WATER PERFORMANCE BENCHMARKS FOR NEW ZEALAND:
an approach to understanding water consumption in commercial office buildings

LEE BINT, NIGEL ISAACS, AND ROBERT VALE

School of Architecture, Victoria University of Wellington, P O Box 600, Wellington

ABSTRACT

Recent research has demonstrated the lack of knowledge concerning the consumption of potable water in commercial buildings. The dependence on this resource is significant, yet there is little understanding of its end-uses, and what constitutes good or bad performance.

This paper details an approach to find suitable water performance benchmarks for commercial office buildings in New Zealand. An onsite investigation has been conducted in a sample of buildings within the Wellington Central Business District (CBD), measuring water consumption against a number of specific demand drivers. This study, together with observations made of international examples, and support from the local billing and supply utility, helped in forming a baseline of expected water performance in similar commercial office buildings within Wellington, and ultimately in New Zealand.

This research: provides an understanding of how purchased water is consumed in commercial office buildings; demonstrates the feasibility of using this data for the development of an accurate benchmarking index system for water efficiency; and presents the beginnings of a useful database for establishing future water benchmarks in other commercial building categories and types. However, this study has also highlighted further research opportunities to be explored regarding water use, water using equipment, and the drivers of water use.

KEYWORDS:

Water consumption; water performance; water efficiency; benchmarks; office buildings.

1. INTRODUCTION

In New Zealand there is currently no information available on how commercial buildings use water, and/or how much water a building is expected to be using for a given purpose. Office buildings in New Zealand represent a large proportion of total commercial buildings, especially in city centres. As water is often metered in these buildings, and then charged on a volume used basis, efficiency strategies can be easily implemented, and monitored.

Benchmarks are indicators of actual water performance, and in the context of this research they are the performance of water consumption and efficiency in commercial office buildings. The primary purpose of a benchmarking measure is to 'normalise' water use with respect to the size and type of the building, which makes possible a method of comparison relative to other buildings with a similar occupied use.

The normalised consumption model is a measure of water consumption against a driver, such as net lettable area (NLA), full time equivalent (FTE) occupants, number of amenities, and so on. Normalised consumption models allow un-biased comparisons to be made, for example between two buildings' water consumption, or between one building and the target benchmark. Examples of this type of normalised benchmark are outlined further in Section 5.

There are two main types of benchmarks commonly used: those used as 'a point of reference' also known as consumption benchmarks; and those that 'designate efficient levels of use' (Dziegielewski, 2000:118) also known as efficiency benchmarks. Both are significant, in that one indicates the standard level of consumption with regard to that region, and the latter leads to an understanding of the levels of water use efficiency within each building. At the present time, no formal water benchmarking system exists in New Zealand. This makes it impossible to compare buildings or regions, other than in terms of total annual consumption per category or per capita. This paper details a study which provides data for the initial development of a water benchmarking system.

2. HOW WATER IS CONSUMED IN AN OFFICE BUILDING

Internationally, only a small number of studies of office building water use are available. For example, the *'Water Efficiency Guide: Office and Public Buildings'* published by the *Australian Government, Department of Environment and Heritage (DEH)*, shows the expected water use in an Australian commercial office building. Figure 1 below shows that the main water uses are in domestic facilities, air-conditioning and leakage within the building. Of course the proportion and the absolute amounts will vary between buildings and regions.

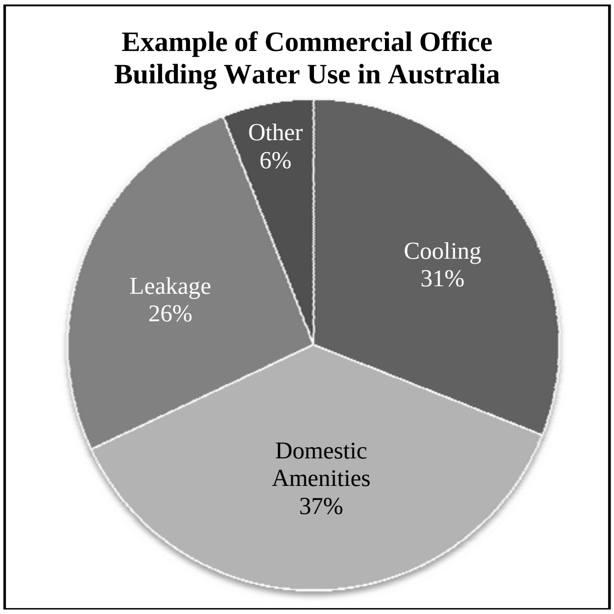

Figure 1: New South Wales (NSW) Example of how Purchased Water is Consumed (Source: Quinn et al, 2006:5).

