Impact of building envelope design on energy consumption of the Auckland library

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Abstract

This pilot study is to investigate impact of building envelope design on energy consumption of Auckland public libraries. There are about 55 public libraries in Auckland. Monthly energy consumption data for a whole year and building plans of the 18 libraries (33% of the total number of public libraries in Auckland) are were used for the study. The study is to investigate relationships between daily mean energy consumptions per unit volume of library building indoor space (kWh/m^3/day) and library building envelope design data. Although it is difficult to purely identify the clear relationship between a single design datum and the energy consumption for different library buildings when other building design factors also affect energy consumption simultaneously in different strengths. The study shows that the relationship between the increase in the design datum's variation such as ratio of building surface to volume and the trend of energy consumption can still be identified. The study presents energy profiles and identifying major design factors related to energy consumption of Auckland public libraries.

1. Introduction

There are a number of previous studies related to impacts of different building design factors on energy efficiency. These design factors are mainly related to building orientation, geometry and envelope. Some studies focus on building orientation, which impacts on solar radiation received [1], [2] and shading [3]. Other studies focus on impacts of building shape [4]–[7] with different orientations [5]–[8] on energy consumptions under different climates [9]. All heat exchanges between indoor space and outdoor space are through the building envelope, which has the greatest impact on building energy consumption [10], [11]. Those studies mainly based on mathematical models and computer simulations can be used to compare different building designs for energy efficiency. Some studies used real building energy consumption data and building design data to investigate relationships between them and impact of building design factors on energy efficiency under local climatic conditions [12]. This study is explore impact of building design factors on energy consumption, which is based on real energy consumption data and building envelope design data of Auckland public libraries. The 18 Auckland public libraries (33% of the total number of public libraries in Auckland) are used for this study. The 18 sample libraries include 15 libraries with one isolated building, 2 libraries with 2 isolated buildings and 1 library within the leisure centre. 7 sample library buildings are one-story buildings, 10 sample library buildings are two-story buildings and 1 sample library building is three-story building. The range of libraries' floor areas is 495 – 2600m2 with a mean floor area of 1292m2. Building design data related to building envelopes were calculated according to building plans of the sample public libraries that are provided by the Auckland Council. The study takes account of the following design data related to building envelope:

- ratio of building surface to volume
- ratio of roof surface area to building volume
- ratio of wall surface area to building volume
- ratio of window surface area to building volume
- ratio of window to floor area

This study converted monthly energy consumption data into annual, winter and summer daily mean energy consumptions per unit volume of library building indoor space (kWh/m3/day). This study uses the mean daily energy usage per unit volume of library building indoor space (kWh/m^3/day) as the basic energy consumption unit, which is closely related to building design, indoor thermal conditions and building thermal performance under the local climatic conditions. Figure 1 shows 12-months daily mean energy consumptions per unit volume of building indoor space (kWh/m3/day) of the eighteen sample libraries. During the winter months from June to August or heating months from May to September, daily mean energy consumptions are higher than other months. During the summer, some libraries' daily mean energy consumptions are slightly higher than the months March, April, October and November without heating as some libraries use air-conditioning for cooling during the summer.

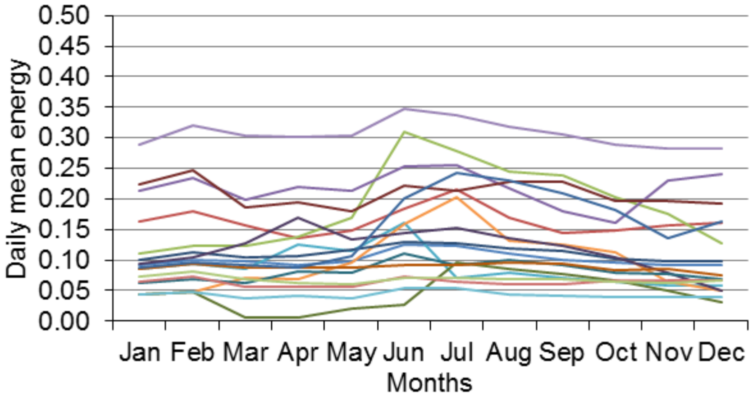

Figure 1: Monthly daily mean energy consumptions of the 18 sample libraries

2. Design Factors and Energy Consumptions

2.1 Impact of ratio of building surface to volume on annual, winter and summer energy

Based on the eighteen sample public libraries, increases in annual, winter and summer energy consumptions are associated with increasing trends in ratio of building surface to volume (see Figure 2-4). Decreasing the mean ratio of building surface to volume in future Auckland library designs or developments can reduce mean energy consumption. The gradient (0.6237) of trend line of winter energy consumptions (see Fig. 2) is generally higher than annual (0.049 in Fig. 3) and summer energy consumptions (0.4258 in Fig.4). Table 1 shows energy consumption data for the sample libraries. Winter energy consumptions of all sample libraries are more than 25% of annual energy consumptions during the 25% time of a year. The mean winter energy consumption is 30.6% of annual energy consumption in the range between 25.4% and 41.2%. The mean summer energy consumption is 22% of annual energy consumption in the range between 14.1% and 26.3%. The sample libraries generally use more energy during the winter than other seasons and decreasing the ratio of building surface to volume will more positively impact on winter energy consumption than other seasons.

