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Testing commercial building energy standards

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The performance of proposed energy efficiency measures for large buildings is tested by computer simulation for a range of building types and uses. It is demonstrated that insulation measures are effective in climates south of Auckland and that glazing and lighting density restrictions perform effectively in nearly all situations.

Keywords: Building codes - energy efficiency - commercial buildings - energy standards

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1. Introduction

This paper summarises the results of a study into the applicability of energy efficiency measures, incorporated into the draft New Zealand Standard *NZS4243 Energy Efficiency - Large Buildings*, to a number of common commercial building types. The energy efficiency measures are based on those derived in previous work based on office buildings (1-3)

Previous work used models of two standard office buildings to derive energy efficiency measures suitable for inclusion in the revised Clause H1 (Energy Efficiency) of the New Zealand Building Code. This work produced recommendations for minimum insulation levels, maximum window-to-wall ratios and maximum installed lighting power density. These were slightly modified and became the basis of the Schedule Method of the draft New Zealand Standard *NZS4243 Energy Efficiency - Large Buildings*. Table 1 summarises the measures.

TABLE 1: Proposed energy efficiency measures.

Measure	Value
Roof insulation	R1.9
Wall insulation - Climate Zone 1	R0.6
Wall insulation - Climate Zones 2 and 3	R1.2
Floor insulation	R1.3
Maximum window-wall ratio	0.5
Maximum lighting density	varies

The simulation studies for this study were performed using the DOE-2.1E building simulation computer program (4). DOE-2.1E is the most recent version of the DOE-2 program developed by the Department of Energy of the U.S.A. DOE-2 has been used in the development of office and commercial building energy efficiency codes in Canada, Hong Kong, the U.S.A and Australia (5-8).

Insulation measures were tested against economic criteria, while the window and lighting measures were based on arguments of reasonable practice.

In the context of the New Zealand Building Code, these measures were proposed to apply to all large buildings above 300 m^2. As this is a significant extension beyond the 3,000 m^2 and 15,000 m^2 office buildings used to derive the results, it is necessary to verify whether these measures are indeed applicable to other building types and sizes.

1.1 Building types

The performance of ten sample buildings is investigated in this paper. These are as follows:

1. **Supermarket.** Warehouse-style building with suspended ceiling, full air-conditioning using split systems. Lighting and internal loads appropriate for retail premises. HVAC operates 0600-2100 Monday-Friday, 0600-1900 Saturday, 0800-1600 Sunday. Floor area: 3000 m^2.

2. **Retail warehouse.** Similar to supermarket but no suspended ceiling and heating and ventilation only. HVAC operates 0600-2100 Monday-Friday, 0600-1900 Saturday, 0800-1600 Sunday. Floor area: 3000 m^2.

3. **School.** Single storey, two classroom block, heated and ventilated, with lighting and internal loads appropriate for a school. HVAC operates 0700-1700 Monday-Friday except school holidays. Floor area: 500 m^2.

4. **Apartment tower.** Ten storey apartment block of square plan and 700 m^2 per floor. Building construction and zoning similar to that used for 15,000 m^2 office building in previous study, including basement car park, but with heating and ventilation only. Internal loads and lighting appropriate for residential occupancy. HVAC operates 24 hours, 7 days. Floor area: 7000 m^2.

5. **Hotel tower.** Physically similar to the apartment tower, but with split system air-conditioning throughout. Internal loads and lighting appropriate for hotel or motel. HVAC operates 24 hours, 7 days.

6. **Retail tower.** Physically similar to the hotel tower but with internal loads and lighting appropriate for retail premises, and a variable air volume air-conditioning system. HVAC operates 0600-2100 Monday-Friday, 0600-1900 Saturday, 0800-1600 Sunday.

7. **Motel row.** Two storey row of motel units, with split system air-conditioning. Internal loads and lighting appropriate for hotel or motel. HVAC operates 24 hours, 7 days. Floor area: 1500 m^2.

8. **Retail/office row.** Two storey row with retail occupancy on ground floor and office occupancy on first floor and separate split system air-conditioning for each. HVAC operates as per retail and office scenarios described above and below. Floor area: 1500 m^2.

9. **Small office building.** Two storey office building similar to that modelled in previous work with full variable volume air conditioning system. HVAC operates 0600-1800 Monday to Friday. Floor area 3000 m^2.

10. **Large office building.** Ten storey office building similar to that modelled in previous work with full variable air volume air conditioning system. HVAC operates 0600-1800 Monday to Friday. Floor area 15 000 m^2.

The small and large office building models are improved versions of those used in previous analyses. The sample buildings were chosen as a cross-section of building types covered by the Large Buildings section of the proposed revised Clause H1.

1.2 Building performance

For the purpose of this study, all building performance figures have been reduced as far as possible to financial measures. To achieve this, the sample tariffs as listed in Table 2 have been chosen to represent the energy costs in the four centres used to characterise different climate zones in this report (9).

The base case insulated scenario for each of the buildings has insulation compliant with the measures described in Table 1, base case internal loads as described in Table 3 and a window-wall ratio of 50%. The performance of these buildings is shown in Figure 1. Note that Auckland is representative of Climate Zone 1, Wellington represents Climate Zone 2, while Christchurch and Invercargill are covered by Climate Zone 3.

TABLE 2: Tariffs used to represent energy costs throughout this report. All buildings use the Commercial A tariff except for the school, which uses Commercial B, and the apartment, which uses the Domestic tariff.

	Commercial A		Commercial B	Domestic
	c/kWh	c/kW/day	c/kWh	c/kWh
Auckland	9.54	4.7	13.75	9
Wellington	7.31	38.6	12.61	9
Christchurch	6.02	28.4	11.84	8.9
Invercargill	6.02	28.4	8.15	11.1

TABLE 3: Internal load indices for different occupancy types.