It has been found in the NSW buildings sampled by the *DEH* that the domestic amenities of office buildings, including restrooms, kitchens, and shower facilities, can be expected to consume approximately 37% of the total annual water bill, although this ranged between 30% and 40%. The cooling functions of the building represent a similar portion (31%), ranging between 30% and 40% of the total annual water bill.

Other water uses include garden irrigation, water used for cleaning and/or ground level retail or food outlets. Food outlets often require water on a different scale to that of a typical office space. Leakage, typically occurring from taps, urinals, cisterns, piping, valves, and pumps, represents approximately 26% of the total annual water consumption (Quinn et al, 2006:5).

3. RESEARCH METHODS

The research reported in this paper is based on investigations of forty-four selected commercial office buildings within the Wellington CBD. Buildings were selected on the criteria of the majority (over 80%) of the NLA being specified as office spaces and their physical address being located within a pre-determined CBD boundary; the most densely populated area of office buildings, thus forming a non-random sample. Details of the buildings are provided in Section 4.1.

This work is designed as a pilot study, with the purpose of developing and testing a methodology as a way to predict and benchmark water consumption in commercial office buildings. This study is built around a building survey; obtaining water use data and analysis strategies.

3.1. Data Collection

The selected method of investigation was a survey level water audit, which involves analysing historical water meter readings together with an on-site investigation to determine the number and types of water using features within the building. The survey entailed five data collection phases to gather enough data for an analysis; these are listed below in a timed order:

BWOF: A BWOF (Building Warrant of Fitness) is a legal document required under Clause 108 of the Building Act 2004 (Department of Building and Housing, 2009). This must be on public display, and outlines information regarding building ownership/management, building age, floor area, maximum occupants, legal description, fire hazard categories, number of levels, and their intended uses, for each building. This was used to determine the contact and preliminary details for each building approached.

Consent: The consent process involved using the information gathered from BWOFs in relevant buildings, and confirming this preliminary information over the phone with building management. A generic consent form was then emailed to the building manager together with a detailed introductory letter about the project. Their consent enabled access to the historical water data from the local billing utility.

Information Sheet: The information sheet required participating building managers/owners to provide details on their building, including: legal information, NLA, FTE occupancy numbers and hours, any changes over the last five or more years, and whether any sub-metering or air-conditioning was present within the building. This was emailed to the building manager and/or owner at the same time as the consent documentation. Observations from other studies, such as the Watermark project in the United Kingdom, noted that these forms should be not more than one page in length in order to improve response rates, and reduce the time consumed by the building managers sourcing the necessary data (Kitchen et al, 2003:9). Also requested on this form is the latest water invoice, which could then be used for verification with both the historical billing data and the water meter number when on-site.

Billing Data: The historical billing data is sourced by using the details provided on the information sheets above, and should be sourced prior to conducting the site visits to get an idea of the water usage for the building.

Site Surveys: Finally, the site surveys required each building to be visited by the auditor, preferably accompanied by the building manager/owner. A generic form was used within each building to ensure all required aspects of the building were observed. These included the type and number of fixtures within restrooms (men’s, women’s, and showers) and kitchen facilities, access to the plant room to observe types of cooling systems servicing the building, and to determine the water meter details, and location within the building.

3.2. Data Analysis

Once a consistent array of data had been collected and formulated, analysis could then begin. Statistical techniques have been adopted from previous international studies (see section 5). The analysis took the form of two phases:

Statistical Techniques: This required entering the data into spreadsheets, which were then investigated using both graphical and numerical analyses. Information was collected on the possible demand drivers of water use, identified from the ‘Information Sheet’, which were then correlated against the water use.

