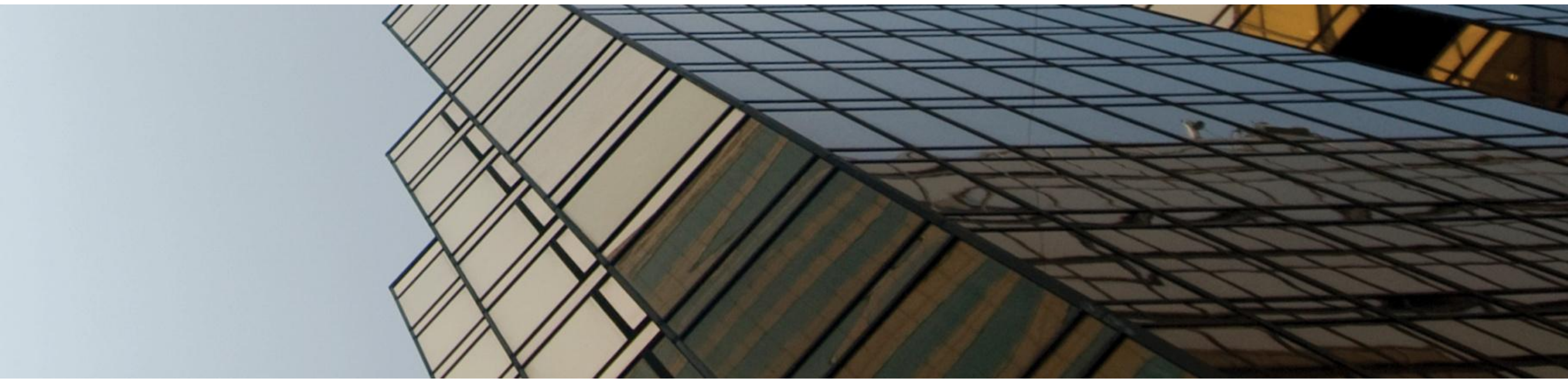
BRANZ



STUDY REPORT SR 260/6 [2011]

BEES INTERIM REPORT

Building energy end-use study - Year 4

ELECTRICAL LOADS

Rob Bishop

Funded by BRANZ from the Building Research Levy

ministry of science + innovation
TE PŪNAHA HIRINGA WHAKAEA

Department of Building and Housing
Te Tari Kaupapa Whare

EECA Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

ISSN: 1179-6197

BEES (BUILDING END-USE STUDY) YEAR 4: ELECTRICAL LOADS

BRANZ Study Report SR 260/6

Rob Bishop – Energy Solutions

Reference

Bishop, R. (2011). BEES (Building energy end-use study) Year 4: Electrical loads, BRANZ study report 260/6, Judgeford.

energy solutions

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

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

- Saville-Smith, K. (2011). BEES (Building energy end-use study) Year 4: Insight into barriers, BRANZ study report 260/1, Judgeford.
- Camilleri, M., & Babylon, W.M (2011). BEES (Building energy end-use study) Year 4: Detailed monitoring, BRANZ study report 260/2, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Delivered daylighting, BRANZ study report 260/3, Judgeford.
- Bishop, R., Camilleri, M & Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: Achieved conditions, BRANZ study report 260/4, Judgeford.
- Bishop, R., Camilleri, M. & Burrough, L. (2011). BEES (Building energy end-use study) Year 4: Temperature Control, BRANZ study report 260/5, Judgeford.
- Isaacs, N. (2011). BEES (Building energy end-use study) Year 4: From Warehouses to Shops - Changing Uses in the Non-residential Buildings Sector, BRANZ study report 260/7, Judgeford.

PREFACE

Understanding how energy and water resources are used in non-residential buildings is key to improving the energy and water efficiency of New Zealand's building stock. Buildings that are more efficient 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, BEES aims 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 1-4.

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

This report presents data and analysis drawn from the detailed monitoring carried out during the fourth year of this six year study. This report looks at the variability in electrical usage density and patterns in the premises studied. Understanding the variability in loads is valuable for efficient electrical wiring in buildings and for electricity supply planning. The data and analysis in this report contributes to answering research questions four to six. This is one of seven interim reports giving a snapshot of analysis completed to date. When all data collection has been completed further analysis will be reported on with the full sample including relationships between end-uses, building types and services.

At this stage of the project, not all the data we need to fully answer the research questions is available. This report only provides analysis and results on buildings less than 9,000 m^2 (size strata 1-4 of the BEES sample). It does not cover the full range of buildings sizes, so these results are not representative of the non-residential building stock. In the remaining two years of the BEES study, further analysis will be carried out using the full sample, which will include buildings greater than 9,000 m^2. Other work that is planned in this area is analysing heating and cooling loads of buildings separately to gain a greater understanding of the causes of variability of electricity demand in buildings.

SUMMARY

- Peak (maximum) and minimum electrical loads have been analysed and results presented for the BEES buildings measured from 2009 to 2011
- A high peak load factor means the electricity use is steady; a low load factor means there is large variation in the electricity use
- Peak electrical loads determine the electrical distribution equipment required in a building.
- Once the detailed monitored is complete on buildings over 9,000 m^2 further analysis will be completed. Heating and cooling loads will be separated, as these loads are typically large and are expected to have an effect on the variability of electrical loads.

This Topic Report presents the analysis of the peak and minimum electrical loads recorded at premises measured during BEES from 2009 to 2011. All premises measured during this time have a floor area of less than 9,000 m^2.

Peak electrical loads are important in building design, as they determine the amount of electrical distribution equipment that must be installed in a building. They are also important to electricity system planners, due to the need for power distribution systems to be able to cope with maximum demands.

For energy auditors, the consistency of the peak loads is important in understanding the dynamics and causes of energy use in buildings.

In larger buildings, weekday electrical loads are normally assumed to vary very little. The ratio of overnight minimum electrical loads to working day peak demands (which we define as Minimum Load Ratio, or MLR) is a measure of how efficient a building is at minimising its loads when the building is not operating. This may show opportunities for savings on the base loads.

Sites with low load factors (high variation in their daily electricity use) will require more wiring capacity, and usually will be charged higher network tariffs relative to their energy purchases because of their high peak loads.

Peak Load Densities (Peak watts per square metre) were under 100 W/m^2 in all premises over 500 m^2. About 5% of the smallest premises had peak load densities of 200 W/m^2 or more.

Load factors were analysed. The “24-hour Peak Load Factor” (24 PLF) was generally low meaning there was high variation in the electricity use over a 24 hour period. Ninety percent of premises were measured under 0.4, over 50% under 0.25, and over 20% under 0.15. However, all the 24 PLFs below 0.2 were for small premises, or those with unusually high Peak Load Densities.

The consistency of weekday (10 am – 4 pm) loads was analysed, via both standard deviation and Weekday Average Load Factor (WD ALF). Except for some small sites, the consistency of weekday loads

was generally good. The largest sites had the most consistent weekday loads, with standard deviations under 15% and WD ALFs over 0.8.

The scale of the overnight loads was examined, using the Minimum Load Ratio (MLR). The median MLR was 0.15. The largest sites had relatively high overnight loads, with MLRs of 0.35 to 0.45.

CONTENTS

FIGURES

GLOSSARY

Load Factor - the ratio of the average load to the peak load (over some time frame) Load factor is a dimensionless factor that is between 0 and 1, and an indicator of how steady an electrical load is over time. A high load factor means the electricity use is steady; a low load factor means there is a lot of variation in the electricity use over time.

In this report we examine two types of load factor: one over 24 hours, and the other over the 10 am – 4 pm weekday core hours.

24-hour Peak Load Factor (24 PLF) = 24-hour average electrical load divided by 24-hour Absolute Maximum recorded electrical load. (NB: this is the most commonly used load factor, by electrical network and building designers).

Weekday Average Load Factor (WD ALF) = Weekday (10 am – 4 pm) average electrical load divided by the Weekday (10 am – 4 pm) Average Maximum [the average of daily maxima] recorded electrical load. (NB: a similar effect was determined by examining the standard deviation of the set of measurements of Weekday load).

