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Article

Comparison of NZ's Energy Efficiency Regulation and Verification Assumptions to Real Building Loads and Operation

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Abstract: The New Zealand building design industry assumes various building model inputs for the consumption of energy through lighting and appliances. It also makes assumptions regarding when these energy consumers are considered to be "turned on". This paper aims to better inform industry energy modellers about the real load and operation of real commercial buildings in New Zealand when compared to New Zealand Standard energy efficiency requirements and assumptions. The paper presents a set of New Zealand relevant commercial building operation information. Typical operation information is provided for three commercial building types: (1) Office; (2) Retail; and (3) Mixed/Other. The information provides low, typical, and high installed building load and operation pattern scenarios for the three building types. The typical data presented in this paper is significantly different to the load requirement and operation modelling assumptions presented in the New Zealand Building code. The results established in this paper are informed by data gathered in the Building Research Association of New Zealand (BRANZ) Building Energy End-Use Study (BEES). The purpose of BEES is to increase knowledge on energy use patterns for the entire New Zealand building stock. The intention of this paper is to disseminate the established knowledge that will eventually update the assumptions used in New Zealand commercial energy models.

Keywords: building energy modelling; building load; operation patterns; Building Energy End-Use Study (BEES); monitored data

1. Introduction

This paper presents typical, high and low building load densities and patterns of use for commercial buildings in New Zealand. Patterns of use refers to the daily use profiles of the load presented as the percentage of load "on" at different time intervals throughout the day. The goal is to better inform building energy modellers about typical lighting and equipment end uses. In the process, this work highlights the differences between the assumptions made when using the modelling verification method to meet the New Zealand Building Code (NZBC) and what is occurring in real buildings [1].

The research is a part of the Building Research Association of New Zealand (BRANZ) Building Energy End-Use Study (BEES). The purpose of BEES is to monitor and analyse the energy and water consumed by non-residential buildings around New Zealand. The project ran for 6 years [2]. BEES aims to provide more insightful knowledge of energy use patterns for the entire New Zealand commercial building stock [3]. Real data is collected within selected premises through the BEES programme from the monitoring of temperature, humidity, light levels, CO_2 levels, occupant and equipment schedules, internal loads and fuel consumption.

This paper is one of two reports which documents better informed building energy models for the New Zealand design industry. The building load and patterns of use conclusions determined in this study informed the creation of prototypical commercial building energy models. The prototypical models are documented on the BRANZ BEES website. The models provide a base case for the building design industry to assess the impact of building load and operation on their buildings energy performance.

Lack of Measured Building Operation Information

Currently, when analysing building energy performance, the New Zealand building design industry must make assumptions about various building model inputs based on New Zealand Standard (NZS) verification method for displaying compliance with NZBC. Inputs to their performance calculation models rely on assumptions about the energy consumed by lights and appliances. Energy modellers assessing energy may use the NZS 4243 Lighting Power Density (LPD) value as a base scenario for what is currently installed in commercial buildings. NZS values are used because there is no other reliable information on the typical building load power densities found in real commercial buildings.

Half of the commercial buildings in New Zealand were built before 2000. This pre-dates the NZBC and NZS 4243 clause regulating the LPD. This can cause modellers to enter into their performance calculation of an existing building retrofit analysis assumed values that may not be typical. Additionally, there is no such NZBC regulated density value for other building loads, such as office equipment and hot water. This results in modellers inputting a value for an Equipment Power Density (EPD) and Hot Water Power Density (HWPD) that is a best guess or an assumption based on what is included in the NZS 4243 modelling method to prove a building design meets the NZBC. Table 1 displays the power density "assumptions" found in the NZS 4243.

Table 1. New Zealand Standard (NZS) 4243 Power densities. Table created using [4,5].

Building Type	Power Densities (W/m^2)		
	Regulated Lighting Power Density (LPD)	**Assumed Equipment Power Density (EPD)**	**Assumed Hot Water Power Density (HWPD)**
Office	12 W/m^2	8.1 W/m^2	Not required
Retail	8–16 W/m^2 depending on retail type	1.1–2.7 W/m^2 depending on retail type	Not required
Mixed/Other	8–18 W/m^2 depending on use type	1.1–8.1 W/m^2 depending on use type	Not required

Note: The Retail and Mixed/other power densities have a range due to the different building types.

The same problem occurs for the operation patterns of building loads. No measured information for the patterns of use of building loads in real buildings is currently published. As a result, an energy modeller is left with little option but to assume when equipment is turned "on" and when it is turned "off" based on the modelling assumptions set in the NZS 4243 energy modelling method. Table 2 presents the operation pattern assumptions found in the NZS 4243 energy modelling method for different building types. There is no evidence that these assumptions will be relevant to how real commercial buildings in New Zealand consume energy.

Table 2. NZS 4243 Lighting and Plug Load patterns of use. Table adapted from [4].

