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Impact of building envelope design on Auckland public library energy consumption

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Abstract: This study investigated impact of building envelope design on energy consumption of Auckland public libraries under local climatic conditions. Energy consumption data and library building envelope design data of the 30 libraries (55% of local library buildings) are used for this study. The study investigated and identified relationships between daily mean energy consumptions per unit volume of library building indoor space (kWh/m3/day) and library building design data such as ratio of building surface to volume. Building design data related to building envelopes were calculated according to building plans of the sample public library buildings. This study converted monthly energy consumption data into annual, winter, heating-months and summer daily mean energy consumptions per unit volume of library building indoor space (kWh/m3/day). This study focuses on impact strength of building envelope design on library annual, winter, heating-months and summer mean energy consumptions and identifies quantitative relationships between the building design data and the energy consumption data, which can be used to proximately estimate the amount of saving energy consumption associated with the change of a design datum for the future library building development. This study also identified some design issues related to energy efficiency of local library building design.

Keywords: Building energy, building envelope, building thermal design, library building design.

1. INTRODUCTION

Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. For public building in Auckland, the heating months are from May to September. There are about 55 public libraries in Auckland. 30 Auckland libraries are randomly selected for this study. Table 1 shows general information of the 30 sample libraries. Original a whole year monthly energy consumption data and library building plans of the 30 libraries are recorded and provided by the Auckland Council. 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 more closely related to building thermal performance under the local climatic conditions. Although different building design factors related to the main architectural feature, building elements and materials can affect the Library building energy consumption differently and simultaneously, the relationship between building design data and library energy consumption data can still be identified (e.g. increase of winter energy is associated with increase of ratio of building surface to volume). With 55% of Auckland public library building design data and energy data, this study identified impact strength of different building elements such as roof, wall, window etc. on local library annual, winter, heating-months and summer mean energy consumptions.

Table 1: General Information of the 30 sample libraries.

General information	Mean	Range
Total floor area	1543 m^2	395 – 12953 m^2
Building height	1 store	1 – 4 store
Total annual energy	267942 kWh	38126 – 3295108 kWh
Total winter energy	77964 kWh	10717 – 930163 kWh
Total summer energy	59807 kWh	9180 – 757949 kWh
Total heating-months energy	125334 kWh	17026 – 1522650 kWh

2. METHODOLOGY

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. Most of those studies are based on computer simulations. Some studies focus on building orientation, which impacts on solar radiation received (Gupta and Ralegaonkar, 2004; Morrissey *et al.* 2011) and shading (Capeluto 2003). Other studies focus on impacts of building shape (Marks, 1997; Mingfang, 2002; Aksoy and Inalli, 2006; Adamski 2007) with different orientations (Marks, 1997; Florides *et al.* 2002; Aksoy, 2006; Adamski 2007) on energy consumptions under different climates (Depecter *et al.* 2001). All heat exchanges between indoor space and outdoor space are through the building envelope, which has the greatest impact on building energy consumption (Manioglu and Yilmaz, 2006; Radhi, 2008). 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 consumption under local climatic conditions (Su, 2011). This study explored impact of library building envelope design on energy consumption, which is based on real energy consumption data and building design data of Auckland public libraries. This study converted monthly energy consumption data into annual, winter, heating-months and summer daily mean energy consumptions per unit volume of library building indoor space (kWh/m^3/day). The all design data related to library building envelop are based on the building plans of the 30 sample library buildings. 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 wall area

3. ENERGY CONSUMPTION

Table 2 shows annual, winter (June to August), heating-months (May to September) and summer (December, January, February) daily mean energy consumptions per unit volume of library building indoor space (kWh/m^3/day). The mean winter energy consumption is 28.9% of annual energy consumption in the range between 25.7% and 39.2%. Winter energy consumptions of all sample libraries are more than 25% of annual energy consumptions during the 25% time of a year (Figure 1). The mean summer energy consumption is 23.6% of annual energy consumption in the range between 16.5% and 25.7%. Summer energy consumptions of 27 libraries (27 out of 30 libraries) are less than 25% of annual energy consumptions during 25% time of a year (Figure 1). The mean heating-months energy consumption is 47.2% of annual energy consumption in the range between 42.2% and 68.7%. Heating-months energy consumptions of all sample libraries are more than 42% of annual energy consumptions during 41.7% of a year (Figure 1). Generally, the sample libraries generally use more energy during the winter and heating-months than summer and other months. Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. The thermal design of Auckland library buildings should focus on winter thermal performance and winter indoor thermal comfort for energy efficiency.

