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AN ECONOMIC ANALYSIS OF ALUMINIUM WINDOW FRAME MAINTENANCE

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PREFACE

Aluminium window frames are becoming increasingly popular in both domestic and commercial buildings. To ensure an adequate lifetime of these components, maintenance will be necessary in future years. When the window frames reach the maintenance stage, rehabilitative coatings or replacement are the two options. This paper presents an economic analysis of these two options.

This report is intended for building owners and maintenance managers.

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REFERENCE

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KEYWORDS

From Construction Industry Thesaurus — BRANZ edition: Aluminium; windowframes; windows; maintenance; coating materials; protective coatings; restoring; cost; durability; New Zealand; buildings; economics.

ABSTRACT

Three categories of buildings were selected; domestic, lowrise commercial and highrise commercial, for an economic comparison of various paint systems on anodised and powdercoated aluminium window frames. The costs of maintenance were calculated as $\$/m^2$ of window frame, and were based on the average labour, preparation, paint and scaffolding hire costs in the Wellington region during the period May-September 1986. The costs of replacement with anodised or powdercoat aluminium window frames, calculated as $\$/m^2$, were also considered. The life expectancies of the various paint systems and of anodised and powdercoated aluminium window frames were used as an indication of their relative durability. A time horizon of 45 years was chosen, this being 33 years after initial maintenance.

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INTRODUCTION

Aluminium window frames occupy the largest proportion of the New Zealand window market. Their durability, air tightness, weight, low maintenance and corrosion resistance result in a window that compares favourably with the more traditional wood and steel window frames.

This report examines the options of replacement or maintenance of aluminium window frames when the degree of surface deterioration requires attention. Three categories of building types were selected, and the replacement and maintenance costs for a hypothetical building in each category was calculated. The expected lifetime cost analysis is made of the options.

The lifecycle cost analysis includes the costs, present and future, of maintenance systems and analyses them as one set of values known as 'net present value'. The future costs are converted to present day values by incorporating the inflation rate and the interest rate. Money invested today will gain interest, but this will be offset to some degree by inflation. Once the net present day values have been arrived at, the alternative maintenance systems can be compared directly.

Aluminium window frames are available with anodised or powdercoated finishes. Anodising is most commonly available in two colours, silver (natural) and bronze. Powdercoating is available in a variety of colours but white and brown are the most popular. A variety of maintenance coatings are suitable for both types of finishes. Both powdercoating and anodising form very smooth coherent finishes and the adhesion of subsequent paint coats is an important factor when choosing a maintenance system. Good surface preparation is essential to ensure that a subsequent coating will not fail prematurely.

Under normal atmospheric conditions, pitting corrosion is the most common form of corrosion on aluminium. Pitting corrosion is the development of localised pits in the surface, due to penetration through the protective surface film. Pits may grow to sizes large enough to be visible to the naked eye. Pitting corrosion does not initially weaken the structural integrity of the material but it creates an unacceptable surface appearance because of roughening of the surface and dirt build-up in pitted areas.

Aluminium Surface Finishes

Anodised Finishes

The thickness of anodising required for architectural aluminium is covered by NZS 3503:1987: Specification for anodic oxide coatings on wrought aluminium for external architectural applications.

Four grades are listed with their average thicknesses in microns:

AA25 grade : 25 microns
AA20 grade : 20 microns
AA15 grade : 15 microns
AA12 grade : 12 microns

The choice of anodising thicknesses used depends on the environment. AA12 grade may be selected for residential use where frequent rainwashing occurs, AA15 grade for exterior use in a mild environment or rural environment where there is no industrial pollution or marine influence, or if frequent rainwashing occurs. However, AA20 and AA25 grades should be selected for exterior uses in polluted or marine environments.

Powdercoated Finishes

Polyester is the most commonly used resin for powdercoating aluminium window frames. It forms a durable, corrosion resistant coating that is also resistant to weathering and sunlight. The minimum thickness sprayed on to aluminium joinery is required to be 40 microns (Architectural Aluminium Association of New Zealand, 1986).

Comparison of Finishes

A powdercoated finish is less abrasion-resistant than an anodised finish, but is more resistant to alkaline and acid conditions. Scratches in powdercoated finishes can be touched up with appropriate air-drying paints, but the repair may be noticeable. Scratches in anodised finishes cannot be touched up, and if the anodising finish is coloured, then scratches may be visible as the underlying metal will differ in colour from the finish. In a marine polluted situation where little or no rainwashing occurs, powdercoated finishes are unlikely to break down as rapidly as anodised finishes. If exposed to strong sunlight, powdercoated finishes will break down more rapidly than anodised finishes (Building Research Association of New Zealand, 1978, 1979).

Maintenance Coatings

Surface preparation involves cleaning of surfaces with detergent and water, followed by a thorough rinsing with clean water. Preparation of damaged areas to provide a mechanical or chemical key is required to assist adhesion of the subsequent coats. Weathering will produce a surface sufficiently receptive for adequate paint adhesion on undamaged areas. Mechanical keying involves abrading the surface before applying a primer, and chemical keying involves etching the metal surface by the application of an etch (or wash) primer. Etch primers are commonly two-component paints, one component containing the inhibitory agent zinc tetroxychromate and the other component phosphoric acid. They are applied as very thin films and can be overcoated with primer and topcoat systems. Etch primers are solely surface conditioners and should always be overcoated because they have poor weather resistance properties. They exhibit good adhesion and are a good substrate for subsequent paint coats.

The primer commonly used on aluminium substrates is zinc chromate. This has been recommended for application over anodised and powdercoated surfaces. The soluble chromate present helps prevent corrosion, and the paint exhibits good adhesion to surfaces previously treated with etch primer or previously painted surfaces. Urethane primer is recommended as suitable for overcoating powdercoated aluminium. This primer exhibits good adhesion and corrosion resistance.

A two component polyurethane topcoat is recommended for anodised and for powdercoated substrates. This paint is very abrasion resistant, shows good weather resistance and high durability, and has a high life expectancy. Alkyd enamel paints have also been recommended for use over etch primers. They exhibit good durability and gloss retention, but are sensitive to adverse conditions while drying, and have a shorter life expectancy than polyurethane topcoats.

COST OF REFURBISHMENT

Design Parameters

The following assumptions were made:

- There is no premature breakdown of the coating due to scratches, mishandling or splashes of cement.

- The condition of the coating is an evenly weathered surface, with approximately 3% of the area showing worse damage. (Damage may be surface roughening caused by pitting, flaking and loss of adhesion, or erosion of the surface.)

- Maintenance washing of the window frames will be performed whenever window-panes are washed.

- The environment is considered to be moderate with exposure to some marine influence and some pollution.

Paint Systems

Preparative methods and recommended paint systems were similar for both anodised and powdercoated finishes on aluminium. Mechanical keying or chemical keying of the damaged areas was followed by application of the paint systems recommended by paint manufacturers and powdercoaters. Primers were used on 3% of the area (where film breakdown had occurred) for both anodised and powdercoated finishes. The paint systems recommended are summarised in Table 1.