Weekday Peak Load Factor (WD PLF) = Weekday (10 am – 4 pm) average electrical load divided by Weekday (10 am – 4 pm) Absolute Maximum recorded electrical load.

Minimum Load Ratio (MLR) - the 24-hour Average Minimum electrical load [the average of daily minima] divided by the Weekday (10 am – 4 pm) average electrical load. It is a measure of how efficient a building is at minimising its loads when the building is not operating.

Peak Load Density - the recorded peak electrical load divided by the floor area that is served, is one of the best methods of normalising peak loads. The resulting value is expressed in watts per square metre.

1. INTRODUCTION

This Topic Report presents the analysis of the maximum and minimum electrical loads recorded at premises measured during BEES from 2009 to 2011. All premises measured during this time have a floor area of less than 9,000 m^2.

Peak electrical loads are important in building design, as they determine the amount of electrical distribution equipment that must be installed in a building. They are also important to electricity system planners, due to the need for power distribution systems to be able to cope with maximum demands.

For energy auditors, the consistency of the peak loads is important in understanding the dynamics and causes of energy use in buildings.

In larger buildings, weekday electrical loads are normally assumed to vary very little. The ratio of overnight minimum electrical loads to working day peak demands (which we define as Minimum Load Ratio, or MLR) is a measure of how efficient a building is at minimising its loads when the building is not operating. This may show opportunities for savings on the base loads.

Sites with low load factors (high variation in their daily electricity use) will require more wiring capacity, and usually will be charged higher network tariffs relative to their energy purchases, compared to sites with higher load factors.

Peak Load Densities (Peak watts per square metre) were under 100 W/m^2 in all premises over 500 m^2. About 5% of the smallest premises had peak load densities of 200 W/m^2 or more.

Load factors were analysed. The "24-hour Peak Load Factor" (24 PLF) (defined in glossary) was generally low. Ninety percent of premises were measured under 0.4, over 50% under 0.25, and over 20% under 0.15. However, all the 24 PLFs below 0.2 were for small premises, or those with unusually high Peak Load Densities.

The consistency of weekday (10 am – 4 pm) loads was analysed, via both standard deviation and Weekday Average Load Factor (WD ALF). Except for some small sites, the consistency of weekday loads was generally good. The largest sites had the most consistent weekday loads, with standard deviations under 15% and WD ALFs over 0.8.

The scale of the overnight loads was examined, using the Minimum Load Ratio (MLR). The median MLR was 0.15, meaning that overnight minimum loads were about 15% of the weekday averages. The largest sites had relatively high overnight loads, with MLRs of 0.35 to 0.45.

2. ANALYSIS OF THE INITIAL BEES DATA

This report analyses time series of whole-facility electrical loads recorded during the BEES detailed monitoring, for maximum and minimum loads.

One of the best methods of normalising peak loads is by dividing the recorded peak load by the floor area that is served. The resulting value is the Peak Load Density in watts per square metre.

There are sixty premises with good electrical load and floor area data recorded during the detailed monitoring process, in this stage of BEES. The distribution of Peak Load Densities, in watts per square metre, is shown in the following graph (Figure 1).

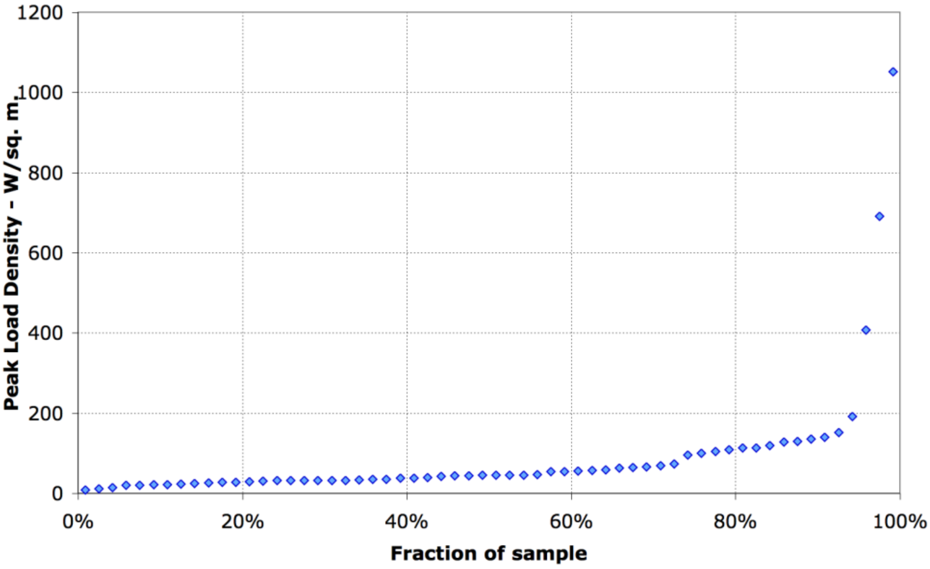


Figure 1: All peak load densities, in increasing order

As can be seen, about 95% of the measured Peak Load Densities are under 200 W/m^2, which is typical electrical system sizing for buildings. The top three range from 400 to over 1,000 W/m^2

Figure 2 shows the same distribution, but limited to the loads under 200 W/m^2

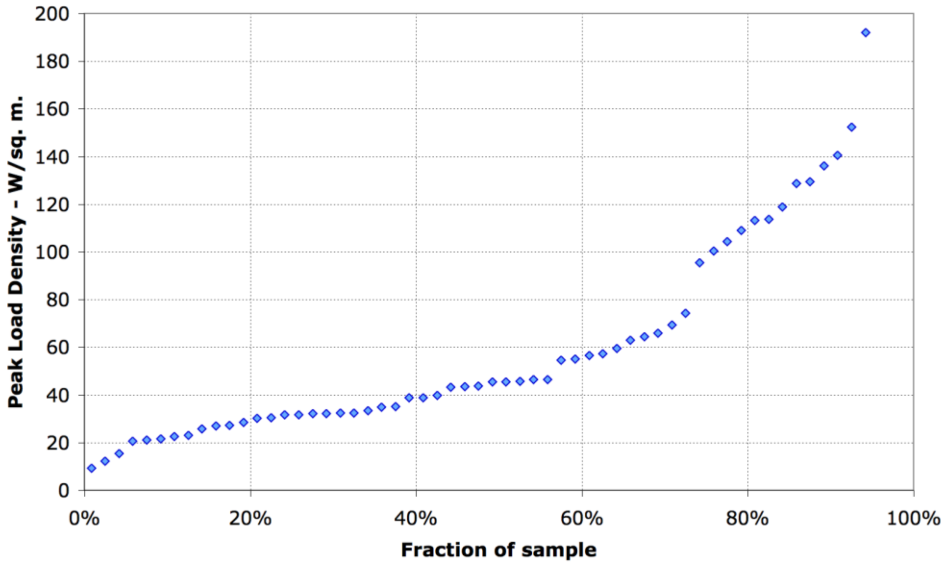


Figure 2: Peak load densities under 200 W/m², in increasing order

As can be seen in Figure 2, over half of the Peak Load Densities were measured at less than 50 W/m². The relevance of this is to support the many anecdotal stories of buildings that have significantly oversized electrical distribution systems (as well as oversized heating and cooling systems).

On the other hand, the top 5% of premises monitored to date with relatively high Peak Load Densities, could potentially have problems in undersized electrical distribution.

Figure 3 shows a chart of Peak Load Density versus floor area in square metres. As can be seen, for floor areas greater than about 500 m², the maximum Peak Load Density is about 100 W/m².