Benchmark Development: The aim of water benchmarking is to produce a consumption figure for individual buildings based on comparisons with other similar buildings. Therefore, a specific consumption figure is calculated for each building within the dataset. Typically, for office buildings, either consumption per NLA (m^3/m^2/year) or consumption per FTE occupant (m^3/FTEO/year) is suggested to be used, which is then subject to ranking, and correlation analysis.

The median of the dataset is then used to determine the ‘typical’ benchmark value, as this covers fifty percent of the population sampled, assuming a normal distribution. Likewise, when determining the ‘best case’ and ‘excessive use’ benchmark value the lower and upper quartile figures are used respectively (Dziegielewksi, 2000:217).

However, when determining bands for efficiency benchmarks, this can differ. Depending on the aim and purpose of the benchmarks, the bands of efficiency benchmarks may vary – an example is displayed below.

EFFICIENCY BENCHMARKS Percent of sample at this level or better	**RATING BAND**		**CONSUMPTION BENCHMARKS Percent of sample at this level or better**
80%	1	Excessive	75%
63%	2	-	
50%	2.5	Typical	50%
36%	3	-	
17%	4	-	
5%	5	Best Case	25%

Table 1: Examples of Efficiency and Consumption Benchmark Rating Bands (Bannister et al, 2005; Waggett et al, 2006).

Both systems give a mid-point rating to half of the sample, with higher and lower rating bands covering better or worse performance. However, the efficiency based system is given as a rating out of five, i.e. 5 out of 5 is considered to be the highest score, while 1 out of 5 is considered to be the lowest score; whereas the consumption rating bands are simply described by their meaning.

This paper will explore both an efficiency benchmark system, and a consumption based system, which will enable comparison with other similar international studies and their benchmarks.

4. RESULTS

The water consumption and billing data provided by the local billing utility gave bi-monthly meter readings for the previous five years to date, thus giving a base of approximately 31 data points per building, with an overall dataset of 1271 points.

4.1. Survey Results

Before commencing the survey phase, a single building was trialled to test the methodology. The feedback gained from this trial proved helpful in the buildings to follow. The trial provided information on the effort required to source the data on information sheets, and simple lessons such as how to find the location of the water meter. The pilot building was a good example of the many types of issues that may arise when on-site.

To date, the response rate from the buildings approached to participate has been approximately 69%; with, at the time of writing, forty-four buildings having a survey level audit completed. The range of data from the selected buildings is listed below.

Data	**Lowest**	**Median**	**Highest**
Building Age	1917	1980	1993
NLA (m^2)	1,494	7,154	24,067
Footprint Area (m^2)	321	758	2,136
FTE Occupancy	35	304	1,450
Annual Water Consumption (m^3)	541	7,896	28,056
Number of Storeys	6	14	32
Number of Domestic Appliances	51	168	362

Table 2: Range of information gathered under field study.

The majority of domestic appliances within the office buildings surveyed showed considerable opportunities for improvement, for example 67% of all buildings’ urinals operated on a cyclic flushing system, rather than sensor or manually activated flushing. 67% of the buildings used a single flushing toilet cistern rather than a dual flush cistern.

4.2. Observations

A high proportion of water meters appeared to have been replaced over the past five years. 59% of surveyed buildings had had at least one water meter replacement within the last five years; this is predominantly due to the fact that 'water meters are replaced on a ten year maintenance cycle' (Gribble, 2010). This high replacement rate required extra investment of time to check and validate the meter reading data. In some cases more than one building was connected to a single water meter, making it difficult to establish which building used that water. Another observation was that most buildings are on a 'gross lease' i.e. the building manager or owner pays the bills directly, which means no monitoring of water use takes place, and there are few incentives to reduce water consumption.

Very few office buildings are entirely used for office purposes. In the sample, most (69%) had either retail of some form, or a restaurant facility occupying ground floor space. These non-office uses may contribute considerably to the total water use, as the manner in which water is used may differ dramatically from that of an office space. However, as this was a consistent finding it was assumed to be typical, as unless sub-metering had been installed it was impossible to further analyse the water use data.