Building Categories

Three categories of building were selected: domestic houses, lowrise commercial buildings and highrise commercial buildings. These selections were based on surveys undertaken by the Building Research Association of New Zealand (BRANZ) in the Whitby and Stokes Valley areas, Lower Hutt and Petone areas and the central Wellington City area for the three categories respectively. The results of these surveys were collated and an 'average building' for each category was produced. Figures 1, 2 and 3 show the various elevations of these 'average' buildings, and the Appendix lists the window size for each category.

Replacement costs (Table 2): Installed prices were obtained from window manufacturers in the Wellington region and from the New Zealand Building Economist (1986) for the price of silver (natural) anodised windows, bronze anodised and powdercoated windows for domestic houses. The installed prices for silver anodised were obtained for commercial buildings and the costs of bronze anodised and powdercoated windows were calculated from the costs of silver anodised aluminium windows. The range of costs was ±8%.

Repainting costs (Figure 4): Average paint costs and the costs for hire of scaffolding were obtained by surveying firms in the Wellington region. Labour costs were obtained from the NZ Painting Contractors Association (Inc). From these figures the repainting costs for the three categories were calculated in dollars per square metre of window frame area ($\$/m^2$). The window frame area for each window was found by calculating the total length of the extrusions used in the construction of the window and multiplying this by the average width of the extrusions. For the lowrise commercial category, painting, using the alternatives of extension ladders or scaffolding, were both calculated. The costs of materials and labour were taken as the rates current in the Wellington region during the period May-September 1986.

The scaffolding costs were calculated on the basis of only one wall scaffolded at a time. In the case of the lowrise commercial building the hire of scaffolding was calculated for two weeks. In the case of the highrise commercial building the scaffolding hire was calculated for eight weeks, this was on the assumption that six people would be employed, as this option is cheaper than employing less people and hiring scaffolding for a longer period of time.

Durability of the Alternative Maintenance Systems

The life expectancies for the buildings, and paint systems, have been estimated from the literature. The useful life of most buildings is in the order of 45-60 years (American Institute of Architects, 1977). This must be viewed only as an approximation, because individual lifetimes of buildings will vary markedly with environment, usage and degree of maintenance. For this project, a building life of 45 years was chosen, as analyses extending beyond 20-30 years have been found to lose their validity due to the uncertainty involved (American Institute of Architects, 1977). The analysis was carried out for 33 years after the initial maintenance at twelve years.

The expected life of anodised finishes on architectural grade aluminium is 12-20 years (Building Research Association of New Zealand, 1981), and powdercoated aluminium is thought to be the same (Building Research Establishment, 1981). Powdercoating technology is relatively new, and little data has been collected on its expected life to first maintenance. The life expectancy for both anodised and powdercoated finishes was chosen as twelve years in this study.

The paint systems listed in Table 1 will vary in durability and life to first maintenance, depending on the types of environments and microenvironments that are present. For the purposes of simplification, it is assumed that the more expensive coatings will have a greater probability of lasting longer than the cheaper alternatives. The expected life of each paint system, and the number of maintenance coats required during a building life of 42 years, are shown in Table 1.

The polyurethane topcoat is considered the most durable paint, and when coupled with a urethane primer, this system has the longest life expectancy. The alkyd enamel is the cheapest system and is the least durable coating. This would not be recommended in situations where superior performance is required, because of its more rapid deterioration.

The environment will be a major factor in determining whether the cheapest alternative is a viable option in practice. In a severe marine or industrial environment, the most expensive paint system (the most durable) would be the recommended choice. But this study assumes that the environmental conditions are not a determining factor: the basis of the choice between alternative maintenance systems is the economics of each system and their future costs.

The basis of the comparison of the alternative maintenance systems is to convert all future costs into present day costs so that the relative values of each system can be compared (Chandler, 1983). Inflation and interest rates are included in the translation of future costs to net present values, and the relative costs of labour, materials, etc are assumed not to change. The net present values have been calculated for each system, and presented in a graphical manner. An uncertainty of ±10% has been included to cover the fluctuations in individual costs and in future costs.

Cost Calculations

The net present values are calculated using the following formula (Gabe, 1983):

$$N = M + \frac{M(1+s)^{Pa}}{(1+r)^{Pa}} + \frac{M(1+s)^{Pb}}{(1+r)^{Pb}} + \ldots$$

Where N = Net present value.

M = Cost of maintenance expressed in present day dollars per square metre. For each system the cost of labour, materials, etc are added together (Figure 4).

Pa = Number of years to second maintenance.

Pb = Number of years to third maintenance.

r = Interest rate.

s = Inflation rate.

r and s were set at 0.16 and 0.10 (16% and 10%). These numbers represent the average inflation and interest rates for the June-September 1986 period (National Business Review, 1986). It should be noted that r and s are very sensitive. If they were set at different interest and inflation rates, the results would show a marked difference.

RESULTS

Figures 5 to 8 present (in graphical manner) the net present values of paint systems 1 to 4 for each building category. The time horizon shown is from 0 to 30 years after first maintenance. An error of ±10% associated with each value is also indicated on the graphs. Figure 9 shows the costs of replacement of anodised and powdercoated window frames. These are compared with the painting costs for the anodised and powdercoated finishes at twelve years after first maintenance for each painting system. Twelve years was chosen because that is the expected life of the replacement window frames: after twelve years they will need replacing or maintenance painting.

The four different paint systems are as follows:

1 = sanding followed by zinc chromate primer and a polyurethane topcoat;
2 = sanding followed by polyurethane primer and topcoat;
3 = etch primer followed by zinc chromate primer and polyurethane topcoat;
4 = etch primer, followed by zinc chromate primer and alkyd topcoat.

The four different paint systems showed the same trends for all categories of buildings. The actual costs of the maintenance painting of aluminium window frames increase from domestic to highrise to lowrise and to lowrise (scaffolding) categories. The highrise and lowrise difference is very sensitive to assumptions about labour.

Surface preparation is the cause of the big difference in costs between paint systems 3 and 4 and paint systems 1 and 2 (Figure 4). The surface preparation step for paint systems 3 and 4 is etch-priming, while for paint systems 1 and 2 it is the more labour intensive hand-sanding.

Domestic Category

Figure 5 shows the comparison of paint systems 1 to 4 for a domestic building. Paint systems 3 and 4, recommended for anodised and powdercoated aluminium finishes, are the most economic choices. Paint system 2, recommended for powdercoated aluminium, is the next most economical paint system, and as it has the greatest durability of all four paint systems, it could be considered as a maintenance coating when a higher durability coating is required.

Window frames in the domestic category are generally expected to be better maintained and exposed to milder conditions than the window frames of the other categories, so paint systems 3 and 4 will be the usual systems selected. Paint system 2 would only be likely to be selected in conditions such as severe environment, or when maintaining a high quality appearance is the most important consideration.