Building Type	Day Type	Patterns of Use (% of Load "on")				
		12 p.m.–8 a.m.	**8 a.m.–11 a.m.**	**11 a.m.–6 p.m.**	**6 p.m.–10 p.m.**	**10 p.m.–12 p.m.**
Office	Week	5%	90%	90%	30%	5%
	Saturday	5%	30%	15%	5%	5%
	Sunday	5%	5%	5%	5%	5%
Retail (Restaurant)	Week	5% (15%)	90% (40%)	90% (90%)	50% (90%)	5% (50%)
	Saturday	5% (15%)	90% (30%)	90% (80%)	30% (90%)	5% (50%)
	Sunday	5% (15%)	40% (30%)	40% (70%)	5% 60%)	5% (50%)
Mixed/Other	Week	5%	90%	90%	5%	5%
	Saturday	5%	24%	5%	5%	5%
	Sunday	5%	5%	5%	5%	5%

Notes: Retail has two patterns of use presented as restaurants a different to general retail. Also, Mixed/Other are the assumptions for a warehouse, but it could be a mixture of all three use types.

New Zealand is not alone with regard to these assumptions and lack of information. The current state of the art in prototypical building models can be found in a US set of prototypical building models [6]. These are based on informed engineering judgements about "typical" or "design" values for building loads and their operation. As part of the BEES modelling research, a set of EnergyPlus Template models [7] were developed which followed the same format as the U.S. prototypical models. The aim of the template models was to reduce the difficulties associated with energy modelling, particularly relating to the ease and speed of creating a model to produce reliable results [8]. The BEES models have the same short comings in that they are built on assumptions about the building loads and their operation. If the BEES models were updated using the measured data presented in this report, they would be more advanced than any prototypical models currently found. The biggest single advantage of updating the models with measured building load and operation patterns is that they offer the potential for building design teams to examine the risk that a predicted building performance is dependent on the assumptions made about people, lighting and equipment used in the design modelling. There have been criticisms of high performance designs due to the fact that they only perform well in the particularly narrow focused situation "assumed" during the performance modelling [9]. The low and high building loads data from BEES allows designers to quickly test realistic design scenarios and establish how robust their design concept is.

2. Methodology

This study uses the measured data for lighting, equipment and hot water energy use from the BEES survey of commercial premises. The BEES team collected data over a four year period from 2008 to 2012. Energy was measured at one minute intervals for a 2–3 weeks' period in a representative sample of New Zealand commercial building premises. The weekly periods were spread throughout the year for different buildings. This means that the energy results could be from a two week period in summer or a two week period in the winter. Because this report only deals with lighting, equipment and hot water the outdoor conditions will have a minimal impact on energy use. This was the case for lighting also as there were no daylight induced electric lighting dimming in any of the premises. For site measurement technique and protocol used for monitoring refer to BEES Years 1 and 2 report [3].

This report presents the power density and patterns of use for lighting, equipment, and hot water. The lighting used is strictly indoor lighting to provide task lighting to the occupants. Equipment is made up of a number of appliances that are used by occupants to undertake day to day tasks and enable businesses to provide a service. Appliances include computers, printers, servers, refrigerators, chillers, water coolers, water boilers, phone systems, security systems, ovens, stove tops, deep fryers, and other appliances used in the day to day use of commercial buildings. Hot water energy use covers the energy used to provide hot water for domestic use, such as hand washing and showers, and commercial use, such as dishwashing.

All results were calculated using the measured average weekday and weekend 10 min interval load. Each 10 min interval measured was averaged against other weekday and weekend 10 min intervals. The power densities were calculated by dividing the maximum measured load (for lighting, equipment, and hot water), by the monitored floor area. The operation patterns were calculated by dividing the measured load by the maximum measured load to establish the percentage of load "on" during that 10 min interval.

A typical, a low and a high energy load scenario is presented in this report. The typical scenario is the Median (50th percentile) load and pattern of use found across the sample of building premises. Because the sample has outliers which can differ greatly from other values, the median provides a good indicator of the most typical value in the sample [10]. The Low scenario is the 10th percentile of measured load and pattern of use across the sample of premises. The High scenario is the 90th percentile of measured load and pattern of use across the sample of premises. The sample sizes vary between the lighting, equipment and hot water assessments and are displayed in Table 3.

The time intervals used in the patterns of use analysis were decided by assessing natural breaks across the whole data set in the amount of load "on" during each hour. For example, 12 a.m. to 5 a.m. is used as there was less than 10 percent difference in load across these hours. The hours were then averaged to get a percentage value of load "on" across these 5 h. These data are presented for 3 different building types. The load was split by building use type because NZS 4243 regulates load for different building types, and the use of different commercial buildings results in very different building load attributes. Table 4 displays the three building types assessed (Office, Retail, and Mixed/Other) and the detailed uses found within each of the three building types.

A further breakdown was made when assessing the lighting, equipment and hot water power densities. The breakdown assessed the impact of building floor area size. Building floor area size was assessed because NZS 4243 regulates building loads for only "large buildings" which it deems are 300 m^2 or greater. The assessment of size indicates whether building size has a significant impact on the building loads. Table 5 displays the breakdown of the different building floor area sizes assessed (small, medium and large), and the percentage of the total commercial building floor area each building size makes up.