4.3. Models of Commercial Water Use

The data was explored for annual, seasonal, or bi-monthly patterns for each building, and any significant trends. It was found though personal communication with the billing and supply utility, that the meter readings are only checked for reasonable consistency with the previous reading corresponding to that period (Fleet, 2009).

In Figure 2 below, the line shows the whole of Wellington CBD average weekly water use across the year (right hand scale) while the columns give the average weekly water use for the sampled buildings (left hand scale). The CBD water data was provided on a weekly basis by the supply utility, however the sample buildings only had bi-monthly revenue readings, so it is only possible to provide two-monthly weekly averages.

It should also be noted that these meter readings are not always made at exactly the same time or on the exact same day; therefore revenue reading periods sometimes vary between metered accounts.

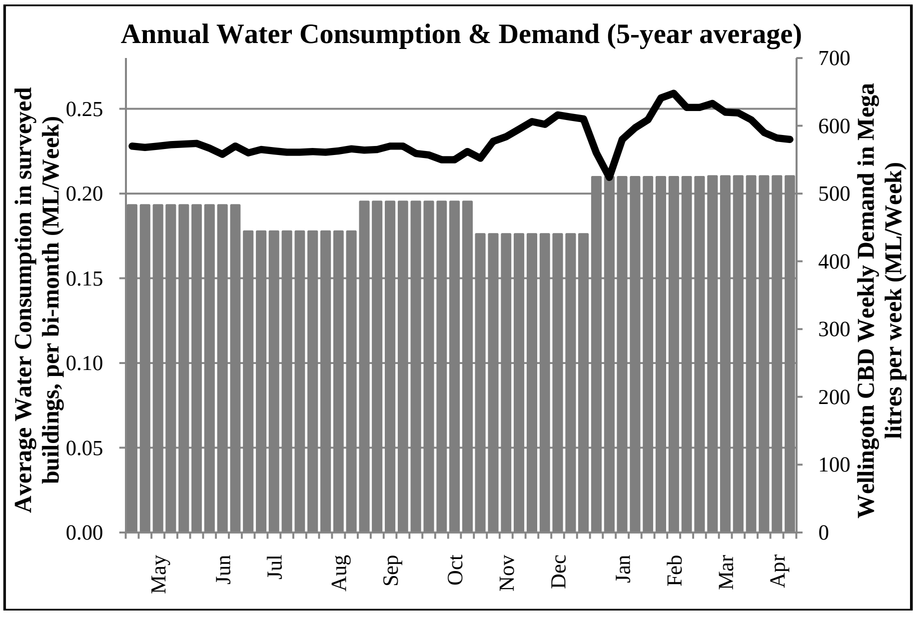

Figure 2: Average Weekly Consumption in Buildings Surveyed (column) & Wellington CBD 5-year average Weekly Demand (line) (Source: Gribble, 2010).

There are approximately 2,106 commercial metered water connections registered within the Wellington CBD. However, it cannot be stated whether or not this is also the number of commercial buildings. This is due to some buildings having more than one registered water meter connection for a single building, or more than one building being connected to a single water meter.

As can be seen in Figure 2 above, for the Wellington CBD the summer months display a trend of higher water consumption. It is hypothesised that this is due to the warmer summer climate, influencing possibly an increased cooling load or increased irrigation.

However, for the buildings of interest, during the December/January/February period when the building is likely to be either shut or with reduced staff numbers for up to three weeks, there is no dip in the water use. This is in contrast to the dip in the CBD water use. The reasons for this have yet to be explored, but on a first view would appear to suggest that the office building water demand is driven not by the presence or absence of occupants, but rather by the water using features of the building itself. On the other hand, the increased summer usage may be compensating for the lack of any decrease.

5. BENCHMARK RESULTS

Five similar international studies were reviewed:

- *CIRIA C657* report '*Water Key Performance Indicators and Benchmarks for Offices and Hotels'* (Waggett et al, 2006),
- *Watermark project* (Kitchen et al, 2003),
- *Water Benchmarks for Offices and Public Buildings* by *Exergy* (Bannister et al, 2005),
- *DEH* (Quinn et al, 2006),
- *Commercial and Institutional End Uses of Water study (CIEUWS)* (Dziegielewski et al, 2000),

It was found that water consumption per NLA or FTE occupancy is the most commonly used normalisation factor. However, all demand drivers identified were tested for their correlation strength with the total water use within the sample of surveyed buildings. In this study, the demand drivers showing the strongest statistical relationship appear to be NLA with an r^2 value of 0.61, and FTE occupants with an r^2 value of 0.59.

