

School Design and Energy Efficiency

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Abstract—Auckland has a temperate climate with comfortable warm, dry summers and mild, wet winters. An Auckland school normally does not need air conditioning for cooling during the summer and only need heating during the winter. The space heating energy is the major portion of winter school energy consumption and the winter energy consumption is major portion of annual school energy consumption. School building thermal design should focus on the winter thermal performance for reducing the space heating energy. A number of Auckland schools' design data and energy consumption data are used for this study. This pilot study investigates the relationships between their energy consumption data and school building design data to improve future school design for energy efficiency.

Keywords—Building energy efficiency, building thermal performance, school building design, school energy consumption

I. INTRODUCTION

IN Auckland, the design of a building should focus more on its internal thermal conditions and thermal performance related to winter conditions to save heating energy and the total energy consumption of the building [1]. To minimise the influence of difference in climates, this study randomly collect monthly energy consumption data for 12 months and the design data derived from the building plans of 34 schools (see Table 1) in Auckland region, which includes 12 intermediate and high schools and 22 primary schools. 13 schools only use electricity and 21 schools use both electricity and gas. The World Health Organisation recommends a minimum indoor temperature for houses of 18°C; and 20-21°C for more vulnerable occupants, such as older people and young children. The current New Zealand Building Code does not have a general requirement for the minimum indoor air temperature, although it has a requirement of 16°C for more vulnerable occupants, such as older people and young children [2]-[5]. According to Auckland climate, Auckland schools only need heating for thermal comfort during the winter. Fig. 1 shows mean monthly energy consumptions of 34 sample schools, 13 schools using electricity only and 21 schools using both electricity and gas. According to different types of energy the sample schools using, Fig.1 shows mean monthly energy consumption data of the sample schools. Mean monthly energy consumption data during the winter months from June to August and likely heating months from May to September are apparently higher than other months and also impacted by the school days (excluding school holidays). Winter energy consumption is significant portion of annual

energy consumption of the sample schools. Mean winter energy consumption is 36% of mean annual energy consumption of the sample schools to compare with 25% of time (see Table I).

TABLE I
GENERAL INFORMATION OF SAMPLE SCHOOL

	Mean	Range
Number of students	570	109 - 2145
Number of isolated buildings	8	1 - 18
Storey of building (storey)	1.2	1 - 3
Number of classrooms	27	7 - 104
Student number per classroom	22	17 - 33
School floor area (m ²)	4829	905 - 21979
Classroom / building floor area	45%	23 - 80%
Floor area per classroom	71m ²	51 - 129m ²
Annual energy (kWh)	219595	16376 - 876233
Winter energy (kWh)	84876	5662 - 394219
Winter / annual energy	36%	29 - 49%
Heating month energy (kWh)	131529	8699 - 606729
Heating months / annual energy	55%	51 - 76%

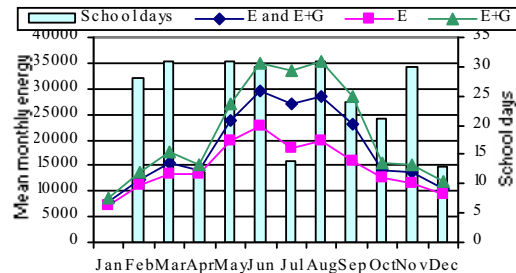


Fig. 1 Monthly energy consumptions of the sample schools

Mean annual, winter and winter extra energy consumption data, which are derived from monthly energy consumption data of the sample schools, are used for this study. This study uses the mean daily energy usage per unit volume of internal space of school building (kWh/m³/day) as the basic energy consumption unit for mean annual, winter and winter extra energy consumptions, which is more closely related to school building thermal design. The difference between mean daily energy usage in the winter months from June to August (or likely heating months from May to September) and the other months (or unlikely heating months) can roughly represent the extra winter energy consumption, which mainly comprises space heating and extra energy for appliances, which are impacted by the winter indoor thermal conditions of the school's buildings. The smaller difference between mean daily usage in the winter months from June to August (or likely heating months from May to September) and the other months (or unlikely heating months) can roughly represent the better internal space thermal conditions and the better thermal performance of a school's buildings in the winter conditions. This study of building passive design mainly focuses on the following building thermal design data, which can affect the

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energy used for space heating. The study explores the relationships between school building design data and mean energy consumption data, which can affect the internal space thermal conditions and the energy used for space heating. A number of school building design data in the following are used for this study. It is difficult to purely identify the clear relationship between a single design datum and the energy used for space heating for the different school buildings when the other building design data also affect the energy used for space heating simultaneously in different strengths. The trend of a particular design datum related to the increase of energy consumption data can still be identified [6]. This study mainly focuses on the trend of the energy used for space heating responding to the change of building design data.