Table 3. Sample sizes used to calculate typical, low and high values.

End-Use	All Buildings	Office	Retail	Mixed/Other
Lighting	101	35	29	37
Equipment	83	28	22	33
Hot Water	30	9	7	14

Table 4. Building type categories.

Building Type	Office	Retail	Mixed/Other
Specific building use types found in each building type	Office-type use	Retailing use, Motor vehicle sales and services, Liquor outlets including taverns, Service stations, Tourist-type attractions	A mixture of office and retail use types. As well as, warehouses, and service buildings.

Table 5. Building size groupings.

Building Size	Small	Medium	Large
Building floor area range	5 to 649 m^2	650 to 3499 m^2	Over 3500 m^2
Percentage of all commercial floor area	20%	40%	40%

3. Results and Discussion

All results displayed in the graphs below are documented on the BEES website [7]. The results presented on the website enable energy modellers to enter the values into energy models more precisely.

3.1. Lighting Power Density (LPD)

Figure 1 displays the typical, high and low LPDs' for an average commercial building (white), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). As can be seen, Retail use types have the highest installed LPD's. This is followed by Offices, and Mixed/Other commercial use types. This trend mimics the trend of the maximum allowable LPD set by the NZS

4243 verification method [5]. It is worth noting that the typical LPDs found in Offices are slightly lower (11 W/m^2) than the value set by NZS 4243 of 12 W/m^2 [5]. By comparison, the LPDs found in Retail premises are similar to the minimum set out in NZS 4243. For Retail NZS 4243 requirement is 8–16 W/m^2 depending on retail use type, and the typical measured LPD across all retail use types is 14 W/m^2 [5]. The typical LPD measured in Mixed/Other commercial use type premises is much lower than the NZS 4243 requirement. NZS 4243 allows for a maximum of 8–18 W/m^2 depending on use type, and the typical measured LPD was 6 W/m^2. Mixed/Other commercial LPDs are below the sample average. Also, the high scenario (20 W/m^2) for Mixed/Other commercial LPD's is not significantly different to the Retail (26 W/m^2) and Office (21 W/m^2) high values as the low and typical scenarios.

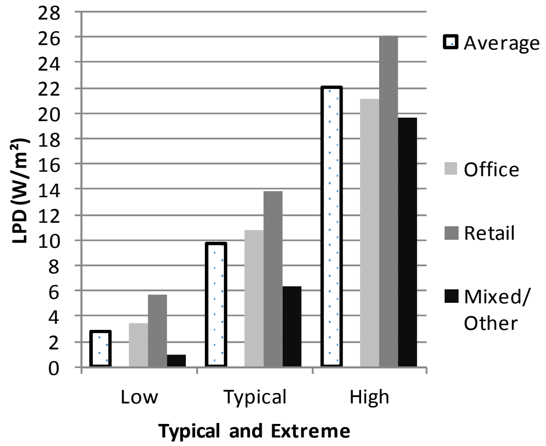

Figure 1. Typical, High and Low LPDs' for different commercial building types.

Figure 2 presents the typical, high and low LPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess if size has an impact on the installed LPD. As can be seen, Medium sized buildings have the highest measured LPDs with a typical value of approximately 13 W/m^2. The LPDs found in Small and Large buildings were the same with 8 W/m^2. The high scenario results suggest that lighting was most dense in Medium and Small sized buildings due to the large building high LPD value being half the Small and Medium sized buildings LPDs. This was likely attributed to smaller buildings being more associated with Retail uses which have higher lighting demands.

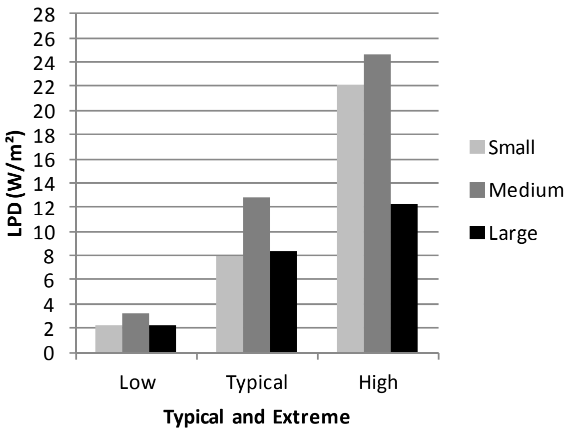

Figure 2. Typical, High and Low LPDs' for different sized commercial buildings.

3.2. Lighting Operation Patterns

Figure 3 displays the Typical (green), High (orange), Low (blue) and NZS 4243 (black) patterns of lighting use for Offices, Retail and Mixed/Other commercial use types.