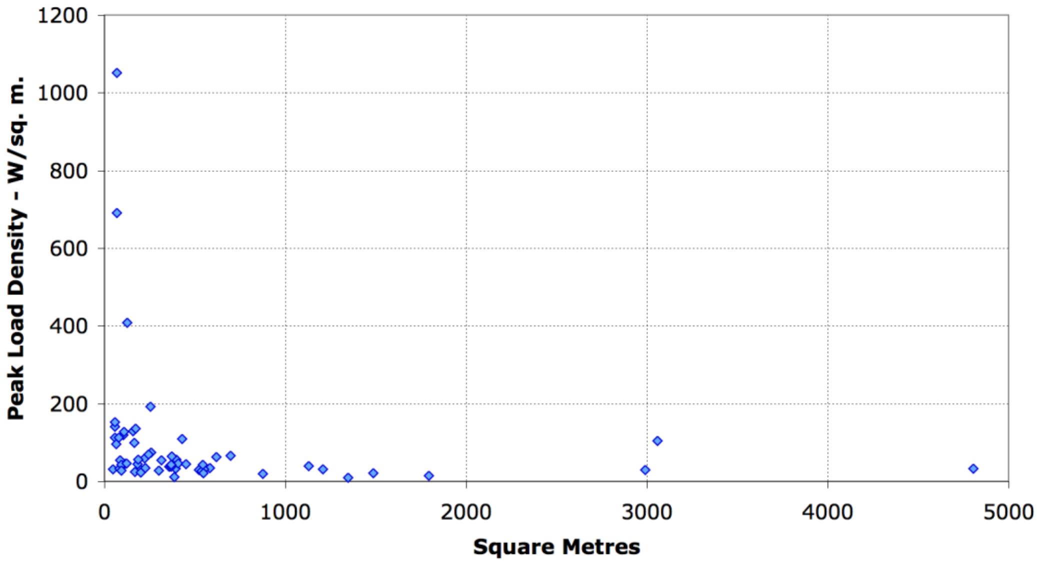


Figure 3: Peak load densities vs. Recorded floor area

The monitored results show that the high Peak Load Densities only occur in relatively small premises, presumably where there are unusual concentrations of electrical load.

Figure 4 shows the Peak Load Densities for the facilities under 1,000 square metres in more detail. As can be seen, the three unusually high Peak Load Densities are all for premises with floor areas under 150 m^2.

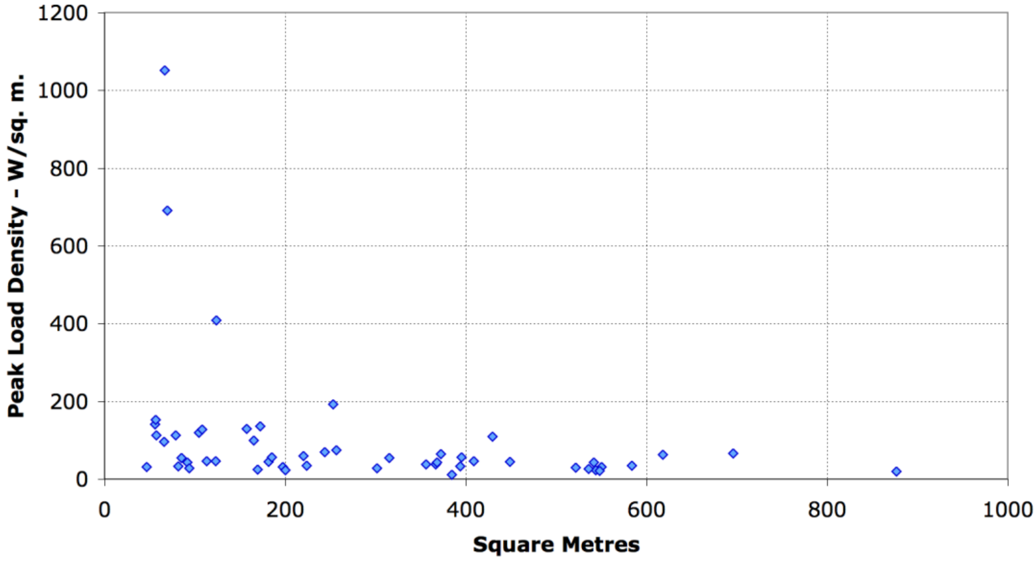


Figure 4: Peak load densities vs. Recorded floor area (lower areas)

Figure 5 shows the prevalence of high Peak Load Densities. It plots the Peak Load Density for each facility against the recorded peak load in kW.

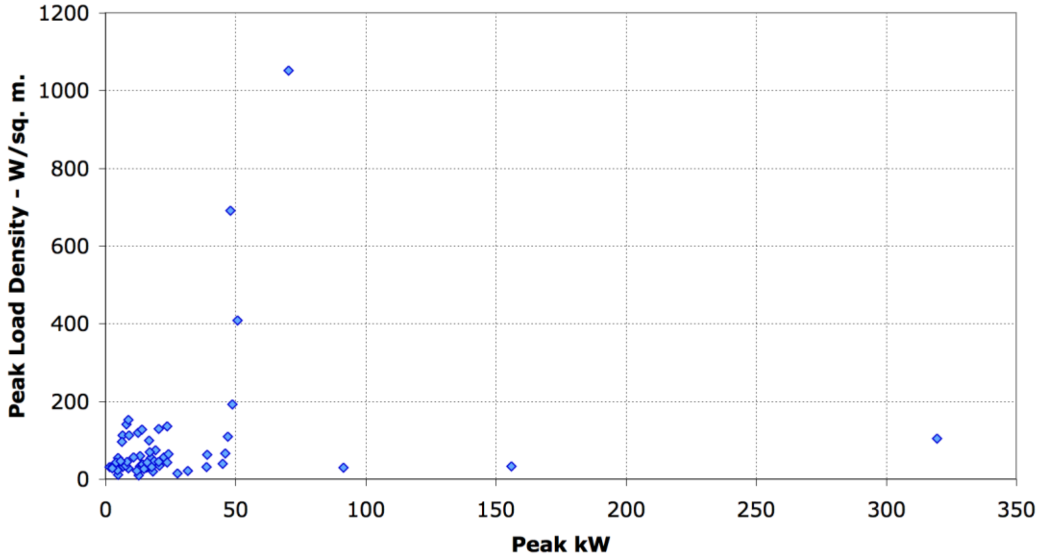


Figure 5: Peak load densities vs. Peak loads

As can be seen in Figure 5, the relatively small floor areas of the premises with high Peak Load Densities means that resulting absolute peak loads are not unusually high. All three of the high Peak Load Densities are associated with absolute peak loads of 70 kW or less.

3. CONSISTENCY OF LOADS

The consistency of electrical loads is also analysed and reported here. This is usually calculated as the "Load Factor", the ratio of the average load to the peak load (over some time frame).

These Load Factors are dimensionless numbers ranging from close to zero (for a facility where loads are near zero most of the time, with a single peak), to unity (for a facility with a completely constant load). In practice, only electric energy-intensive facilities with 24 hour operation, like some computer data centres, have load factors over about 0.8.

For this analysis, we define several types of load factors:

24-hour Peak Load Factor (24 PLF) = 24-hour average electrical load divided by 24-hour Absolute Maximum recorded electrical load.

This shows the consistency of loads over a full 24-hour day. This 24 PLF is what is typically reported as the "load factor" for electrical installations.

Weekday Average Load Factor (WD ALF) = Weekday (10 am – 4 pm) average electrical load divided by Weekday (10 am – 4 pm) Average Maximum [the average of daily maxima] recorded electrical load.

This shows the consistency of weekday loads, which are normally the highest loads. WD ALF values approaching 1.0 show very consistent weekday loads.

Weekday Peak Load Factor (WD PLF) = Weekday (10 am – 4 pm) average electrical load divided by Weekday (10 am – 4 pm) Absolute Maximum recorded electrical load.

This again shows the consistency of weekday loads. WD PLF values will be lower than WD ALF, as this load factor uses the single highest recorded peak, instead of the average of the highest daily peaks.

Minimum Load Ratio (MLR) = 24-hour Average Minimum electrical load [the average of daily minima] divided by Weekday (10 am – 4 pm) average electrical load.

This value shows how low the (typically overnight) minimum load goes, compared to the weekday average load. In contrast to the other load factors, a lower MLR usually indicates a more efficient operation, as this indicates lower loads when the facility is less used.

3.1 Consistency of Loads – 24 hr Peak Load Factors

Figure 6 shows the distribution of measured 24 PLFs from the initial BEES premises.

