

Hotel Design and Energy Consumption

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Abstract—A hotel mainly uses its energy on water heating, space heating, refrigeration, space cooling, cooking, lighting and other building services. A number of 4-5 stars hotels in Auckland city are selected for this study. Comparing with the energy used for others, the energy used for the internal space thermal control (e.g. internal space heating) is more closely related to the hotel building itself. This study not only investigates relationship between annual energy (and winter energy) consumptions and building design data but also relationships between winter extra energy consumption and building design data. This study is to identify the major design factors that significantly impact hotel energy consumption for improving the future hotel design for energy efficient.

Keywords—Hotel building design, building energy, building passive design, energy efficiency.

I. INTRODUCTION

HOTELS are the big energy users, and are thus likely to gain the greatest benefits from improved energy efficiency (Isaacs 1996). The previous study showed that an average hotel used most of its energy on heating and refrigeration in New Zealand. An average hotel used its energy on space heating (31%), water heating (22%), refrigeration (31%), cooking (12%) and lighting (3%). Average annual energy consumption per bed (22167MJ) is more than other accommodation categories such as Bed and Breakfast (11200MJ), motel (5122MJ), and Backpacker (7613MJ) [1].

For minimizing impacts of different hotel facilities and climates, a number of Auckland 4-5 stars hotels with a central air-conditioning system for space heating and cooling, which use both electricity and gas, are selected for this study. This study focuses on the relationships between hotel building design and energy consumption.

18 sample hotels include 15 hotels with 1 isolated building, 3 hotels with 2, 3 or 5 isolated buildings. The range of floor areas is 3128-44415m² with a mean floor area of 19064m². The range of hotel guestroom number is 25 - 455rooms with a mean number of guestrooms of 235rooms. The range of guestroom floor areas is 25 - 66m² with a mean of 40m². The range of ratio of total guestroom floor area to hotel floor area is 29% - 69% with a mean of 53%. There are 7 hotels with indoor swimming pools and 11 hotels without.

Historic surveys showed that the range of annual energy consumption per guestroom of large hotels in New Zealand is

from 2075 to 50678 kWh and the average is 22371kWh [2]. The range of annual energy consumption per guestroom per year of the 4-5 stars hotels in Auckland for this study is 6932 kWh to 36792 kWh and the average energy consumption is 20030kWh, which is close to the average energy consumption of the large hotels in New Zealand.

Based on 18 sample hotels, this study investigates the relationships between their energy consumption data and building design data for developing passive design guides for hotel building energy efficiency. The following hotel building design data are used for this study:

- Ratio of building surface and volume
- Ratio of total wall area to building volume
- Ratio of north wall to total wall area
- Ratio of window and wall area
- Ratio of total roof area and building volume
- Ratio of north window and north wall area

II. ENERGY CONSUMPTION DATA

Table I shows energy consumption data of sample hotels. The sample hotels annually use more electricity than gas. The sample hotels use 17% more energy per guestroom during winter than summer. In account of room occupancy, the hotels use 40% more energy per guestroom during winter than summer. Fig. 1 shows the mean occupancy of the sample hotels. The summer mean occupancy (73%) is higher than winter (61%) of the sample hotels. The sample hotels averagely use 19% more energy during winter than summer. Total winter months' energy consumptions of all the hotels are more than 25% of total annual energy consumption for the 25% time of year (see Fig. 2). Total three summer months' energy consumptions of all the hotels are less than 25% of annual total energy consumption for the 25% time of year (see Fig. 3). The mean ratio of total winter energy to total annual energy is 28% and the mean ratio of total summer energy to total annual energy is 23% for the 25% time of a year. The mean winter energy consumption per guestroom during the winter is 17% more than summer when the winter occupancy is lower than the summer occupancy. Taking the occupancies into account, the mean winter energy consumption per guestroom during the winter is 40% more than summer. Generally the Auckland summer is comfort as the summer temperatures are rarely over 28°C. Auckland has a temperate climate with comfortable warm and dry summer, the summer temperatures are rarely over 28°C, and mild and wet winters, the winter temperatures are rarely below 5°C. Using 17°C as a base temperature, Auckland Heating Degree Days is 1017 and Cooling Degree Days is 381 [3]. Commonly an Auckland building uses more energy during the winter than summer as

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the space heating energy consumption is more than the space cooling energy consumption for thermal controls. The Auckland hotel building thermal design should more focus on winter thermal performance and indoor thermal comfort for energy efficiency [4].