Occupancy type	Occupant density (m^2/person)	Lighting density (W/m^2)	Equipment density (W/m^2)
Retail	28	23	2.7
School	7	15	5.4
Apartment	24	8.5	2.8
Hotel/Motel	23	15	2.7
Office	22	18	9.1

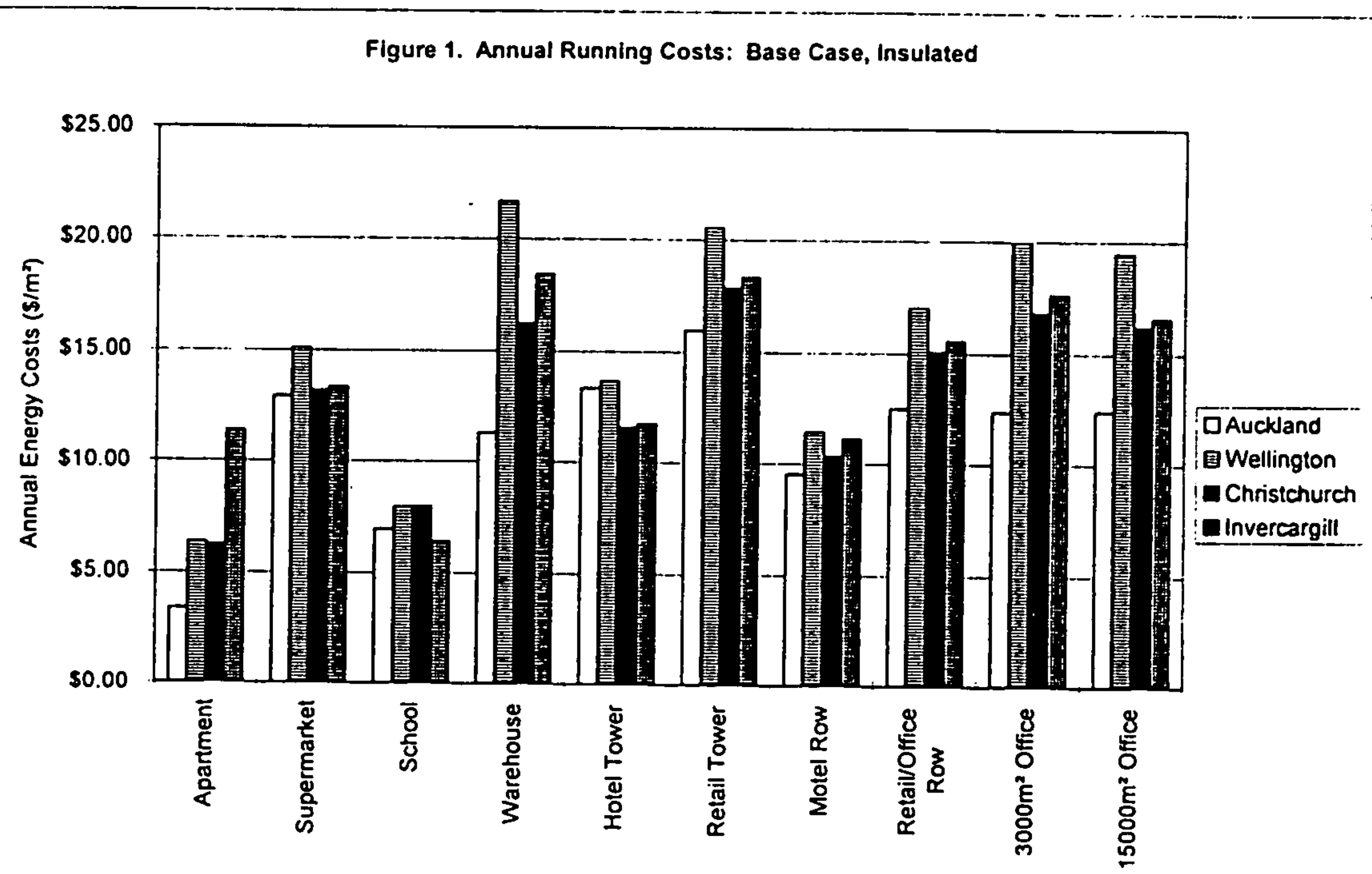

FIGURE 1: Annual running costs: Base case, Insulated.

2. Performance of insulation measures

The proposed insulation measures result in energy and peak demand savings in all the buildings studied. As noted in previous work, the prediction of energy savings is more robust than the prediction of peak savings due to the fact the latter is dependent on a single event rather than the summation of a whole year. As a result, predicted peak savings have been reduced by 50% in the analysis of savings due to the proposed measures. This will tend to underestimate savings. The effect of insulation on energy costs is shown in Figure 2.

