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A value engineering analysis of timber windows

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Cost effectiveness of products and services has become very important in today's highly competitive market. The customer needs a product that accomplishes its required functions with economy. Value engineering is a very interesting management technique that analyses alternative solutions and identifies the best possible option. The presented work analyses various designs of timber and aluminium clad timber windows on value energy parameters to determine their overall functional performance and cost effectiveness. Life-cycle costing of windows has been carried out over a 40-year life span taking into account all the major cost factors involved. Running cost, the dominant element in life-cycle cost of windows, has been calculated for four possible maintenance options. Results have indicated that an 'air-filled triple-glazed aluminium-clad timber window' is the value engineered choice amongst the range of window designs studied; it is the most cost effective when employed with gas and paint for space heating and maintenance purposes respectively.

1 Introduction

Windows are amongst the most sensitive elements in a building envelope; also, due to their multi-disciplinary role, they are important not only for their effects on the interior environment but also for the energy performance of the building. Owing to remarkable technical developments over the years, windows are available in a wide range of designs and functions. There are a number of factors that play an important role in the selection of windows i.e., comfort, energy efficiency, quality, durability, maintenance, style and price. Amongst these selection parameters, it is normally price that becomes the decisive factor. The customer wants to have a cost effective window that with its intended features brings along satisfaction and economy.

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Value engineering (VE) is a practice that aims to achieve value for money. Value engineering is a very helpful management technique that can be used to identify alternative approaches for satisfying the requirements of a product while lowering costs and ensuring technical competence in performance. Value engineering aims at developing methods of reducing life-cycle cost to a minimum while maintaining the desired functions of the product.

The present work aims to analyse timber and aluminium-clad timber windows on value engineering parameters to determine their overall functional performance and cost effectiveness. Functions or performance criteria of a window have been described. Six different glazing designs in timber and aluminium-clad timber frames have been compared on the defined value engineering parameters. Life-cycle costing has been carried out for the studied window designs over a 40-year period to determine the optimum window design that provides the best functionality to the customer

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at the lowest cost of ownership over the whole life of the window.

2 Value engineering

Value engineering is a system of analysis to ensure that facilities and equipment are designed, constructed, serviced and commissioned such that they may be used and maintained over a lifetime of use at the lowest possible cost of ownership.

The Society of American Value Engineering defines value engineering as:

> The systematic application of recognized techniques which identify the function of a product or service, establish a monetary value for that function, and provide the necessary function reliability at the lowest overall cost.[1]

The key to value engineering is holistic design; the selection of each window component has knock on-effects on running and maintenance costs throughout the life of a window. Value engineering is not about short-term cost cutting; rather it is about providing the most cost-effective long-term project solution.

Value engineering studies rely on the services provided by a task team or group of individuals. The idea is to fully define the problem and its function and to arrive at a cost-effective solution representing the best value. A team with the proper balance of commitment, competence, and stimulation is the most critical factor for a successful value analysis. In value engineering, 'function' is the most vital aspect. Function is the purpose or objective of the product or operation under consideration on those explicit performance characteristics that must be possessed by the hardware if it is to work or sell. A user purchases an item (or service) because it will provide certain functions at a cost the user is willing to pay. If the item does not do what it is intended for, then it is of no use to the buyer no matter how low the cost may be. Similarly, spending more money to increase the function of an item beyond that which is needed does not increase the value to the prospective buyer. Since insufficient functionality is unacceptable and too much functionality is wasteful, function must be carefully defined. This is the only way associated costs may be determined and properly assigned. The initial efforts in a VE study must therefore be directed towards determining the user's actual needs i.e., the performance qualities or characteristics that must be maintained if the item is to be made useful. By defining the function, one learns which characteristics of the design are really required. Thus proper identification of function is very important to the successful implementation of value engineering.

2.1 Life-cycle cost analysis

Life-Cycle Cost Analysis (LCCA) can be applied in any area of economic decision-making. LCCA is particularly relevant to the proper identification and evaluation of the costs of durable assets. As a result, it is of special relevance to the building industry. Whether complete buildings or individual building elements are considered, a decision is being made to acquire assets that are intended to last and to be used for a number of years. These assets will commit the owner or user not only to the initial capital costs, but also to subsequent running costs, and periodic repair or replacement costs. Equally importantly, decisions made at the initial design stage will invariably affect future running costs and the economic use of the building element. For example, there are different ways to heat a building and to illuminate it, each with different initial and running cost profiles.