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

II. RATIO OF BUILDING SURFACE TO VOLUME

The ratios of building surface to volume of the sample school buildings are in the range of 0.32 to 0.67 with a mean ratio of 0.45. Ratio of building surface to volume is one of most important design factor for indoor thermal condition and energy efficiency. A 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, hot water and other appliances which can be affected by indoor thermal conditions during the winter. An increase in winter extra energy consumption is associated with an upward trend in the ratios of building surface to volume of the sample school buildings (see Fig. 2). As the mean extra winter energy is a large portion (41%) of the mean winter energy and the mean total winter energy consumption is also a large portion (36%) of the mean total annual energy consumption of the sample schools, an increase in winter energy consumption and annual energy consumption is also associated with an upward trend in the ratios of building surface to volume of the sample schools (see Fig. 3-4). An increase in ratio of winter extra energy to winter energy and ratio of winter energy to annual energy are also associated with an upward trend in the ratio of building surface to volume of the sample school buildings (see Fig. 5-6). Decreasing the ratio of building surface to volume of school buildings can reduce winter extra energy, and also reduce winter energy and annual energy consumptions of the school buildings.

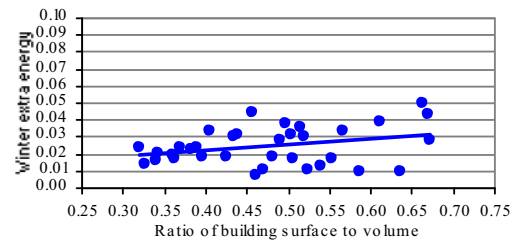


Fig. 2 Winter extra energy data (kWh/m²/day) of the sample schools

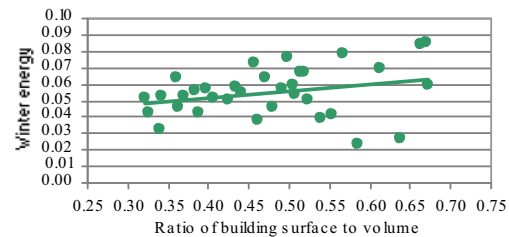


Fig. 3 Winter energy data (kWh/m²/day) of the sample schools

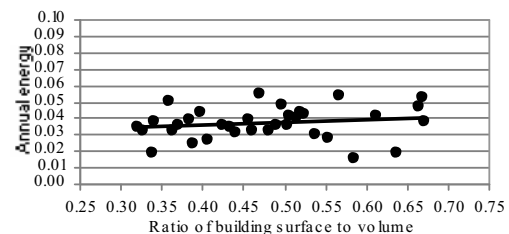


Fig. 4 Annual energy data (kWh/m²/day) of the sample schools

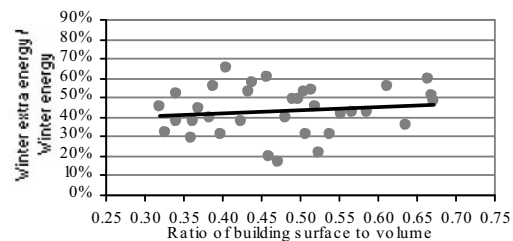


Fig. 5 Ratio of winter extra to winter energy of the sample schools

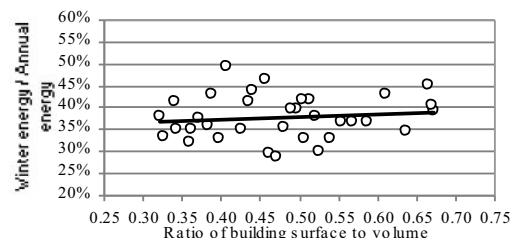


Fig. 6 Ratio of winter energy to annual energy of the sample schools

Ratios of building surface to volume in the range of 0.32 to 0.67 with a mean ratio of 0.45 of the sample school buildings are related to all isolated buildings in each sample school. Isolated buildings of the sample schools are in the range of 1 to 18 with a mean of 8 in number. Building height of the sample schools are in the range of 1 to 3 storeys with a mean of 1.2 storeys. The mean (0.45) and range (0.32 to 0.67) of ratios of building surface to volume of the sample schools are slightly lower than the mean (0.6) and range (0.4 to 0.9) of Auckland houses [6] and much higher than the mean (0.17) and range (0.09 to 0.24) of Auckland hotel buildings [1]. For the multi-storey building with permanent heating, the ratio of building surface to volume should be less than 0.3 for reducing heat loss and saving the energy for space heating [7]. For an isolated school building design, reducing the ratio of building surface to volume can normally reduce the heat loss through the envelope and save heating energy of the building during the winter. For a school design with a group of isolated buildings and the same building floor area, increasing number of isolated buildings will significantly increase ratio of building surface to volume, increase heat loss and winter extra energy and winter energy consumptions of the school buildings during the winter.