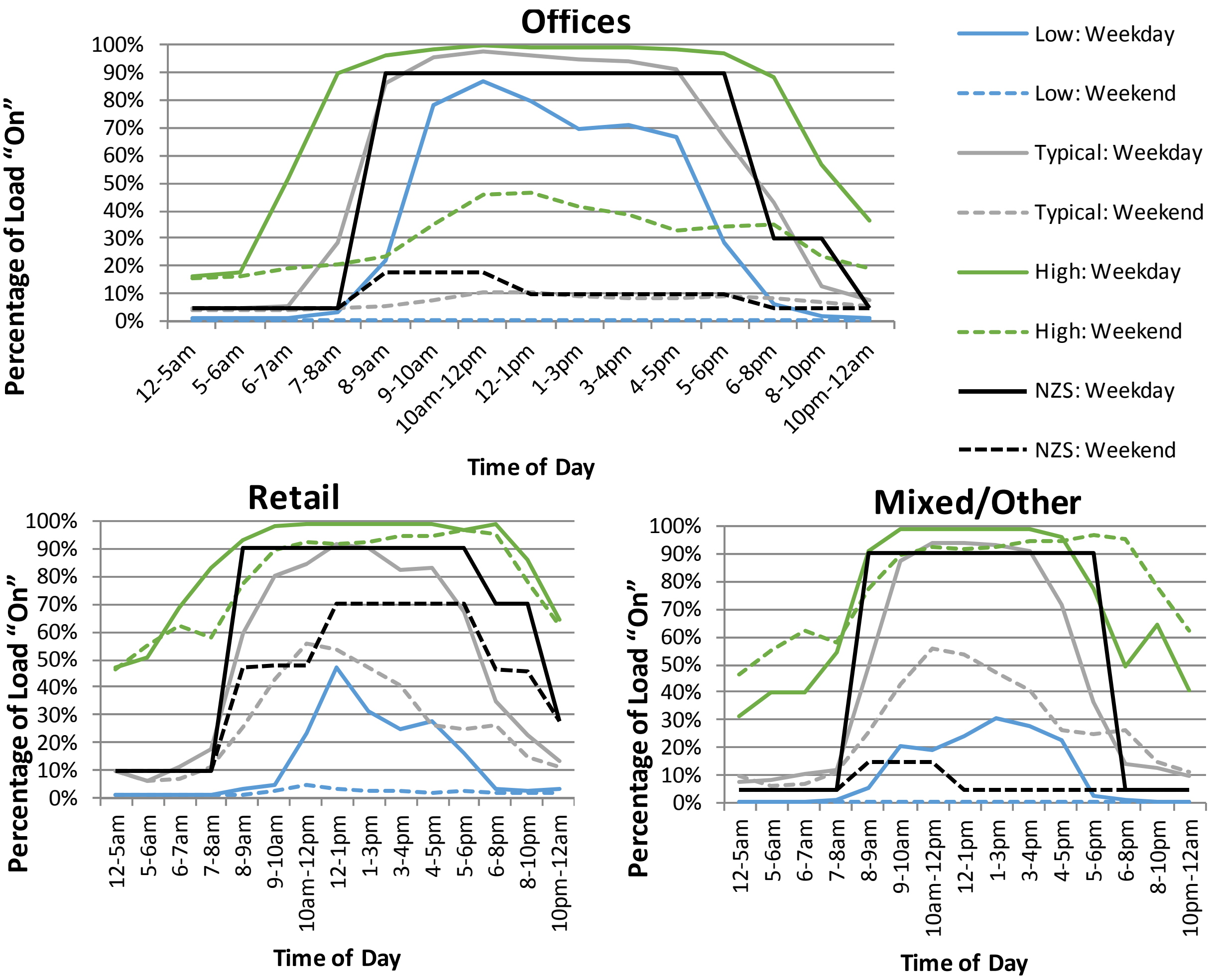

Figure 3. Typical and Extreme Lighting Patterns' of use for different commercial building types. Notes: The Retail pattern of use was an average between the NZS 4243 retail and restaurant patterns. The weekend patterns were an average of the NZS 4243 Saturday and Sunday patterns of use.

As can be seen, Offices have the largest difference in usage patterns between weekdays and weekends. The typical lighting usage of an Office was higher (80%–90% turned "on") than Retail and Mixed/Other commercial uses during the weekdays (70%–80% turned "on"). Retail and Mixed/Other commercial uses have less difference in usage patterns between weekdays and weekends (20%–40% difference) when compared to Offices (60%–70% difference). This fits with expectations that Retail and Mixed/Other commercial use buildings have more intense and longer weekend hours compared to Office buildings. Interestingly, the high use Retail and Mixed/Other use types have almost as intense weekends as weekdays compared to the lighting in high use Offices.

The typical lighting use pattern for Offices was similar to the NZS 4243 assumed pattern of use. However, the Retail and Mixed/Other patterns sit between the typical and high scenario patterns of use. If the NZS 4243 assumptions were used in an energy model, then the model would slightly overestimate the amount of lighting turned "on" in a typical building.