Table 2: Energy consumption (kWh/m^3/day) of the sample libraries

General information	Mean	Range
Annual mean energy	0.0946	0.0429 – 0.2064
Winter mean energy	0.1079	0.0505 – 0.2230
Summer mean energy	0.0866	0.0333 – 0.1945
Heating-months mean energy	0.1030	0.0472 – 0.2175
Ratio of Winter to Annual	28.9%	25.7% – 39.2%
Ratio of Summer to Annual	23.6%	16.5% – 25.7%
Ratio of Heating-months to Annual energy	47.2%	42.2% – 68.7%

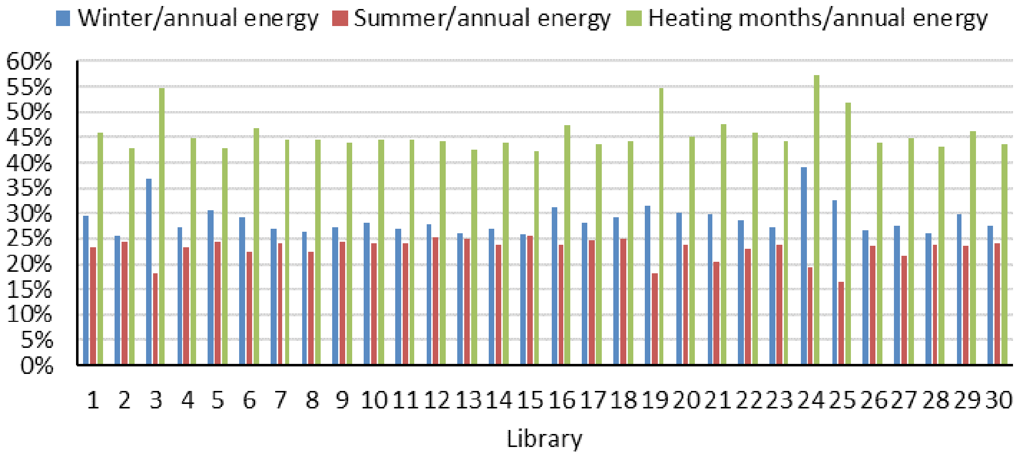

Figure 1: Ratios of winter, summer and heating-months to annual energy consumption

4. IMPACT OF BUILDING ENVELOPE DESIGN ON ENERGY CONSUMPTION

4.1 Ratio of building surface to volume

The mean ratio of building surface to volume of the 30 sample library buildings is 0.36 in the range between 0.08 and 0.56. A library building with a high ratio of building surface to volume has a large external surface area per unit of indoor space from which to lose heat to the outdoors, and uses more energy for space heating and other appliances which can be affected by indoor thermal conditions during the winter months. An increase in the ratios of building surface to volume of the sample library is associated with an upward trend in annual, winter, heating-months and summer daily mean energy usage per unit volume of library building indoor space (Figure 2 - 5). For the energy data and building design data of the 30 sample libraries, the gradient of trend lines of winter energy (0.0995) and heating-months energy (0.1099) are higher than annual (0.0993) and summer (0.0829). Changing or reducing ratio of building surface to volume can impact winter energy and heating-months energy more than summer energy as winter energy and heating-months energy are bigger portions of annual energy than summer energy.

Decreasing the mean ratio of building surface to volume in future Auckland library developments can reduce the mean energy consumption. For example, based on the 30 sample library buildings (55% of local library buildings), the gradient of the trend line of winter energy consumption related to ratios of building surface to volume is 0.0995 and the mean winter energy consumption is 0.1079 kWh/m^3/day. Based on the sample library building design and energy data, if the mean ratio of building surface to volume of future Auckland library buildings is reduced from 0.36 to 0.26, future development with a mean ratio of 0.26 could potentially be reduced by 0.00995 kWh/m^3/day (0.0995 × (0.36 - 0.26) = 0.00995) of the mean winter energy consumption and save 10% (0.00995 ÷ 0.0995 = 10%) of mean winter energy consumption. The mean ratio of building surface to volume, the mean energy consumption and the gradient of the trend line of daily mean real energy usages associated with variation of the ratios of building surface to volume of the current Auckland public library buildings can be used as baseline to estimate energy consumption of future library development.