Lowrise Category

Figure 6 shows the comparison of paint systems 1 to 4 for a lowrise building with window frames that can be reached by an extension ladder, and Figure 7 shows the comparison of paint systems 1 to 4 for a lowrise building with window frames that require maintenance painting from scaffolding. A comparison of the two options, scaffolding and extension ladders, shows that extension ladders are a cheaper alternative to scaffolding, if the building design and height allows the option.

Paint systems 1 and 2 were the most expensive, but may be considered if the severity of environmental conditions outweigh monetary considerations. Of these two systems, paint system 2 is the most economical, and, as it is the most durable coating, could be selected as an alternative to paint systems 3 and 4.

Highrise Category

Figure 8 shows the comparison of paint systems 1 to 4 for highrise buildings. The pattern shown by the other categories is repeated, with paint systems 3 and 4 proving to be the most economical, and paint system 1 more expensive than paint system 2. The final choice of the paint systems will be based on environmental factors, resulting in occasions when the more durable paint systems 1 or 2 may be selected, either initially or in the future.

Replacement

For all three categories, replacement is very much more expensive than painting the existing window frames (Figure 9 and Table 2). The cost of replacement also involve maintenance painting costs for a further 18 years, as the life expectancy of a replacement window is only 12 years. So actual costs of replacement would include net present values of future maintenance painting in addition to the initial cost of replacement.

Replacement would be considered only in situations where other factors override the economic costs of the replacement windows, such as excessive damage to the glazing and window hardware, or excessive deterioration of the finish from severe environmental conditions or poor maintenance.

Durability

The life expectancies of the paint systems (Table 1) are an indication of their relative durabilities. Paint system 2 is the most durable coating, and could be considered in conditions where environmental aesthetic factors take precedence over economic factors.

Other Considerations

When factors other than economic need to be considered, a more durable and more expensive coating may be necessary. Important considerations are the environment the building is in, and the required standard of building appearance.

Environment: In severe conditions such as marine, exposed, industrial, or areas of thermal activity, the life expectancy of the paint systems may be appreciably shortened, and a more durable coating may be necessary. Buildup of pollution, windborne salts or sulphur emissions on window frames may hasten the rate of deterioration of the frames if they are not regularly cleaned.

Appearance: This may be more important than economic factors in other situations. Buildings of high public profile, or private buildings, where appearance is the most important consideration, may require paint systems with a high durability or high gloss appearance. Buildings that are visible to the public, or have prominent windows, may also require a more durable coating. Replacement may be chosen if appearance is very important, or if the condition of the window frame has deteriorated to such an extent that painting will not restore the appearance - for example, if pitting is large enough to be visible. If the window frames are badly degraded, another option is to use a more thorough surface preparation, such as hand-sanding rather than etch-priming, and in this case paint systems 1 and 2 would be selected.

CONCLUSION

The aluminium window frame maintenance life cycle cost analysis for the four different paint systems showed the same general trends for each category (domestic, lowrise, lowrise (scaffolding), and highrise) although the lowrise/highrise order is sensitive to the way labour is organised. The etch primer followed by zinc chromate primer and a polyurethane topcoat, and etch primer followed by a zinc chromate primer and an alkyd topcoat proved to be the most economical, after which came the sanding followed by polyurethane primer and topcoat, and then sanding followed by zinc chromate primer and polyurethane topcoat. Surface preparation was the most important factor in the difference between costs of the various paint systems. Hand-sanding was more expensive than the use of an etch primer on deteriorated areas.

The maintenance costs ($\$/m^2$ of window frame area) increased for domestic, highrise, lowrise and lowrise (scaffolding) categories respectively. Scaffolding proved to be more expensive than the use of extension ladders on the same lowrise building, and replacement is more expensive than repainting for all categories. If powdercoated aluminium window frames are to be painted, the more expensive paint system could be considered in some situations, but it would be uneconomical for the expensive paint system for anodised aluminium window frames to be applied.

In the final selection of a maintenance system for aluminium window frames, the external factors such as environment, amount of pollution, and other considerations (e.g., acceptable appearance and visibility of window frames) will be as important as the economic factors.

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Table 1: Maintenance Coatings

		I	II	III	IV
Preparation	Etch Priming			X	X
	Sanding	X	X		
Primers	Zinc Chromate	X		X	X
	Urethane		X		
Topcoats	Polyurethane	X	X	X	
	Alkyd				X
Suitable Over	Powder Coating		X	X	X
	Anodising	X		X	X
Dry Film Thickness		150	150	170	145
Lifetime of Paint System		6	8	5	4
No. of Repaints in 33 Years		5	4	6	8

Table 2: Replacement Costs

Finish	Domestic ($\$/m^2$)	Lowrise Category ($\$/m^2$)	Highrise Category ($\$/m^2$)
Anodised Natural	626	1129	965
Anodised Bronze	856	1157	989
Powdercoated	875	1185	1013

Figure 1 : East, north, west and south elevations of a domestic category 'average' building.