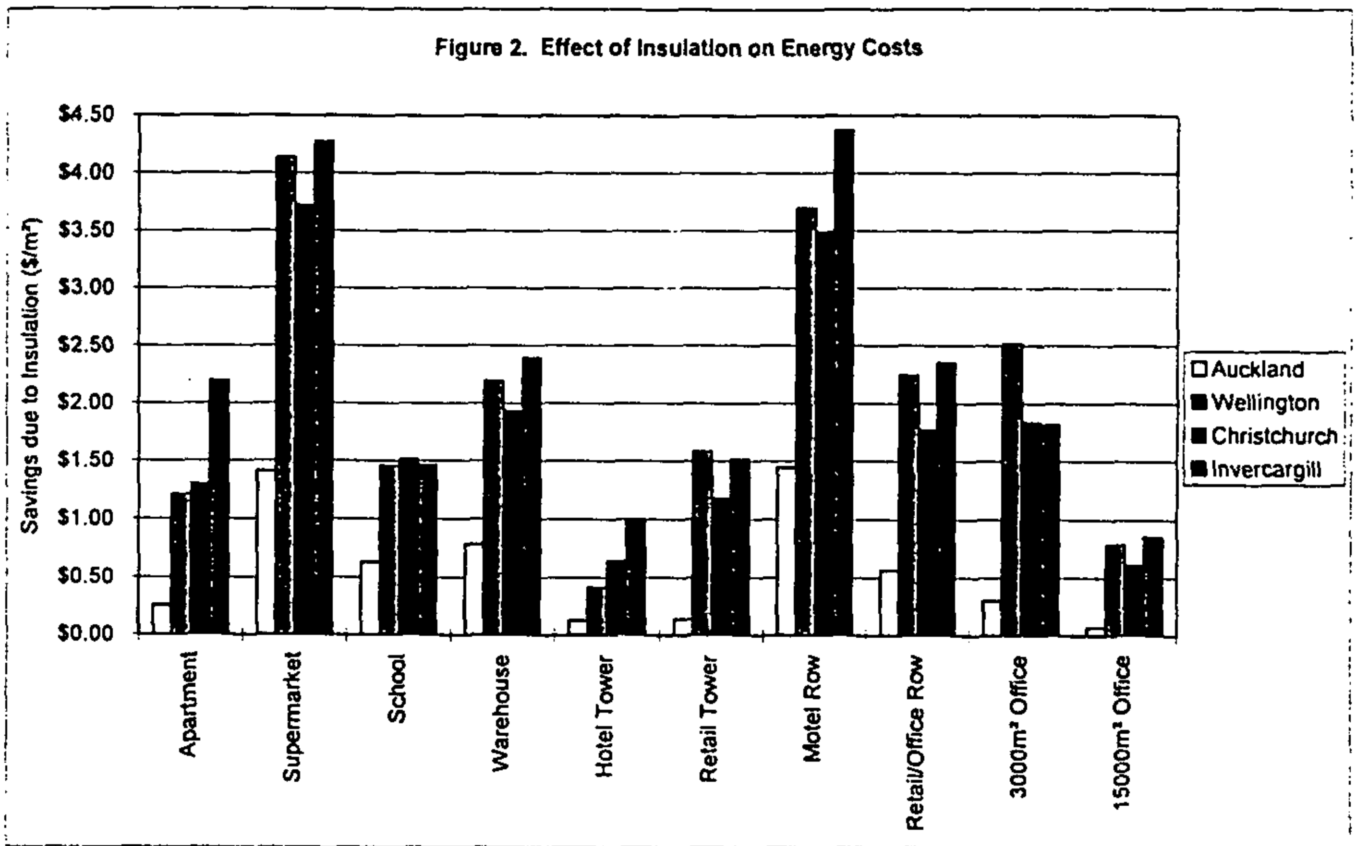

FIGURE 2: Effect of insulation on energy costs.

Figure 3 presents the results in terms of the rate of return from the owner/occupier's perspective, based on an evaluation of representative costs to achieve the level of insulation required by NZS4243. In all cases south of Auckland the returns on insulation costs are above the +10% minimum rate of return, which was prescribed as being the lowest acceptable performance for a measure to be incorporated into the NZ Building Code.

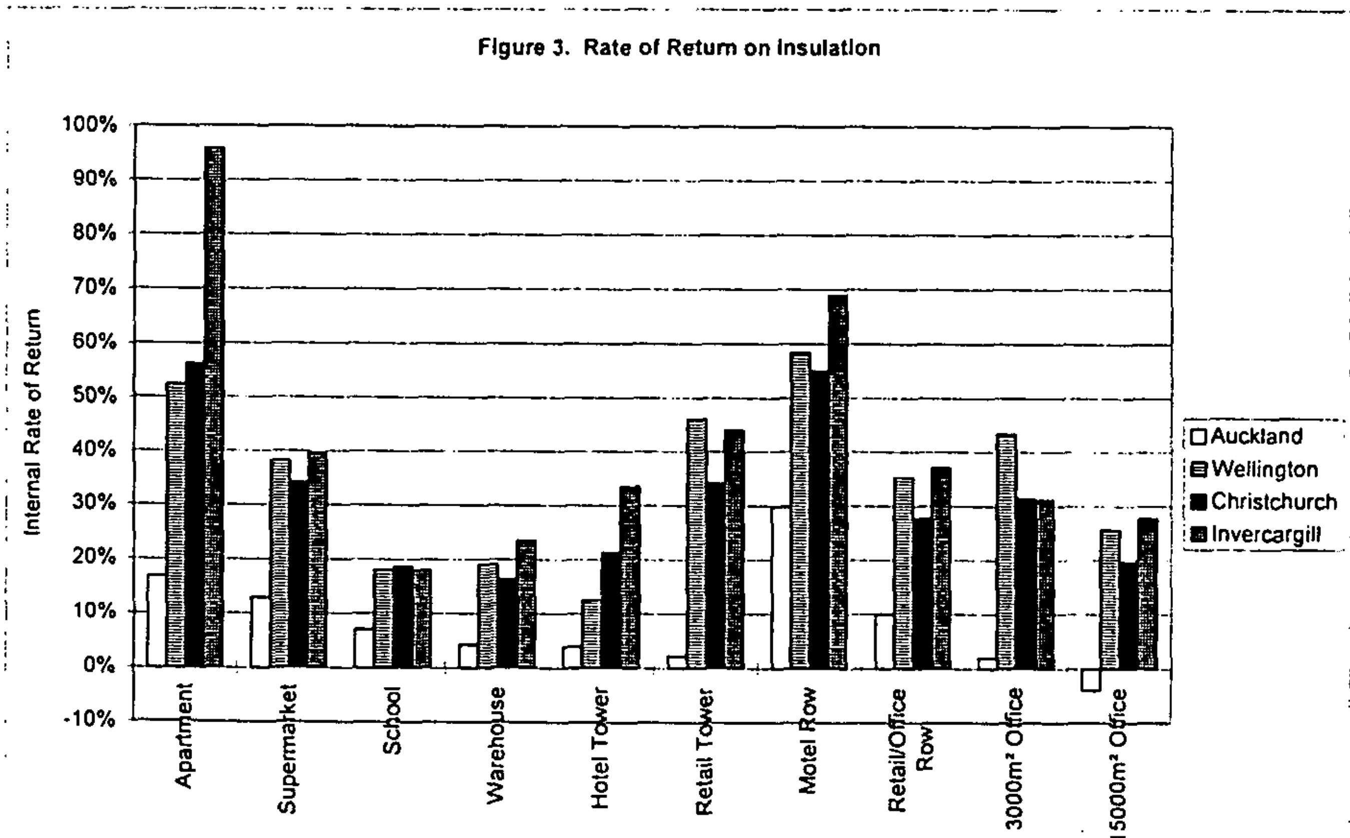

FIGURE 3: Rate of return on insulation.