Life-cycle cost analysis is defined as:

> Life-Cycle Costing is an economic assessment of an item, area, system or facility that considers all the significant costs of

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ownership over its economic life, expressed in terms of equivalent dollars.[2]

Life-cycle cost analysis techniques have the following major applications[3]:

1) an evaluation technique helping to choose between competing options, whether these relate to a complete building, system or a material;
2) a basis for predicting future running costs;
3) a management tool to ensure that the facility is being used effectively and that maximum value for money is being obtained;
4) a basis for budgeting for future expenditure;
5) a means of considering total cost rather than merely initial capital cost.

Since LCCA relies on the projection into the future, the selection of the economic criteria and speculation of future changes is critical. These include the choice of methodology, discount rate, analysis period, maintenance schedule and frequency of component replacement criteria that vary from project to project as discussed by Woodward,[4] Ashworth[5] and Kirk and Dell'isola.[2]

3 Scope and boundaries of present work

The scope of any value engineering effort depends on the size and complexity of the project. The highest return can be expected when VE is performed at the early stages of the project life-cycle, when implementation costs are lower. This is the time before major decisions have been incorporated into the design and when VE recommendations have the greatest impact on costs.

Timber is the traditional and one of the most prominent window materials while aluminium-clad timber windows are also an established product on the market. A thorough value engineering of windows is beyond the boundaries of this study. The presented work provides the guidelines that can be implemented for producing value-engineered windows. Six different glazing designs in timber and aluminium-clad timber frames have been compared on the defined value engineering parameters. Life-cycle costing has been carried out to determine the optimum window design that provides the required functionality to the customer at the lowest cost of ownership over the whole life of the windows.

4 Value engineering of the windows under study

4.1 Function of a window

Functionally, a window can be defined as a 'transparent wall'. Basically a window is composed of two parts, frame and glazing unit.

Frame: Window frames are available in a wide range of framing materials such as; aluminium, timber, aluminium-clad timber, PVC, hybrid and composite, and fibreglass.

Glazing unit: Glazing units are available in numerous compositions depending upon the elements involved, such as:

- number of glass panes (glazing layers)
- infill gases
- low emissivity coatings

The frame and glazing combination that make-up a window are required to meet following essential characteristics:

- control heatflow
- control airflow
- control condensation
- control water vapour flow, rain and snow penetration
- control solar and other radiation
- control sound transmission
- provide strength and rigidity
- be durable, and economical to be maintained
- maintain satisfactory performance over service life

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- be appealing and harmonious with the surroundings
- be environmentally sustainable

Value engineering analysis of a window, therefore, aims to achieve the above stated functionality at the lowest possible cost over the entire life of the window. Different windows, depending upon frame and glazing composition, meet different levels of performance. The service life cost of a window is driven by its design; the nature of the materials and technology involved, both in the frame and glazing unit, determine the life-cycle cost.

4.2 Life-cycle cost analysis of windows

4.2.1 Capital cost

Capital cost is the initial investment to buy and get the window installed. Capital costs for windows with six different glazing combinations (produced by same manufacturer) in timber and aluminium-clad timber frames are provided in Table 1.[6] Aluminium-clad timber windows are slightly more expensive than timber windows due to the additional cost of aluminium cladding involved. It is also shown that capital costs of windows vary with the glazing composition employed. Capital cost is a function of all the four involved variables i.e., frame, glazing layers, low-e coating and infill gas. It is seen that an air-filled window is the cheapest amongst the range of studied windows. The introduction of a low-e coating, infill gas or further glazing layer has a direct impact on the capital cost. Krypton is an expensive gas to produce compared with argon, which adds to the capital cost.

4.2.2 Running cost

The running cost of any product or project is normally several times more than its capital cost. Running cost of windows is composed of a number of different hidden costs. For the studied windows, the running cost consists of the following:

- heating/energy cost
- painting/staining cost
- cleaning cost
- breakdown costs; wear and tear such as break-down of handling or locking system, any problems with ventilation or sealing system or breakage of glazing.

All costs have been calculated for a period of 40 years assuming an annual inflation rate of 3%,[7] and using Single Compound Amount Formula (SCA) that provides the future sum of money in terms of present value, as described here:

$$F = P^{*}(1+i)^{N}$$

Where: P = a present sum of money; F = a future sum of money; i = an inflation rate; N = number of inflation years.