The national and international energy surveys for the hotel sector commonly use kWh/room/year as the units to present the energy used in the hotels. The mean energy data use per room in the national energy survey can be used to show the general profile of energy used in the hotel business. Using different units to compare the energy used in different hotels may lead to different results. The question is what energy unit is appropriate to be used to present or compare energy consumptions or energy efficiency related to the different hotel building designs, especially to compare the energy used for internal space heating and cooling. The mean energy used for space heating and cooling per unit of the volume indoor space is more appropriately used for the comparison of building thermal design for energy efficiency. This study uses annual and winter consumption per m³ of indoor space per day (kWh/m³day) as basic energy data for this study, and also uses the difference of energy consumption between winter months and other months, which represents extra winter energy consumption mainly including space heating energy and other extra energy consumption related to the winter indoor thermal conditions.

TABLE I
ENERGY CONSUMPTION DATA OF HOTELS

Energy	Mean	Range
Annual total	5099283kWh	529490-11700000kWh
Electricity / annual	59%	47-92%
Gas / annual	41%	8-53%
Annual per room	20030kWh/room	6932-36792kWh/room
Annual per m ²	251kWh/ m ²	90-434kWh/ m ²
Winter / annual	27.8%	26.4-31.4%
Winter per room	5520kWh/room	2175-10031kWh/room
Winter per m ²	70 kWh/ m ²	25-48 kWh/ m ²
Summer / annual	23.4%	20-25%
Summer per room	4702kWh/room	1399-8585kWh/room
Summer per m ²	59 kWh/ m ²	21-101 kWh/ m ²
Heating month/annual	45%	42-47%

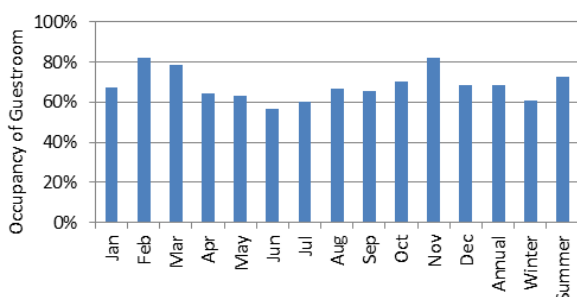


Fig. 1 Occupancy of sample hotels

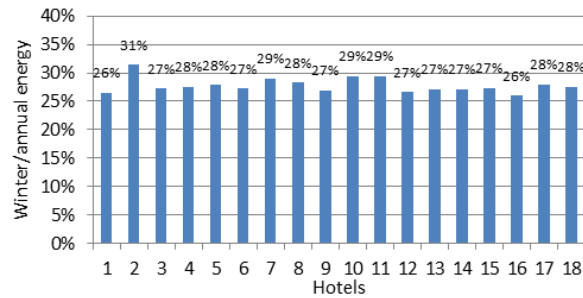


Fig. 2 Ratio of total winter to annual energy consumptions

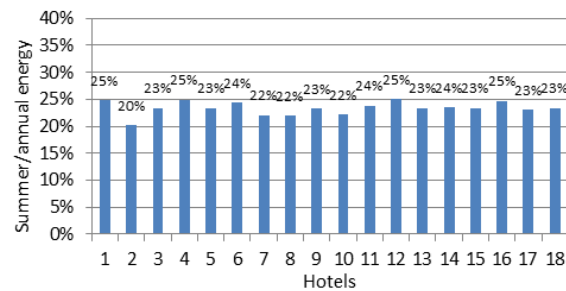


Fig. 3 Ratio of total summer to annual energy consumptions

III. BUILDING DESIGN AND ENERGY DATA

A. Ratio of Building Surface to Volume

The ratios of building surface to volume of sample hotels are in the ranges of 0.045 to 0.372 with a mean ratio of 0.124. Only two hotels' ratios are higher than 0.3 [5]. The ratio of building surface to volume for a multi-storey residential building with the permanent heating should be less than 0.3 for saving space heating energy. An increase in annual and winter energy consumption is associated with an upward trend in the ratios of building surface to volume of the sample hotels (see Fig. 4-5). An increase in extra winter energy consumption is associated with an upward trend in the ratios of building surface to volume of the sample hotels (see Fig. 6). A building with a low ratio of building surface to volume has a small external surface area per unit of indoor space from which to lose heat to the outdoors, and uses less energy for space heating and other appliances, which can be affected by indoor thermal conditions during the winter.