3.3. Equipment Power Density (EPD)

Figure 4 displays the Typical, High and Low EPDs' for the average commercial building (white), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). Mixed/Other commercial use types have the lowest typical EPD with 5 W/m^2. Offices were the second lowest equipment focused use type with a typical EPD of 8 W/m^2. Retail has the highest typical EPD of 15 W/m^2. This suggests that Retail buildings are the highest equipment energy intensive building type. This finding makes sense as Retail buildings contain premises which are often used for food sales that include refrigeration and cooking. Retail also has a significantly larger high scenario EPD than the other building types, with an EPD of 58 W/m^2. The typical EPD of Offices was similar to the NZS 4243 assumption of 8 W/m^2. However, the other two building types typical EPD's were well above the NZS 4243 assumed EPDs (refer to Table 1 for NZS 4243 assumptions). This highlights the difference between the theoretical EPD and the real buildings EPD. The impact this would have on energy models would be large considering the amount of internal heat gains that would not be modeled using the NZS 4243 assumptions.

Figure 5 presents the typical, high and low EPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess the impact of building size on the installed EPD. Small sized buildings were the most equipment focused with a typical EPD of 13 W/m^2. Medium and Large buildings have a substantially lower density of equipment installed with a typical EPD of 6 and 7 W/m^2 respectively. This trend follows in the high EPD scenario. However, small buildings have a much larger EPD (59 W/m^2) when compared to both Medium and Large sized buildings, which have high EPDs of 38, and 18 W/m^2 respectively. This suggests that Small and Medium sized buildings are dominated by Retail loads while larger buildings are dominated by Office loads.

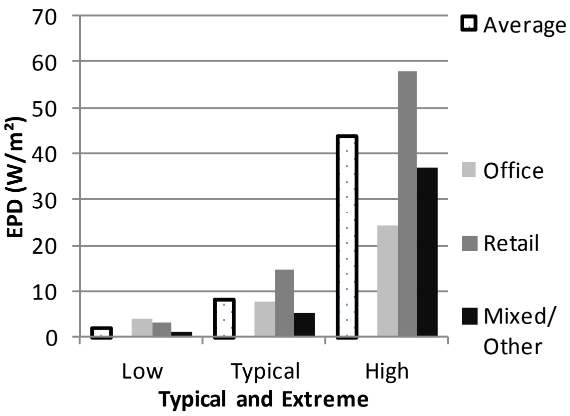

Figure 4. Typical, High and Low EPDs' for different commercial building types.

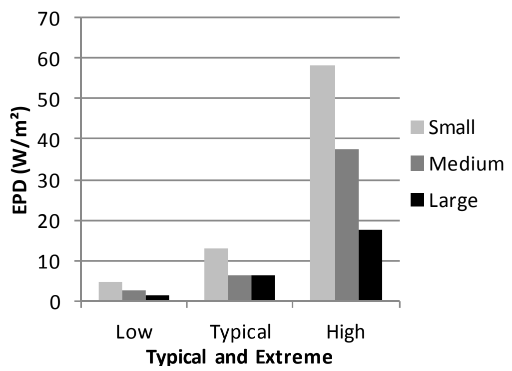

Figure 5. Typical, High and Low EPDs' for different sized commercial buildings.

3.4. Equipment Operation Patterns

Figure 6 displays the Typical (green), High (orange), Low (blue) and NZS 4243 (black) patterns of equipment use for Offices, Retail and Mixed/Other commercial use types.