Figure 5 shows annual, winter and summer daily mean energy consumptions per unit volume of building indoor space (kWh/m3/day). Some sample libraries' monthly and annual energy consumptions are "outstanding" and significantly higher than the other libraries. The libraries No. 2, 3, 4, 8 and 15 are the top 5 annual energy consumption libraries (see Table 2). For the top 5 annual energy consumption libraries, the mean floor area is 707m2 and significantly smaller than the other libraries (1479m2). Mean ratios of winter to annual energy consumptions of the top 5 annual energy consumption libraries and the other libraries are 29.9% and 30.9%. Mean ratios of summer to annual energy consumptions of the top 5 annual energy consumption libraries and the other libraries are 23.3% and 21.6%. They are close to mean ratios of winter (30.6%) and summer (22.0%) of all sample libraries. Annual daily mean energy consumption per unit volume of building indoor space (0.2162kWh/m^3day) of the top five annual energy consumption libraries No. 2, No. 3, No, 4, No. 8 and No. 15 is 2.4 times of Annual daily mean energy consumption (0.0897kWh/m^3day) of the other libraries as the mean ratio of building surface to volume (0.45) of the top five annual energy consumption libraries is significantly higher than other libraries (0.32). The top 5 annual energy consumption libraries have single glazed windows. Small library buildings potentially use more energy than large libraries as smaller library buildings have higher ratios of building surface to volume. A library building with a higher ratio has larger building surface area to lose more heat during the winter and get more heat gain during the summer per unit volume of building indoor space, which is not good for energy efficiency.

The ratio of building surface to volume for a multi-storey building with the permanent heating should be less than 0.3 for saving space heating energy [13]. Ratios of building surface to volume of the four libraries No.9, 11, 12 and 16 are less than 0.3. The mean ratio of building surface to volume of the four libraries is 0.24 and much lower than other libraries (0.39). Annual, winter and summer daily mean energy consumptions per unit volume of building indoor space, and annual, winter and summer energy consumptions per unit are of building floor of the four libraries are significantly lower than the other libraries (see Table 3) as their ratios of building surface to volume are much lower than others and less than 03. Mean ratios of winter to annual energy consumptions of the four libraries and the other libraries are 31.7% and 30.3%. Mean ratios of summer to annual energy consumptions of the four libraries and the other libraries are 21.8% and 22.1%. They are close to mean ratios of winter (30.6%) and summer (22.0%) of the all sample libraries. Decreasing ratio of building surface to volume through designs of building size, sharp, geometry, building envelope and elements is crucial to reduce library building energy consumption. Ratio of building surface to volume should be considered as the first design factor for future library building energy efficiency.