An increase in summer energy consumption is associated with an upward trend in the ratios of building surface to volume of the sample hotels (see Fig. 7). A building with a low ratio of building surface to volume has a small external surface area per unit of indoor space from which to get heat gain to the indoors, and uses less energy for space cooling during the summer.

An increase in ratios of winter to annual energy is associated with an upward trend in the ratios of building surface to volume of the sample hotels (see Fig. 8). An increase in ratios of summer to annual energy is associated

with a downward trend in the ratios of building surface to volume of the sample hotels (see Fig. 9). As winter energy consumption is a larger portion of annual energy consumption to compare with summer energy consumption, it results increase of total annual energy consumption.

B. Ratio of Wall Area to Building Volume

The ratios of wall to building surface area are in the ranges of 54% to 93% with a mean ratio of 77%, which is significantly higher than the mean ratio of 55% of local houses, which based on the research related to the 200 Auckland houses [6]. As the wall area is the major portion of building surface area of sample hotels, an increase in annual, winter and extra winter energy is also associated with an upward trend in the ratios of wall area to building volume of the sample hotels, which is similar as ratios of building surface to volume (see Fig. 10-12). The roof area is the smaller portion of building surface area to compare with the wall area. The upward heat loss through hotel roof is protected by the floor structures. The wall for most guestrooms is the only external wall for heat exchange with outdoor. Comparing with the roof, the wall thermal design more significantly impacts indoor thermal condition and energy efficiency for a multi-story hotel building.

C. Ratio of North Wall to Total Wall

The building with a good orientation has higher ratio of north wall to total wall area. There are not clear and strong relationships between annual, winter and extra winter energy consumption data and ratios of north wall to total wall (see Fig. 13-15). An increase in annual, winter and extra winter energy is not associated with a downward trend in the ratios of north wall to building volume of the sample hotels (see Fig. 16-18). A hotel building with large north wall area has more exposure surface area to the sun and also increasing surface area to loss heat. As the winter daily sun hours are much shorter than the nighttime and hotel building is thermally controlled by air-conditioning system, the negative impact of increasing north wall surface area to increase heat loss could weaken or override the positive impact of increasing north wall surface area to get more sun heat.

D. Ratio of Window to Wall Area

A window is commonly weak area with a much lower R value than the wall, which can negatively impact the indoor thermal conditions. An increase in annual and winter energy is associated with an upward trend in the ratios of north wall to building volume of the sample hotels (see Fig. 19-20). An increase in annual and winter energy is associated with an upward trend in the ratios of north wall to building volume of the sample hotels (see Fig. 21). An increase in annual and winter energy is associated with an upward trend in the ratios of north window to north wall of the sample hotels (see Fig. 22-23).

E. Ratio of Roof Area to Building Volume

For a multi-story hotel building design, the ratio of roof area

to building volume decreases with increase of height of building. An increase in annual and winter energy is associated with an upward trend in the ratios of roof area to building volume of the sample hotels (see Fig. 24-25). Increasing the ratio of roof area to building volume can increasing the negative impact on winter indoor thermal condition, which could result more winter and annual energy consumption.

