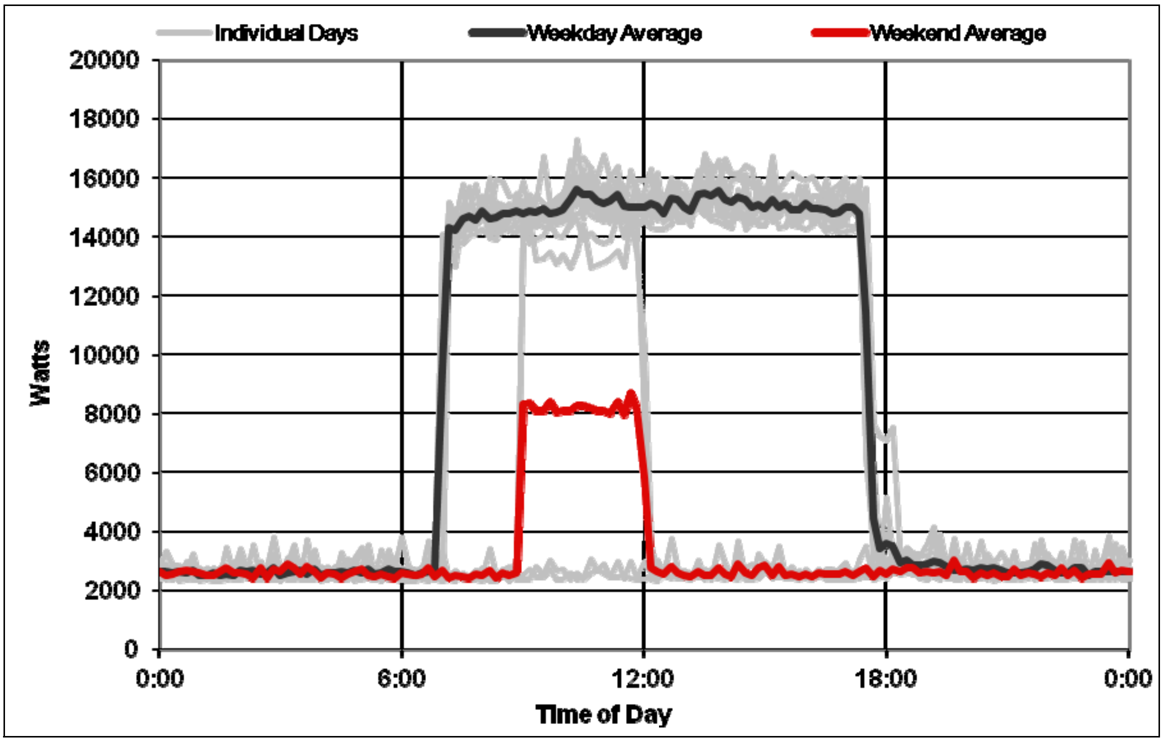


**Figure 4: Average Daily End-use Electrical Load Profile for Building Supplies**

As can be seen, there was about 2,500 watts of continuous base-load and effectively all lights were in use on weekdays from about 7am until just before 6pm, when the store closed. Some lights were on Saturdays from about 9am until noon, but none were on Sunday.

The revenue data for the premise showed a noticeable peak of energy use in winter, presumably for space conditioning and the extra lighting due to shorter days for the offices and retail space. Thus, the HVAC energy was adjusted to ensure that the end-use EUIs totalled the same as that from the annual energy purchase records.

The distribution of energy end-use loads for this site is shown in Table 8.

**Table 8: Distribution of End-use Loads for Building Supplies**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/$m^2$) | **EUI** (kWh/$m^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| HVAC | 2.5 | 3,653 | 2 | 2 | 1,461 |
| Lighting | 18.1 | 46,510 | 11 | 28 | 2,572 |
| Other Loads | 5.2 | 15,446 | 3 | 9 | 2,992 |
| **Total** | | **65,609** | | **39** | |

## 3.2 Hardware Store – 14 kWh/$m^2$ (EUI)

This was an irregularly-occupied, minimally conditioned retail premises and warehouse. The measured floor area was 384 $m^2$. During a normal working day a total of four occupants was typical, resulting in an average of 96 $m^2$/person.

This space also showed poor space conditioning, with excessive ventilation (444 ppm $CO_2$ average) and temperature swings.

The revenue data for this site showed an average daily usage of 15 kWh/day, with a winter peak of 22 kWh/day falling to 10 kWh/day in summer).

The loads were difficult to discern, with very little definitely being lighting. Most of the loads were other loads, which may have included some lighting. There was a dedicated hot water circuit, but this used almost no energy during the time of the monitoring.

Figure 5 shows the total electrical load profile for this premise. The grey lines are the loads for individual days, the solid black line is the average for weekdays and the solid red line is the average for all weekend days. There was a base load of around 200 W, possibly due to security lighting and/or the standby power of the electronic appliances (cash tills, computers, etc). The relatively small number of high peaks (up to 4 kW) comes from the use of a high load piece of equipment (such as an oven or space heater).

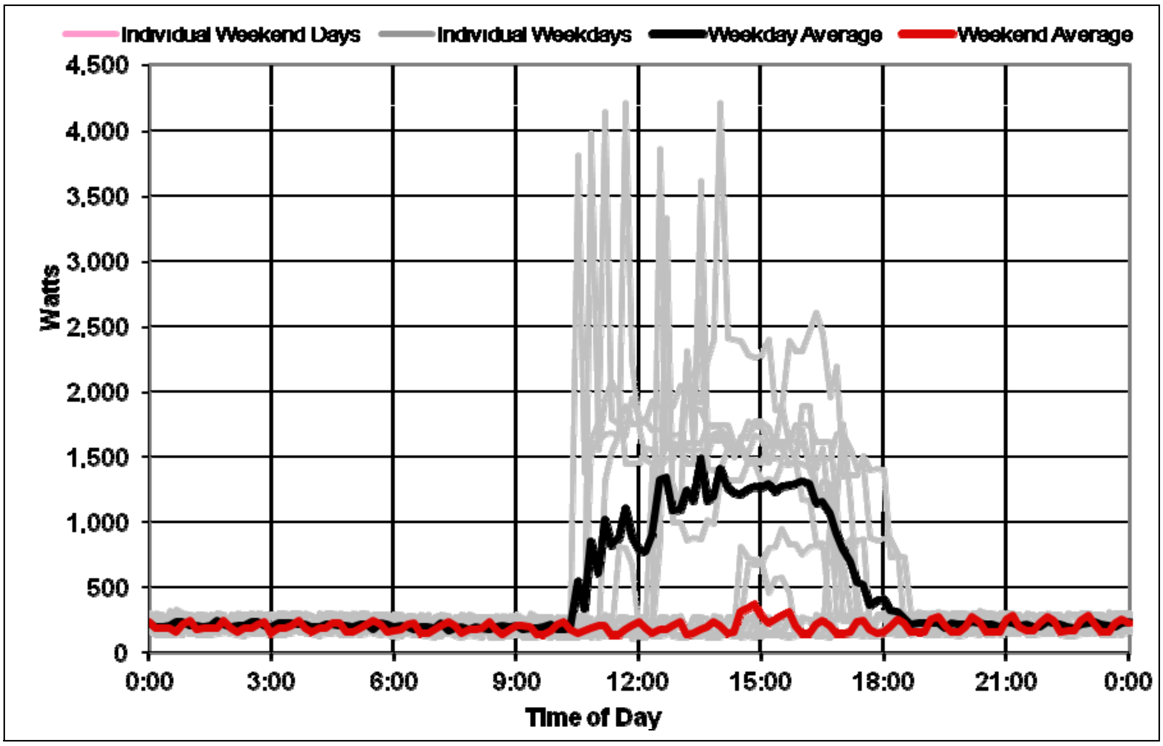


**Figure 5: Total Electrical Load Profile for Hardware Store**

The distribution of energy end-use loads is as shown in Table 9 for this site.