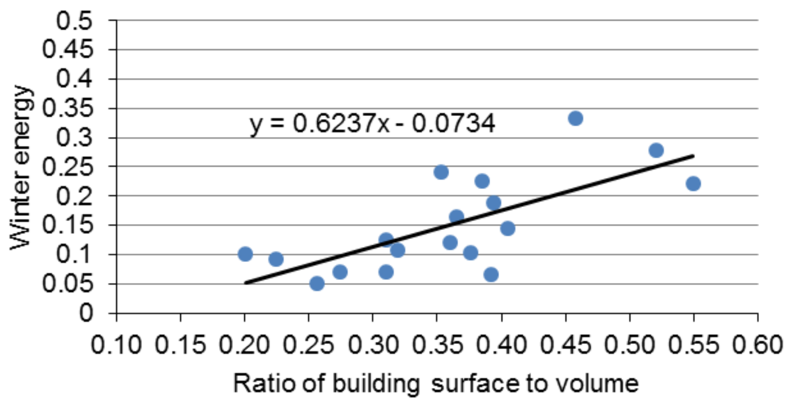

Figure 2: Winter energy (kWh/m^3/day) and ratio of building surface to volume

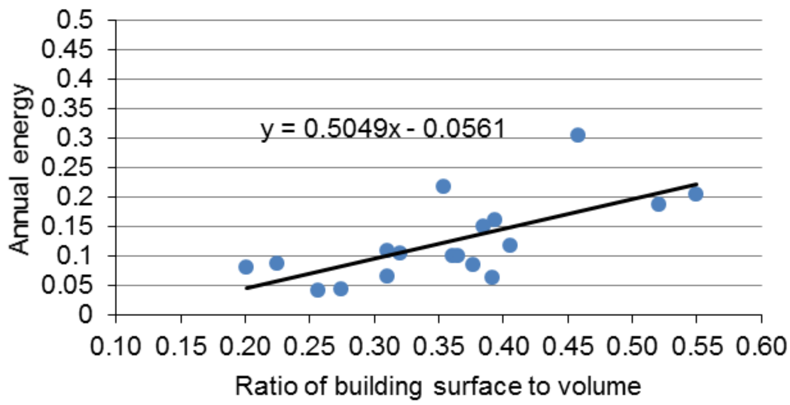

Figure 3: Annual energy (kWh/m^3/day) and ratio of building surface to volume

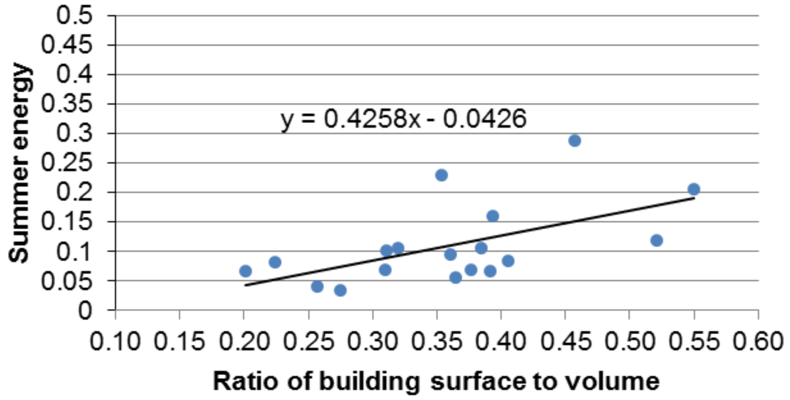

Figure 4: Summer energy (kWh/m^3/day) and ratio of building surface to volume

Energy (kWh)	Mean	Range
Annual	182265	75048 - 369953
Winter: Jun, Jul & Aug.	56278	19629 - 138504
Winter/annual	30.6%	25.4% - 41.2%
Summer: Dec, Jan & Feb.	39469	13198 - 65581
Summer/annual	22.0%	14.1% - 26.3%
Winter/summer	1.5	1.0 – 2.9
Heating months: May-Sep.	87118	31076 - 202805
Heating months/annual	47.3%	40.8%-59.6%

Table 1: Energy consumption data for the sample libraries.

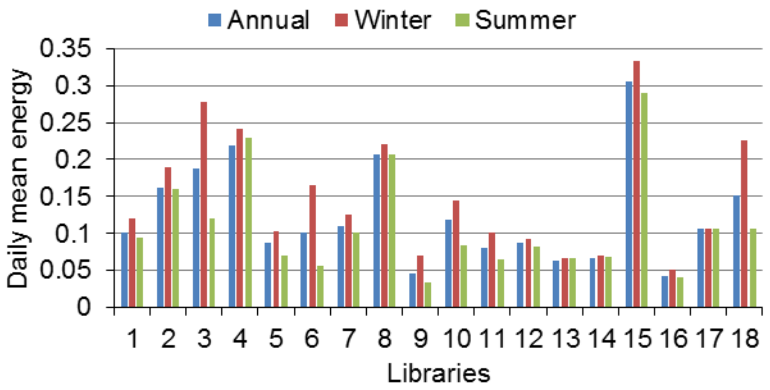

Figure 5: Annual, winter and summer energy (kWh/m3/day) of the sample libraries

Energy	5 libraries	Other libraries	Difference
Annual(kWh/m^3day)	0.2162	0.0897	2.4 times
Winter(kWh/m^3day)	0.2525	0.1109	2.3 times
Summer(kWh/m^3day)	0.2008	0.0752	2.7 times
Annual(kWh/m^2)	261	130	2.0 times
Winter(kWh/m^2)	77	40	1.9 times
Summer(kWh/m^2)	61	28	2.2 times

Table 2: Energy data of the top 5 annual energy consumption libraries

Energy	4 Libraries	Other libraries	Difference
Annual(kWh/m^3day)	0.0644	0.1421	45.3%
Winter(kWh/m^3day)	0.0789	0.1706	46.2%
Summer(kWh/m^3day)	0.0559	0.1207	46.3%
Annual(kWh/m^2)	96	186	51.6%
Winter(kWh/m^2)	29	56	51.8%
Summer(kWh/m^2)	21	41	51.2%