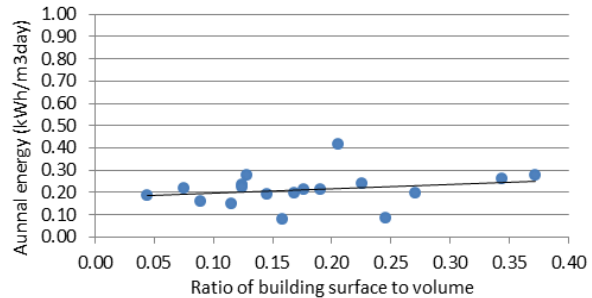


Fig. 4 Annual energy and ratios of building surface to volume

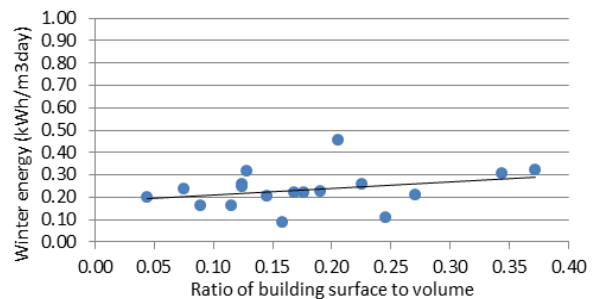


Fig. 5 Winter energy and ratios of building surface to volume

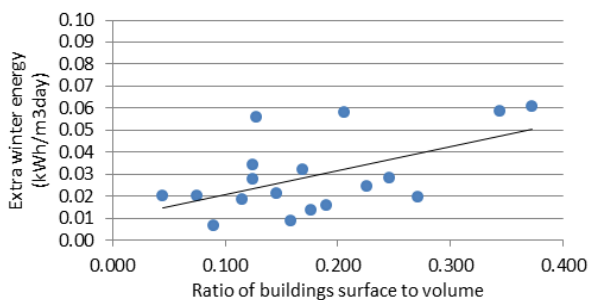


Fig. 6 Extra winter energy and ratios of building surface to volume

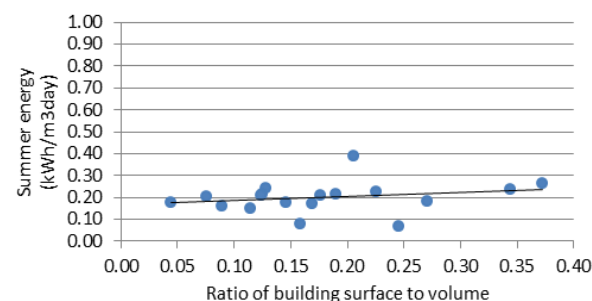


Fig. 7 Summer energy and ratios of building surface to volume

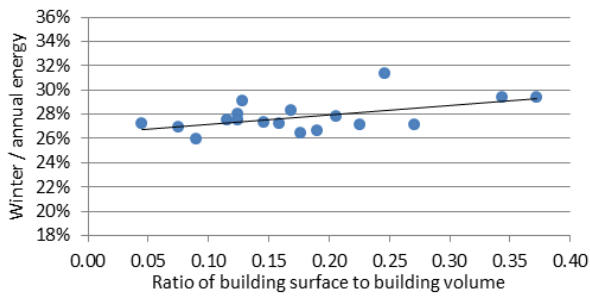


Fig. 8 Ratios of winter to annual energy and ratios of building surface to volume

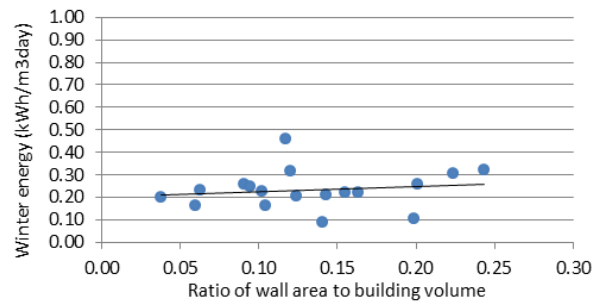


Fig. 12 Extra winter energy and ratios of wall area to building volume

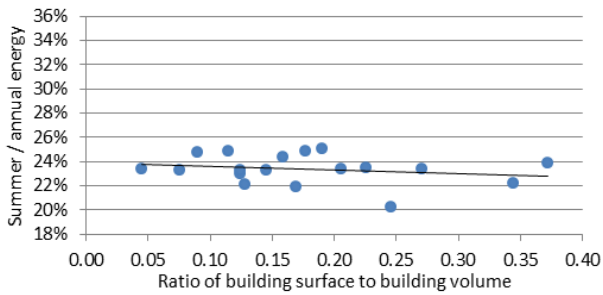


Fig. 9 Ratios of summer to annual energy and ratios of building surface to volume