Heat loss. Windows can be a major source of energy loss or gain in buildings, especially in harsher climates. Energy is transmitted through a window via radiation, conduction, convection and air leakage. Windows have a direct impact on the energy efficiency of any given building. The improved characteristics of windows can lead to substantial energy savings as a result of their use. Energy cost in the form of heat loss through the window is a major part of the life-cycle cost of the window.

Energy cost. Energy required for space heating is supplied either by electricity or gas. Energy cost, the cost of energy required for space heating, is a major part of the life-cycle cost of the window. Energy cost that becomes particularly significant in harsher weather conditions can be significantly reduced by selecting well insulated glazing units that employ modern technologies such as multiple glazing, inert infill gases and low-e coatings. For the same outdoor and room temperature conditions the heat loss through different windows differs because of their respective U-values. The total heat lost is a function of the U-value of a given

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Table 1 Life-cycle costing of aluminium clad timber and timber windows at an Edinburgh location with six different glazing compositions – with four different running options – gas/paint, gas/stain, electricity/paint and electricity/stain-commercial applications

	Timber windows				Edinburgh	
	4-16Air-4	4-16Air-e4	4-16Ar-e4	4-10Kr-e4	e4-16Air-4Air-e4	e4-16Ar-4-16Ar-e4
U-Value (W/m^2-K)	3.6	2.1	2.0	1.7	1.6	1.5
Costs (£)						
Capital	143	154	173	209	162	193
Electricity	1043	599	571	485	457	428
Gas	301	173	165	140	133	124
Painting	90	90	90	90	90	90
Staining	180	180	180	180	180	180
Cleaning	893	893	893	893	893	893
Totals						
Electricity/Paint	2168	1737	1726	1677	1602	1604
Electricity/Stain	2258	1827	1816	1767	1692	1694
Gas/Paint	1426	1311	1321	1332	1278	1300
Gas/Stain	1516	1401	1411	1422	1368	1390
	Al-clad Timber					
	4-16Air-4	4-16Air-e4	4-16Ar-e4	4-10Kr-e4	e4-16Air-4-16Air-e4	e4-16Ar-4-16Ar-e4
Capital	171	183	201	237	190	221
Electricity	1043	599	571	485	457	428
Gas	301	173	165	140	133	124
Painting	14	14	14	14	14	14
Staining	33	33	33	33	33	33
Cleaning	893	893	893	893	893	893
Totals						
Electricity/Paint	2120	1689	1679	1629	1554	1556
Electricity/Stain	2139	1708	1698	1648	1573	1576
Gas/Paint	1378	1263	1273	1284	1230	1252
Gas/Stain	1397	1282	1292	1303	1249	1271

window. The lower the U-value the higher the thermal resistance and lesser the heat loss. U-value depends upon a number of factors such as geometric structure of window and glazing unit, glazing unit composition i.e., glass type, infill gases and low-emissivity coatings. U-value has been calculated by the following expression.

$$1/U = 1/h_{si} + \Sigma R + 1/h_{so}$$

Where: U = U-value; h_{si} = heat transfer coefficient for the interior surface of the window, W/m^{2}K; h_{so} = heat transfer coefficient for the exterior surface of the window, W/m^{2}K; ΣR = sum of resistances of the individual layers of the window, m^{2}K/W.

Heat loss through the windows has been calculated according to local climate conditions throughout the year. Figure 1 shows the annual heat loss for the studied glazing compositions at an Edinburgh location. It is observed that for a double glazed air-filled window (4-16Air-4) of size 1.2 m × 1.2 m, the annual heat loss is 251 kWh, while for a triple-glazed argon-filled window with low emissivity coating this heat loss is reduced to 102 kWh[6]. It shows that a 60% reduction in heat loss can be achieved by employing glazing units with low U-value. The reduction in heat loss cuts down the energy cost by the same percentage.

Another important aspect of energy cost is the fuel used for space heating, gas and/or electricity. Gas, being cheaper than electricity can significantly cut down the energy cost if used as the heating medium. In Figure 2 comparison of annual electricity and gas costs for the studied windows has been presented for Edinburgh that shows that gas costs only 29% of the electricity cost.