Specific Consumption Unit	Correlation Coefficient (r^2)
Age of Building	0.03
FTE Occupant Density	0.11
Hours of Operation	0.19
Number of Domestic Amenities	0.48
Number of Storeys	0.50
FTE Occupants	0.59
NLA	0.61

Table 3: Regression Analysis of Specific Demand Drivers for CBD Office Buildings.

A value of 1 represents a perfect relationship, and 0 shows no relationship. Both NLA and FTE occupant drivers show a moderate relationship to be occurring (Clark et al, 2008:55). As the number of FTE occupants have been found to be very unreliable, and at times difficult to calculate accurately, NLA is assumed to be the most pragmatic normalisation measure for this study – and it is also a measure that is known for most buildings.

It has been suggested that cooling systems are responsible for a large proportion of the total annual water bill (Sydney Water, n.d.). Analysis of the Wellington CBD sample comparing naturally cooled and mechanically cooled buildings, found strong and moderate individual relationships to water consumption, as shown in Table 4 below.

Analysis also showed that there was no significant difference in the correlation for both high and low NLA of the buildings surveyed; therefore it is assumed that these benchmarks may be used for different sizes of buildings.

Relationship between NLA and Annual Water Consumed	**Correlation Coefficient (r^2)**
Naturally Cooled Buildings	0.72
Mechanically Cooled Buildings	0.55
All Buildings	0.61

Table 4: Regression Analysis of NLA Demand Driver for Mechanical vs. Natural methods of Cooling.

Below is a visual plot for the buildings surveyed, showing the relationship between annual water consumption and the NLA of each building. Naturally cooled buildings have been separated from mechanically cooled buildings, as shown in the legend, but appear to be smaller in size (NLA) than the bulk of the mechanically cooled buildings.

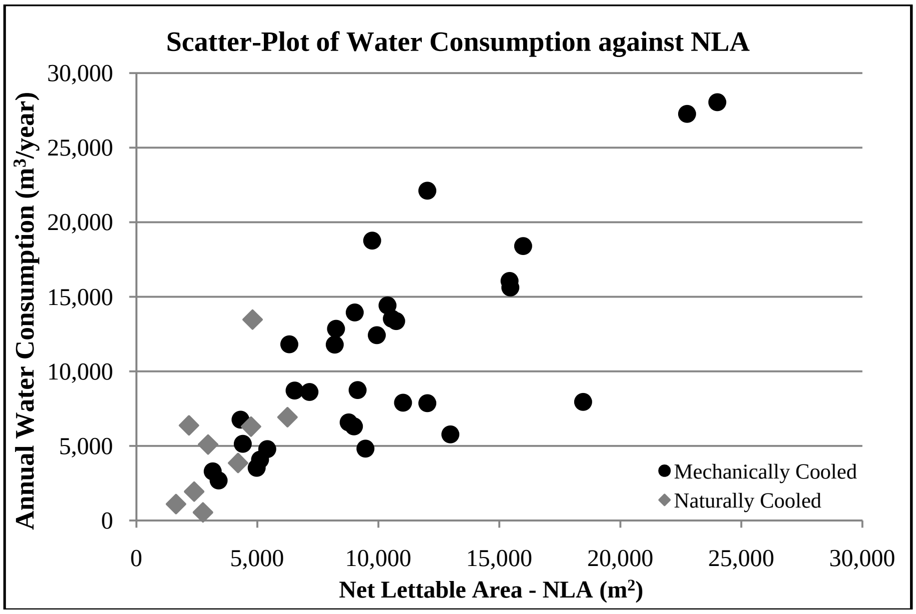

Figure 3: Most Statistically Appropriate Demand Driver Scatter-Plot.