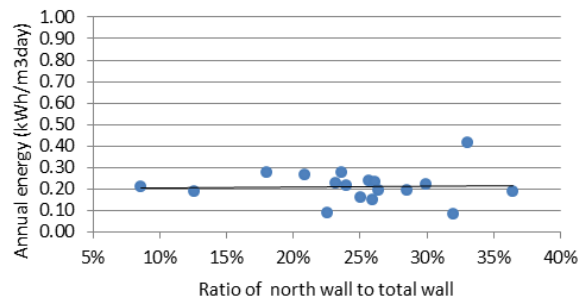


Fig. 13 Annual energy and ratios of north wall to total wall area

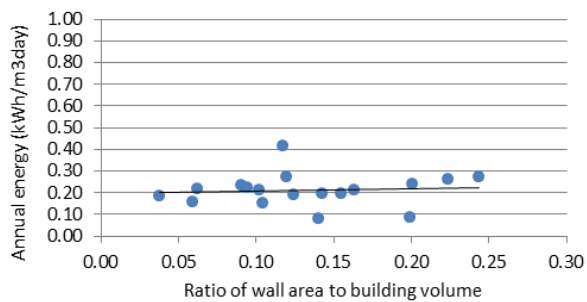


Fig. 10 Annual energy and ratios of wall area to building volume

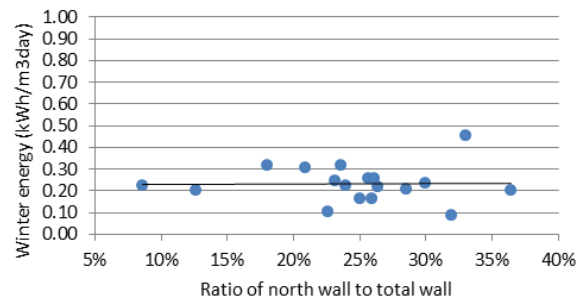


Fig. 14 Winter energy and ratios of north wall to total wall area

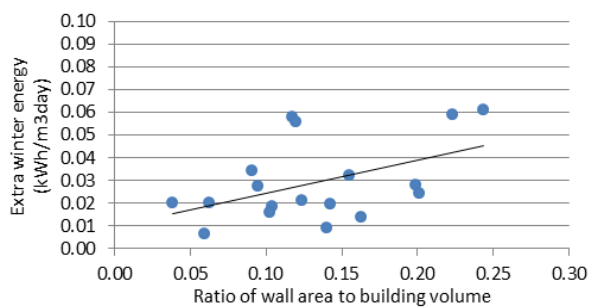


Fig. 11 Winter energy and ratios of wall area to building volume

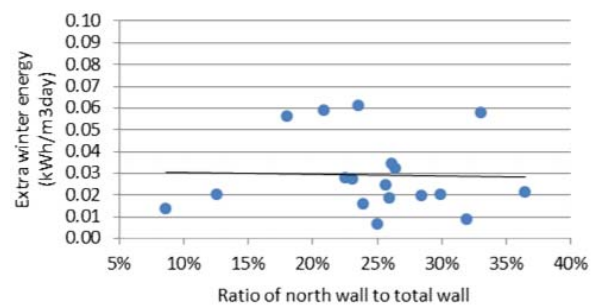


Fig. 15 Extra winter energy and ratios of north wall to total wall area

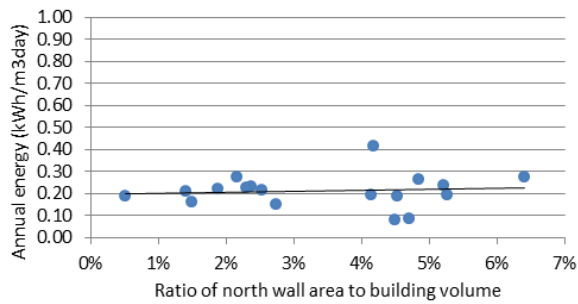


Fig. 16 Annual energy and ratios of north wall to building volume

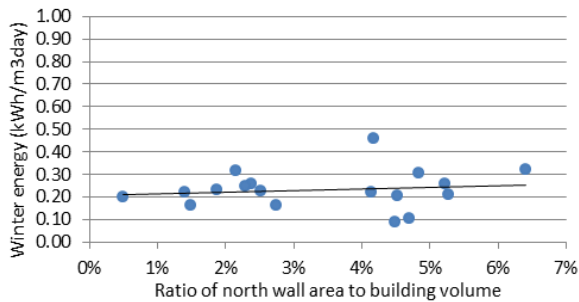


Fig. 17 Winter energy and ratios of north wall to building volume

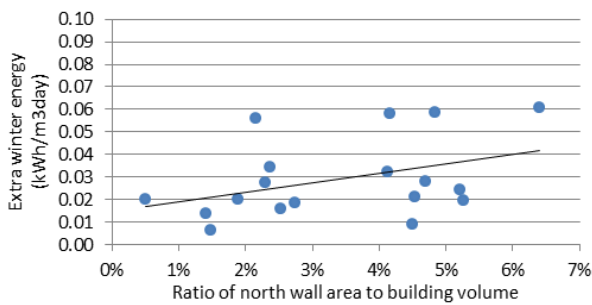


Fig. 18 Extra winter energy and ratios of north wall to building volume

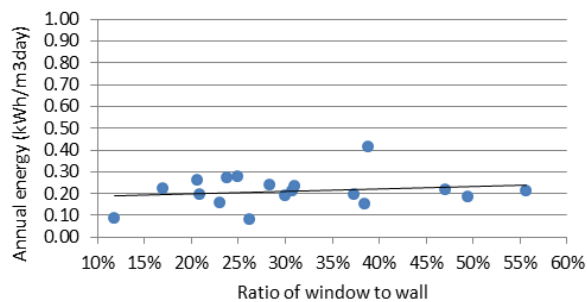


Fig. 19 Annual energy and ratios of window to wall area

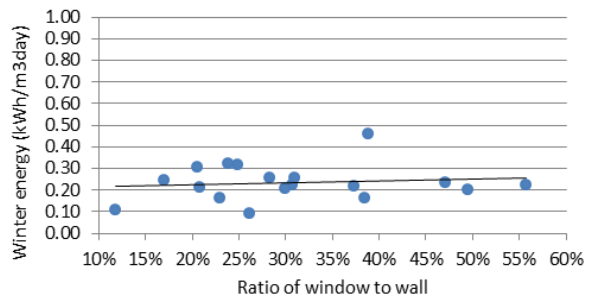


Fig. 20 Winter energy and ratios of window to wall area

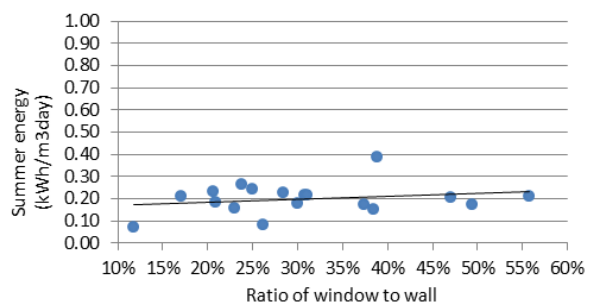


Fig. 21 Summer energy and ratio of window to wall area

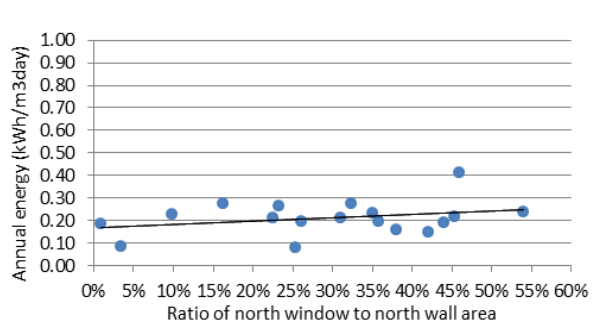


Fig. 22 Annual energy and ratios of north window to north wall

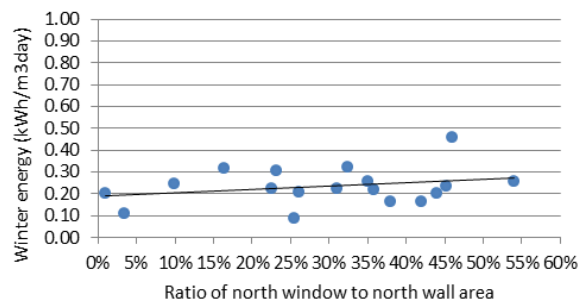


Fig. 23 Winter energy and ratios of north window to north wall