Most of Auckland public libraries are small and low-rise isolated buildings (Figure 6). The mean floor area of the 30 sample library buildings is 1543 m^2 in the range between 395 m^2 and 12952 m^2 and the mean annual energy of 30 sample library buildings is 0.0946 kWh/m^{3}day in the range between 0.0429 kWh/m^{3}day and 0.2064 kWh/m^{3}day. Floor area of the 18 sample libraries are less than 1000 m^2. The mean ratio of building surface to volume of those 18 small libraries is 0.41 and their mean annual, winter, heating-months and summer energy are 0.1020 kWh/m^3/day, 0.1154 kWh/m^3/day, 0.1105 kWh/m^3/day and 0.0946 kWh/m^3/day. Floor area of other 12 sample libraries are more than 1000 m^2. The mean ratio of building surface to volume of the 12 libraries is 0.27 and their mean annual, winter, heating-months and summer energy are 0.0836 kWh/m^3/day, 0.0966 kWh/m^3/day, 0.0917 kWh/m^3/day and 0.0747 kWh/m^3/day. Small library buildings with larger ratio of building surface to volume use more annual, winter, heating-months energy and summer energy.

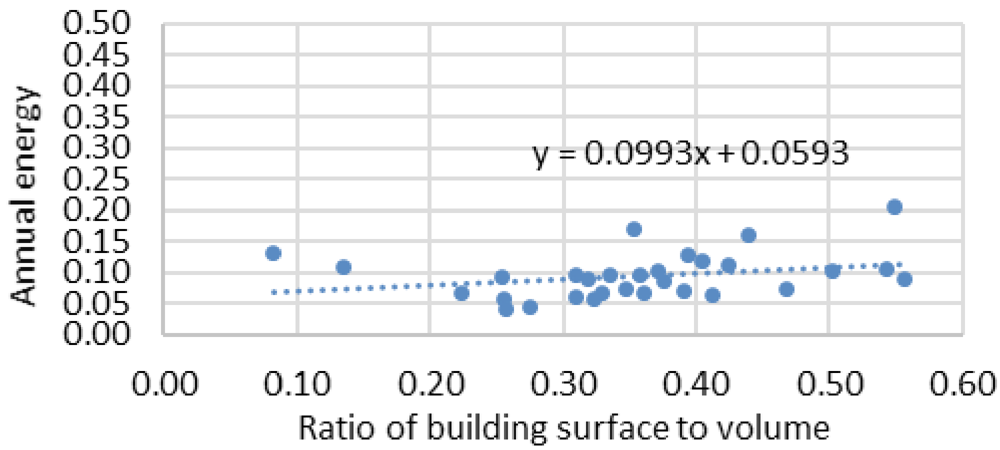

Figure 2: Annual energy (kWh/m^3/day) and ratio of building surface to volume

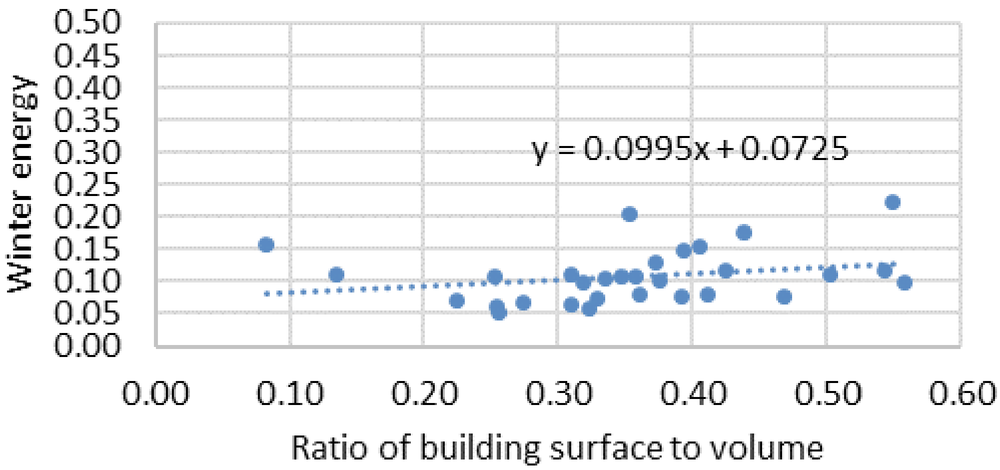

Figure 3: Winter energy (kWh/m^3/day) and ratio of building surface to volume

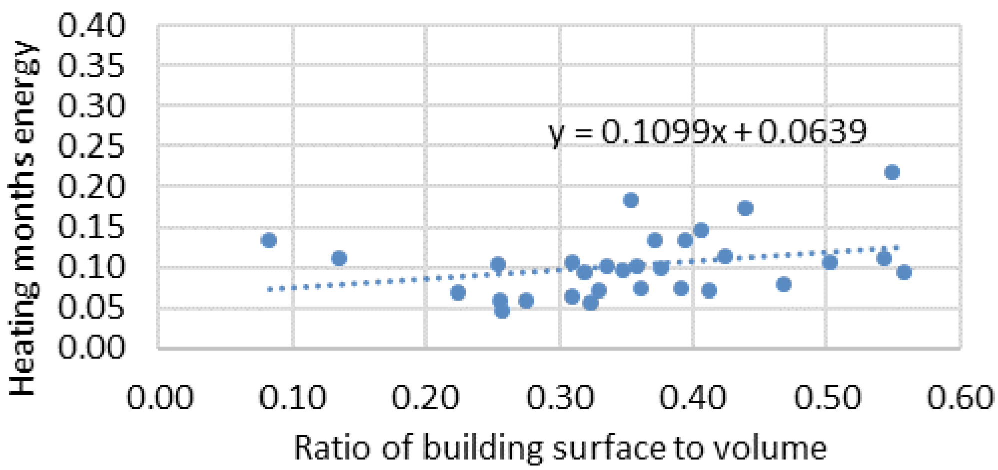

Figure 4: Heating-months energy (kWh/m^3/day) and ratio of building surface to volume

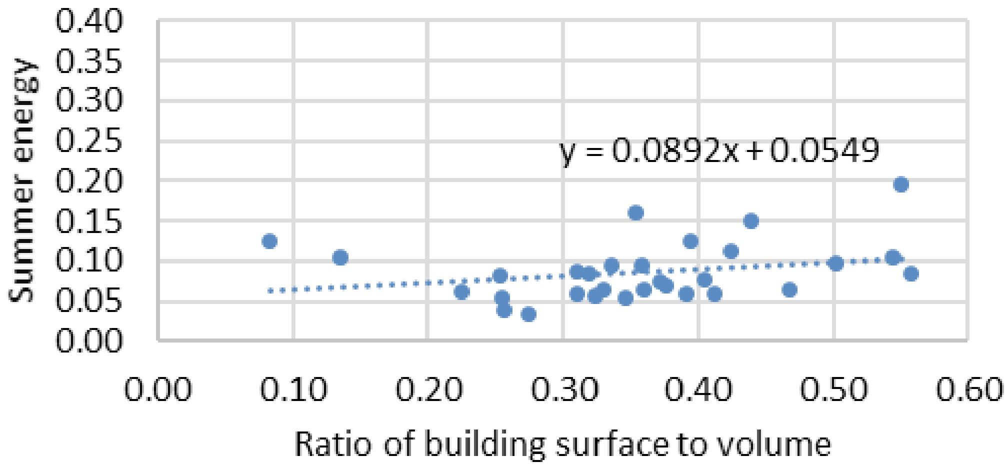

Figure 5: Summer energy (kWh/m³/day) and ratio of building surface to volume

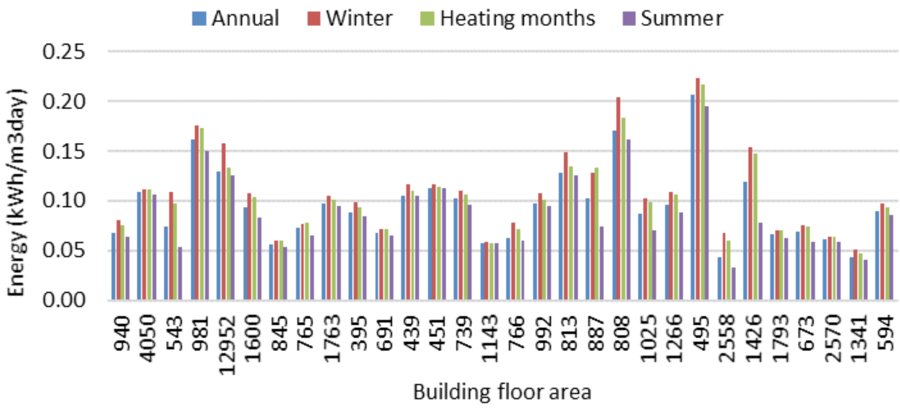

Figure 6: Energy consumptions (kWh/m³/day) and building floor area (m²)