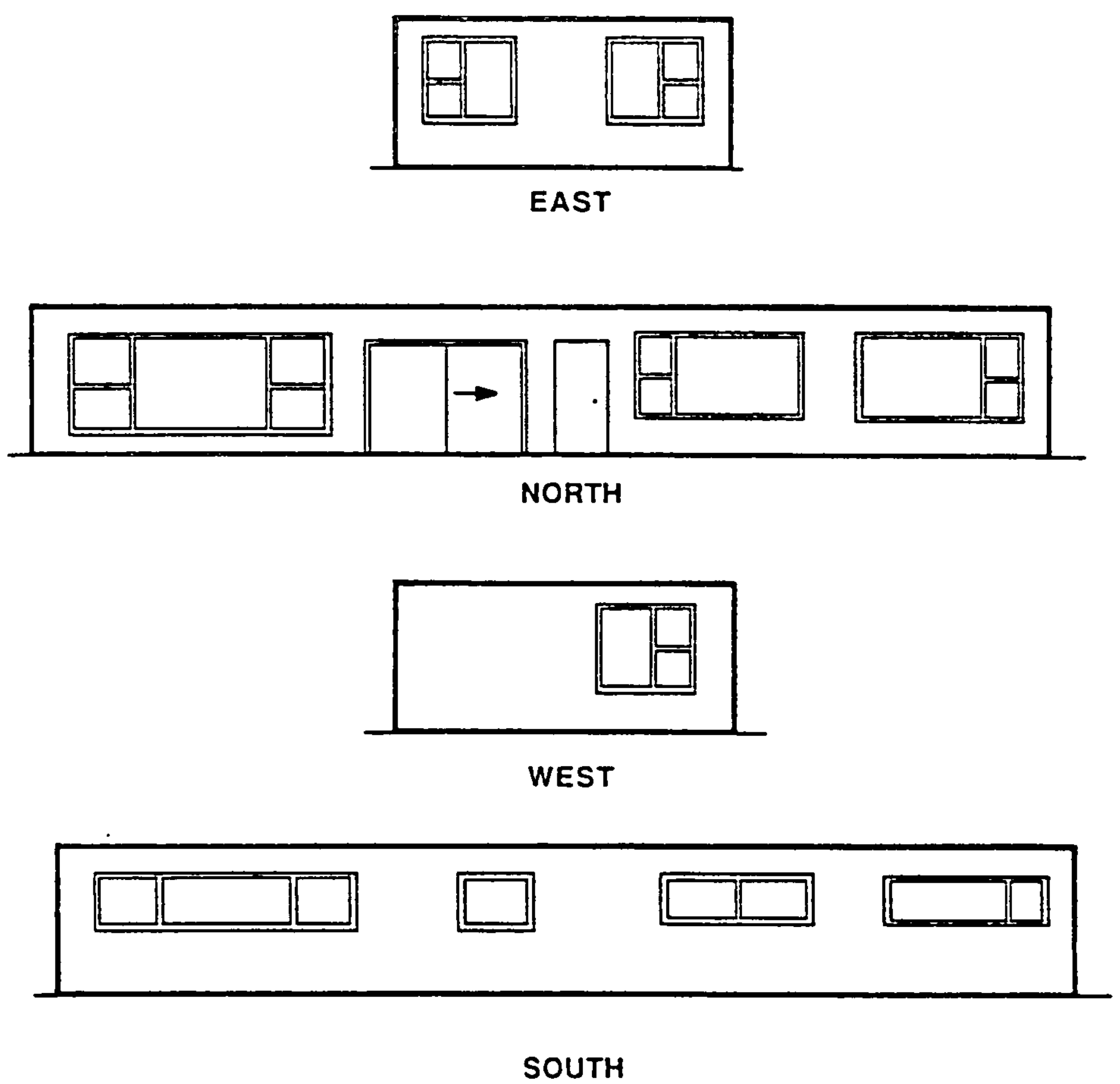


Figure 3 : North and south elevations of a lowrise category 'average' building.

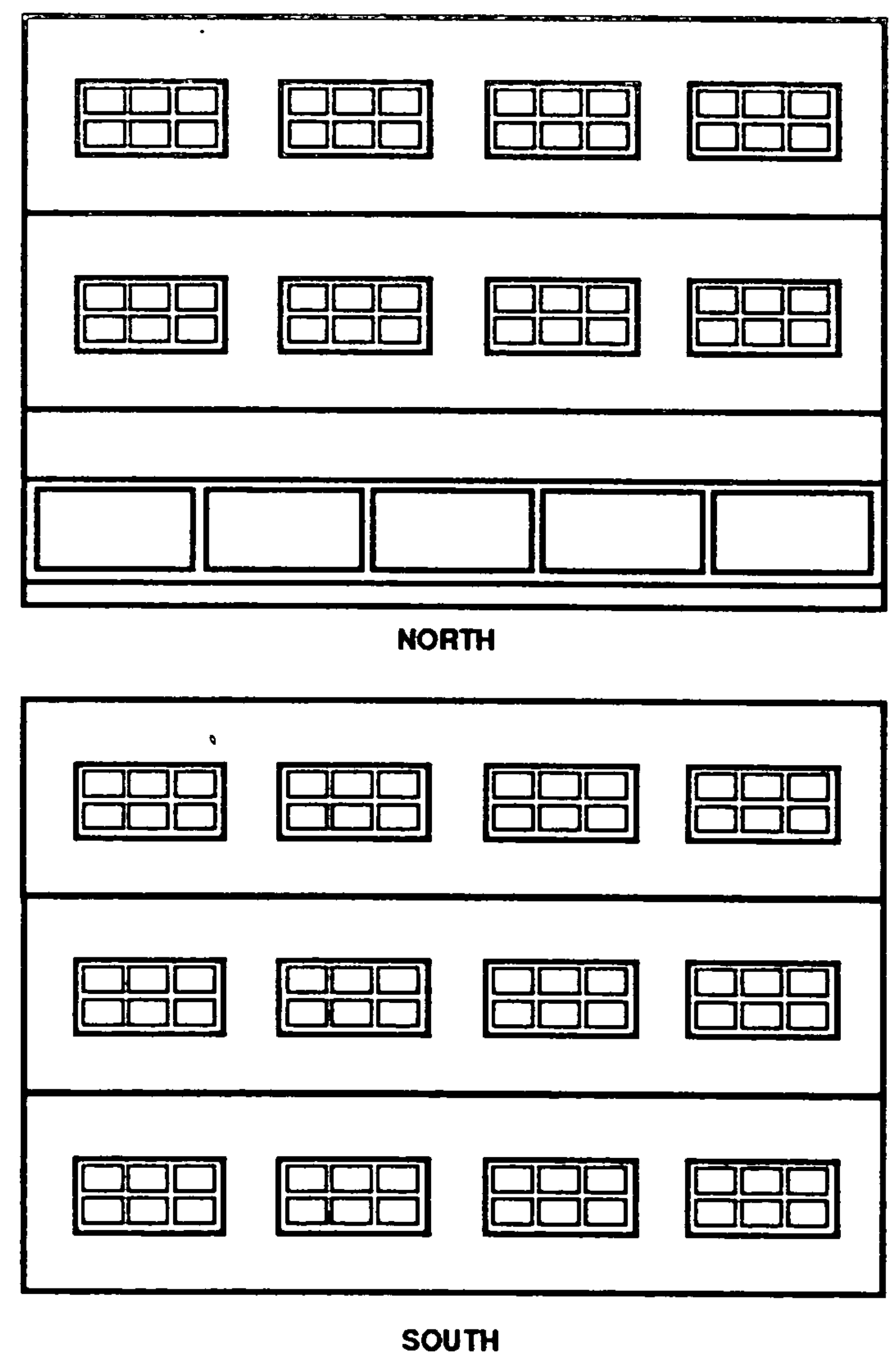


Figure 3 : North and south, east and west elevations of a domestic category 'average' building.