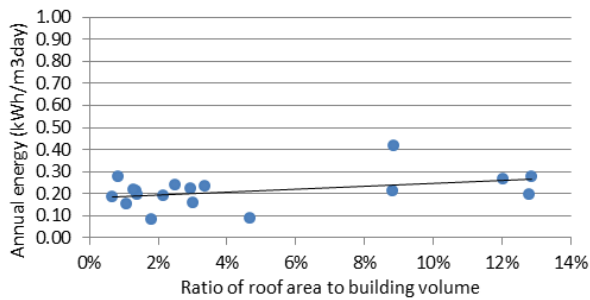


Fig. 24 Annual energy and ratios of roof area to building volume

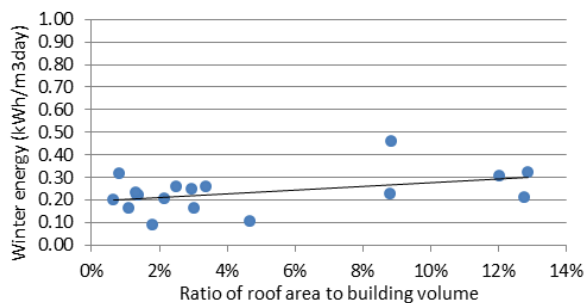


Fig. 25 Winter energy and ratios of roof area to building volume

IV. CONCLUSION

According to the monthly electricity and gas energy consumption data of 18 sample hotels, the mean total winter energy consumption, the mean winter energy consumption per room and the daily mean winter energy consumption per unit of indoor space are more than the summer when the mean winter occupancy is lower than the summer. An Auckland hotel building thermal design should more focus on the hotel winter thermal performance than the summer.

Actual monthly energy consumption and building design data of hotels can be used to investigate relationship between energy consumptions and building design data and identify the major design factors that significantly impact the hotel building thermal performance responded to the local climate and building energy consumption based on daily energy consumption data per cubic meter of indoor space volume.

For the multi-story 4-5 stars hotels with a regular or squarish form, and air-conditioning system, comparatively the ratio of building surface to volume is a more important design factor, which significantly impacts on building indoor thermal condition and energy efficiency. Reducing the surface area per unit indoor space