III. RATIO OF ROOF AREA TO BUILDING VOLUME

Ratios of roof area to building volume of the sample buildings are in the range of 0.17 to 0.37 with the mean ratio of 0.25. Auckland houses with 1 to 2 storeys height loses about 40% of its heat through ceiling and roof during the winter. Building roof of Auckland school buildings with 1 to 3 storeys height should be major building element or portion of envelope from which to lose heat to outdoor or the sky. Increasing number of low-rise isolated buildings can increase ratio of roof area to building volume for a school's buildings with the same floor area. An increase in winter extra energy consumption and winter energy consumption are associated with an upward trend in the ratios of roof area to building volume of the sample school buildings (see Fig. 7-8). Reducing number of isolated building and increasing building height can decrease ratio of roof area to building volume and reduce winter extra energy and winter energy consumptions of school buildings during the winter.

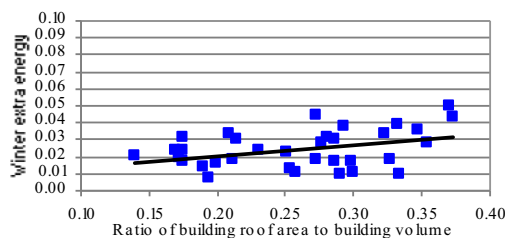


Fig. 7 Winter extra energy (kWh/m²/day) of the sample schools

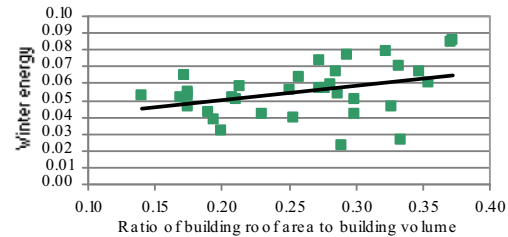


Fig. 8 Winter energy (kWh/m²/day) of the sample schools

IV. RATIO OF WINDOW TO WALL AREA

Ratios of window to wall area of the sample school buildings are in the range of 0.11 to 0.46 with a mean ratio of 0.23. An increase in winter extra energy consumption and winter energy consumption are associated with an upward trend in the ratios of window to wall area of the sample school buildings (see Fig. 9-10). Windows are commonly weak elements of building thermal performance. Most windows of the sample schools' buildings are single glazed windows. The thermal resistance (R-value) of a single glazed window (0.26 m² °C/W) is very low compared with walls (1-1.9 m² °C/W) and roofs (2.9-3.5 m² °C/W) insulated in accordance with the current standard [8]. Increasing ratio of window to wall area of the school buildings, which have single-glaze windows with the low R-value, will increase heat loss through envelope of school buildings and heating energy. When the single-glaze window design meet the requirement of day lighting, minimizing the ratio of window to wall area can reduce the heat loss and heating energy during the winter.

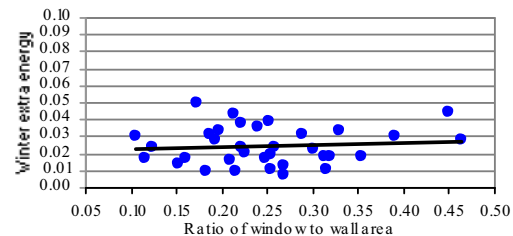


Fig. 9 Winter extra energy (kWh/m²/day) of the sample schools

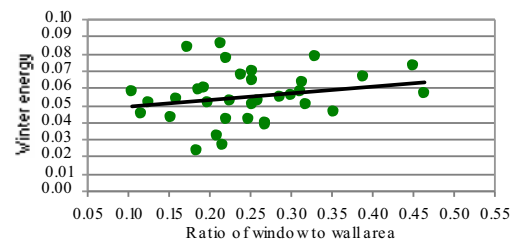


Fig. 10 Winter energy (kWh/m²/day) of the sample schools

V. RATIO OF NORTH WALL TO TOTAL WALL AREA

Ratios of north wall to total wall area of the sample buildings are in the range of 0.17 to 0.40 with a mean ratio of 0.26. Auckland is located in the Southern Hemisphere; walls on the north, east and west sides of a building can get direct

sunlight. A school's buildings with better orientation usually have a higher ratio of north wall to total wall area. A school's buildings with a higher ratio of north wall to total wall area should obtain more passive solar heating and save heating energy during the winter, but an increase in the ratios of north wall to total wall area is not associated with a downward trend in winter extra energy consumption and winter energy consumption of the sample school buildings (see Fig. 11-12). Most windows of the sample school buildings are single-glazed. The mean ratio of north window to north wall area (0.28) of the sample school buildings is higher than the mean ratio of east (0.20), west (0.19) and south (0.23) windows. Therefore increasing the ratio of north wall to total wall area also significantly increases the north single-glazed window area with a low R-value compared with the insulated walls. The negative effect of increasing the ratio of north window to north wall area, which increases heat loss, can be stronger than the positive effect of increasing the ratio of north wall to total wall area for the school buildings with single-glazed windows.