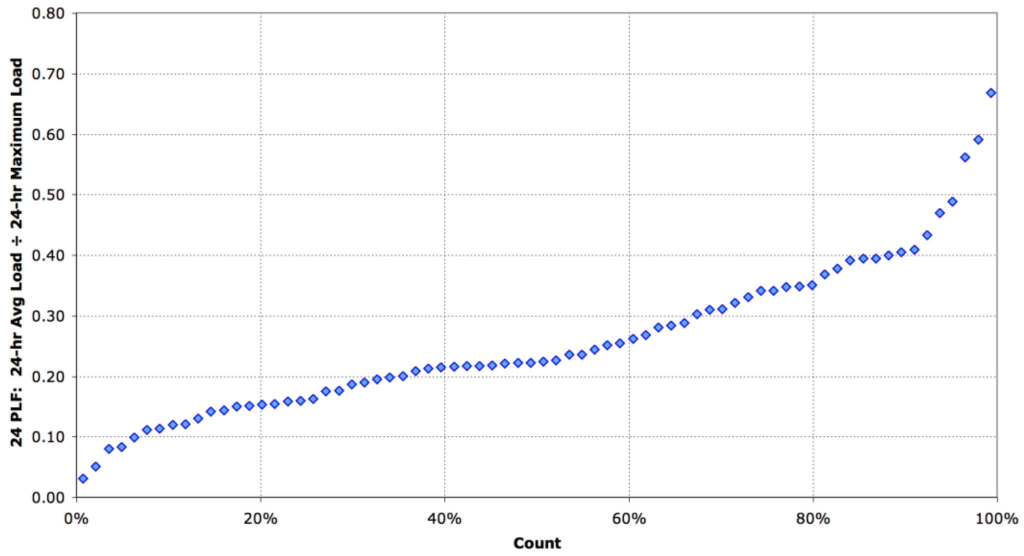


Figure 6: 24 PLF (24 hour Peak Load Factor) distribution

As can be seen from Figure 6, most of the premises monitored to date in BEES have low (24 PLF) load factors. Ninety percent of premises are under 0.4, over 50% are under 0.25, and over 20% are under 0.15.

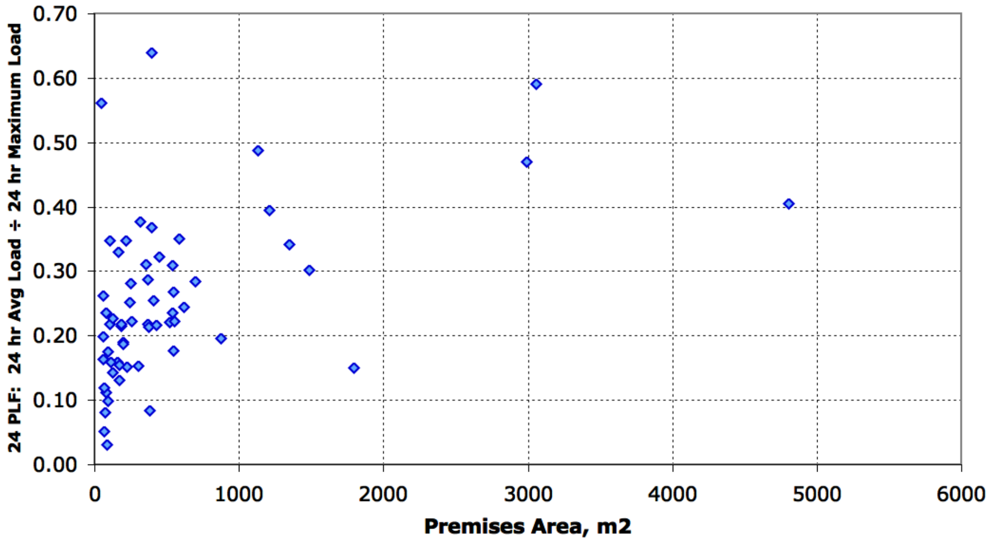


Figure 7: 24 PLF (24 hour Peak Load Factor) vs. Premises floor area (m^2)

To see if the low load factors are related to the size of the premises, Figure 7 plots the 24 PLF versus the floor area of each premises.

As can be seen in Figure 7, almost all the low 24 PLFs occur in the smaller sites. Most of the sites with floor areas under 1000 m^2 had 24 PLFs under 0.3, and almost all the sites over 1000 m^2 had 24PLFs over 0.3. The one outlier site, of about 1800 m^2 with a 24 PLF value of 0.15, has one of the lowest peak power densities measured (15 W/m^2).

Similarly, Figure 8 plots the 24 PLF versus the peak electrical load for each site.

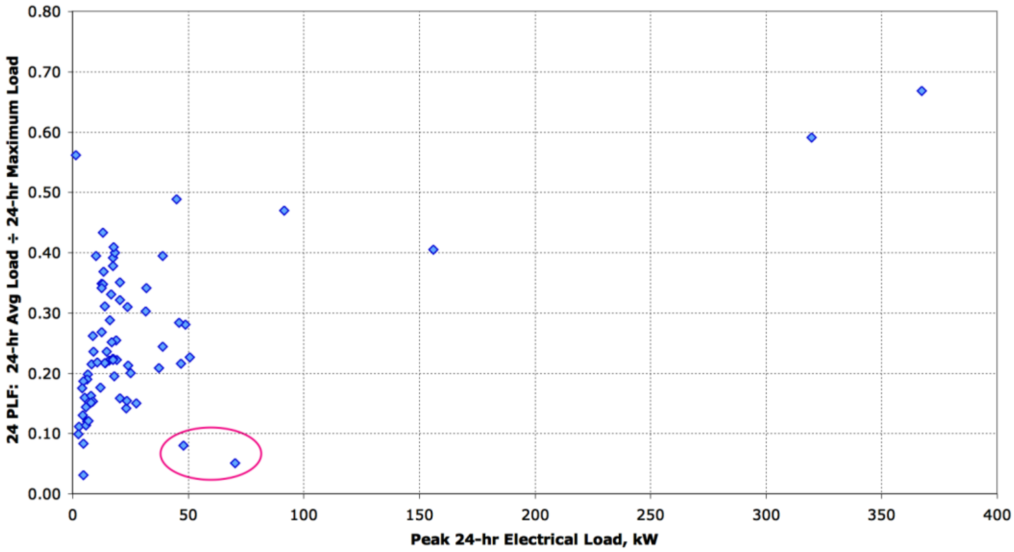


Figure 8: 24 PLF (24 hour Peak Load Factor) vs. Peak load

This graph also shows that all the low Peak Load Factors occur in sites with a low 24 peak load factor. Almost all of the sites with peak loads under 50 kW had 24 PLFs under 0.4, and all the sites over about 75 kW had 24 PLFs over 0.4. There were two outlier sites (circled), with peak loads of about 48 kW and 70 kW and 24 PLF values under 0.1, which are those with the unusually high peak power densities (over 600 W/m^2) in small areas (under 70 m^2) examined in a previous section. Other than those two, the only values for 24 PLF below about 0.2 are for premises with very small loads. Finally, Figure 9 plots the 24 PLF versus the peak electrical load density for each site.