**Table 9: Distribution of End-use Loads for Hardware Store**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** ($W/m^2$) | **EUI** ($kWh/m^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| HVAC | | 1,920 | | 5 | |
| Lighting | 0.3 | 73 | 1 | 0 | 233 |
| Other Loads | 3.9 | 3,319 | 10 | 9 | 855 |
| **Total** | | **5,367** | | **14** | |

## 3.3 Garden Shop – 25 kWh/m$^2$ (EUI)

This is a regularly-occupied, but poorly-serviced retail premises. Though it was partially open to outdoors when open for business, the humidity and $CO_2$ levels were consistently high. The floor area was 303 m$^2$.

During a typical working day there were 22 people occupying the premises, which is equivalent to an average of 14 m$^2$/person. The space was not well space-conditioned, with temperatures recorded between 6°C and 26°C. Although the space was partially open to outdoors, and hence well ventilated, the $CO_2$ levels were consistently over 1,000 ppm. This may be due to the plants releasing $CO_2$ during the non-daylight hours, bags of compost decomposing, the proximity to car parking and the location of the $CO_2$ meter which was on the desk in the manager's office, a room that was not as well ventilated as the rest of the shop.

The electrical load pattern showed a consistent overnight load for security and signage lighting, with a slightly higher daytime usage. This site had various water pumps that were manually switched on and off for water circulation in fountains which caused regular load spikes. The total electrical load for this site is shown in Figure 6, below.

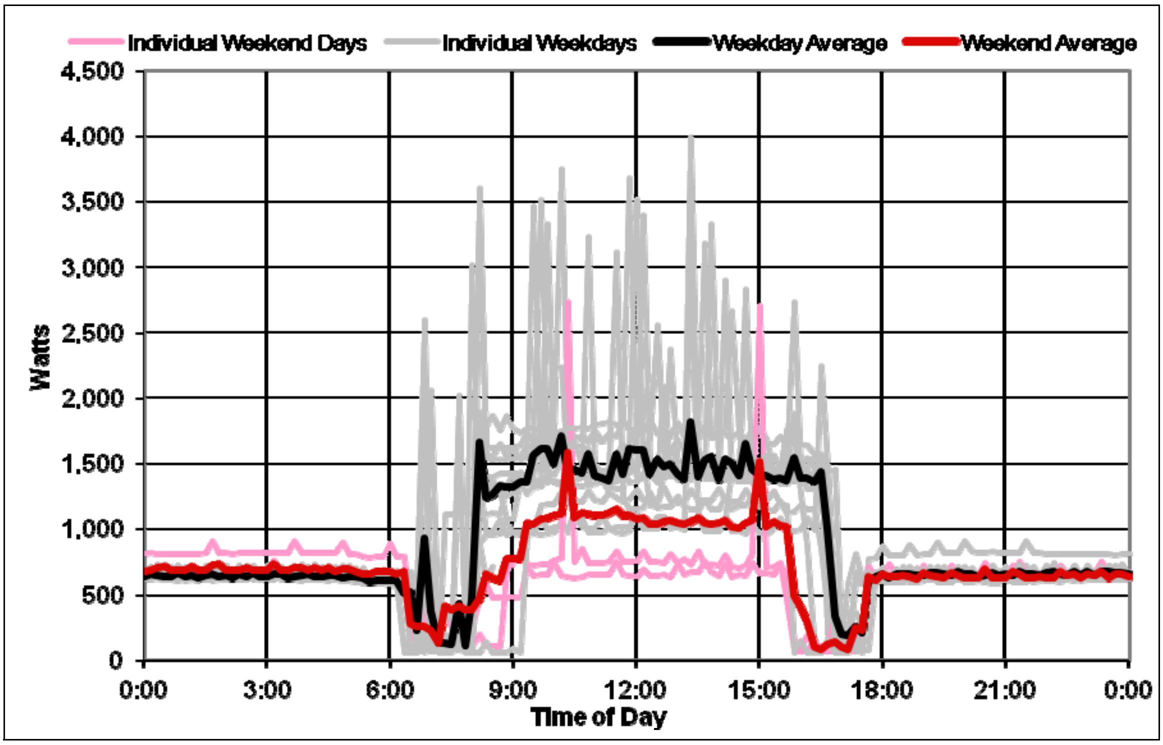


**Figure 6: Average Daily End-use Electrical Load Profile for Garden Shop**

There was no visible space conditioning at this site, nor was there any evident seasonal or temperature-dependent loads. The distribution of energy end-use loads is shown in Table 10 for this site.

**Table 10: Distribution of End-use Loads for Garden Shop**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 1.5 | 3,594 | 4.9 | 12 | 2,412 |
| Other Loads | 0.3 | 89 | 0.9 | 0 | 323 |
| Other | 2.2 | 3,740 | 7.4 | 12 | 1,677 |
| **Total** | | **7,424** | | **25*** | |

*Totals may not add due to rounding.

## 3.4 Office/Warehouse – 25 kWh/m$^2$ (EUI)

This premise contained an office and warehouse, as well as an electronics laboratory and computer server facility. The floor area of the premise was 1,680 m$^2$.

During a normal working day there were 15 people occupying the premise, which is equivalent to an average of 103 m$^2$/person. As the offices form only a proportion of the premise floor area, this may reduce the size of the EUI from what would otherwise be expected if this premise was entirely offices. The space was well conditioned, with office temperatures between 18°C and 22°C during working hours, and the ventilation was generally well controlled. Space $CO_2$ levels averaged about 700 ppm during normal working hours, with occasional peaks above 1,000 ppm. This is shown in Figure 7, below.