4.2 Building envelope elements: roof, wall and window

For the 30 sample libraries, 18 libraries are 1 story buildings, 11 libraries are 2 store buildings and 1 library is 4 store building. Most of Auckland libraries are small and low-rise isolated buildings. A low rise building such as a house with 1 to 2 stories loses more heat through roof than wall during the winter. Auckland houses with 1 to 2 stories loses about 40% of its heat through ceiling and roof and about 20% of its heat through wall during the winter. The ratios of roof area to building volume of the sample library buildings are 0.03 to 0.37 with a mean ratio of 0.22 and the ratios of wall area to building volume are 0.05 to 0.22 with a mean ratio of 0.14. An increase in the ratios of roof area to building volume and the ratios of wall area to building volume is associated with an upward trend in annual and heating-months daily mean energy usage per unit volume of library building indoor space (Figure 7 – 8; Figure 10 – 11). The gradients of the trend line of roof (0.1148 for annual, 0.1248 for heating-months) are higher than wall (0.0327 for annual, 0.0549 for heating-months). For Auckland small and low rise isolated library buildings, decreasing the ratio of roof area to building volume can cause a more positive impact on annual and heating-months energy consumption than decreasing the ratio of wall area to building volume. Most windows of the sample library buildings are single glazed windows. Only 6 libraries have double glazing window. An increase in the ratios of window area to building volume of the sample library buildings is associated with an upward trend in annual and heating-months daily mean energy usage per unit volume of library building indoor space (Figure 9, Figure 12). The gradients of the trend line of window (0.1747 for annual, 0.1526 for heating-months) are higher than roof (0.1148 for annual, 0.1248 for heating-months) and wall (0.0327 for annual, 0.0549 for heating-months). Windows are commonly weak elements of building thermal performance. The thermal resistance (R-value) of a single glazed window (0.15 m² °C/W for aluminum window frame and 0.19 m² °C/W for wooden or PVC window frame) is very low compared with walls (1.9-2.0 m² °C/W) and roofs (2.9-3.3 m² °C/W) insulated in accordance with the standard (SNZ, 2009). For Auckland small and low rise isolated library buildings, decreasing the ratio of window area to building volume can cause a more positive impact on annual and heating-months energy consumption than decreasing the ratio of roof area to building volume and the ratio of wall area to building volume.

Increasing the ratio of window to wall or floor for improving day lighting is in contradiction with decreasing the ratio of window to wall or floor for reducing heat loss and space heating energy. The ratios of window to wall of the sample library buildings are in a wide range of 5% to 68% with a mean ratio of 34%. The mean ratio of window to wall of the sample library buildings is over 30%. Ratios of window to wall of 10 sample library buildings (33% of the 30 sample libraries) and 7 sample library buildings (23% of the 30 sample libraries) are more 40% and 50%. Natural day lighting should always be the main source of lighting in the local library, 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 wall or floor area which can create major heat loss during the winter, excessive solar heat gain during the summer, direct sunlight and glare, which is not good for library building energy efficiency.