Table 3: Energy data of the lowest 4 annual energy consumption libraries

2.2 Impact of roof, wall and window design on energy

Increases in ratios of roof, wall and window areas to building volume are associated with increasing trends in annual energy consumption (see Figure 6-8). The gradient (1.0284 in Figure 6) of trend line of ratio of window area to building volume is generally higher than ratio of wall area to building volume (0.7638 in Figure 7) and ratio of roof area to building volume (0.432 in Figure 8), which are based on 18 sample library buildings (33% of the total number of public libraries in Auckland).

The mean ratio of roof area to building volume of the top 5 annual energy consumption libraries is 0.28 and higher than the other libraries (0.2). The top 5 annual energy consumption library buildings are one or two stories buildings and the mean floor area is only $707m^2$. Previous study shows the mean floor area of Auckland houses is $182m^2$ with the range of floor area 31 - $446m^2$, which based on 200 different sample houses in the Auckland urban area [12]. Auckland houses with one to two stories loses about 40% of its heat through ceiling and roof during the winter. The thermal performance of local small library buildings are more close to big house than multi-story buildings.

The libraries No. 9, 11, 12 and 16 are the lowest annual energy consumption libraries. Annual daily mean energy consumption of the library No. 16 is marginally lower than the other three libraries No. 9, No. 11 and No. 12. The library No. 16 has insulation and double-glazed windows. The other three libraries have insulation and signal-glazed windows. Windows are commonly weak elements for building thermal design. The thermal resistance (R-value) of a single glazed window (0.15 m^2 °C/W for aluminum window frame and $0.19m^{2}$°C/W for wooden or PVC window frame) is very low compared with walls ($1.9\text{-}2.0m^{2}$°C/W) and roofs ($2.9\text{-}3.5m^{2}$°C/W) in accordance with the current standard [14]. Ratio of window area to building volume should be considered as the second design factor for future library building energy efficiency. Reducing ratio of window area to building volume can more positively impact on annual energy consumption than ratio of roof and wall surface to building volume. A library building with a high ratio of building surface to volume potentially increases ratios of window area to building volume and ratio of roof area to building volume, which is not good for building energy efficiency.

An increase in the ratios of window to floor area is associated with an increasing trend in annual energy consumption (see Figure 9). Day lighting is very important for a library. Increasing the ratio of window to floor for improving day lighting is in contradiction with decreasing the ratio of window to volume for reducing heat loss and space heating energy. Natural day lighting should always be the main source of lighting in libraries, supplemented by electric light when the daylight fades. The window design for library buildings should not only meet the minimum requirement of day lighting but also avoid the big ratio of window to building volume which can create major heat loss during the winter, excessive solar heat gain during the summer, direct sunlight and glare.

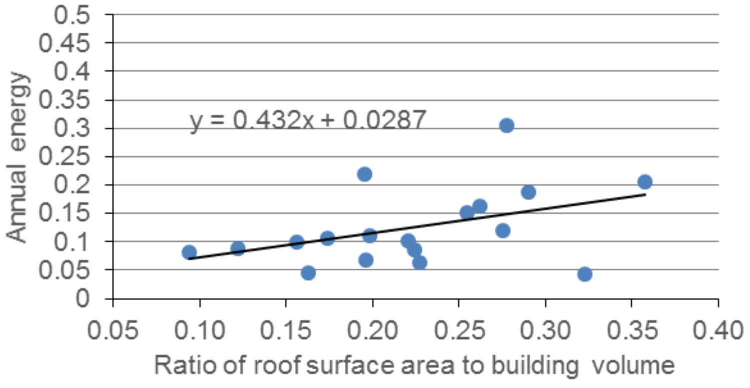

Figure 6: Annual energy (kWh/m^3/day) and ratio of roof surface area to building volume