In Auckland, however, six out of the ten buildings show a rate of return of less than +10% on the insulation investment. For the four other buildings in Auckland, the rates of return are lower than for other centres. The reason for this can be traced to the low size of actual energy savings, as illustrated in Figure 4.

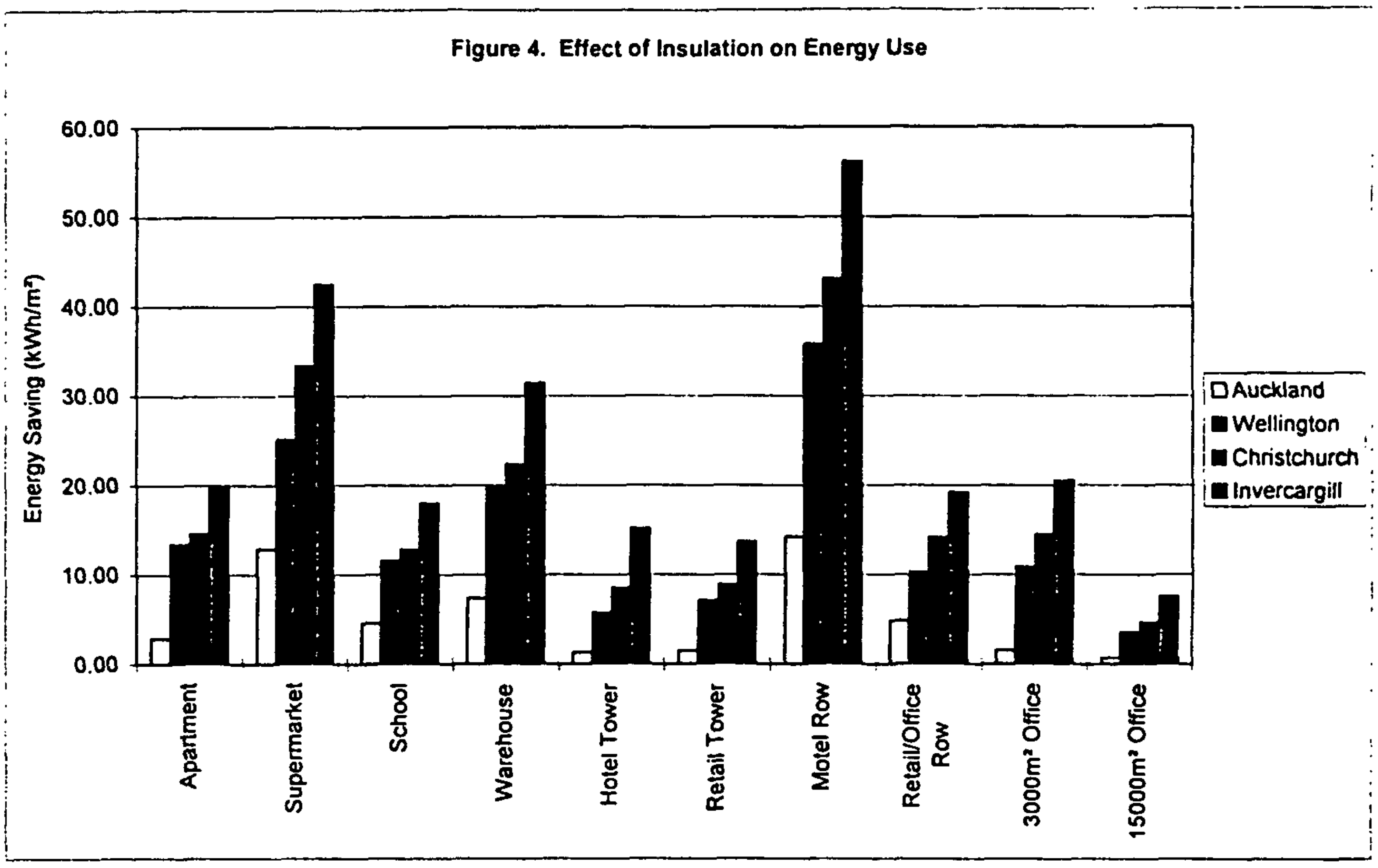

FIGURE 4: Effect of insulation on energy use.

Thus the proposed measures for Auckland produce unsatisfactory returns in the majority of the sample buildings, and in general produce only a relatively small saving in energy. Although the motel row and supermarket buildings in particular show acceptable insulation performance, it is clear that the proposed measures for Climate Zone 1 are not supported as a suitable minimum standard on the basis of this purely economic analysis. It is noted in this context that the rate of return for roof insulation only in Climate Zone 1 is comparable to that for roof and floor insulation, e.g. +8.8% for the hotel tower, +2.4% for the Retail Tower and -6.1% for the 15,000 m² Office.

It is useful at this stage to reconsider the original study that produced the insulation recommendation to establish the reasons for the change. This earlier study had recorded +18.7% and -6.5% as the rates of return for the 3,000 m² and 15,000 m² office buildings, respectively. These rates are different from those calculated in the second study, which incorporated some minor improvements to the simulation models. However, had the previous results been repeated in this study, it would not have changed the conclusions as there would still have been five buildings with an unacceptable rate of return on insulation.