Painting/staining cost. Timber windows are required to be painted or stained regularly in order to maintain their appearance and to provide resistance against weathering degradation. Externally, timber windows are recommended to be painted and stained on a 5- and 3-year cycle respectively. Internally, windows are painted normally after a life-cycle of 10 years or more frequently depending upon the personal preferences, and staining can be carried out every 5 years. The total cost of internal paint on a 10-year cycle, over a 40-year life of window is calculated as £13.95. The total cost of internal stain of a window based on 5-year cycle, is calculated as £33.00. Similarly, costs of external paint or stain based on 5 and 3-year cycles are calculated as £75.93 and £146.85 respectively. Therefore over the 40-year life, painting and staining costs of

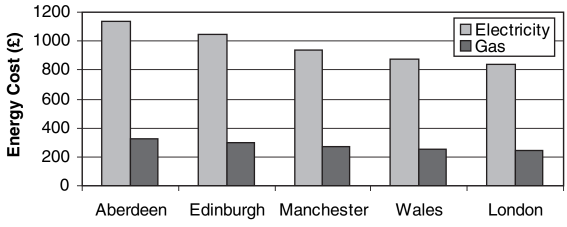

Figure 2 Energy (heat loss) cost over the 40-year life of a double-glazed air-filled window.

a timber window are calculated to be £89.88 and £179.85 respectively (Table 1).[6]

Aluminium-clad timber windows are painted or stained internally only, as they do not require any external maintenance. Aluminium-clad timber windows normally come in powder coated or anodized surface finish over the aluminium profile. The powder coating paint on the aluminium cladding is expected to be stable enough to last over the studied period, hence externally it requires no painting maintenance.[6] Timber underneath the cladding does not require any surface treatment either. Internal painting or staining cost of window is the same as for a timber window. Therefore for an aluminium-clad timber window painting and staining options involve a total cost of £13.95 and £33.30 respectively over the 40-year service life. Figure 3 shows cost effectiveness of aluminium cladding, as it provides a comparison between life-cycle

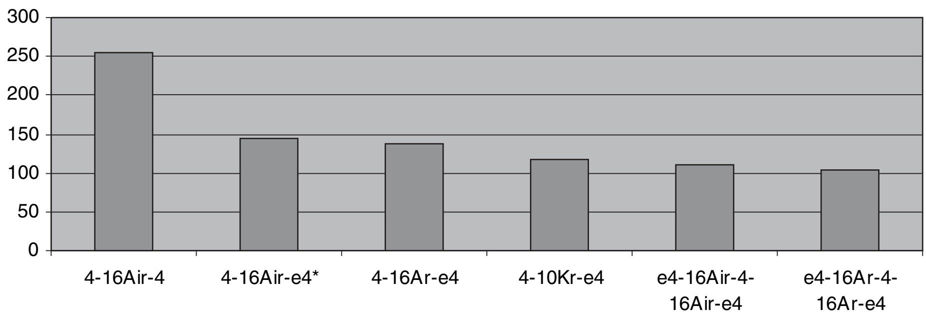

Figure 1 Annual heat loss of different glazing compositions. Note: *Glass thickness—cavity and inert gas—glass thickness; Double-glazed air-filled window; 4 mm glass pane—16 mm wide cavity filled with air—low-e coating on 4 mm thick glass pane.

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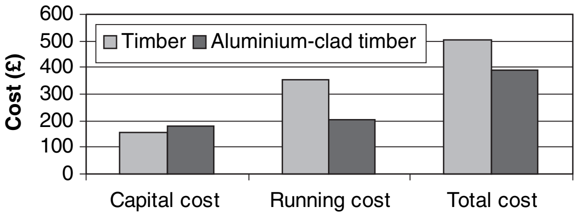

Figure 3 LCC comparison of low-e, air-filled unclad timer and Al-clad timber windows — Gas and staining maintained — domestic application; Edinburgh.

costing of an air-filled double glazed timber and a similar aluminium-clad timber window. It may be seen that in terms of capital cost an aluminium-clad timber window is more expensive than a timber window, however due to the lower staining cost involved, the aluminium-clad timber window becomes the cheaper option in terms of life-cycle costing.

Cleaning cost. Cleaning cost could be quite a significant proportion of the life-cycle costing of windows. The yearly cost of cleaning a window has been estimated as £12 per year, that gives the total cleaning cost over 40-year life equivalent to £892.91.[6] Cleaning cost is associated with windows only in commercial applications since cleaning of windows through hired services is not a common practice in domestic applications.

Unpredicted maintenance and repair cost. Breakdown or wear and tear costs are relative costs i.e., they depend on the exposed conditions and level of maintenance carried out. These are unscheduled costs that do not fall into the routine running cost. This work therefore does not cover them.