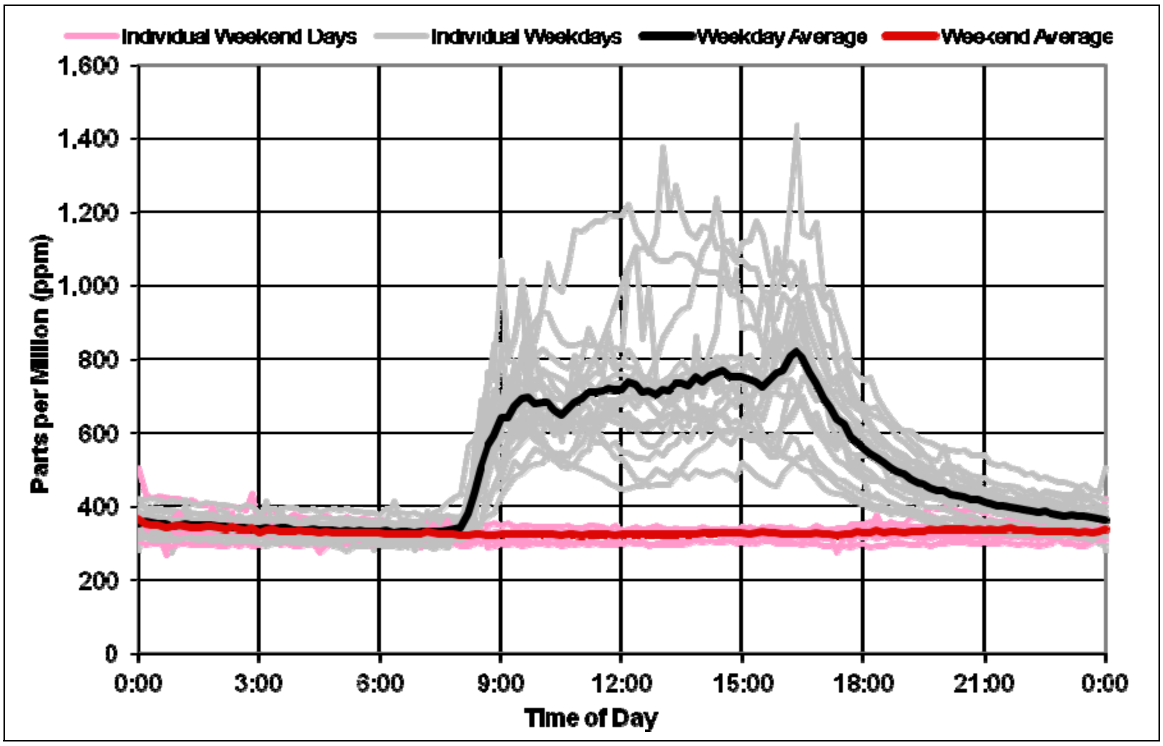


**Figure 7: Average Daily $CO_2$ Load Profile for the Office/Warehouse**

The electrical loads varied from day-to-day due to frequent switching of the other loads, as shown in Figure 8. Interestingly, the weekend daytime load was lower than the night-time load, probably due to the security lighting operating overnight.

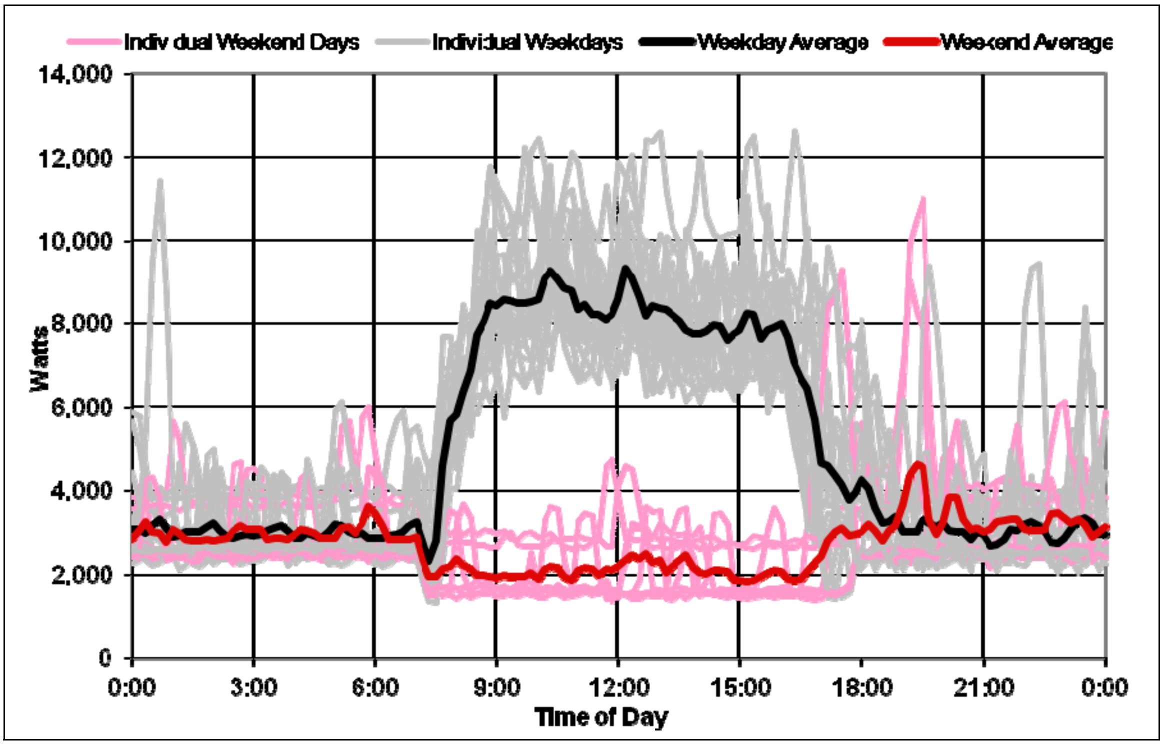


**Figure 8: Average Daily End-use Electrical Load Profile for the Office/Warehouse**

This premise also had a dedicated server rack which operated at almost constant load equivalent to 8,484 hours at full load out of 8,760 hours in a year. The distribution of energy end-use loads is shown in Table 11 below, for this site.

**Table 11: Distribution of End-use Loads for the Office/Warehouse**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 5.7 | 17,581 | 3.7 | 11 | 3,061 |
| Other Loads | 4.9 | 10,877 | 3.1 | 7 | 2,241 |
| Server | 0.4 | 3,063 | 0.2 | 2 | 8,484 |
| Lab | 0.6 | 3,273 | 0.4 | 2 | 5,237 |
| Hot Water | 2.0 | 2,204 | 1.3 | 1 | 1,084 |
| HVAC | 1.8 | 1,531 | 1.2 | 1 | 830 |
| **Total** | | **38,529** | | **25*** | |

*Totals may not add due to rounding.

## 3.5 Retail/Factory – 45 kWh/m$^2$ (EUI)

This premise was a retailer that manufactured its own products on site, which entailed a floor area of 405 m$^2$.

During a normal working day there were 16 people occupying the premises, which is equivalent to an average of 25 m$^2$/person. The premises was not space-conditioned, with an open loading bay door to the back normally left open, so it was very well ventilated! Measured space $CO_2$ levels were virtually equivalent to outdoors, with averages about 400 ppm and the highest peaks just over 500 ppm. This ventilation was the only cooling provided in summer, with recorded temperatures regularly above 30°C throughout the premises.

The electrical load pattern is shown in Figure 9 in the same format as previously. The load is quite variable, due to manual switching of other loads and machines.