The original recommendations were therefore made on the assumption that the large office was not representative of the general building population. This study has demonstrated that this assumption was incorrect because unacceptably low rates of return on insulation are widespread throughout a number of buildings that can be considered to represent common structures. This suggests that the conclusions of the previous study were significantly affected by the limited scope of building types investigated at that stage. This is an important problem, given that many overseas building codes are developed on the basis of a single office building model, equivalent to one or other of the two office buildings in this study. It is clear that a more broad ranging approach should be required in future studies both in New Zealand and overseas.

It was originally recommended on the basis of the above findings that the minimum insulation values for Climate Zone 1 should be reviewed. However, the subsequent review determined that roof insulation should be retained because of its role in preventing unacceptable radiative gains from ceilings on sunny days. Radiative gains have a high impact on perceived conditions, and as a result such gains are often compensated by ad hoc lowering of cooling set points and even the installation of additional air-conditioning capacity. As a result, the potential impact on energy efficiency can be significantly higher than can be predicted by the DOE-2 models used in this study.

2.1 Sensitivity of insulation performance

In order to examine the sensitivity of insulation performance to other variables in building construction and use, alternate cases based on changes in window-wall ratio (WWR), internal loads, lighting and tariff have been assessed. Bannister et al (10) lists details of the definition of each of these scenarios, but in each case other than the tariff, a range encompassing nearly all expected types of building design and use was used. Typically internal load and lighting extremes were half and twice the base case. The alternative tariff scenario is based on a single averaged tariff throughout the country. Figures 5 and 6 illustrate the rate of return on the insulation costs for a range of scenarios in which these factors have been independently varied.

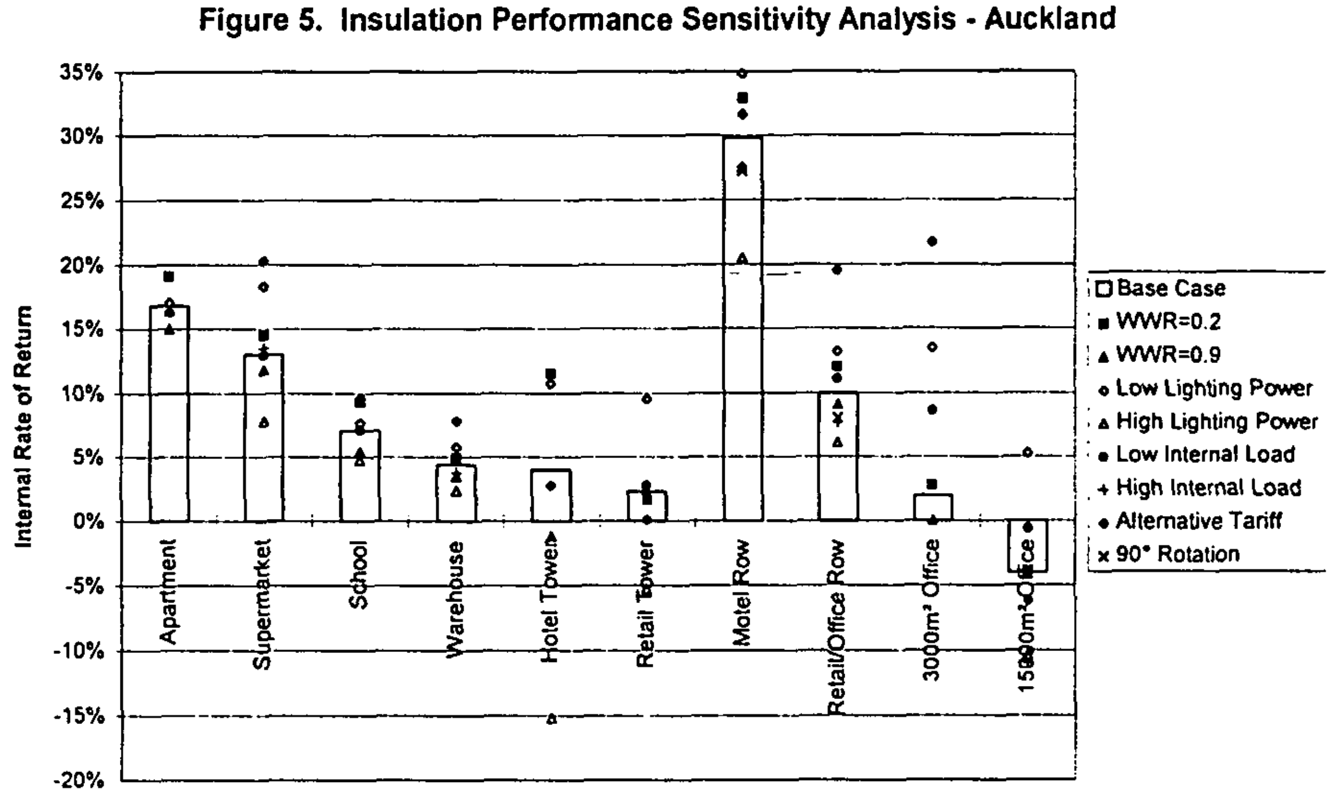

FIGURE 5: Insulation performance sensitivity analysis – Auckland.