should be a focus for hotel building thermal design for energy efficiency. The wall area is more important surface area for hotel indoor thermal comfort and the wall thermal function is critical for the hotel building thermal design for energy efficiency. Window area is weak thermal resistance surface area with a low R value. Ignoring window thermal design could damage the entire hotel building thermal design in terms of energy efficiency.

REFERENCES

- [1] S. Becken, Energy use in the New Zealand accommodation sector, Landcare Research and Tourism Research and Education Centre (TREC), Lincoln University, 2000.
- [2] N. Isaacs, and N. Crocker, Commercial building energy survey: hotels, Centre for Building Performance Research, Victoria University of Wellington, 1996.
- [3] L. Lind, *Swedish Ground Source Heat Pump Case Study (2010 Revision)*, GNS Science Report 2010/54. 30p
- [4] B. Su and Q. Wang, "Building passive design and hotel energy efficiency," In N. Ghafoori (Ed.), in *Proceedings of The Fifth International Structural Engineering and Construction Conference (ISEC-5)*, pp.851-855, London: Taylor & Francis group, 2009.
- [5] J. P Liu, *Architectural Physicals*, Beijing: China Construction Industry Publication, 2000.
- [6] B. Su, "The impact strength of building passive design on housing energy efficiency," *Architectural Science Review*, vol. 54, no. 4, pp. 270-276, December 2011.