Of the mechanically cooled buildings, 67% employed water cooled chillers and water cooled heat rejection units (cooling towers). The remaining 33% of mechanically cooled buildings utilised air cooled chillers and heat rejection systems.

Outliers were manually removed from the dataset where evidence of irregular input was found. Buildings where water meter failures were observed were removed from the analysis for the corresponding periods, as five years' worth of historical billing data was retrieved, annual analysis was still made possible by using the remaining (assumed to be accurate) four years' worth of data.

5.1. Benchmark Measures

The normalisation measure (as identified above) will be referred to as the normalised water consumption, or N, measured as cubic metres of water per square metre of NLA per year (m^3/m^2/year). A histogram is used to demonstrate the range of normalised annual average water usage. It is important to view the data in graphical form to give an indication of the spread of the data between best and worst case water users.

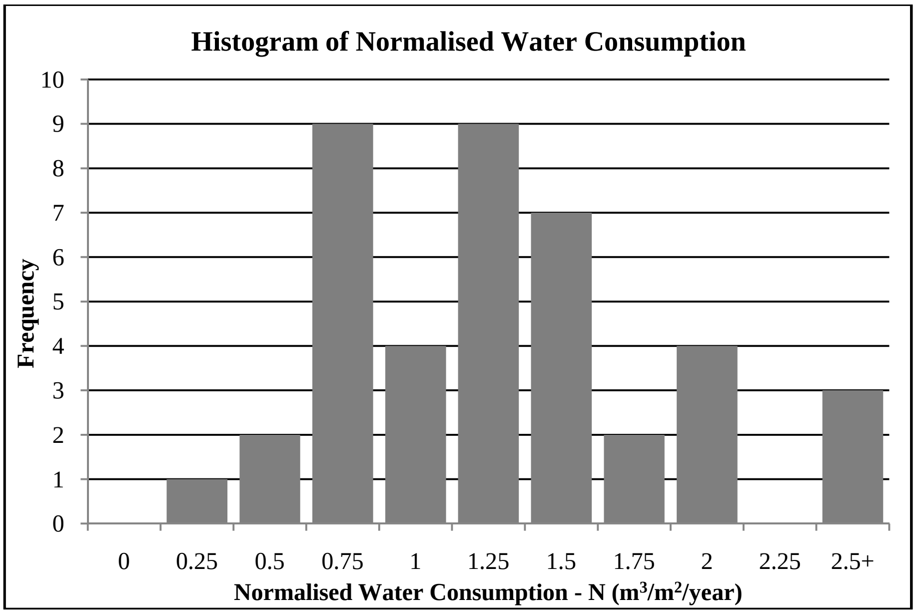

Figure 4: Histogram with Bell-Curve.

In Figure 4 above, only forty-one counts have been used – the reason being that in some cases multiple buildings share a single water meter, therefore only the total values can be used (unless sub-metering is installed to accurately divide their water use).

By examining the histogram, above, the midpoint can be estimated to be approximately $1.25m^3/m^2$/year, with fewer buildings at either end of the scale. The shape of this demonstrates a skewed normal distribution of the data, while a skew value of 1.57 shows that data is skewed to the positive side of the distribution.

5.2. Benchmark Values

Consumption Benchmarking: In order for this benchmark to be meaningful and accurate, it must take into account the sample population. A consumption benchmark will state a typical value for that population, being the median value (fiftieth percentile). Occasionally a best and worst practice value will also be given as the twenty-fifth and seventy-fifth percentiles respectively, which is commonly referred to as 'Best Case' and 'Excessive Use' in similar studies, such as those outlined under Section 5.

The calculated median water consumption intensity across the entire data set is $1.17m^3/m^2$/year, which is close to the above estimated midpoint. It is important to note here that when configuring the benchmark values, the median value has been used as the best representation of 'typical', not the mean [average] value.

The best case consumption benchmark is calculated using the 25^{th} percentile of the dataset, or the lower quartile, $0.72m^3/m^2$/year. The excessive use consumption benchmark uses the 75^{th} percentile, or the upper quartile of $1.39m^3/m^2$/year. This is further outlined in Table 5, and Figure 5, below.