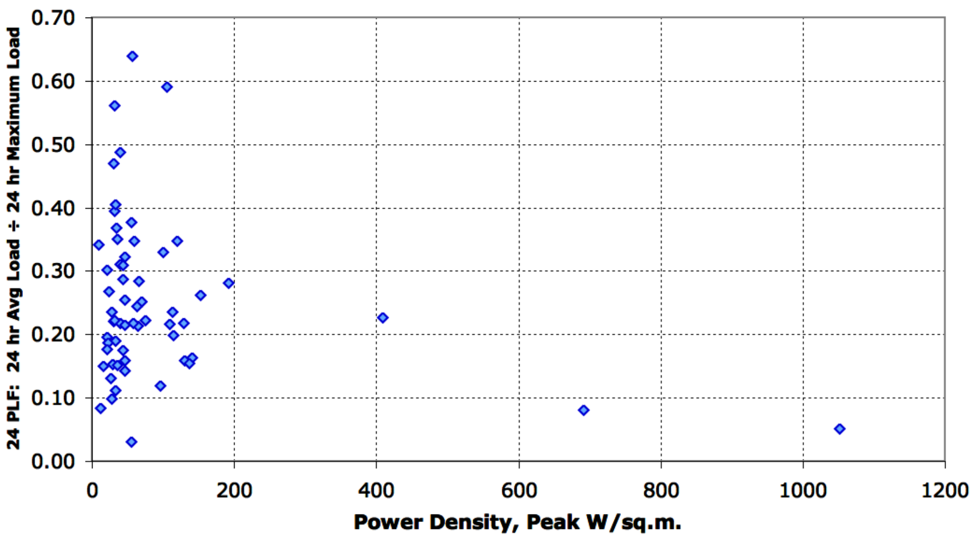


Figure 9: 24 PLF(24 hour Peak Load Factor) vs. Peak load density

3.2 Consistency of Loads – Weekday Load Variations

The consistency of the weekday electrical load is examined with two measures. The first is the standard deviation of the Weekday 10 am – 4 pm loads. Loads that are more consistent result in lower standard deviations (as a percentage of the average Weekday load). Many large offices have weekday loads that are almost constant, and would thus have very low standard deviations.

Figure 10 shows the distribution of standard deviations of the Weekday electrical load.

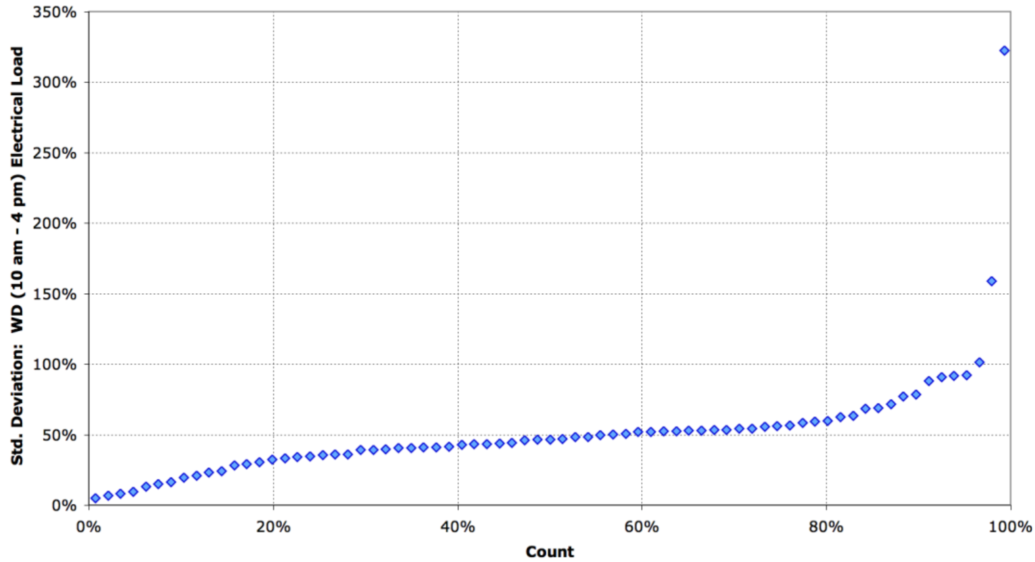


Figure 10: Distribution of Standard Deviations of WD load

As can be seen from Figure 10, about 5% of the distribution has standard deviations of over 100%, indicating widely varying loads. These loads are expensive to design for, because they are so "spiky" and sometimes require electrical supplies much higher than normal.

Figure 11 is a "close-up" of the values under 100%.

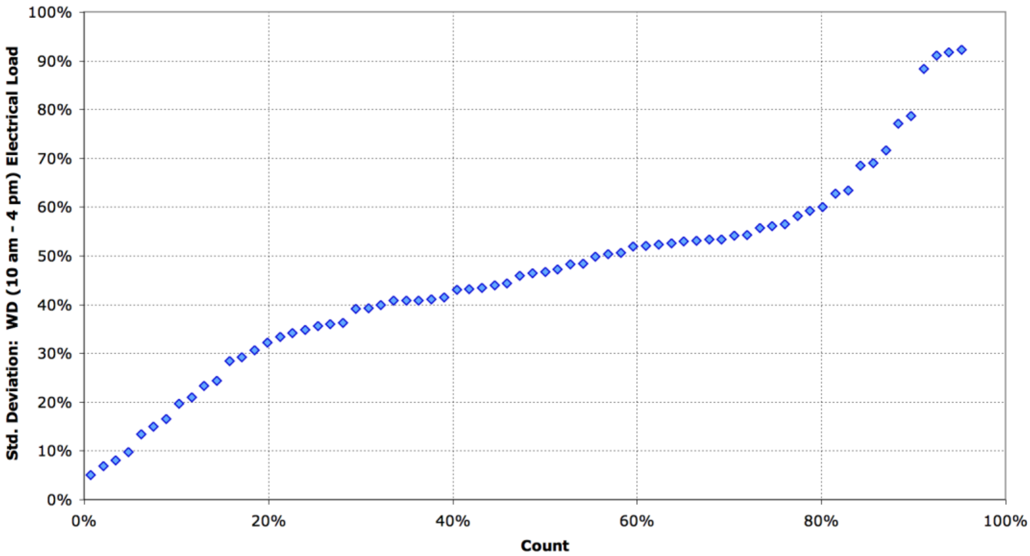


Figure 11: Distribution of Standard Deviations of WD load – Values <100%

Figure 11 shows the results for the majority of premises analysed. The ones with very low standard deviations are a minority, with only the lowest 10% showing standard deviations under 20% of their average load. However, almost 80% have standard deviations under 60% of their average load.

Figure 12 shows the Weekday standard deviations plotted against the measured Peak Electrical Loads for each site, to determine if the larger variations are occurring at the smaller sites.

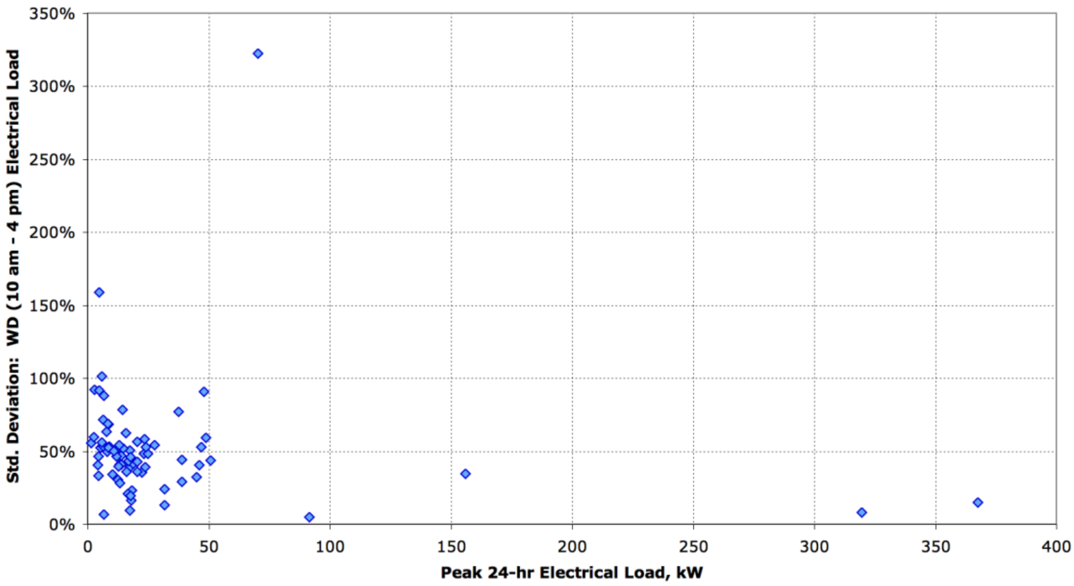


Figure 12: Standard Deviations of WD load vs. Peak electrical loads

Figure 12 shows that the sites with low 24 hour peak electrical loads are the ones with some of the smallest standard deviations in their weekday loads. The two sites with standard deviations over 100% include the site with the anomalously high load density, and another very small site. In general, the larger the site, the more consistent (smaller the standard deviation) of weekday load.