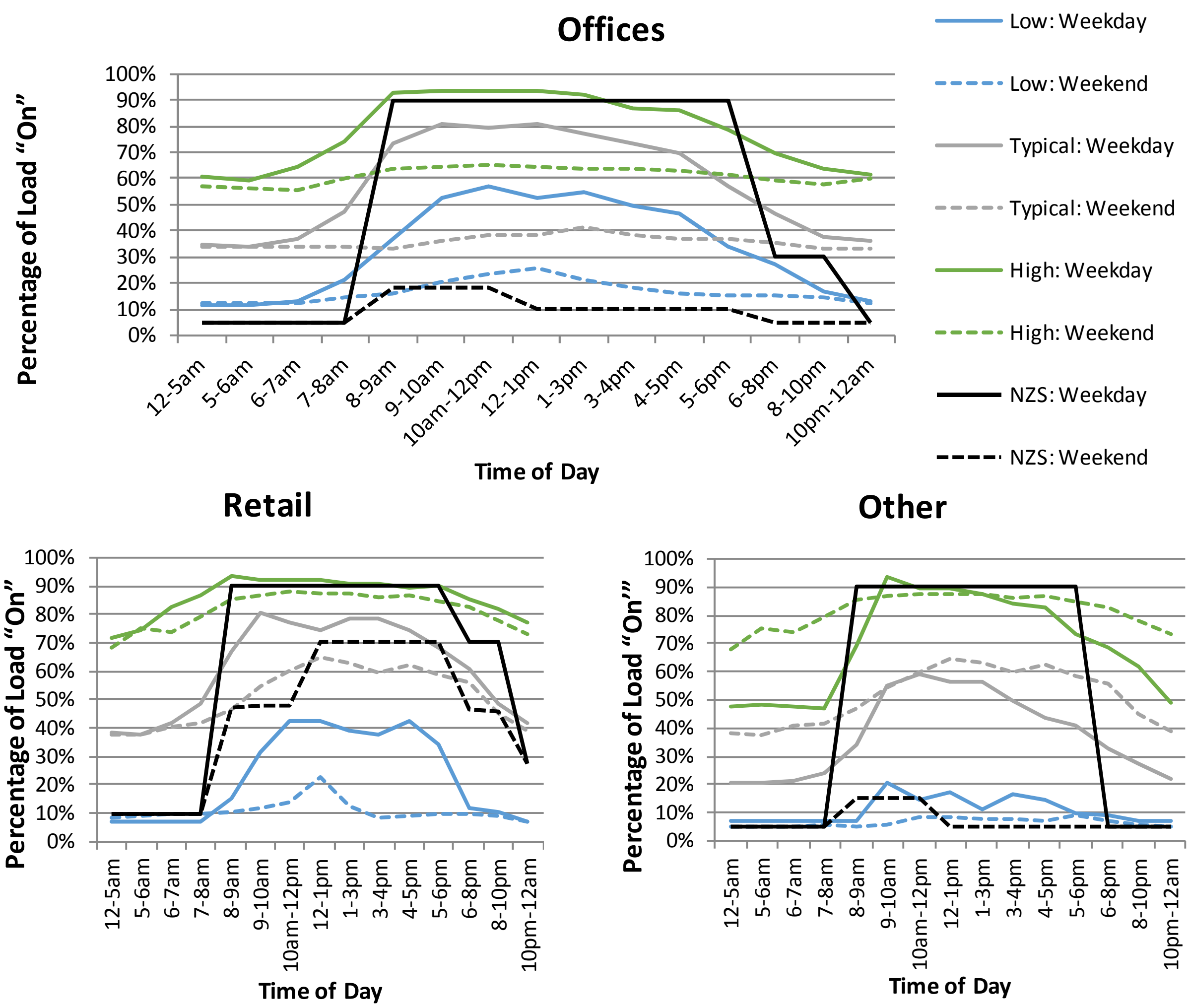

Figure 6. Typical and extreme equipment patterns' of use for different commercial building types. Note: The Retail pattern of use was an average between the NZS 4243 retail and restaurant patterns. The weekend patterns were an average of the NZS 4243 Saturday and Sunday patterns of use.

Offices have the least energy intensive patterns of use as seen by the amount of load that was left "on" during unoccupied periods. This was shown by the weekend and night load percentages. Also, Offices have the biggest difference between night and daytime load patterns. This was highlighted by the larger peaks in equipment energy use of approximately 30%–50% during daytime hours. Office weekday patterns of use have a consistent peak of use whereas their weekend schedules were more or less consistently flat throughout the weekend. This was shown by the weekend day loads not being significantly different to the overnight use. Retail buildings have the most energy intensive patterns of use. This was highlighted by the larger percentage of equipment "on" and for longer periods of time. This was further reinforced by the fact that Retail buildings have higher EPD's (refer to Figure 4). Furthermore, the greater the energy intensity of a Retail premise, the closer the weekend pattern of use was to the weekday pattern. The daytime pattern of use peak in Retail premises (20%–30% more equipment "on") was not as large when compared to Offices (30%–50% more equipment "on"). This could be due to the large refrigeration loads running consistently throughout the whole day, while only a small number of appliances were turned "on" during occupied hours. Unlike Office and Retail, the weekend patterns of use were higher than the weekday patterns of use in Mixed/Other commercial use buildings. The weekday and weekend on Mixed/Other use buildings also have a definite daytime peak of equipment use. Consistent with Retail, the daytime peaks were not as large as for Offices; however, there was a bigger daytime peak during weekdays when compared to the weekends. Also, the weekend loads were more consistently "on" and the weekend night loads were greater than the weekday night loads. This could be due to premises with restaurant and other food type having longer weekend hours.

The results indicate that the common perception among energy auditors, but not in building codes or standards, of equipment being left "on" during unoccupied hours is true. Half of the installed equipment load in Offices was left on overnight. Over a yearly period this equates to a large sum of energy that is essentially wasted. Coupled with this being typical across the commercial building stock, it would seem there is large potential for energy savings if equipment is turned off over night.

The NZS 4243 patterns of use assume that 10%–20% more equipment is turned "on" during daytime hours in Office and Retail buildings, and 10%–30% more in Mixed/Other buildings. The NZS 4243 patterns of use sit between the Typical and High scenarios for all three building types during daytime hours and around the Low scenario during night hours. Therefore, if the NZS 4243 assumptions are used in the model, they would overestimate the amount of equipment turned "on" during daytime and underestimate equipment turned "on" during night hours in a typical building.