Consumption Benchmark	Percent of Population at this level or better	Normalised Water Consumption
Excessive Use	75%	1.39 m^3/m^2/yr
Typical	50%	1.17 m^3/m^2/yr
Best Case	25%	0.72 m^3/m^2/yr

Table 5: Proposed Consumption Rating Bands for the Sample Population (*n*=41).

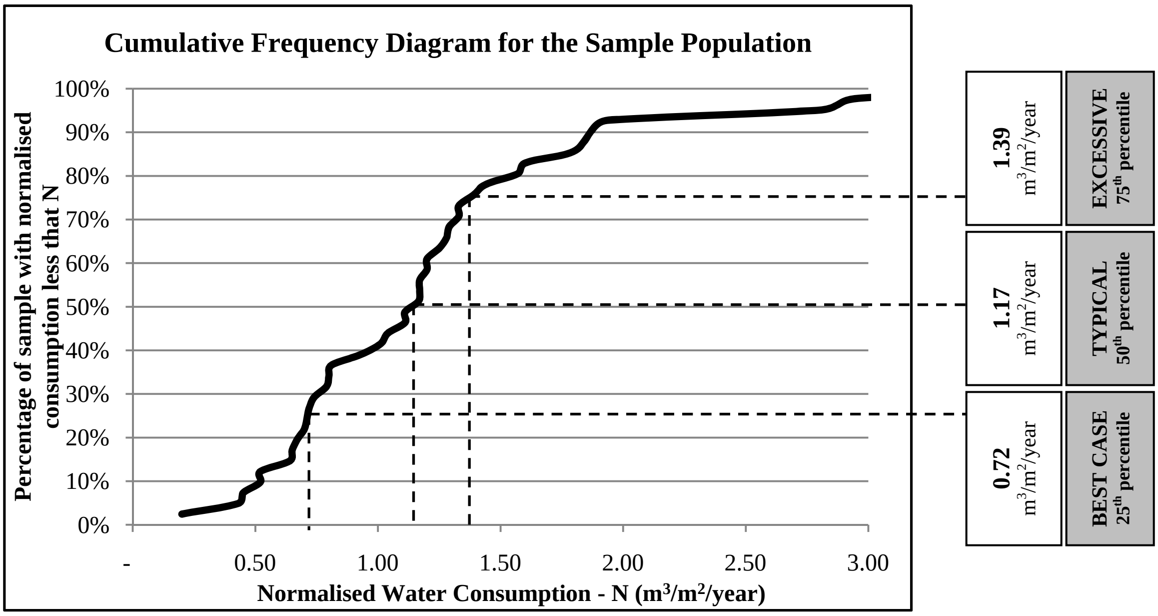

Figure 5: Cumulative Distribution of Normalised Water Consumption (*n*=41).

This chart divides the data into quartiles to establish the median point that might be considered the typical water consumption for an office building.

Efficiency Benchmarking: The middle tier of efficiency will normally equate to the typical consumption benchmark outlined above, but not always, and such benchmarks are generally given as a rating out of five. Efficiency benchmarks follow the same principles as the consumption benchmarks, where their bands are determined by percentiles. It is the efficiency benchmarks which are included into some building sustainability rating tools – such as *NABERS* (Quinn et al, 2006).

There are certain rules which are used to create the rated bands of efficiency, such as those outlined by Bannister et al (2005), below:

1 80% of the sample population should be encompassed;
2 The median value should represent the typical value;
3 The best score should 'represent a level of efficiency essentially beyond normal technological solutions, but attainable through innovation'; and
4 The rated bands of efficiency should be equal/linear.

However, Rules 2 and 4 take precedence over Rules 1 and 3 in the event of any discrepancy between these requirements (Bannister et al, 2005:17). These rules have been used to form the efficiency benchmarks given in Table 6.

Efficiency Benchmark	Percent of Population at this level or better	Normalised Water Consumption
1	80%	1.57 m^3/m^2/yr
2	67%	1.29 m^3/m^2/yr
2.5	50% (Typical Value)	1.17 m^3/m^2/yr
3	40%	1.01 m^3/m^2/yr
4	26%	0.73 m^3/m^2/yr
5	5%	0.45 m^3/m^2/yr

Table 6: Proposed Efficiency Rating Bands for the Sample Population (*n*=41).