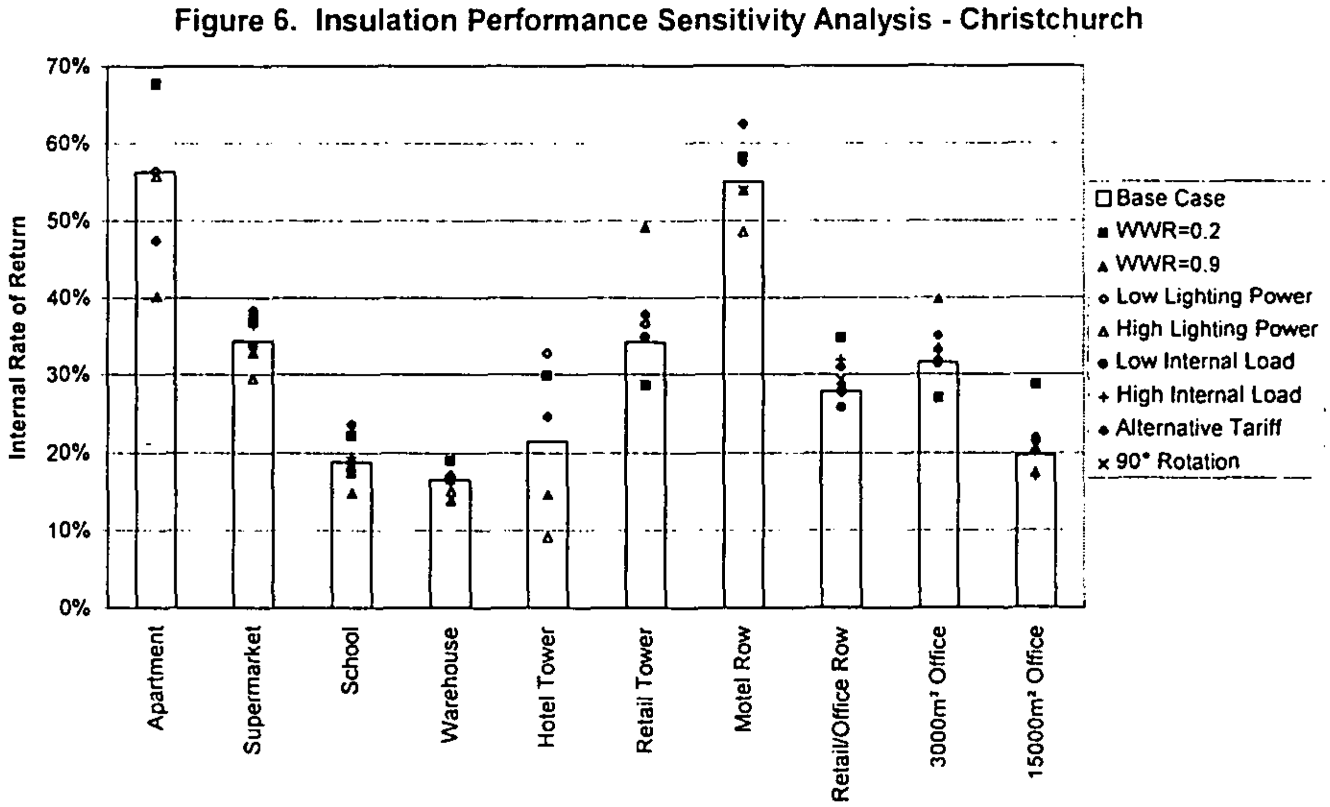

FIGURE 5: Insulation performance sensitivity analysis – Christchurch.

In both Auckland and Christchurch, the alternate cases generally follow the same trend as the base, i.e. in Auckland, most cases fall below +10% while in Christchurch most cases lie above +10%. As a result, it is concluded that the economic viability of insulation is robust with respect to variations in building structure and tariffs.

3. Lighting

The capital costs of lighting cannot easily be evaluated from a purely financial perspective, as reducing lighting intensity to as low as 10 Wm^{-2} normally results in capital cost savings. Thus the effect of lighting measures have been evaluated from the perspective of their relative effect on total energy costs.

Figure 7 shows the effect of lighting density on total building energy use. The values shown are based on the average increase in total energy costs per m² for a 1 Wm^{-2} increase in lighting density over a range extending between approximately half and twice the base case lighting density.