The second measure used to examine the consistency of the weekday load is the "Weekday Average Load Factor" (WD ALF) as defined above (the ratio of Weekday 10 am – 4 pm average load to Average Maximum load during the same time interval). This dimensionless factor is between 0 and 1. The closer the WD ALF is to 1, the more consistent is the load during this time interval.

Figure 13 shows the distribution of WD ALFs for this sample of BEES premises.

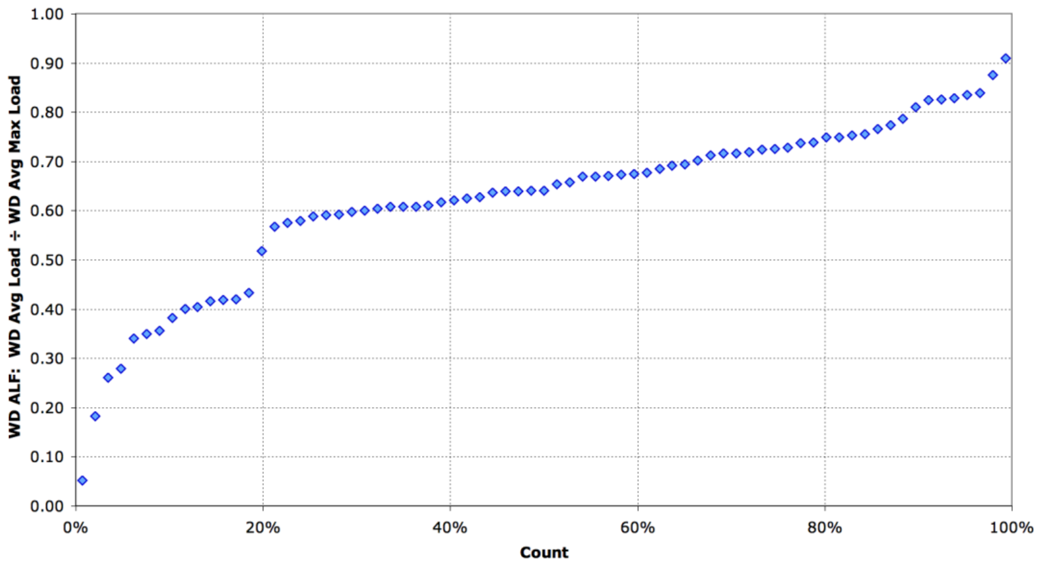


Figure 13: WD ALF (Weekday Average Load Factor) distribution

As can be seen from Figure 13, most of the WD ALFs for this sample of BEES premises are reasonably high. Almost 80% of the WD ALFs shown are over 0.55. The top 10% are over 0.80. This means that most Weekday loads are generally quite consistent.

Figure 14 shows the relationship of standard deviations of Weekday Electrical Load to WD ALFs for this sample of BEES premises.

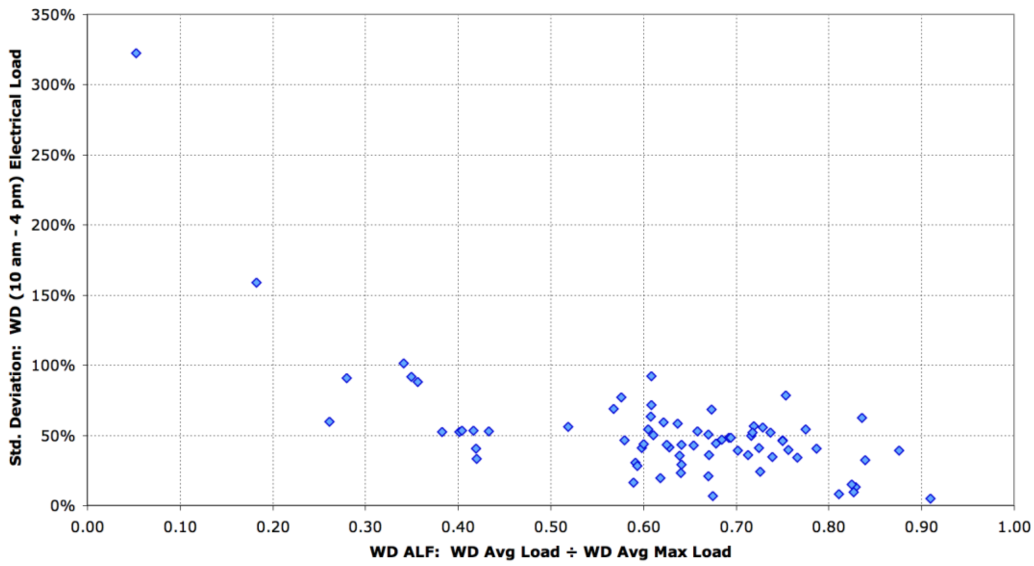


Figure 14: Standard deviations of WD load vs. WD ALF

As expected, the highest standard deviations generally correspond to the lowest WD ALFs, and the lowest standard deviations to the highest WD ALFs. However, there is not a straight-line relationship, as each factor is measuring a slightly different effect.

Figure 15 shows the WD ALFs plotted against the measured Peak Electrical Loads for each site, to confirm that the lowest WD ALFs are occurring at the smaller sites.

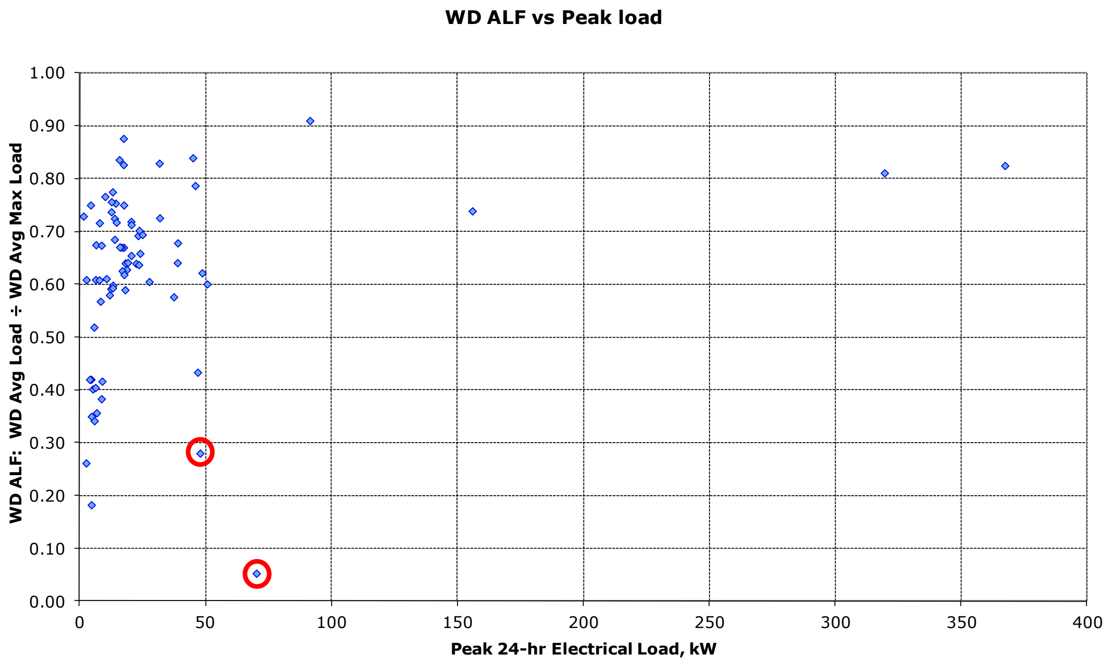


Figure 15: WD ALF (Weekday Average Load Factor) vs. 24 hour Peak load

As can be seen, with the exception of the two sites (in red circles) with unusual load densities (over 400 W/m^2) and peak loads of 48 and 70 kW, the WD ALF is usually over 0.6 for all, but the smallest sites.

This confirms that weekday loads are quite consistent, for all but the smallest, and highest power density sites.