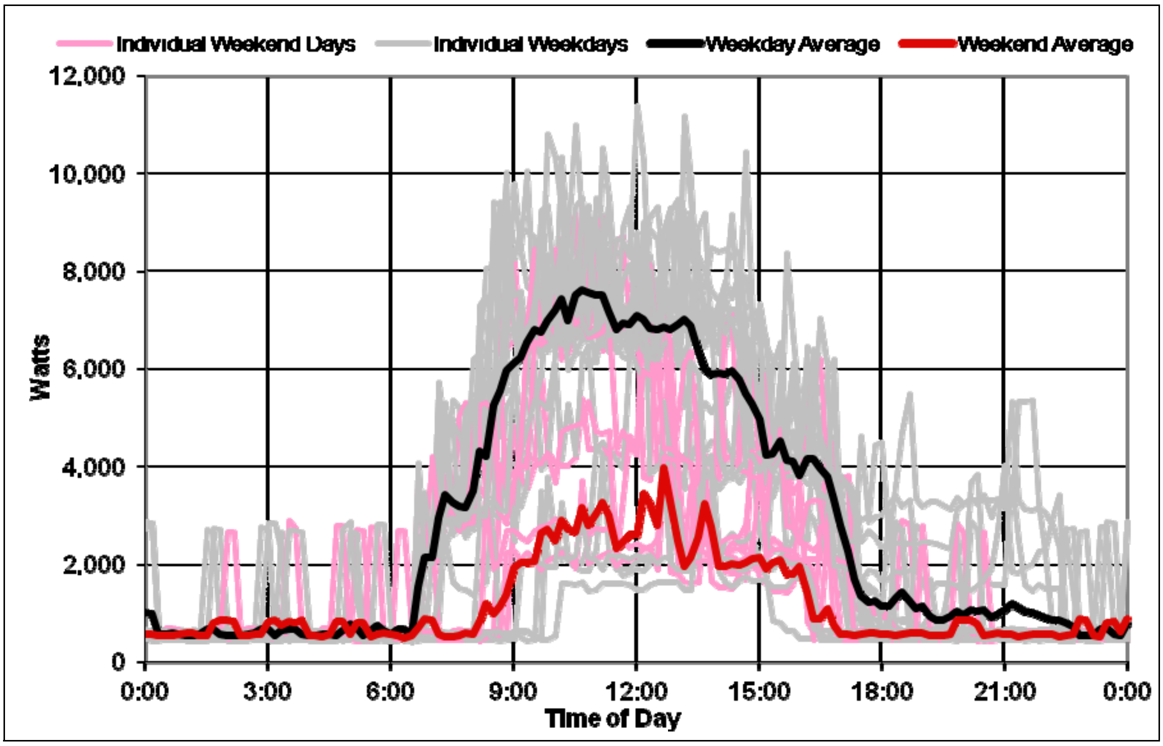


**Figure 9: Average Daily Total Electrical Load Profile for Retail/Factory**

There was no discernible temperature-dependent load for this premise (unsurprisingly, as there was no space conditioning equipment use during the summer). The distribution of energy end-use loads is shown in Table 12 below, for this site.

**Table 12: Distribution of End-use Loads for Retail/Factory**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 1.7 | 5,461 | 4.1 | 13 | 3,270 |
| Other Loads | 4.0 | 3,547 | 9.9 | 9 | 889 |
| Hot water | 4.8 | 2,478 | 11.9 | 6 | 513 |
| Machines | 7.9 | 6,973 | 19.4 | 17 | 887 |
| **Total** | | **18,396** | | **45** | |

## 3.6 Activity Centre – 43 kWh/m$^2$ (EUI)

This premise was a Church school building which was very irregularly used. During the monitoring, it was only used two part-days per week.

The floor area of the premise was 85 m$^2$. When occupied, there were approximately 48 people on the premises, which is equivalent to under 2 m$^2$/person. The space was not heated and poorly ventilated, with observed space $CO_2$ levels over 1,000 ppm almost every time the space was occupied.

Because the electrical loads are so irregular day-to-day, an averaged load profile is not shown for this site. Instead, a "time series" showing the spikes in load when the space was occupied every few days is shown as Figure 10.

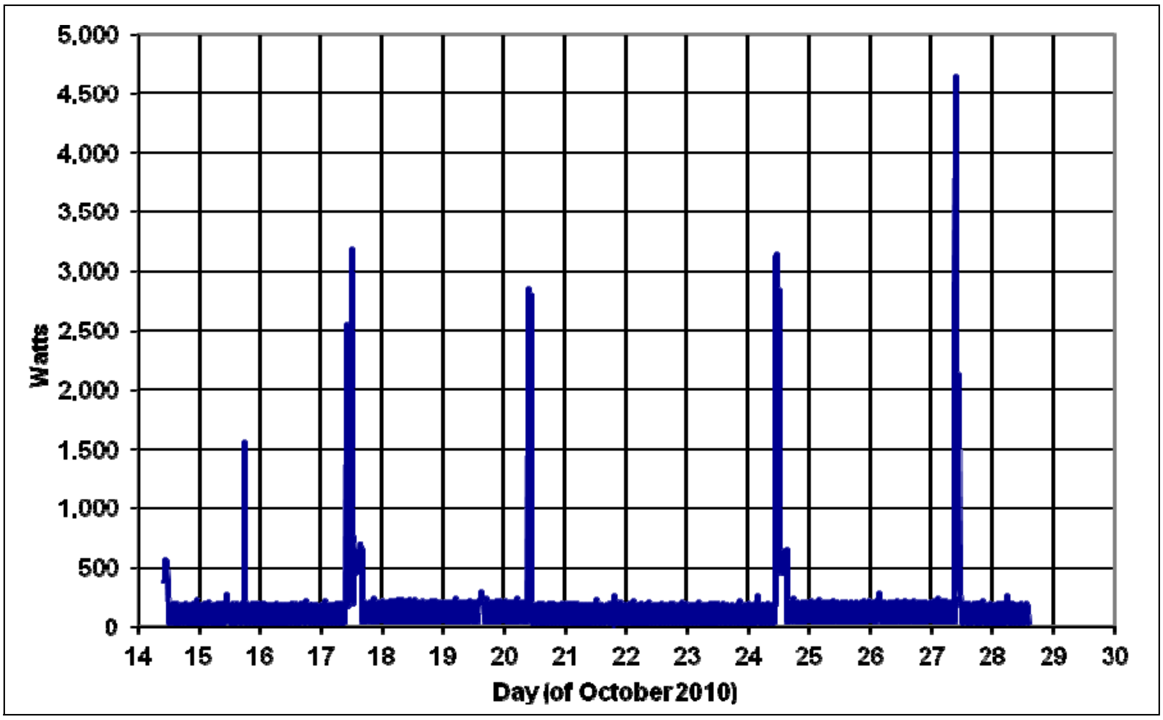


**Figure 10: Total Electrical Use Time Series for Activity Centre**

The revenue data for the premise indicated there was much higher energy use in winter, presumably for heating the premise when it was being used. The HVAC energy was adjusted to ensure that the end-use EUIs totalled the same as that from the annual energy purchase records.

During the monitoring over the spring period, 77% of this space's energy use was due to the operation of the refrigerator (113 W) and Zip water heater. But on an annual basis, almost 70% of the load was estimated to be due to space heating!

The distribution of energy end-use loads is shown in Table 13 below, for this site.

**Table 13: Distribution of End-use Loads for Activity Centre**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 0.1 | 22 | 1.0 | 0 | 255 |
| Other Loads | 4.6 | 307 | 53.8 | 4 | 67 |
| Refrigeration | 0.3 | 832 | 3.4 | 10 | 2,917 |
| HVAC | | 2,380 | | 28 | |
| Hot water | 2.5 | 114 | 29.1 | 1 | 46 |
| **Total** | | **3,655** | | **43** | |

# 4. HIGH EUI PREMISES

## 4.1 Fish and Chips Shop – 723 kWh/m$^2$ (EUI)

This premise was a takeaway food shop, specialising in “fish and chips”. The electrical loads were irregular, but very high when cooking was occurring. The daily average electricity usage was 93 kWh/day and the highest daily electricity usage was 139 kWh/day over the monitored period. Gas was used for cooking in addition to electricity.

The floor area of the premises was 69 m$^2$. During a normal working day, there were ten people occupying the premises, which is equivalent to an average of 7 m$^2$/person.

Temperatures in the space during peak times were recorded between 18°C and 21°C. The space $CO_2$ levels during occupancy averaged less than 500 ppm indicating very high ventilation rates. Illuminance levels measured were generally low, averaging about 50 lux during working hours. An acceptable level would be about 240 lux. This is the recommended maintained illuminance for “Ordinary or Moderately Easy” visual tasks, specifically including food preparation, according to Table 3.1 of AS/NZS 1680.1:2006 (SNZ, 2006).

The electrical load pattern was quite concentrated during peak hours, as shown in Figure 11.