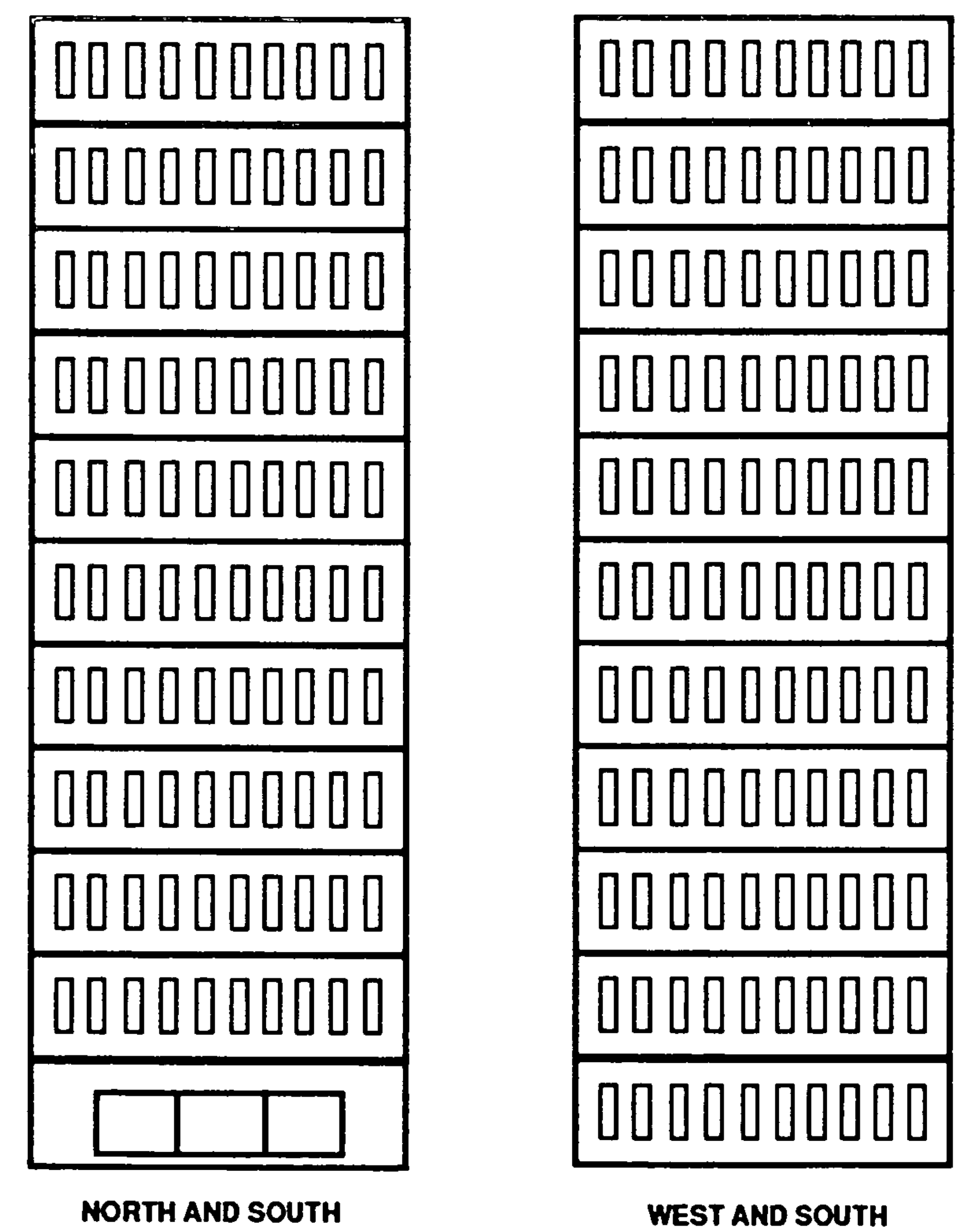


Figure 4 : Average Costs of Repainting

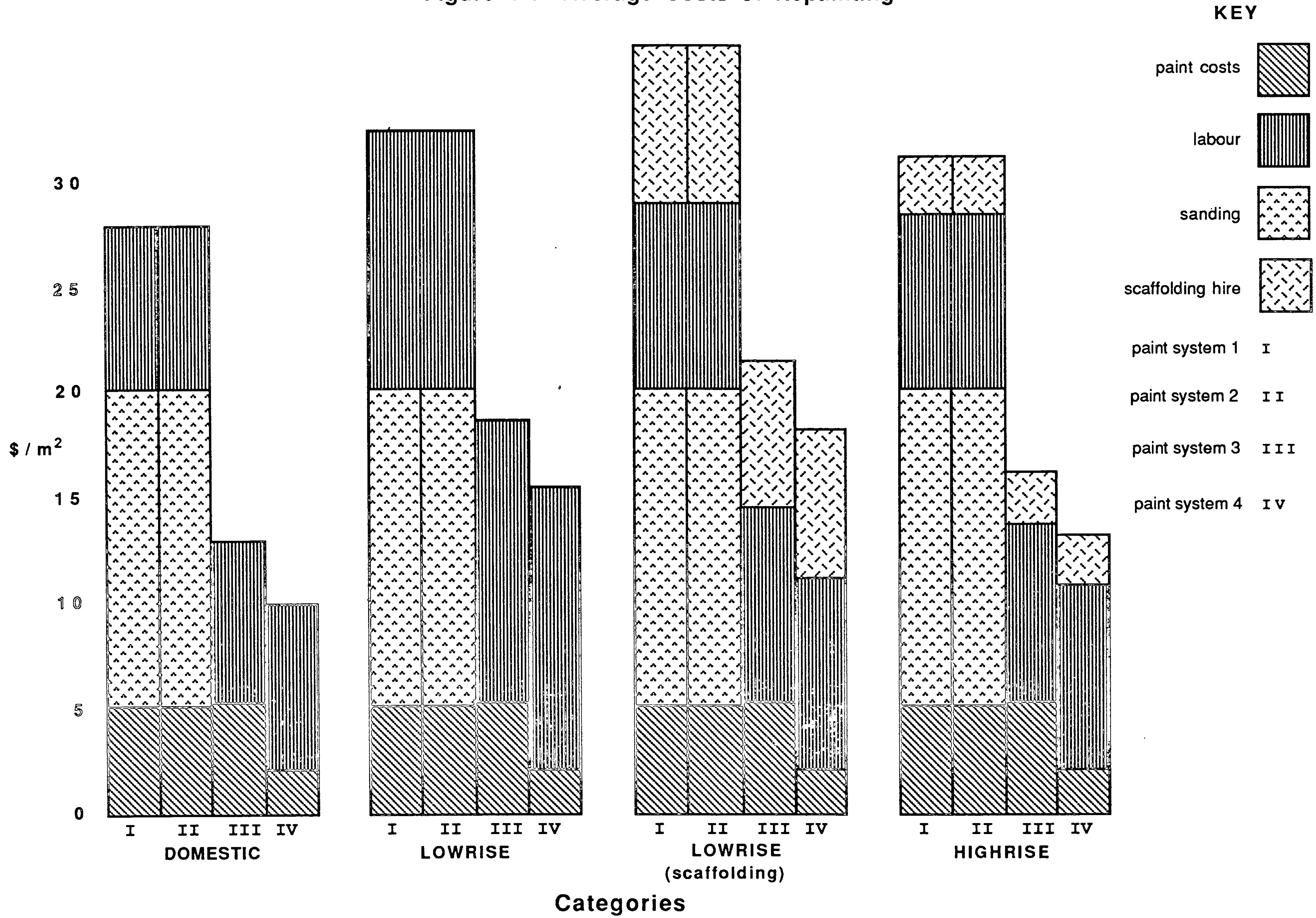


Figure 5 : Net Present Value Costs - Domestic Category

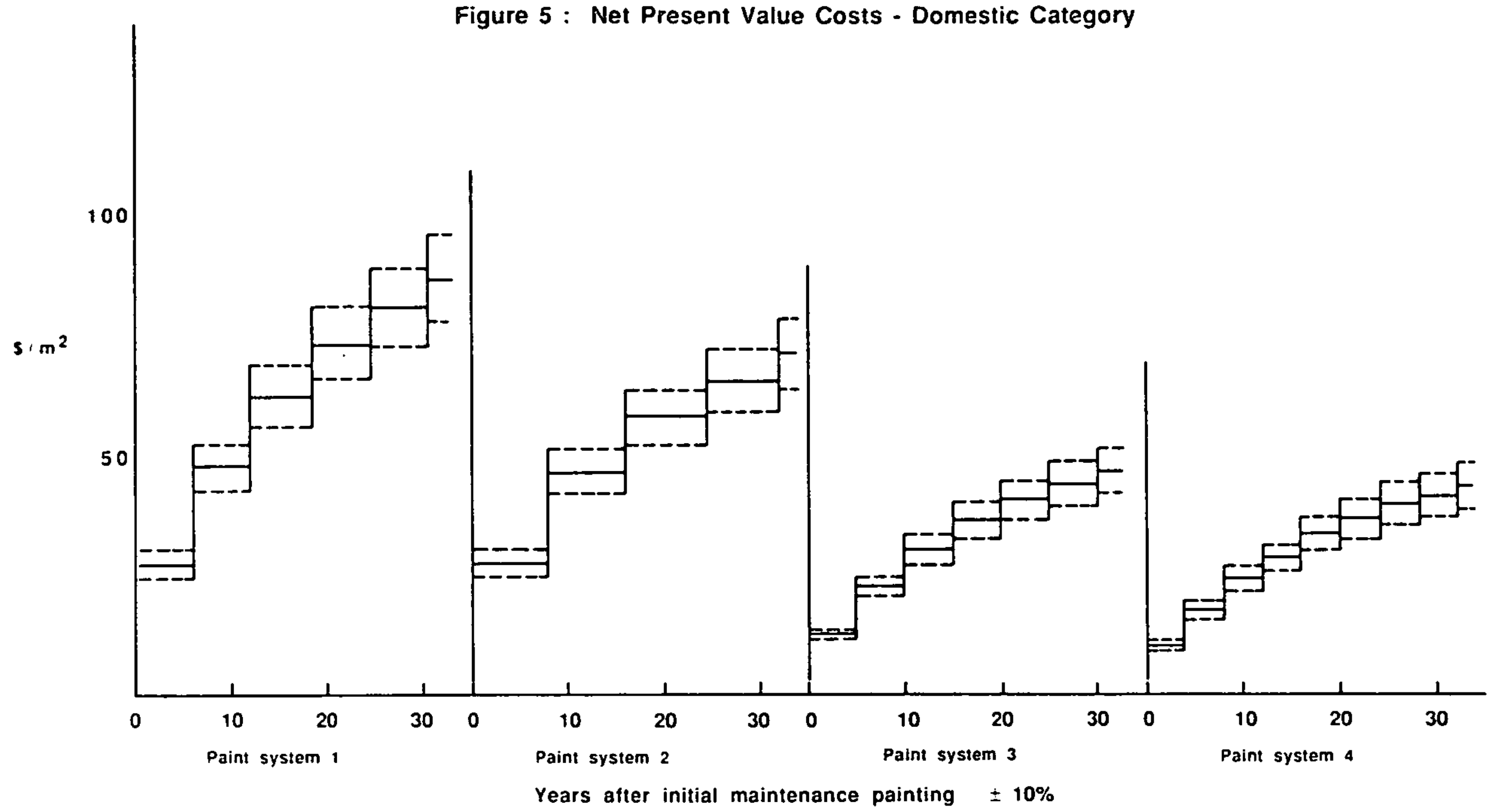


Figure 6 : Net Present Value Costs - Lowrise Category

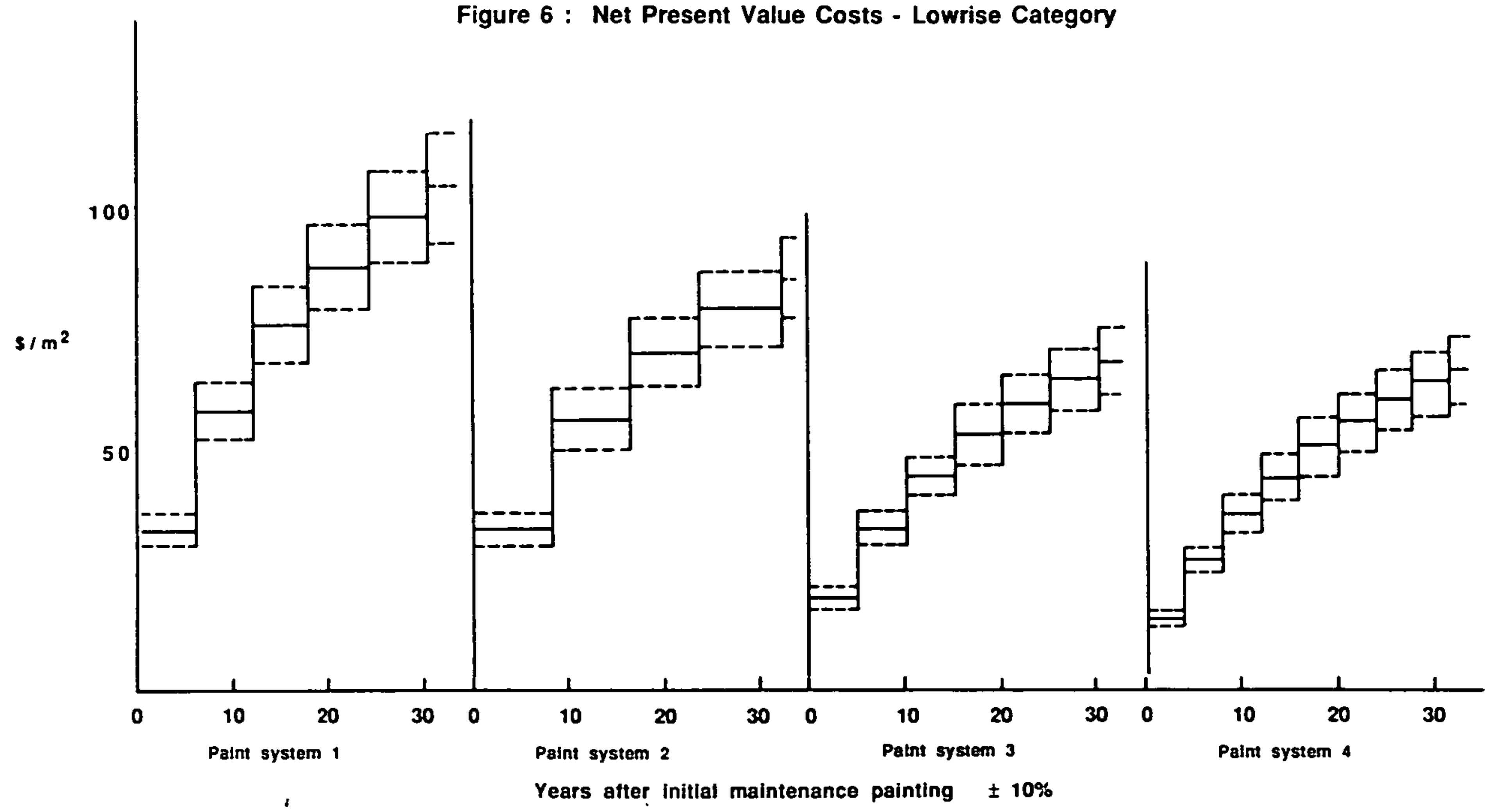