4.3 Durability and service life

Durability is one of the important features desired in any window and largely depends on the type and quality of materials employed. The durability of a window has a direct impact on its maintenance and the length of its service life. An important element that determines the durability of windows is their weathering performance. Weathering is defined as:

> The breakdown and alteration of materials near the earth's surface to products that are more in equilibrium with newly imposed physico-chemical conditions.[8]

Every material experiences some sort of degradation during its service life due to its exposure to environmental and surrounding conditions. In a window the frame materials are more sensitive towards weathering than the glazing unit. The environmental factors such as ultraviolet radiation (UV), temperature, humidity, oxygen and pollution can all cause significant detrimental effects on appearance and properties of the material. The natural weathering process results from a complex combination of chemical, mechanical and biological changes, all of which occur simultaneously and affect each other. These processes cause degradation resulting in increased maintenance requirements and reduced service life in the long run. In frames, these characteristics i.e., resistance against environmental conditions and over-all maintenance requirement, vary significantly from material to material.

Service life is defined as:

> The period of time after installation during which a building or its parts meets or exceeds the performance requirements.[9]

Service life of a product is not only a quantifiable technical property, but it also has an aesthetic and fashionable side to it. Berge[10] speaks on similar lines and says that it is quite a challenge to design a product that can outlast the swing of fashion. Especially with technical equipment, it is also important to consider an optimal durability rather than a maximum durability. Changes to new products can often show a net economical gain in terms of energy-saving criteria. Ashworth[5] states that the obsolescence that eventually occurs in both design and technology is perhaps the main

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reason why generally sound components are removed and replaced. In other situations components decay or are damaged. Several authors, such as Seeley[11] and Ferry[12] highlighted common scales that normally determine the life span of a product. Ferry and Flangen,[12] for example, lists five determinants for a product's life expectancy; functional life, physical life, technological life, economic life; and social and legal life.

An accelerated weathering programme and a survey analysis has been carried out to investigate the durability and service lifespan of the frames in the compared window designs i.e., timber and aluminium-clad timber.

4.3.1 Accelerated testing

In accelerated tests, one or more environmental factors are intensified so that the degradation process takes place more rapidly. The results are obtained after a time, much shorter than in real life, which may be counted in weeks, days, hours or even in minutes.[13] In the study undertaken, a number of different accelerated tests such as immersion test; dry–wet cyclic test, temperature-humidity test and ultraviolet test have been carried out to determine the weathering performance of windows. These entire tests have specific testing environment and applications. For example, dry–wet cyclic testing of window samples was carried out under controlled conditions in the testing chamber for duration of 96 h, with three cycles per hour. While each cycle involved 2 min of water spray, 15 min of UV radiation and 3 min of heating at 55°C.

Results of these tests have indicated that aluminium-clad timber windows have better weathering resistance against environmental conditions. Figure 4 (a) shows that timber windows received the weathering impacts in the dry–wet cyclic test as they experienced slight colour change. Figure 4 (b) and (c) shows that aluminium-clad timber windows with both the powder coated and anodized surface finishes, received no weathering impacts under the same test. The results of the test show that aluminium-clad timber windows exhibit better resistance against weathering conditions and hence have a higher level of durability than timber windows.

4.3.2 Survey

A survey has been carried out with the help of local housing authorities, surveyors and architects within the UK to estimate the service life of windows in real life. The survey was questionnaire-based in which organizations were asked to indicate the appropriate experienced/expected service life of various windows from the options provided i.e., below 20 years, 20–30 years, 30–40 years, 40–50 years, 50–60 years and above 60 years. A statistical analysis of the survey results, presented in Table 2, shows that timber and aluminium-clad timber windows have an average service life of 40 and 47 years respectively. The causes reported for the end of service were various i.e., functional obsolescence, aesthetic obsolescence and economical obsolescence. It has been reported that replacement of windows for aesthetic reasons is quite a common practice during the refurbishment of properties even if the windows were serving their purpose satisfactorily. There were quite a significant number of reports stating that both the aluminium clad timber and timber windows last well above 60 years. It has also been reported that aluminium cladding on timber windows provides them with a greater degree of durability and also reduces the maintenance cost.