Finally, Figure 16 plots the WD ALF for each BEES site against its 24 PLF (24 hour Peak Load Factor).

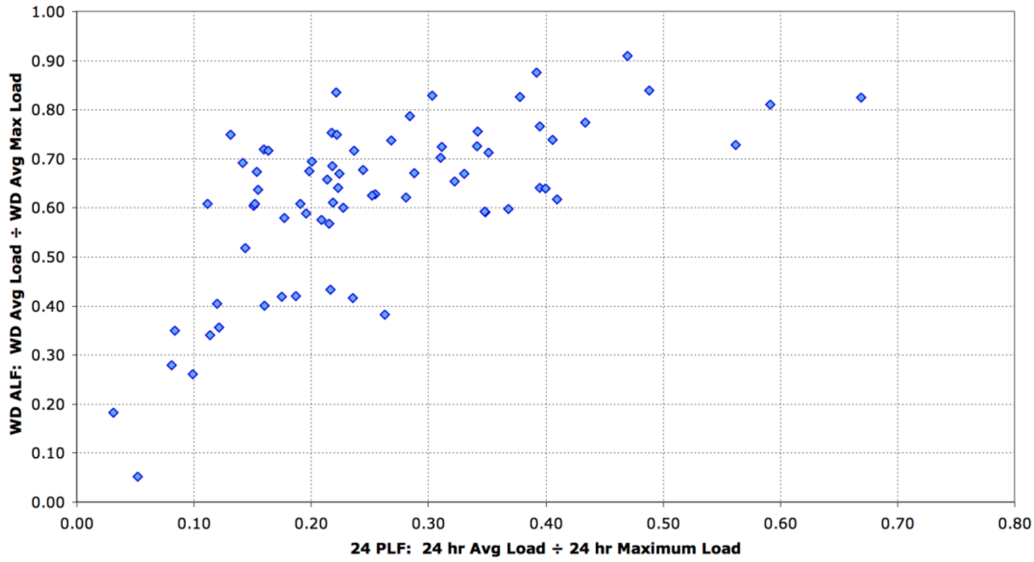


Figure 16: WD ALF (Weekday Average Load Factor) vs. 24 PLF

As can be seen from Figure 16, there is a good correlation between sites with high WD ALF values (so consistent weekday electrical loads) and those with high 24 PLFs (so high overall load factors).

3.3 Consistency of Loads – Variations between Workday and Overnight

The overnight loads of premises are often sources of cost-effective energy savings, as most premises are unoccupied at night, so the loads could theoretically be very low. There are no commonly accepted benchmarks for how low overnight loads would be in efficiently operated premises.

In this report, we examine the Minimum Load Ratio (MLR), which is defined as the ratio of the overnight minimum electrical load [the average of daily minima] to the Weekday (10 am – 4 pm) average load. In efficiently operated premises, where overnight loads are very low compared to weekday loads, this ratio would be low.

Figure 17 shows the distribution of observed MLRs for this sample of BEES premises.

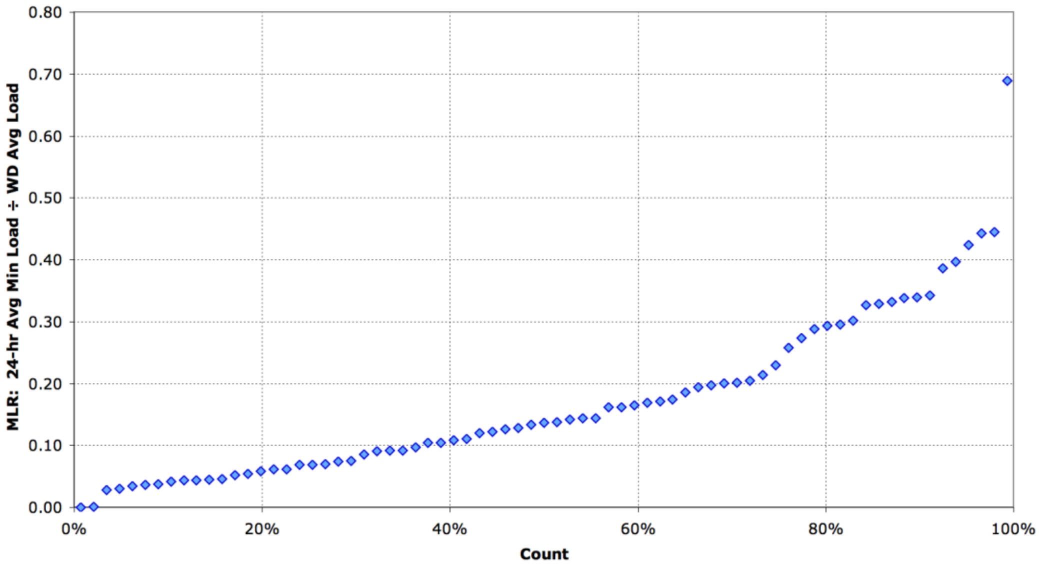


Figure 17: MLR (Minimum Load Ratio) Distribution

As can be seen, the median MLR is about 0.15. About 70% of recorded MLRs are below 0.2, and only the highest 10% are above 0.35. Two of the MLRs were close to zero, with average overnight recorded minimum loads in these premises of under 20 watts!

Figure 18 plots the MLR versus the 24-hr Peak Load Factor (24 PLF). These two factors may be related, although different effects influence them.

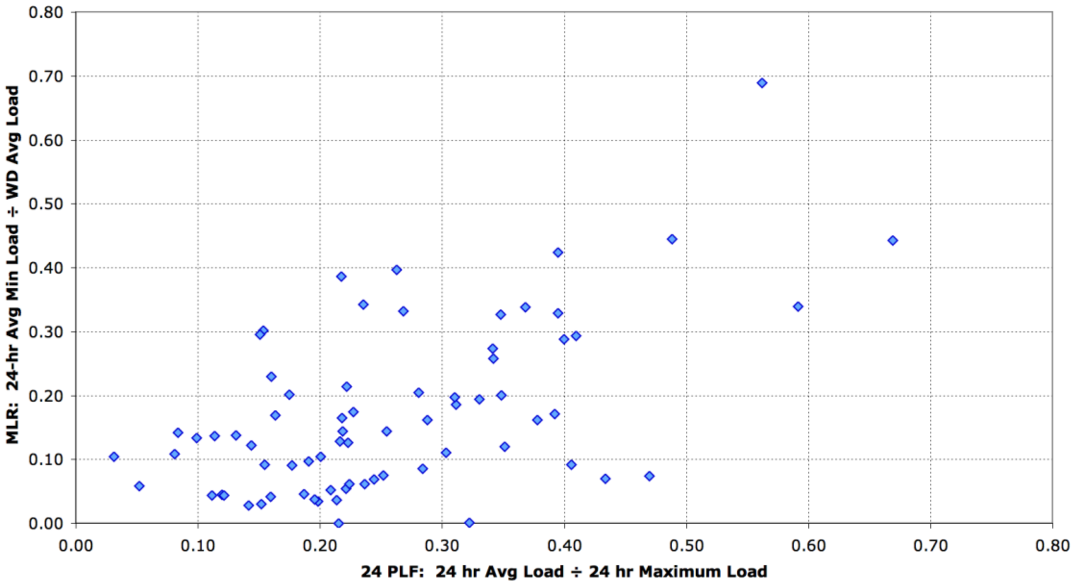


Figure 18: MLR (Minimum Load Ratio) vs. 24 PLF

As can be seen, there is a slight correlation between MLR and 24 PLF, though there is a significant amount of scatter. Theoretically, a facility could have both a low MLR (if it had a very low daily average minimum load, even if for a very short time) and a high 24 PLF (if most of the time its load was very consistent).

Figure 19 plots the plots the MLR versus the premises floor area, to show how the MLR relates to the size of a facility.