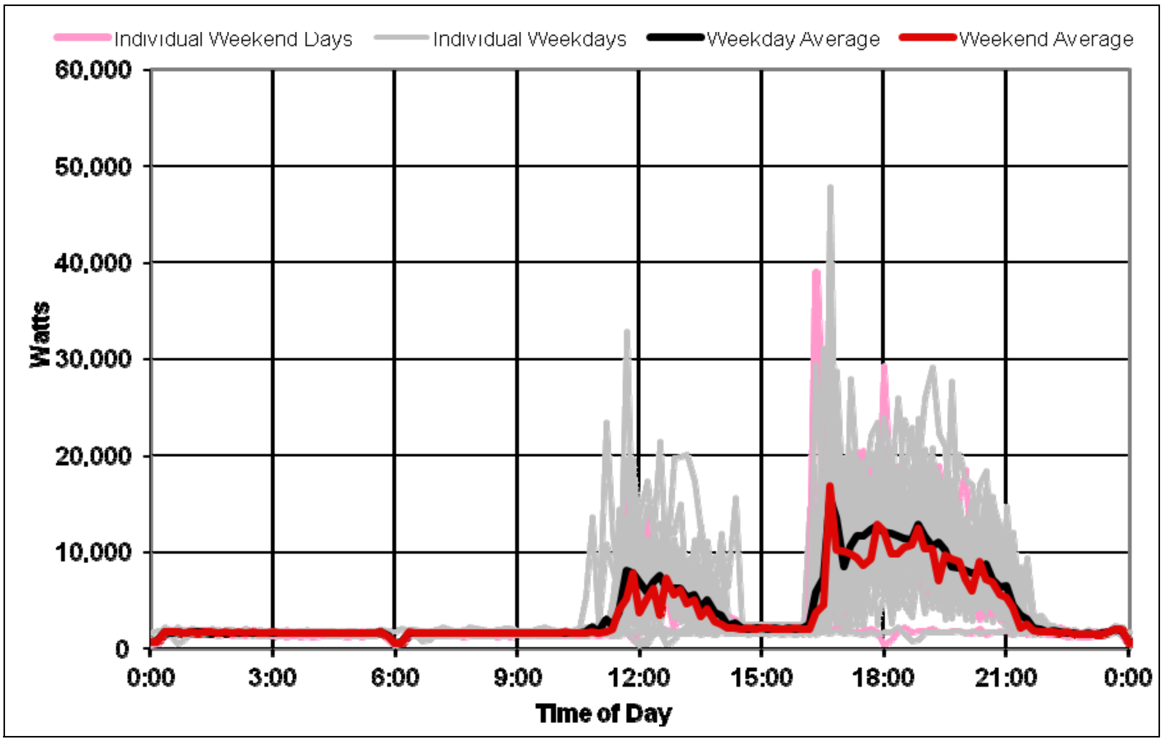


**Figure 11: Average Daily Total Electrical Load Profile for Fish and Chips Shop**

Revenue data indicated that the loads were not seasonal or temperature-dependent. The other loads were concentrated at the same times as the cooking loads. It is likely that they were related to the cooking.

The distribution of energy end-use loads is shown in Table 14 for this site.

**Table 14: Distribution of End-use Loads for Fish and Chips Shop**

| End-use | Peak Load (kW) | Energy Use (kWh/Yr) | Peak Load Density (W/m$^2$) | EUI (kWh/m$^2$) | Full Load Hours per Year (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 1.6 | 1,579 | 23.6 | 23 | 971 |
| Other Loads | 10.5 | 12,691 | 151.6 | 184 | 1,213 |
| Cooking – Electricity | 35.9 | 13,478 | 520.3 | 195 | 375 |
| Cooking – Gas | | 12,154 | | 176 | |
| Refrigeration | 1.6 | 9,998 | 23.1 | 145 | 6,264 |
| **Total** | | **49,900** | | **723** | |

## 4.2 Restaurant – 303 kWh/m$^2$ (EUI)

This premise was a restaurant and cafe. Compared to the fish and chips shop, the loads were much lower and less "peaky".

The floor area of this premise was 165 m$^2$. During a normal working day, there were 39 people occupying the premises, which is equivalent to an average of 4 m$^2$/person.

The premise was well space-conditioned, with temperatures consistently between 18°C and 22°C. Ventilation was generally very good, with space $CO_2$ levels averaging about 700 ppm during the busiest times. However, about once a week they would exceed 1,000 ppm, yet there was no obvious pattern for when this peak occurred. The highest single reading was over 2,500 ppm, this could be due to a high carbon dioxide activity happening close to the sensor – such as food being burnt!

The electrical load pattern was relatively spiky, with multiple large loads (cookers, dishwashers, etc) switched on and off regularly, as shown in Figure 12, below.

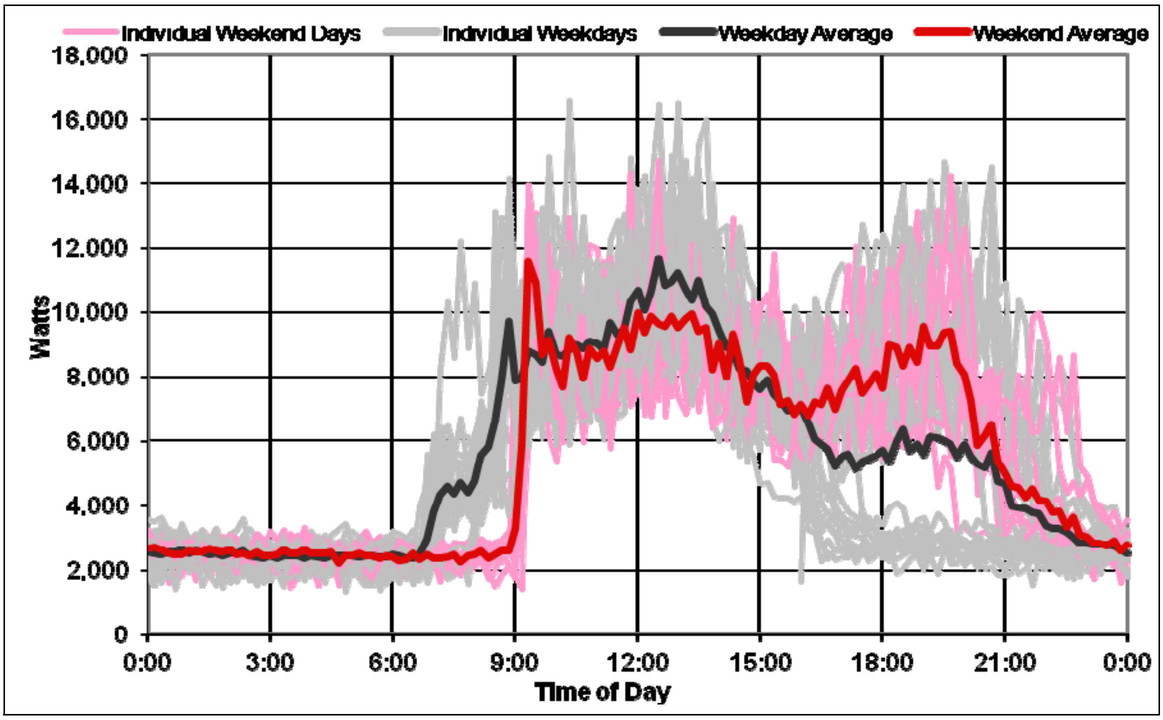


**Figure 12: Average Daily Total Electrical Load Profile for Restaurant**

As can be seen, the "weekday average" line (solid black) is somewhat deceiving in the evenings, as the restaurant was only open two weeknight evenings per week.

The distribution of energy end-use loads is shown in Table 15 for this site. There was no dedicated water heating circuit, so the service water heating load was taken as (most of) the load from the commercial dishwasher circuit.