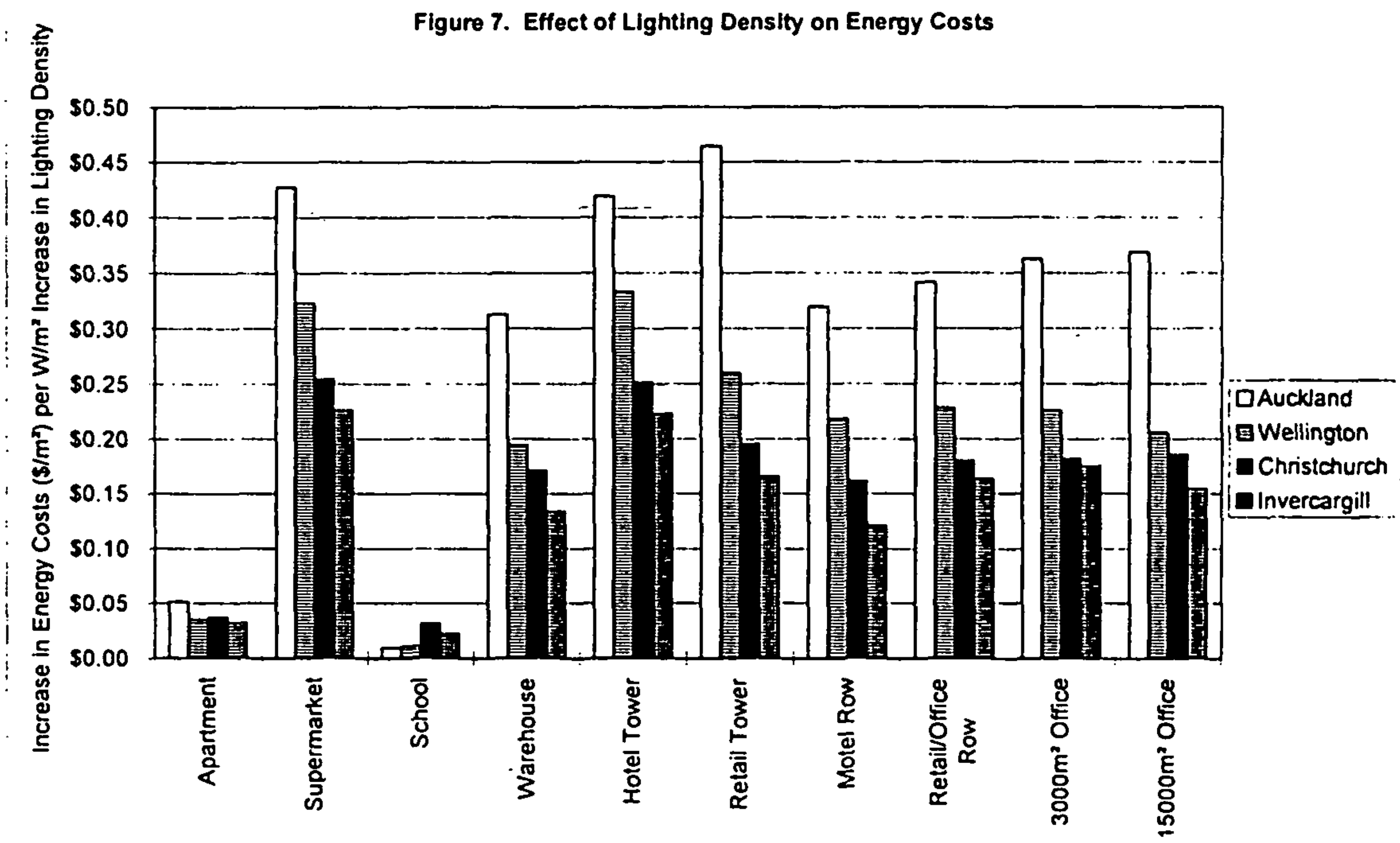

FIGURE 7: Effect of lighting density on energy costs.

It can be seen from Figure 7 that cost increases are often largest in Auckland, which is due to the fact that lighting energy affects cooling requirements significantly in warmer climates. By contrast, lighting density has relatively little effect in the apartment - which would not be subject to the lighting provisions of NZS4243 - and the school. In the case of the school, the fact that the tariff has no peak demand tariff is a significant factor. The equivalent figures for the school using the commercial A tariff are in the range $0.15±0.03. Thus in the case of school buildings on a peak demand tariff, the lighting measures are reasonable.

In general, it would be expected that decreased lighting densities in commercial buildings with low occupancy will save more on peak demand than energy savings. As there is a trend towards increased use of capacity and demand related charges, the proposed measures are reasonable for all commercial buildings.

4. Window-wall ratio

As with lighting, the capital costs of reducing window area are generally negative, so that direct rate of return analyses are not appropriate. Thus the approach used is to examine the degree to which window-wall ratio affects energy costs.

Figure 8 presents the increase in energy costs per m² of floor area for every 10% increase in window-wall ratio, based on the average rate of increase in energy costs from 20% to 90% window-wall ratio. This averaging is reasonable because in all situations where there is a significant relationship between window-wall ratio and energy, it was found to be approximately linear.

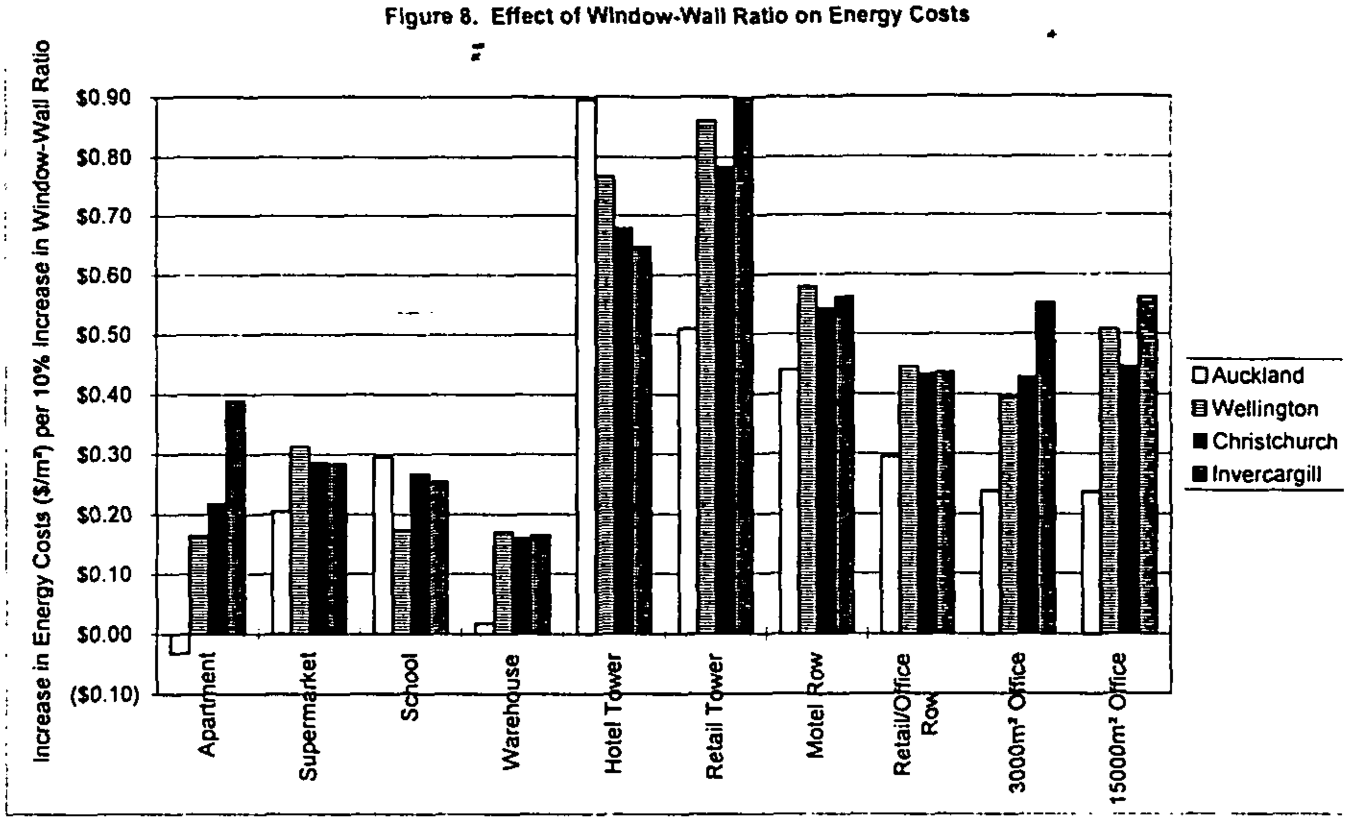

FIGURE 8: Effect of window-wall ratio on energy costs.