3.5. Hot Water Power Density (HWPD)

Figure 7 displays the typical, high and low HWPDs' for average commercial buildings (white), Offices (light grey), Retail (dark grey), and Mixed/Other commercial use types (black). Retail buildings have the largest HWPD with 7 W/m^2 for a typical building and 24 W/m^2 for high use buildings. This was most likely due to the food use types associated with Retail using larger amounts of hot water compared to Offices and Mixed/Other commercial use types. Office and Mixed/Other use type HWPD's were below the average for commercial buildings with 3 and 2 W/m^2 respectively. The high scenario HWPDs for Office and Mixed/Other building types were significantly lower than the Retail HWPD.

Figure 8 presents the typical, high and low HWPDs' for Small buildings (light grey), Medium sized buildings (dark grey), and Large buildings (black) to assess if size has an impact on the installed HW-PD. The typical HWPD was relatively similar for each of the three building size groups. However, the "high" scenario indicates that Medium-to-Large sized buildings have higher demand for hot water when compared to Small buildings. This may occur from larger buildings needing to service a greater number of occupants when compared to smaller buildings.

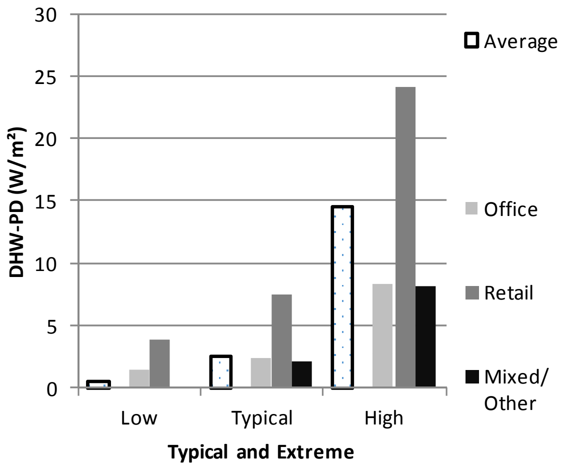

Figure 7. Typical, High and Low HWPDs' for different commercial building types.

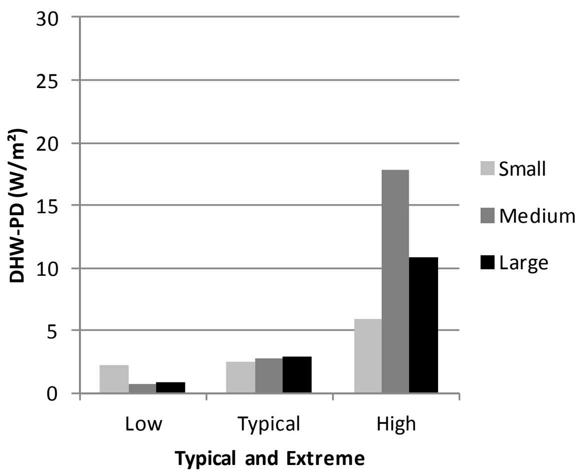

Figure 8. Typical, High and Low HWPDs' for different sized commercial buildings.

3.6. Hot Water Operation Patterns

Figure 9 displays the typical (green), high (orange) and low (blue) patterns of hot water use for Offices, Retail and Mixed/Other commercial use types. Office hot water energy use was very different between weekday and weekend, but also from nighttime to daytime use. Office hot water use was much lower overnight, by approximately 30%–40%, as well as during the weekend with a 20%–40% smaller daytime peak of hot water energy usage. Retail hot water energy use patterns have consistent trends across both weekdays and weekends. The intensity of use between weekdays and weekends also does not change considerably (less than 10%–20%). Mixed/Other commercial use types consume more hot water energy in the weekends than during weekdays. This was consistent with the equipment patterns of use for Mixed/Other use building types.