**Table 15: Distribution of End-use Loads for Restaurant**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Cooking | 9.0 | 10,502 | 55 | 64 | 1,167 |
| Hot Water | 6.8 | 7,577 | 41 | 46 | 1,121 |
| Lighting | 2.2 | 7,674 | 13 | 47 | 3,519 |
| Other Loads | 6.0 | 17,106 | 36 | 104 | 2,860 |
| Refrigeration | 1.3 | 6,999 | 8 | 42 | 5,310 |
| **Total** | | **49,858** | | **303** | |

## 4.3 Supermarket – 459 kWh/m$^2$ (EUI)

This premise was a large, well-maintained supermarket. It had very consistent loads day-to-day. The floor area of the premise was 3,621 m$^2$.

During a normal working day, there were around 210 people occupying the premises, which is equivalent to an average of 17 m$^2$/person. The space was well conditioned, with temperatures controlled between 18°C and 21°C (though reaching 24°C in the bakery). Ventilation was notably well -controlled, with typical space $CO_2$ levels peaking at about 850 ppm. The extreme peaks over a month were to 1,200 ppm.

The electrical load pattern was very constant day-to-day, as shown in Figure 13, below.

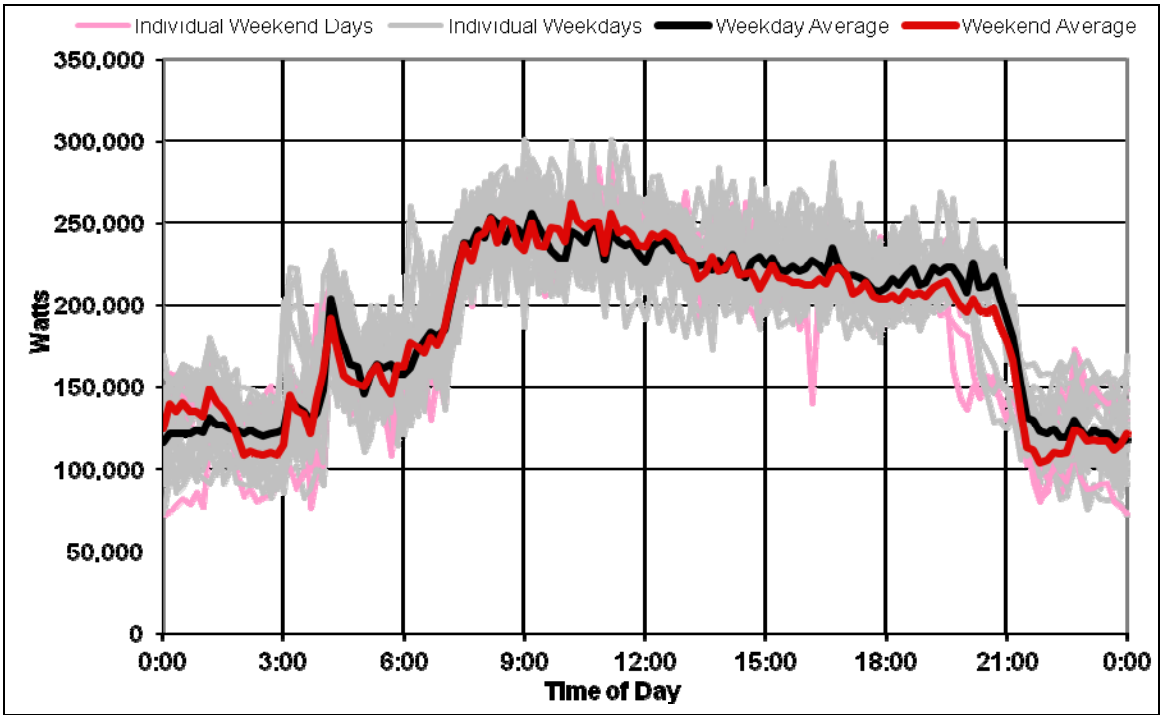


**Figure 13: Average Daily Total Electrical Load Profile for Supermarket**

The revenue data showed a slightly temperature-dependent load, with a small cooling peak (due to air-conditioning). The monitoring was carried out in spring, with the loads recorded about 7% higher than the annual average. So, if the monitored loads were adjusted to match the annual loads, they would have to be reduced (which would not have accounted for the cooling peak). Thus, the loads presented below are not adjusted to account for summer air-conditioning.

The distribution of energy end-use loads is as shown in Table 16 below for this site. The majority of the water heating was done by a boiler fuelled by six large LPG cylinders. There were also two smaller instant electric systems that are part of the other loads.

**Table 16: Distribution of End-use Loads for Supermarket**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Cooking | 64.2 | 121,098 | 18 | 33 | 1,887 |
| HVAC – Electricity | 37.3 | 107,832 | 10 | 30 | 2,891 |
| HVAC – Gas | | | | | |
| Water Heating – Gas | | | | | |
| Lighting | 23.4 | 122,723 | 6 | 34 | 5,238 |
| Other Loads | 90.4 | 485,619 | 25 | 134 | 5,372 |
| Refrigeration | 141.7 | 824,692 | 39 | 228 | 5,819 |
| **Total** | | **1,661,964** | | **459** | |

The pattern of end-use loads over a typical day is plotted below, in Figure 14. The high overnight base load can be seen to be due largely to the refrigeration, but there is also a sizable “Other” plug load and a smaller “Light” load.

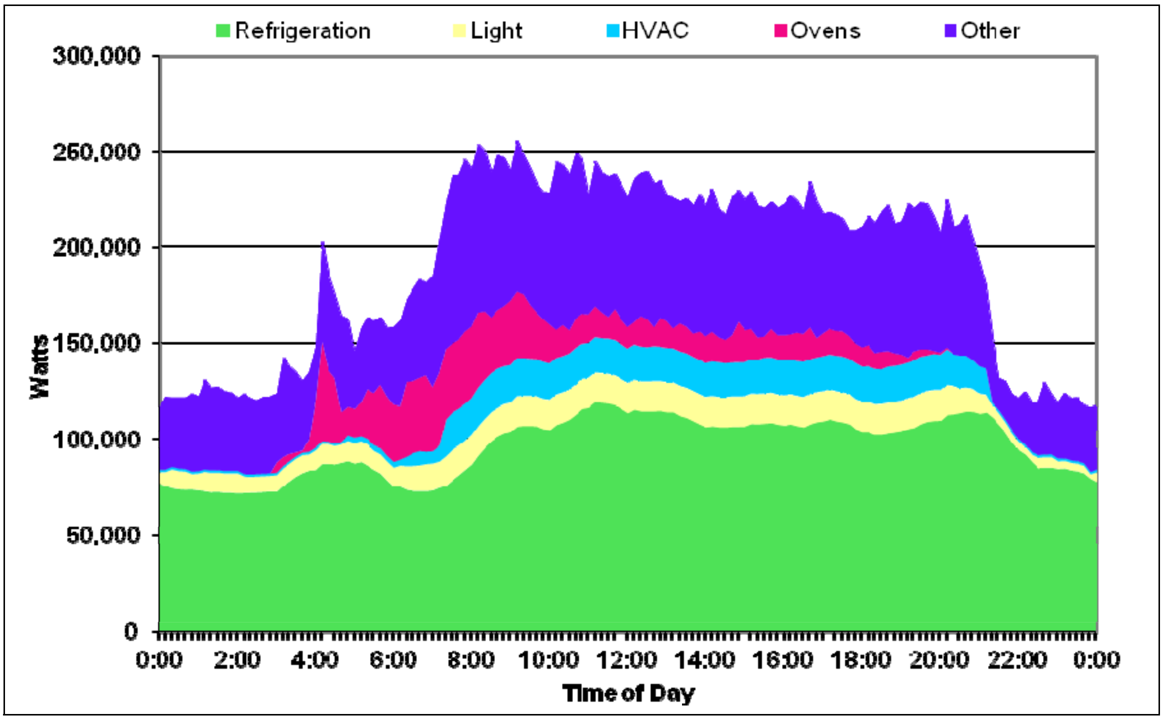


**Figure 14: Average Daily End-use Load Profile for Supermarket**

## 4.4 Liquor Store – 401 kWh/m² (EUI)

This premise was a liquor store, with one large walk-in refrigerated beer room and several small refrigerators. The floor area of the premise was 298 m². During a normal working day there were around 20 people occupying the premises, which is equivalent to an average of 15 m²/person.