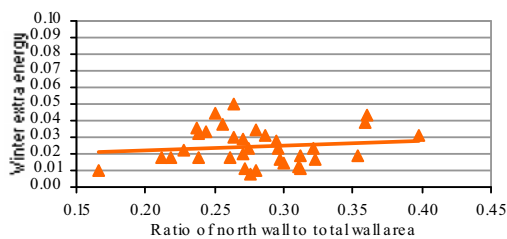


Fig. 11 Winter extra energy ($\text{kWh/m}^2/\text{day}$) of the sample schools

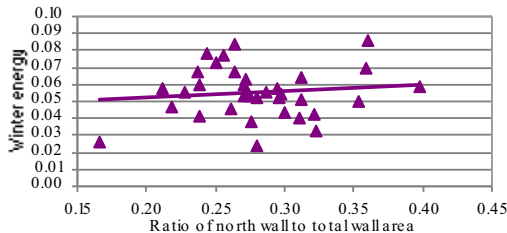


Fig. 12 Winter energy ($\text{kWh/m}^2/\text{day}$) of the sample schools

VI. RATIO OF NORTH WINDOW TO NORTH WALL AREA

Ratios of north window to north wall area of the sample buildings are in the range of 0.14 to 0.52 with the mean ratio of 0.28. Building with large north windows are simply a local building design convention for passive solar heating. An increase in the ratios of north window to north wall area is not associated with a downward trend in winter extra energy consumption and winter energy consumption of the sample school buildings (see Fig. 13-14). The single-glazed windows on north walls create a large portion of wall area with very low thermal resistance (R-value) compared with insulated walls and roofs. A school building with sufficient insulation within walls and roofs can lose a lot of heat through these large windows with very low R-value during the winter. The direct sunlight is not suitable for a learning and teaching classroom environment, which can weaken the benefit of large north

window for passive solar heating. Increasing the ratio of north window to north wall area does not positively impact the energy efficiency of the school buildings with single-glazed windows.

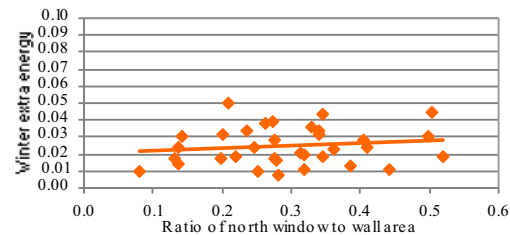


Fig. 13 Winter extra energy of the sample schools

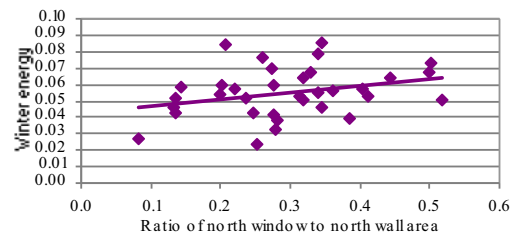


Fig. 14 Winter energy of the sample schools

VII. CONCLUSION

As the sample schools have an average of 8 isolated buildings, with an average building height of 1.2 storeys, the mean ratio of building surface to volume of the local school buildings is much higher than the local multi-storey buildings and quite close to the local houses. Auckland school design convention with many low-rise isolated buildings speared on a large school site area is not energy efficiency under the local climate. Normally using a central heating system is more efficient than many individual heaters for the same floor area of indoor spaces. The conventional local school design can ruin the efficiency of central heating system. It is necessary and the first step for the energy efficiency to change conventional school design to achieve the low ratio of building surface to volume of whole school buildings, and then individual building, which can really reduce heat loss through envelopes of school buildings and heat loss in transfer between buildings.

Successful school building design for energy efficiency should take different design data into consideration as a whole. Ignoring one design datum could damage the entire school design for energy efficiency. A school building with good insulation loses a lot of heat through these single-glaze windows with a very low R-value. The single-glaze windows can ruin the energy efficiency design of the whole building. The negative impact of single-glaze windows could weaken or override the positive effect of good orientation and increasing the ratio of north wall to total wall area. If the R-value of a window can be significantly increased, for example double glazed window, a large window on the north wall can truly and

positively impact on the energy efficiency and the indoor thermal conditions of a local school building.

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