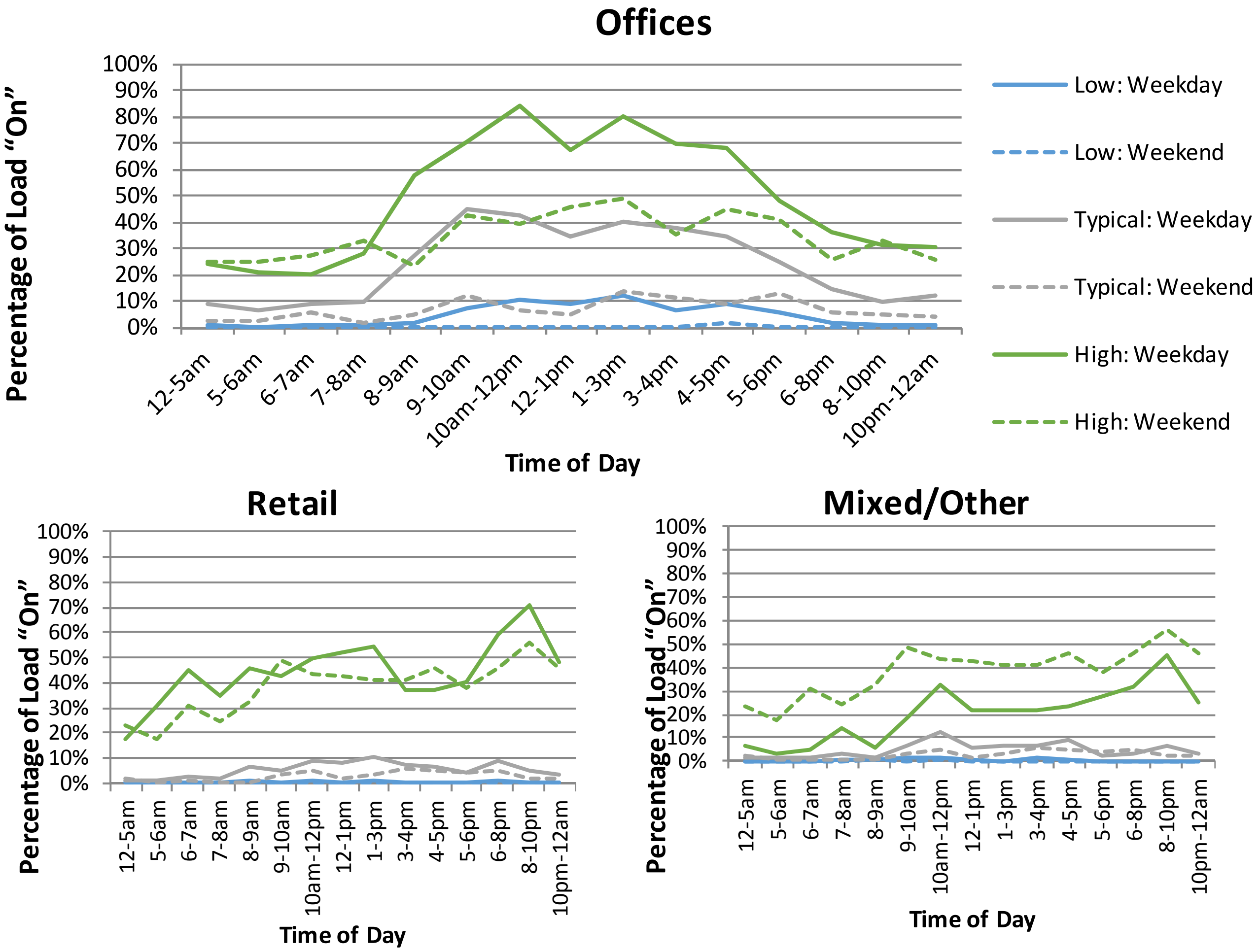

Figure 9. Typical and extreme DHW patterns' of use for different commercial building types.

4. Conclusions

This paper presents the typical, high and low building load densities and their operation patterns for commercial buildings in New Zealand. It fills the gap for the shortfall in information available for commercial building designers and environmental engineers. The shortfall relates to the lack of information regarding building loads found in real commercial buildings. Additionally, this paper compares the building loads found in real commercial buildings to the loads regulated in the NZS 4243 and the assumptions used in the modelling method for comparing energy use to prove the building code has been met.

The results established in this paper indicate that the current NZS 4243 values for power densities and associated schedules are not representative of existing building design in New Zealand. It has been found that the NZS 4243 values for the LPD are indicative of the typical LPDs found in existing buildings. It suggests that typical commercial buildings are designed to just meet the code and not to be any more energy efficient than they need to be. The Retail and Mixed/Other lighting patterns of use overestimate the amount of weekday lighting turned "on". The EPDs found in real buildings were significantly higher for Retail and Mixed/Other commercial use type buildings than the assumptions made in the NZS 4243 modelling method. This results in an underestimation of equipment energy use and internal heat gains if the NZS 4243 values were used. If concerned about assumptions affecting the performance of the building design, an energy modeller could double the power densities or reduce them by a third. By doing so, it roughly estimates the extreme lighting and equipment scenarios which occur across the commercial building stock.

Additionally, the common perception that equipment is left "on" during unoccupied hours is true. Half of the installed equipment load in Offices was left "on" overnight. Over a yearly period this equates to a large sum of energy that is essentially wasted. This combined with the typical values across the commercial building stock indicates that there is large potential for energy savings if equipment is turned off overnight in Offices.

The conclusions are relevant internationally. Building codes and standards suffer the same limitations as the New Zealand building standards which incorrectly assume no equipment or lighting use overnight. The U.S. prototypical models have same assumption limitations and it is likely these assumptions are used elsewhere internationally. These operational patterns were input as "good engineering judgement". It shows that good judgement needs to be informed and updated using the results presented in this thesis in the absence of a countries own experimental data (which is advised to be gathered). Furthermore, the High and Low scenario can be used as a way of altering prototypical models internationally. They can be used as a ratio to be used as a basis for overseas design as well.

These conclusions provided the basis for the creation of prototypical models, as well as the update of existing template models. The models are founded on the real building performance established in this study and the BEES studies. Each model contains New Zealand relevant materials, constructions, building loads, patterns of use, and HVAC system type and properties.

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Author Contributions

Shaan Cory and Michael Donn conceived and designed the experiment; Shaan Cory performed the experiment; Shaan Cory analysed the data; Andrew Pollard contributed materials; Shaan Cory and Michael Donn wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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