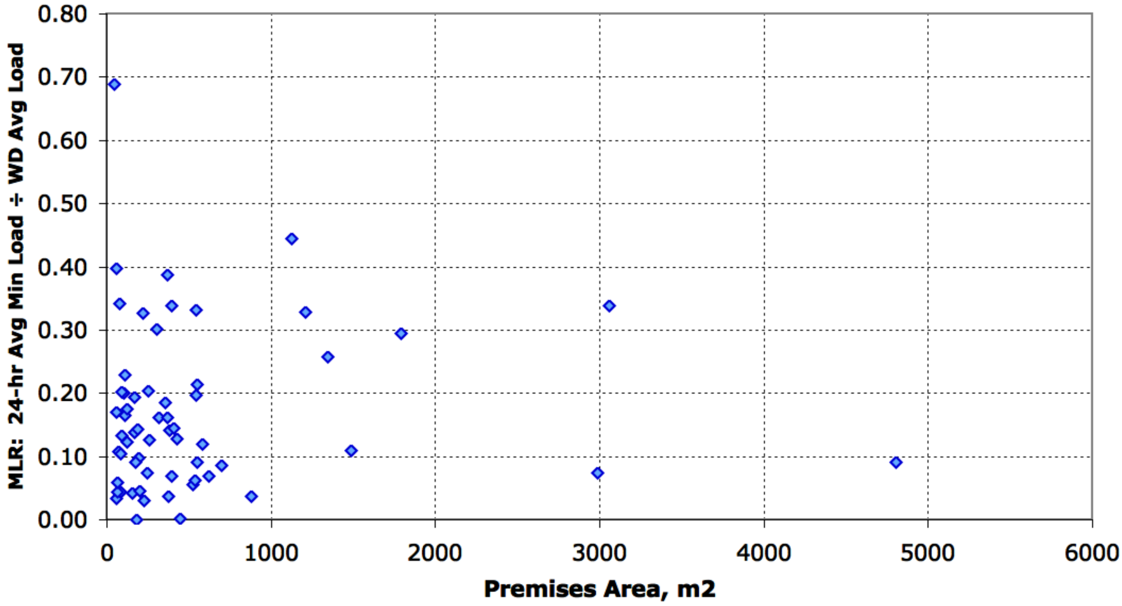


Figure 19: MLR (Minimum Load Ratio) vs. Premises floor area

The most outstanding feature of this chart is the scatter that exists throughout the range of floor areas, though the smallest sites (under about 500 m^2) appear to have a higher concentration of low MLRs, averaging about 0.15.

Likewise, Figure 20 plots the MLR versus the measured 24 hr Peak Load, to see how the MLR relates to the (electrical) size of a facility.

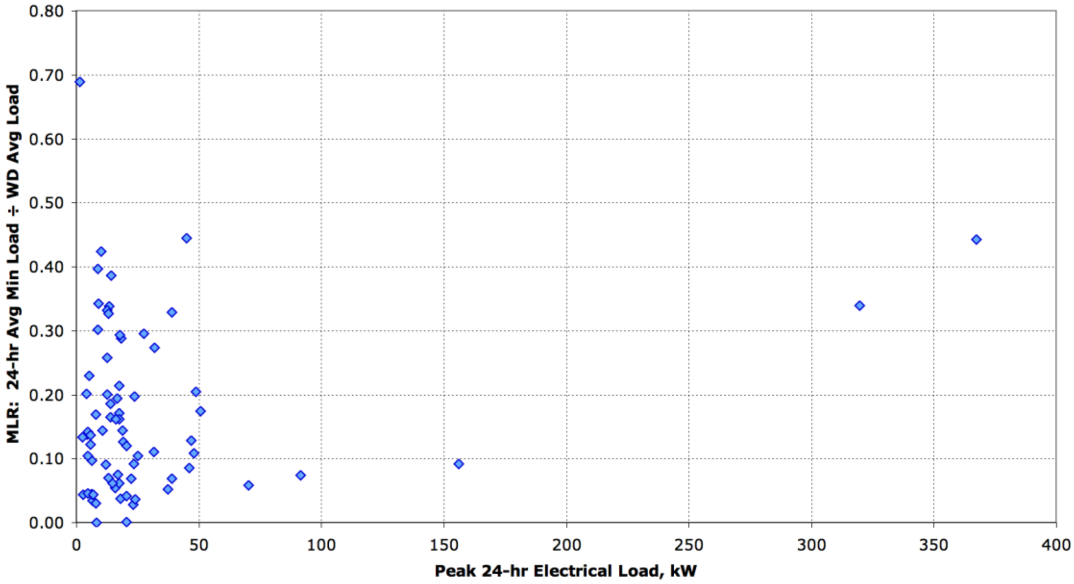


Figure 20: MLR (Minimum Load Ratio) vs. 24 hour Peak Load, kW

As can be seen from Figure 20, there is a wide variance in the MLR values for very small premises, those with peak loads between about 50 and 250 kW show MLRs under 0.10 (so good overnight operation), and the premises with loads over about 300 kW have higher MLRs, above 0.3.

Finally, Figure 21 plots the MLR versus the Peak Electrical Load Density, to see how the MLR relates to the (electrical) size of a facility.

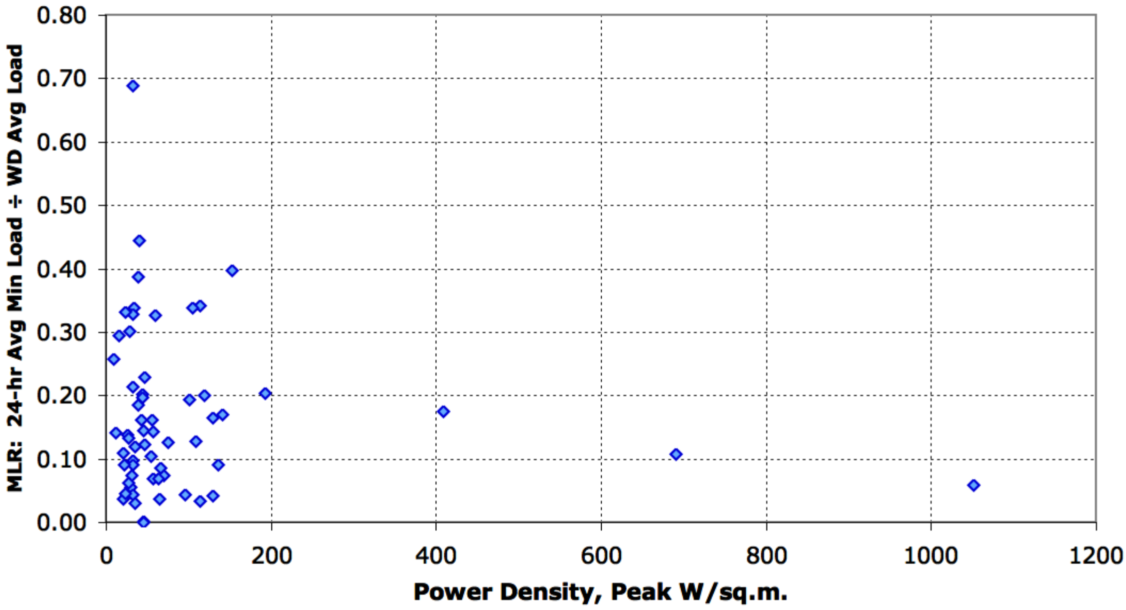


Figure 21: MLR (Minimum Load Ratio) vs. Peak Load Density, W/m²

As can be seen from Figure 21, there does appear to be a correlation between Peak load density and MLR, such that the premises with the highest power densities have the lowest MLRs. All the premises with Peak Densities above about 200 W/ m^2 have MLRs of under 0.2. This shows that these high-power-density sites have almost there entire load switched off for at least part of the time.

4. NEXT STEPS

This is an interim report covering mostly smaller buildings, and because the larger sites showed different behaviour than the small sites in terms of load profiles, this analysis looked at again when the data from above 9,000 m^2 premises is available.

At the time of this report, there was insufficient data available to separate the loads of the monitored premises into their temperature-dependent (the portion used for heating and cooling), and temperature-independent portions. It is believed that some of the variability in loads is due to temperature effects (i.e. more heating required when it is cold outside), and in future years, when longer data sets are available, this approach should be considered. This will probably reduce the variability in many of these load profiles, and allow the energy performance of the analysed buildings to be better understood.