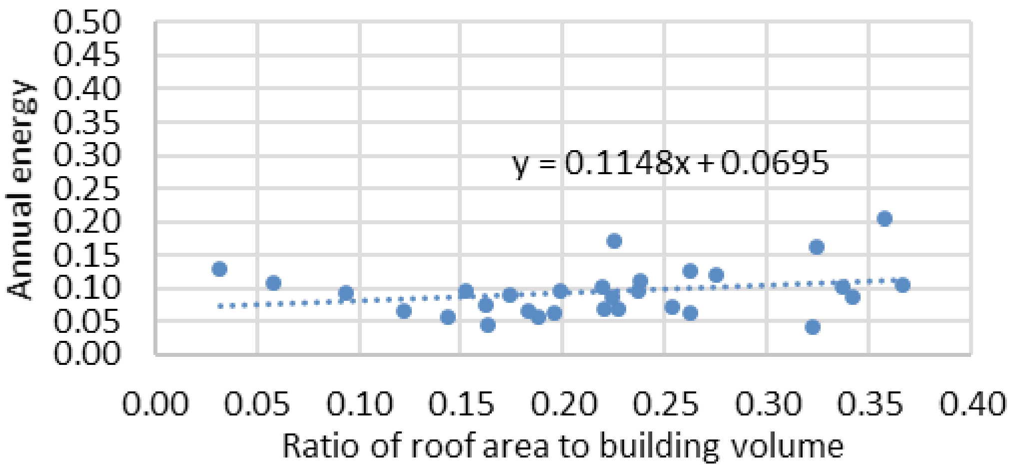

Figure 7: Annual energy (kWh/m³/day) and ratio of roof area to building volume

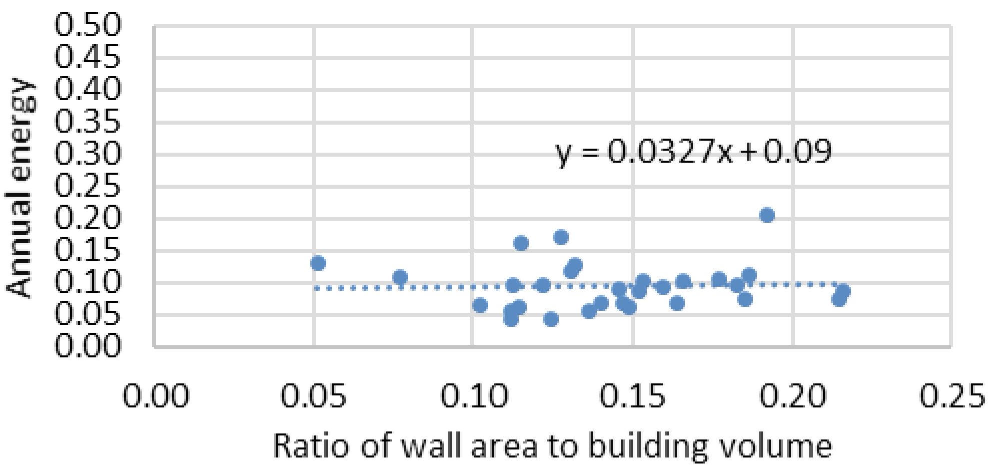

Figure 8: Annual energy (kWh/m³/day) and ratio of wall area to building volume

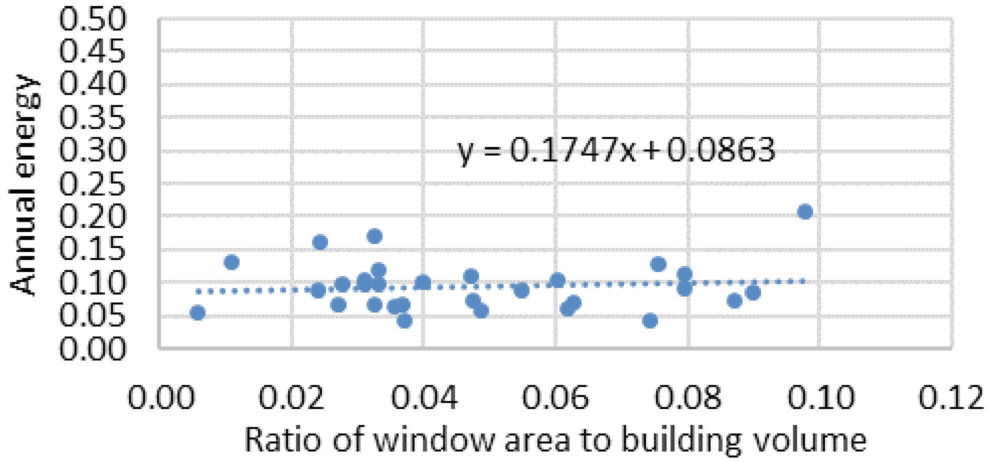

Figure 9: Annual energy (kWh/m³/day) and ratio of window area to building volume

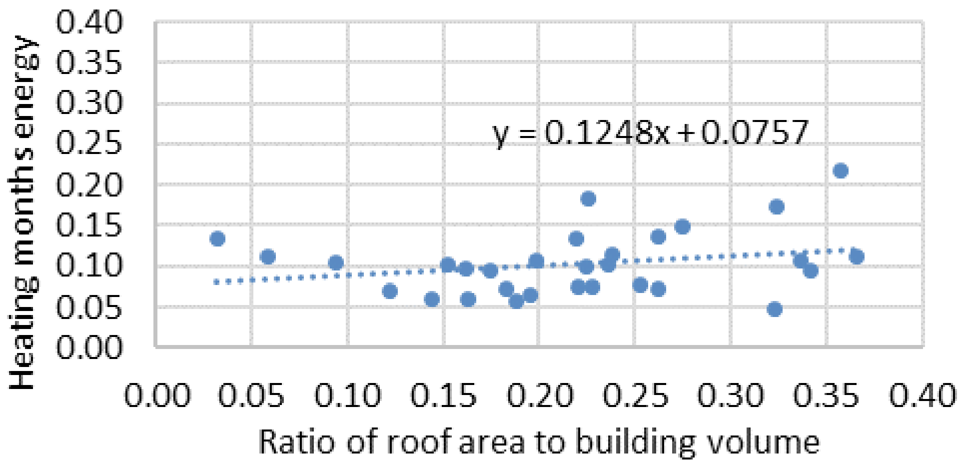

Figure 10: Heating-months energy (kWh/m³/day) and ratio of roof area to building volume

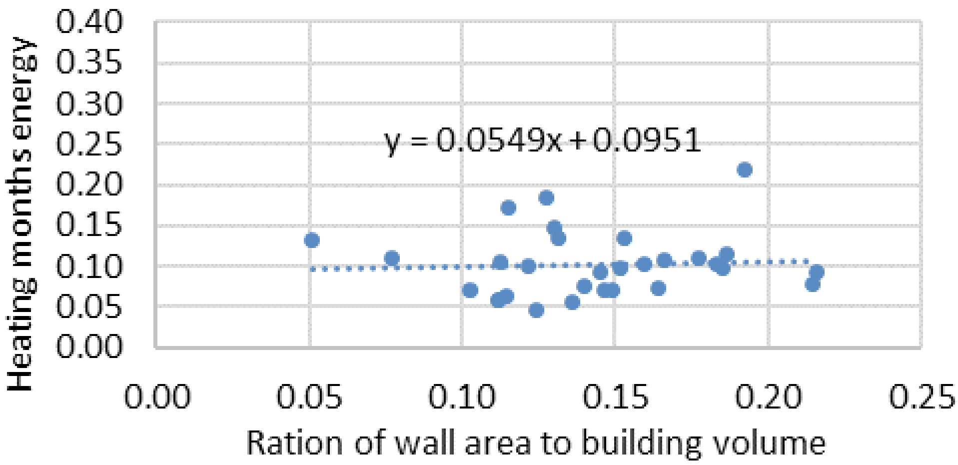

Figure 11: Heating-months energy (kWh/m³/day) and ratio of wall area to building volume

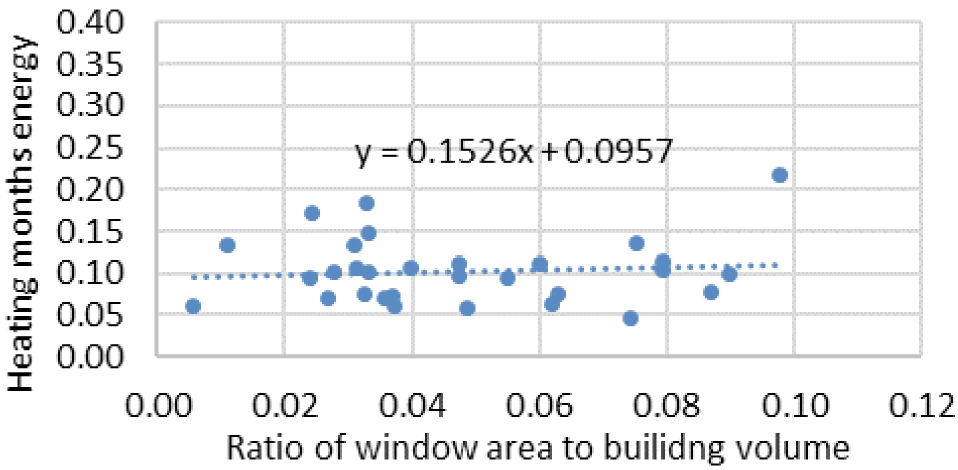

Figure 12: Heating-months energy (kWh/m^3/day) and ratio of window area to building volume

5. CONCLUSIONS

Based on energy data of the 30 sample libraries, the mean winter energy consumption of Auckland public libraries is 28.9% of annual energy consumptions during the 25% time of a year, the mean heating-months energy consumption of Auckland public libraries is 47.2% of annual energy consumptions during the 41.7% time of a year and the mean summer energy consumption of Auckland public libraries is about 23.6% of annual energy consumptions during the 25% time of a year. Auckland public libraries use more energy during the winter and heating-months than other seasons. According to current library energy consumption data, Auckland library thermal design should more focus on winter thermal performance and reducing heating-months energy for building energy efficiency.