The relative effect of window-wall ratio is determined by a number of factors. In the majority of the sample buildings, larger windows causes both heating and cooling loads to rise, with significant effects on energy costs. These effects are generally lower in Auckland, except for the Hotel Tower where cooling load increases are higher than in other buildings. In the ventilation-only buildings, the window-wall ratio has a relatively minor effect on energy costs, particularly in Auckland. However, this has to be reconciled against the effects on internal temperatures, as illustrated in Figure 9.

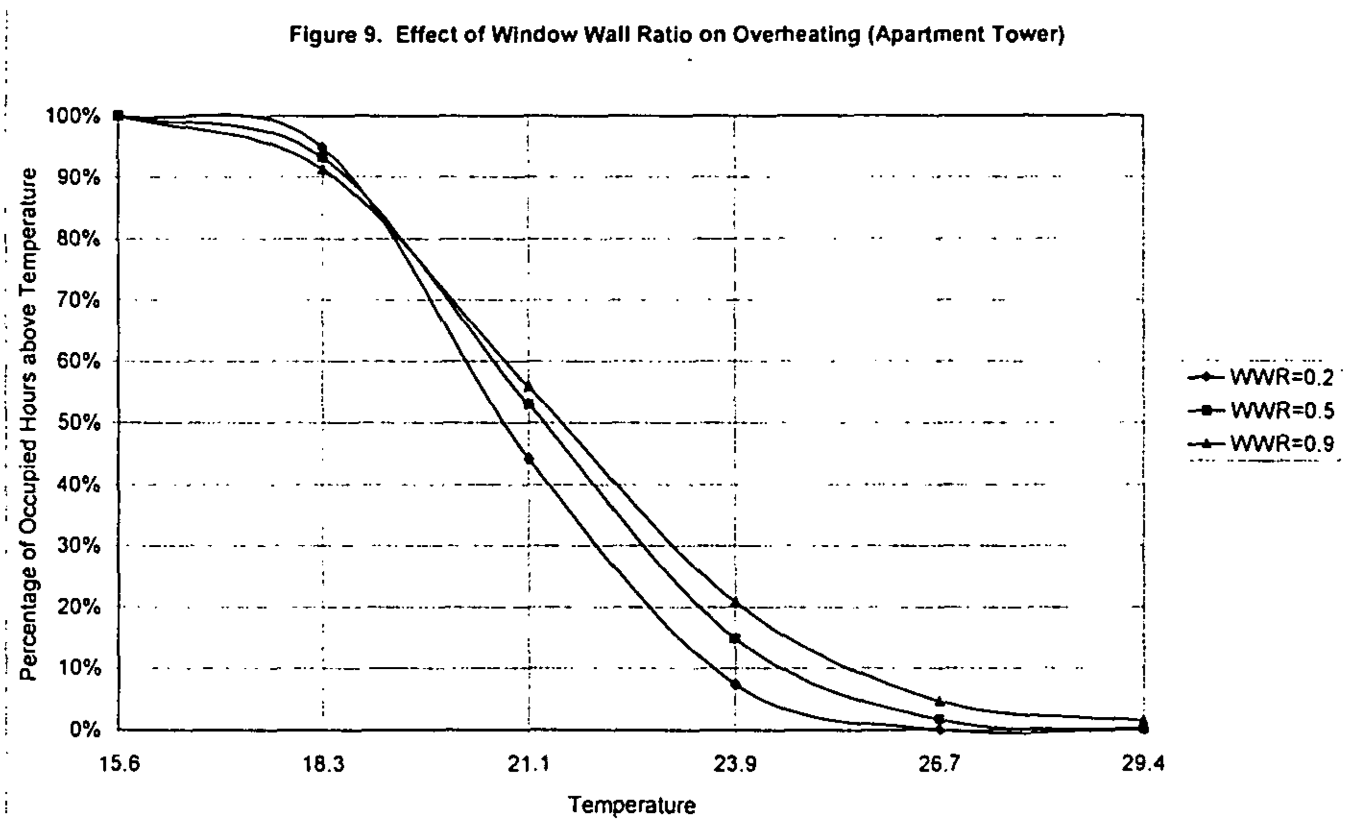

FIGURE 9. Effect of window-wall ratio on overheating (apartment tower).

Figure 9 shows the effect of increasing the window-wall ratio on the average temperature of an intermediate floor of the apartment tower in Auckland. It can be seen that the larger window area produces a substantial increase in overheating, with conditions effectively moving from acceptable to unacceptable around the region of the 50% window-wall ratio mark.

It would, however, be incorrect to assign any significance to the 50% window-wall ratio in this, as other buildings respond differently. The temperatures in the warehouse, for instance, are comparatively insensitive to window-wall ratio, with all window sizes producing acceptable internal temperatures. This is a direct function of the fact that this building has a large floor area in proportion to its window area. In general, the vast majority of buildings would be expected to experience problems with overheating when window areas exceed 50% of wall area.

From an energy perspective, the key risk with an overheated naturally ventilated building is that air-conditioning will eventually be installed to improve comfort conditions. Once such additional services have been provided, energy use will be strongly affected by large window sizes.

As a result it was concluded that the proposed 50% window area limit is justifiable for all relevant buildings in all climate zones as proposed in NZS4243.

5. Conclusions

The results of a study into the applicability of energy efficiency measures proposed for inclusion in the draft New Zealand Standard NZS4243 Energy Efficiency in Large Buildings have been presented. It has been demonstrated that insulation measures are effective in climates south of Auckland and that glazing and lighting density restrictions perform effectively in nearly all situations. It has been shown that the use of office building models as the sole focus of energy efficiency studies is inadequate, as the results are not necessarily a good representation of the wider building population.

6. Acknowledgments

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