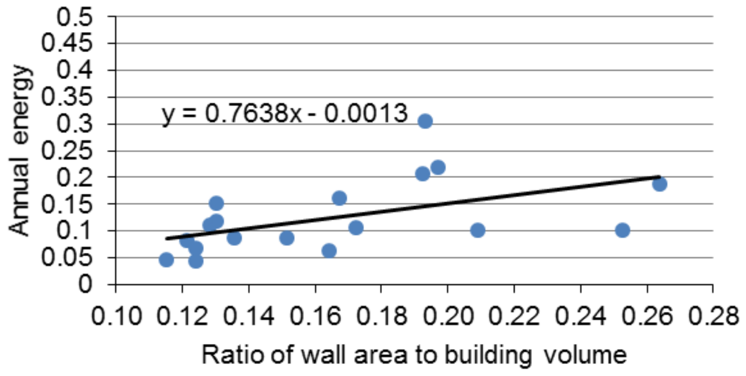

Figure 7: Annual energy (kWh/m^3/day) and ratio of wall area to building volume

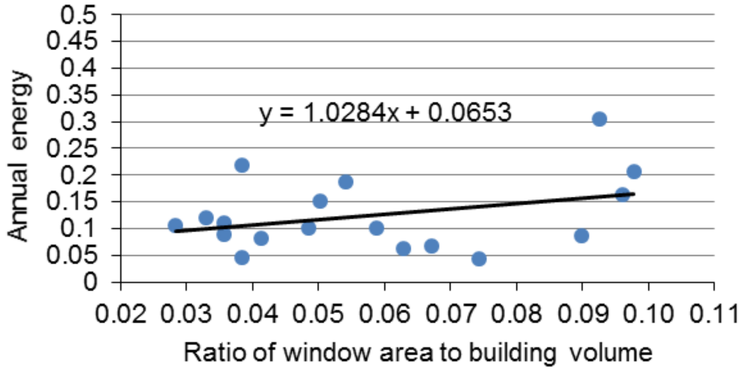

Figure 8: Annual energy (kWh/m^3/day) and ratio of window area to building volume

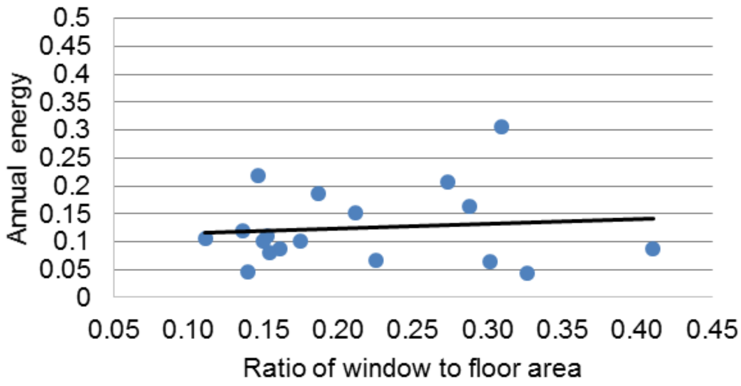

Figure 9: Annual energy (kWh/m³/day) and ratio of window to floor area

3. Conclusion

Based on the eighteen sample public libraries, increases in annual, winter and summer energy consumptions are associated with increasing trends in ratio of building surface to volume. Decreasing ratio of building surface to volume through designs of building size, sharp, geometry, building envelope and elements is crucial to reduce library building energy consumption. Ratio of building surface to volume should be considered as the first design factor for future library building energy efficiency. Based on energy data of the eighteen sample libraries, the mean winter energy consumption of Auckland public libraries is about 30% of annual energy consumptions and the mean summer energy consumption of Auckland public libraries is about 22% of annual energy consumptions during the 25% time of a year. The sample libraries generally use more energy during the winter than other seasons. Auckland library design should more focus on winter thermal performance for building energy efficiency. The gradient of trend line of winter energy consumptions associated with ratio of building surface to volume is generally higher than annual and summer energy consumptions. To decrease the ratio of building surface to volume will more positively impact on winter energy consumption than other seasons.

Increases in ratios of roof, wall and window areas to building volume are associated with increasing trends in annual energy consumption. Based on the 18 sample library buildings, the gradient of trend line of ratio of window area to building volume is generally higher than ratio of wall area to building volume and ratio of roof area to building volume. Window area are generally weak part of building envelope with low R-value for building thermal design. Even using double glazed windows, the R-value is still very low compared with wall or roof, and increasing the ratio of window area to building volume can still cause stronger negative impact on annual energy than increasing the ratios of roof and wall to building volume. Ratio of window area to building volume should be considered as the second design factor for future library building energy efficiency. Reducing ratio of window area to building volume can more positively impact on annual energy consumption than ratio of roof and wall surface to building volume. A library building with a high ratio of building surface to volume can also potentially increases ratios of window area to building volume and ratio of roof area to building volume, which is not good for building energy efficiency. Increasing the ratio of window to floor for improving day lighting is in contradiction with decreasing the ratio of window to volume for reducing heat loss and space heating energy. The window design for library buildings should not only meet the minimum requirement of day lighting but also avoid the big ratio of window to building volume which can create major heat loss during the winter.

4. References

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