The space was kept quite cool, with temperatures between about 16°C and 18°C, and quite well ventilated, with $CO_2$ levels averaging about 550 ppm and never exceeding 650 ppm during the monitoring. The space illuminance was also generally low, never exceeding 200 lux.

The electrical load pattern was almost flat over 24 hours, as shown in Figure 15, below. The slight increase in load during the opening hours is due to the lighting and other loads that operate then. However, the dominance of the refrigeration systems, which operate 24 hours per day, means that the load profile is almost “flat”.

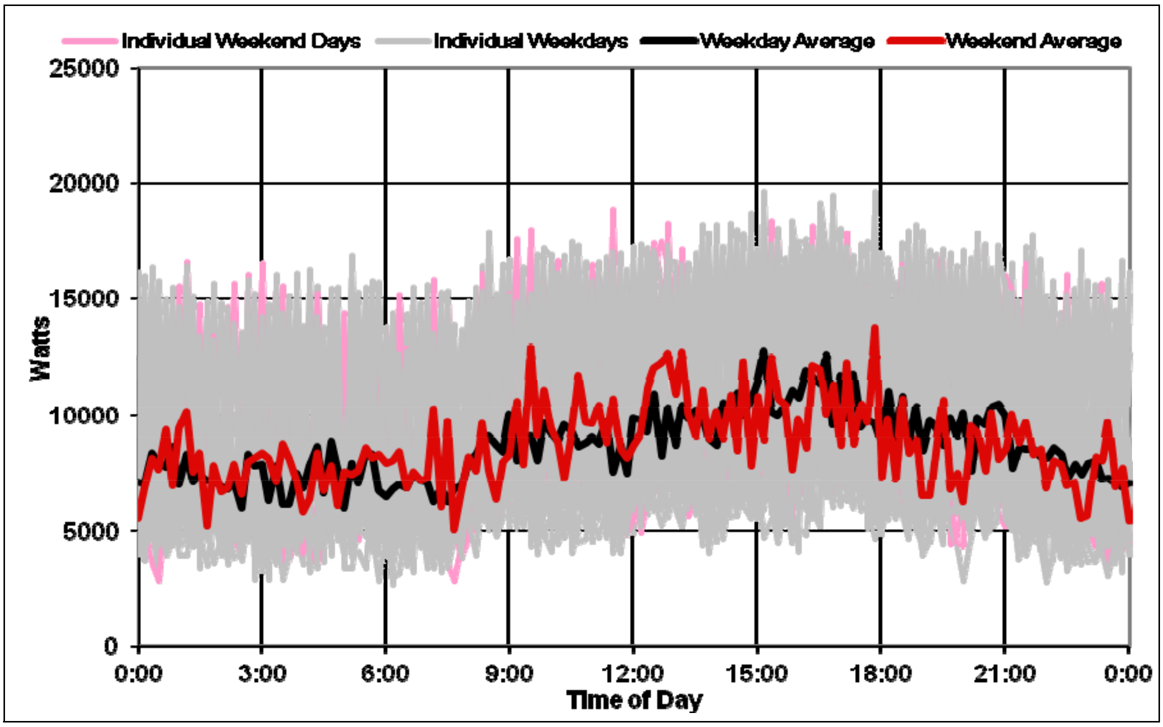


**Figure 15: Average Daily Total Electrical Load Profile for Liquor Store**

Observing the revenue data for this site shows that it is not temperature-dependent. This implies that the refrigeration systems are not operating efficiently, as theoretically their power demand should be proportional to temperature. There is an observed space heating load, but only about 5% as large as refrigeration, less than the expected variation of refrigeration loads with temperature.

The distribution of energy end-use loads is shown in Table 17 below, for this site.

**Table 17: Distribution of End-use Loads for Liquor Store**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** ($W/m^2$) | **EUI** ($kWh/m^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Hot Water | 1.3 | 494 | 4 | 2 | 373 |
| HVAC | 1.8 | 5,168 | 6 | 17 | 2,849 |
| Lighting | 2.0 | 6,778 | 7 | 23 | 3,322 |
| Other Loads | 3.9 | 7,514 | 13 | 25 | 1,945 |
| Refrigeration | 21.3 | 99,659 | 72 | 334 | 4,673 |
| **Total** | | **119,613** | | **401** | |

Figure 16 shows the average weekday electrical load. The refrigeration load is not only the largest load, it also does not vary greatly across the day. The daytime use of lighting and HVAC can be clearly seen.

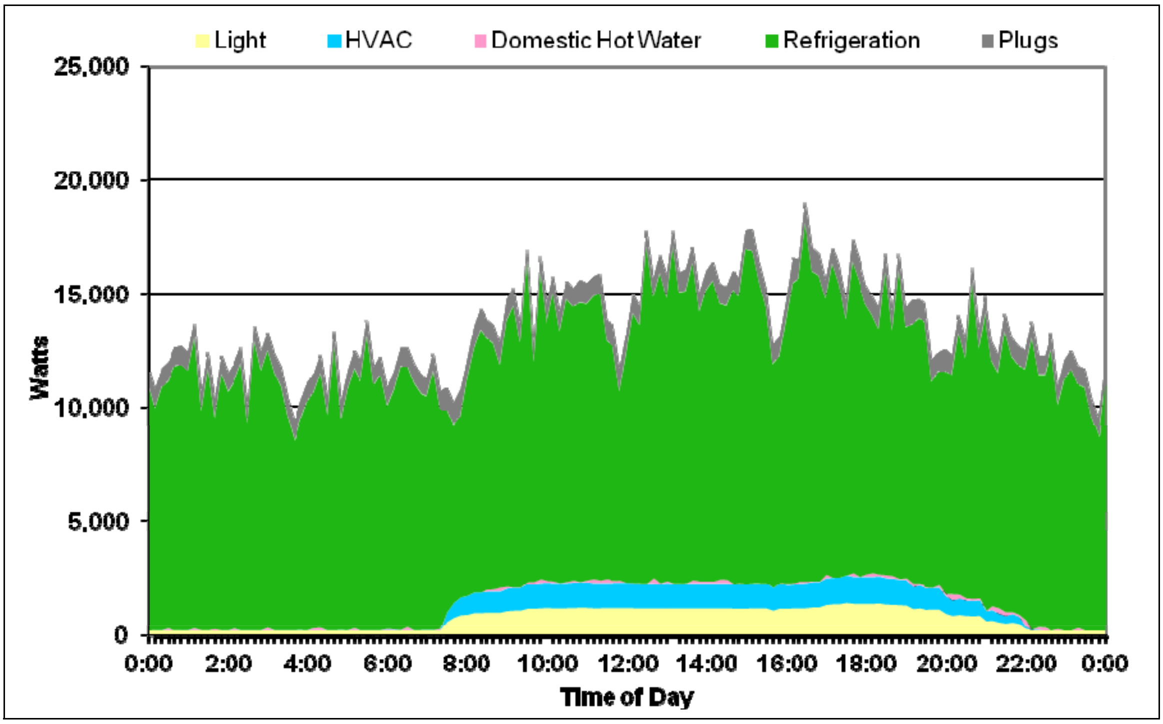


**Figure 16: Liquor Store Average Weekday Electrical Load**

## 4.5 Butcher Shop – 777 kWh/m$^2$ (EUI)

This premise was a retail butcher shop, where food was prepared, stored and sold. The floor area of the premises was 216 m$^2$. During a normal working day there were around 18 people occupying the premises, which is equivalent to an average of 12 m$^2$/person.