In Table 6 above, 80% of the sample population has been adequately covered, the median value has been used to determine the typical benchmark (2.5), the best score is represented by only 5% of the sample population, and the full rating bands are spread equally apart by 0.28 m^3/m^2/year.

6. INTERNATIONAL COMPARISON

Internationally very little work has been published with regard to water consumption and water performance benchmarking, other than those studies outlined in section 5. Within those published studies, the rating band percentiles have not been displayed or are not clear, therefore, only the typical values can be accurately compared as the fiftieth percentile of the dataset.

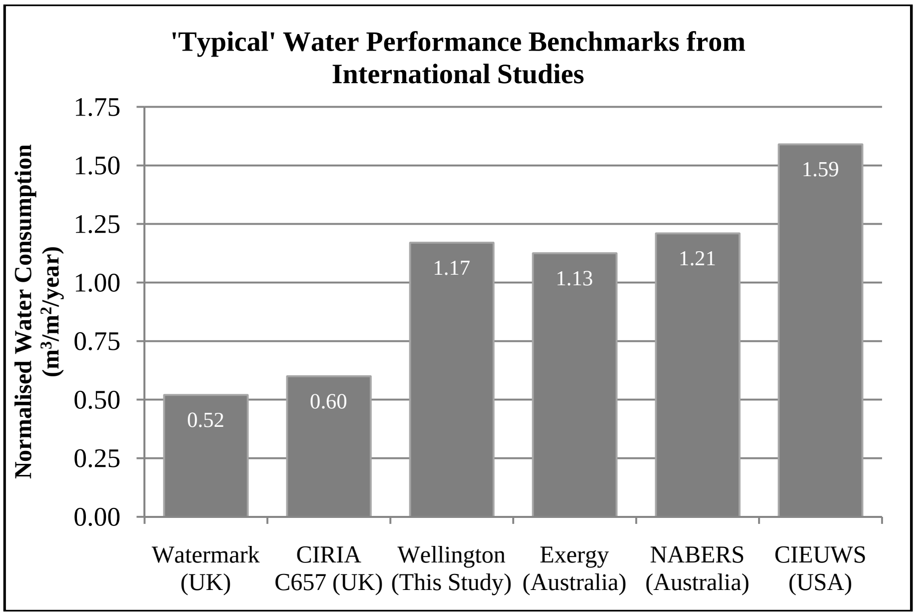

Figure 6: Typical Water Performance Benchmarks from International Studies.

In Figure 6, above, it shows that the selected Wellington CBD office buildings, on average, are performing better than the American and Australian buildings. However, the United Kingdom examples appear to be much more water efficient than any other region studied to date. It should be noted that these figures have not been adjusted in any way for climatic differences.

7. CONCLUSIONS

From this study, it has been established that the data collected from some forty-four commercial office buildings within Wellington CBD, has provided the grounds for both preliminary consumption and efficiency water benchmarks to be established.

7.1. Key Findings

It is concluded that both FTE Occupants and NLA are similarly appropriate in a statistical sense. However, NLA was determined the most pragmatic normalisation factor to be used for water performance benchmarking in New Zealand. The typical water performance for the studied buildings is approximately $1.17m^3/m^2$/year. Internationally, this is on par with similar Australian buildings (*NABERS*, *Exergy*), and demonstrates far better performance than the American studied buildings (under *CIEUWS*); while British buildings appear to use much less water.

7.2. Future Recommendations

As this is a pilot study based only on selected Wellington office buildings, further work is needed using a larger national random sample which will enhance the confidence of the resultant benchmarks. The variability in the data from this study can be used to determine an appropriate sample size which will provide the required confidence interval to make these results statistically significant.

As over half of the water meters in the studied buildings had been replaced in the last five years, there may be opportunities to improve the longer term meter performance. The project will continue to collect information on the durability of water meters.

The lack of seasonal variation in the selected office building water use suggests that water use may not be driven by the occupants, but rather by the types of water using appliances found within the building. This research has also provided the beginning of a database for developing and establishing water performance benchmarks in other industrial and commercial building categories.

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