As Auckland has low population density and small communities, most of public libraries are small and low rise isolated buildings. Based on the energy data and design data of the 30 sample library buildings, small library buildings use much more annual, winter, heating-months and summer daily mean energy per unit volume of building indoor space than the large libraries as the smaller library buildings have higher ratios of building surface to volume. Current Auckland public library buildings with a high ratio of building surface to volume are not energy efficiency under the local climate. For improving the energy efficiency of new library developments, designers should change the current library design convention from small and low rise isolated building to multi-stories building or integrated development.

According to envelope design data and energy data for the 30 sample library buildings, the window area is the weakest portion of the envelope, having the lowest R-value, and more negative impact on winter, heating-months and summer energy consumption than roof and wall. For the future Auckland library building envelope design, the first thing to do for building energy efficiency is to reduce ratio of window to building volume; and secondly, the roof area, which has more negative impact on winter energy than the wall area. The ratios of window to wall of the sample library buildings are in a wide range of 5% to 68% with a mean ratio of 34%. The small ratios cannot meet the minimum requirement of day lighting and the big ratios can create major heat loss during the winter. The New Zealand building code should give some acceptable solutions for library window design related to ratio of window to wall or floor, which can balance the minimum requirement of day lighting and prevention of excessive heat loss.

Based on real energy consumption data and building envelope design data of the current Auckland library buildings, the quantitative relationship between building envelope design data and daily mean energy consumption data can be identified. The gradient of the trend line of decreasing daily mean energy associated with the variation of building envelope design datum such as the ratio of building surface to volume or the ratio of window area to building volume of the current Auckland library buildings can be used as baseline to estimate energy consumption of future library development.

References

Adamski, M. (2007) Optimization of the form of a building on an oval base, *Building and Environment*, 42(4), 1632-1643.

Aksoy, U. T., and Inalli, M. (2006) Impacts of some building passive design parameters on heating demand for a cold region, *Building and* Environment, 41(12), 1742-1754, December.

Capeluto, I. G. (2003) Energy performance of the self-shading building envelope, *Energy and Buildings*, 35(3), 327-336.

Depecter, P., Menezo, C., Virgone, J., and Lepers, S. (2001) Design of building shape and energetic consumption, *Building and Environment*, 36(5), 627-635, June.

Florides, G. A., Tassou, S. A., Kalogirou, S. A., and Wrobel, L. C. (2002) Measures used to lower building energy consumption and their cost effectiveness, *Applied Energy*, 73(3-4), 299-328, November-December.

Gupta, R., and Ralegaonkar, R. B. (2004) Estimation of beam radiation for optimal orientation and shape decision of buildings in India, *Architectural Journal of Institution of Engineers India,* 85, 27-32.

Manioglu, G., and Yilmaz, Z. (2006) Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort, *Energy and Buildings*, 38 (3), 266-272.

Marks, W. (1997) Multicriteria optimisation of shape of energy-saving buildings, *Building and Environment*, 32(4), 331-339.

Mingfang, T. (2002) Solar control for buildings, *Building and Environment*, 37(7), 659-664.

Morrissey, J., Moore, T., and Horne, R.E. (2011) Affordable passive solar design in a temperate climate: an experiment in residential building orientation, *Renewable Energy*, 36(2), 568-577.

Radhi, H. (2008) A systematic methodology for optimising the energy performance of buildings in Bahrain, *Energy and Buildings*, 40(7), 1297-1303.

SNZ, (2009) *New Zealand Standard 4218-2009 Thermal insulation: housing and small buildings*. Wellington, New Zealand: Standards New Zealand.

Su, B. (2011) The impact strength of building passive design on housing energy efficiency, *Architectural Science Review*, 54(4), 270-276.