Figure 7 : Net Present Value Costs - Lowrise (scaffolding) Category

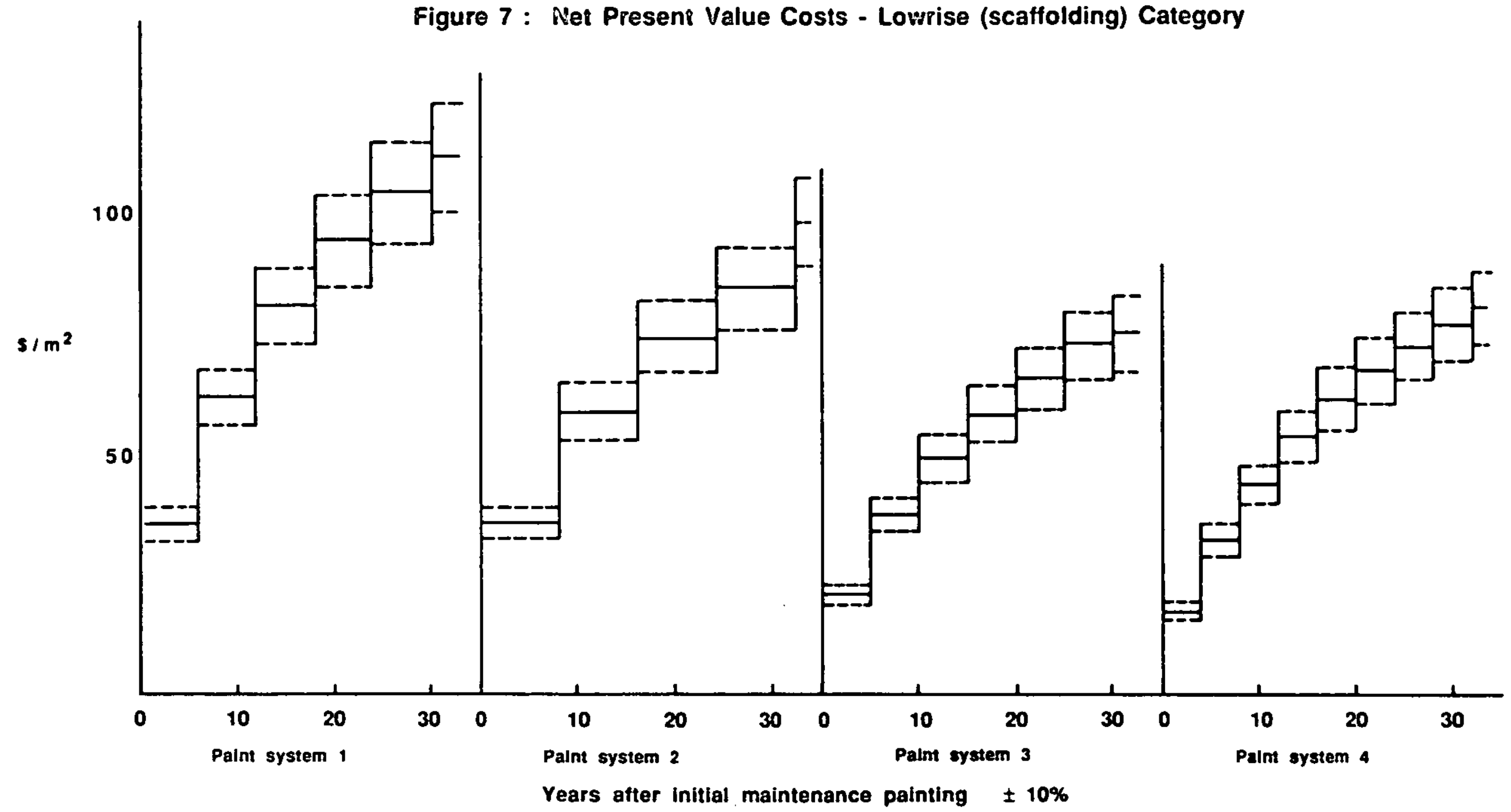


Figure 8 : Net Present Value Costs - Highrise Category

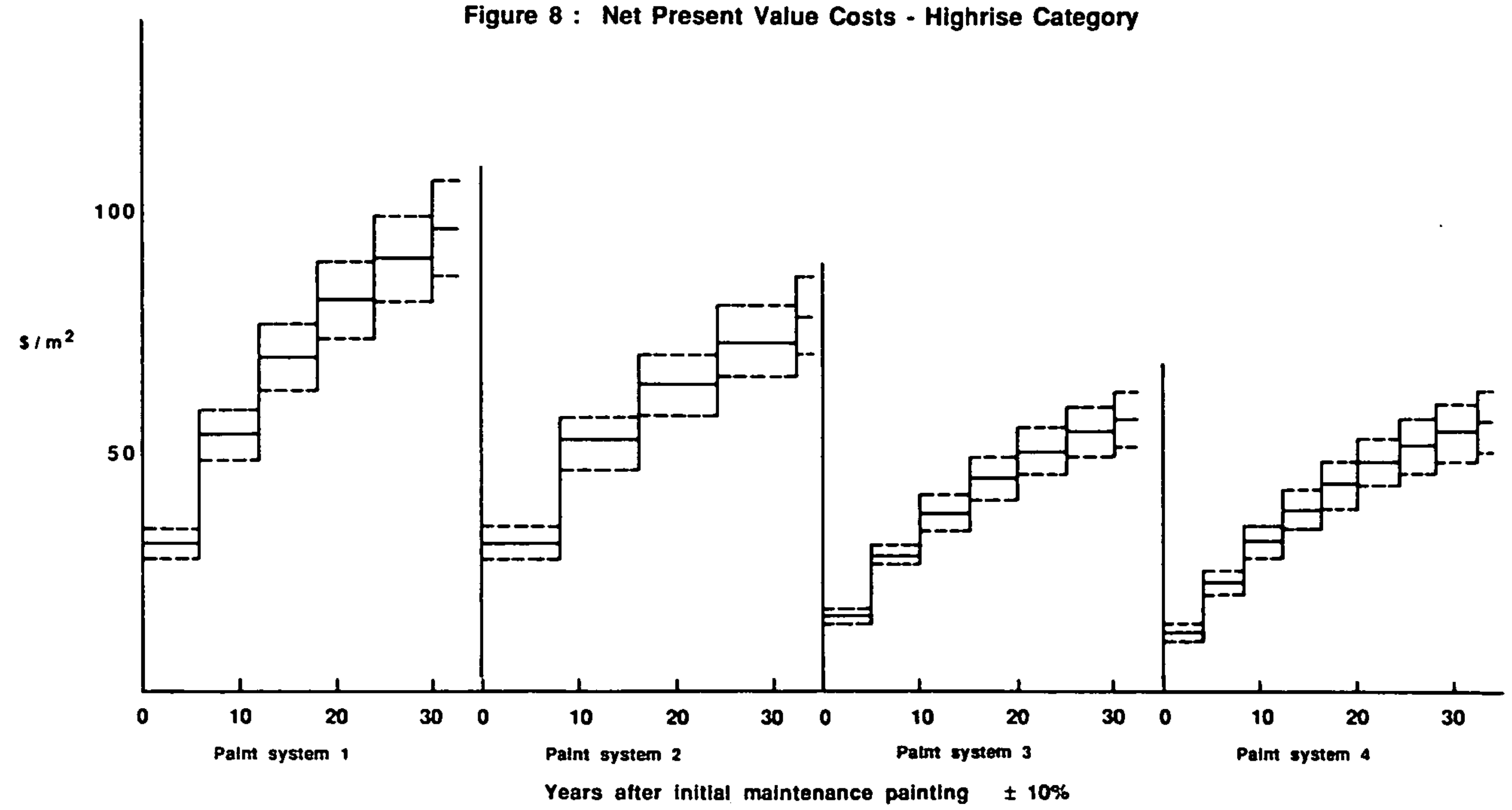
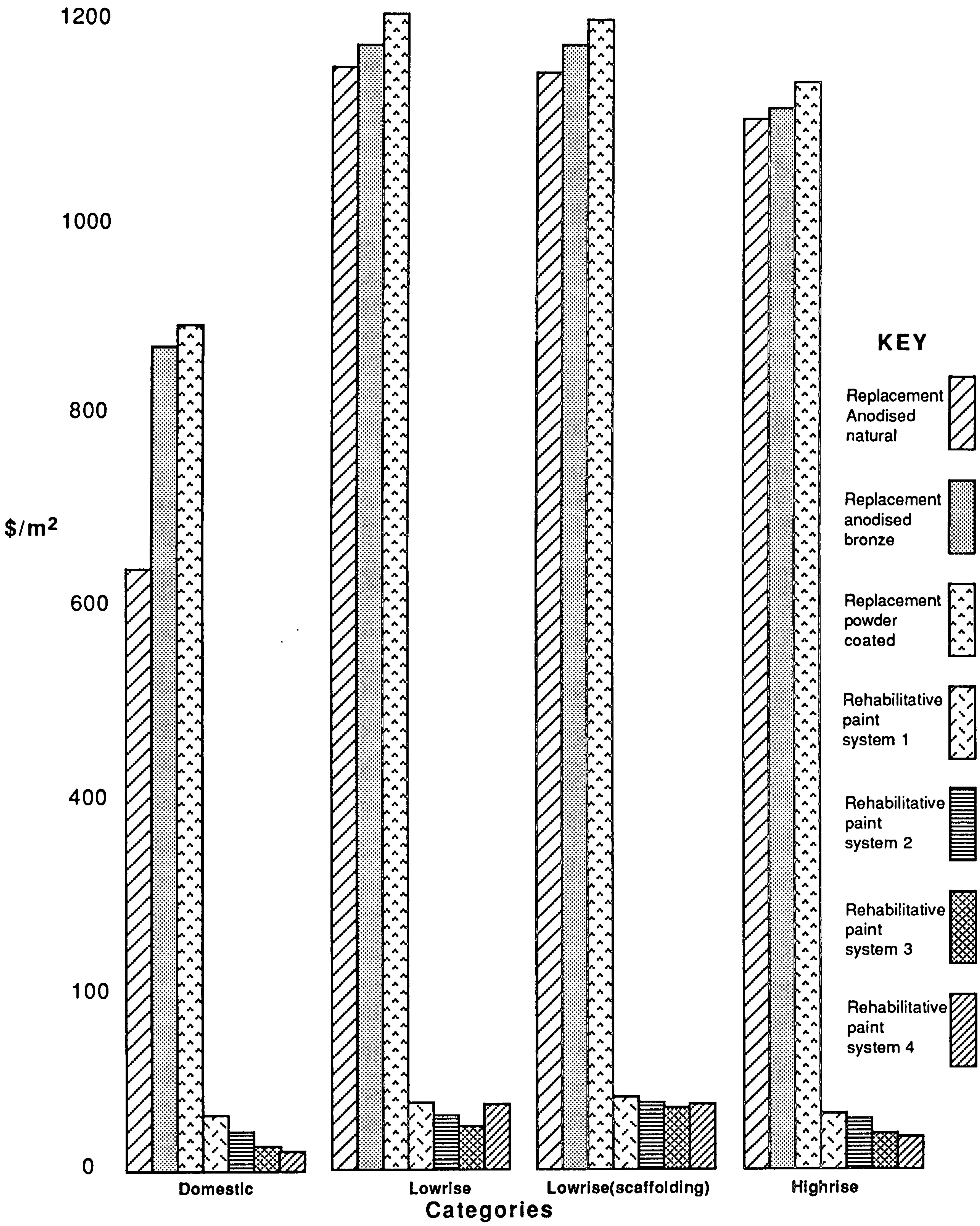


Figure 9 : Replacement costs and repainting costs, 12 years after initial maintenance



APPENDIX

		Window frame Area (m^2) per Window
Window sizes of domestic category building:		
Ranch Slider	2 x 1.8m, 2 panes	0.48
3 Windows	1.4 x 2.4m, 3 panes	0.49
2 Windows	1.2 x 1.4m, 3 panes	0.35
2 Windows	0.8 x 12.2m, 2 panes	0.32
1 Window	1.6 x 3.2m, 5 panes	0.90
1 Window	0.8 x 1.4m, 2 panes	0.26
1 Window	0.8 x 1.6m, 2 panes	0.28
1 Window	0.8 x 0.6m, 1 pane	0.14
1 Window	0.6 x 2.6m, 3 panes	0.38
Window sizes of lowrise commercial category building:		
40 Windows	4 x 9m, 6 panes	2.15
5 Windows	5 x 9m, 3 panes	1.90
Window sizes of highrise commercial category building:		
380 Windows	3 x 2m, 4 panes	0.75
6 Windows	3 x 8m, 2 panes	1.25

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