The space was rather poorly space-conditioned. The temperature did get up to 30°C during the monitored period in the public area, however the temperatures in other areas of the premise were cooler.

The electrical load pattern was very constant day-to-day, as shown in Figure 17, below.

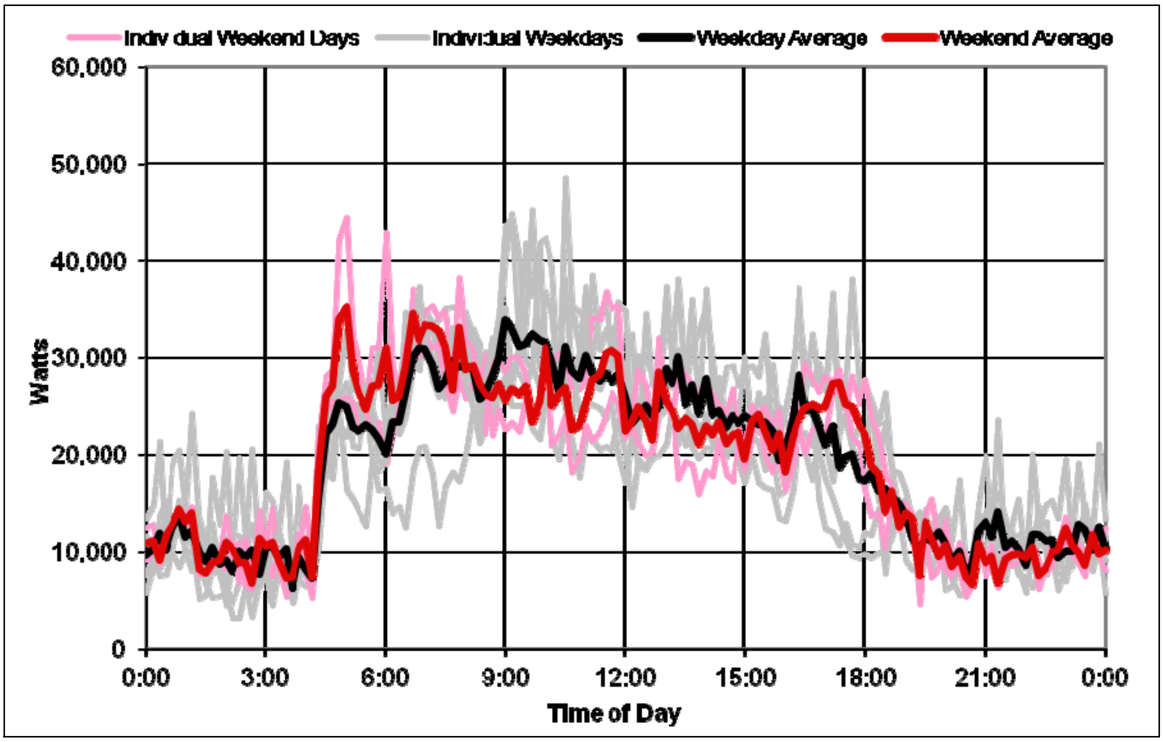


**Figure 17: Average Daily Total Electrical Load Profile for Butcher Shop**

The distribution of energy end-use loads is as shown in Table 18 below, for this site. This site also includes an end-use called "Other" which accounts for a refrigerated shipping container "temporarily" parked on site to give more food storage space. The monitoring was done not long before Christmas which was a particularly busy time for the store.

**Table 18: Distribution of End-use Loads for Butcher Shop**

| **End-use** | **Peak Load** (kW) | **Energy Use** (kWh/Yr) | **Peak Load Density** (W/m$^2$) | **EUI** (kWh/m$^2$) | **Full Load Hours per Year** (FLH/Yr) |
|---|---|---|---|---|---|
| Lighting | 2.4 | 10,512 | 11.2 | 49 | 4,333 |
| Other Loads | 8.9 | 27,591 | 41.3 | 128 | 3,092 |
| Refrigeration | 13.3 | 61,513 | 61.5 | 285 | 4,632 |
| HVAC | 5.8 | 32,151 | 26.9 | 149 | 5,533 |
| Hot Water | 5.7 | 9,065 | 26.3 | 42 | 1,594 |
| Cooking | 11.6 | 9,544 | 53.9 | 44 | 819 |
| Other | 10.7 | 17,531 | 49.4 | 81 | 1,641 |
| **Total** | | **167,905** | | **777** | |

*Totals may not add due to rounding.

# 5. CONCLUSIONS

The work reported in this document was driven by a need to understand why some of the BEES monitored premises had very low, or very high, EUI. Initially there was a concern that the monitoring had not collected data on all energy uses or that anomalous businesses had been selected. This report has shown that the monitoring was comprehensive and that a range of reasons for very high or very low EUI could be found.

A comparison of premise's total energy use runs the risk of size overwhelming any load-driven variation – large floor area premises would be expected to use more energy than small floor area premises. For this reason, comparing the energy use of different premises is often done by the use of Energy Use Intensity (EUI), defined as the annual total energy purchased by that site, divided by the assigned floor area. This allows comparisons of premises of different sizes, which is usually the largest determinant of the differences in energy use between different premises.

Work done to date in BEES has shown that the range of EUIs observed is much wider than that previously experienced for New Zealand premises.

This report analyses some of the highest and lowest EUI premises to determine the characteristics of these premises that cause such low or high per square metre energy use.

The analysis has shown that variation in premise use results in some buildings having a higher or lower EUI. While the previous experience (showing EUIs generally in the range 100-250 kWh/m$^2$) was for relatively large offices, operated a consistent number of hours each week and with relatively well-controlled space conditions (temperature, illuminance and air quality), the BEES premises show anomalously low EUIs were smaller, occupied by fewer people for fewer hours and often poorly space conditioned.

The BEES premises with anomalously high EUIs were invariably associated with food handling (cooking and/or refrigeration), so their high process loads caused the high energy use. It has been shown that in all premises concerned with selling food (restaurant, fish and chips shop, supermarket and liquor store) the refrigeration plant is operating for far longer hours than the cooking equipment. This may be due to undersized refrigeration plant having to operate for long hours to achieve the desired conditions, poor control, poorly-insulated storage areas or some other cause. This may offer opportunities for significant energy and cost savings.

Space conditioning was, in general, poor. Temperatures and $CO_2$ levels fluctuated even in some of the high EUI premises.

Overnight energy use also appeared to be higher than required, suggesting there may also be opportunities for improved energy efficiency, whether by improved controls or by replacement with more efficient equipment.

What was interesting was the absence of offices from the very low or very high EUI. While retail premises can be expected to have a wide variable in EUI, the extremes may offer lessons for the more moderate energy using retail premises.

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