5 Value engineered window design

Life-cycle costing of the studied window designs for commercial applications (taking into account the cleaning cost) has been summarized in Table 1. The life-cycle costing scenario in the present study has suggested four different options — running cost has been

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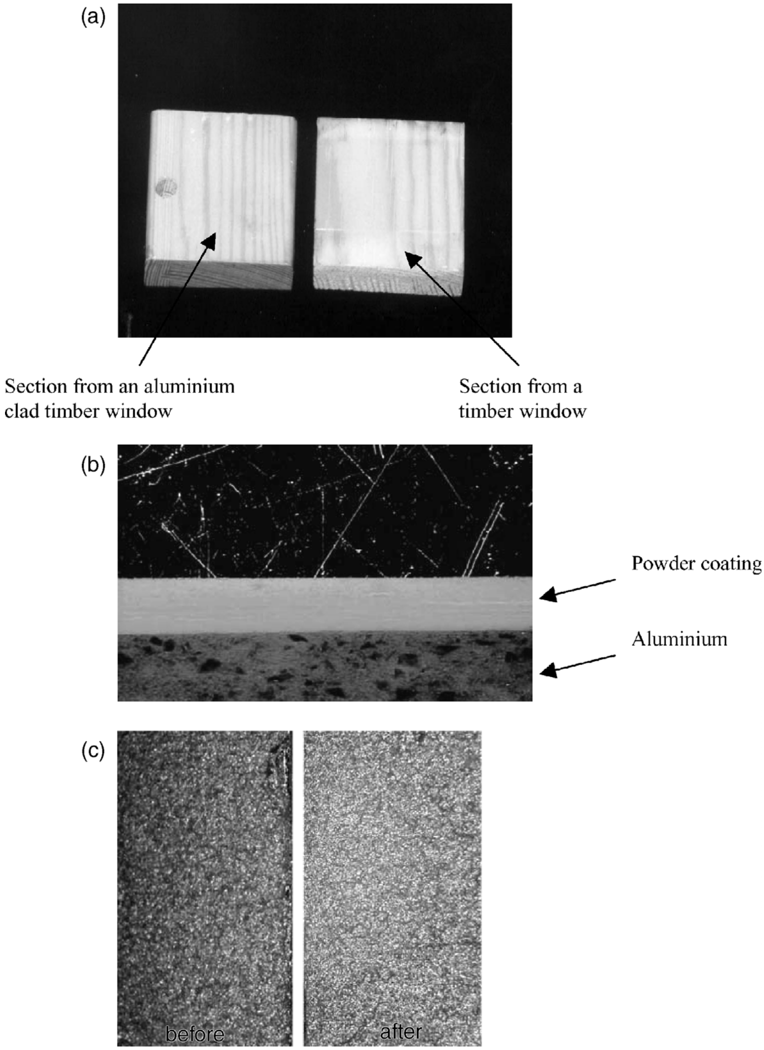

Figure 4 (a) Slight discoloration of timber window sample (right) under dry–wet cyclic test while timber underneath the cladding retained its colour (left); (b) Microscopic image of powder-coated aluminium cladding sample after dry–wet cyclic test, with no sign of any damage to coated layer at a magnification of $\times 100$; (c) Microscopic image of anodized aluminium cladding sample, before and after dry–wet cyclic test, showing no signs of corrosion at a magnification of $\times 100$.

estimated based on types of space heating (gas or electricity) and maintenance (paint or stain). There are four possible combinations for the running cost; electricity–paint, electricity–stain, gas–paint and gas–stain. It is seen that despite higher capital cost aluminium-clad timber windows are more economical than timber windows in terms of life-cycle costing, which suggests it is the maintenance cost that plays the dominant role in life-cycle costing.

With the help of life-cycle cost analysis it is seen that aluminium-clad timber windows are cheaper than timber windows due to the smaller maintenance cost associated with the former. Results gathered from the survey

Table 2 Survey analysis results

Window (Frame type)	Estimated service life (years)		
	Mean	Median	Inter-quartile range
Timber	39.6	35	16.3
Al-clad Timber	46.7	45	10

and accelerated tests present aluminium-clad timber windows as more durable and having a longer life than timber ones. Furthermore, within the aluminium-clad timber windows, running cost differs with the type of glazing composition. A graphical comparison of life-cycle costing for windows in domestic applications has been provided in Figure 5, that shows that amongst the whole range of windows studied, the optimum window design i.e., the most cost effective and economical over the service life, is the 'air-filled triple-glazed aluminium-clad timber window'.

Survey results, which mainly focused on the comparison of service life of windows based on frame types, show that aluminium-clad timber windows have a longer service life than timber windows. Similarly results of accelerated tests indicate that aluminium-clad timber windows have better weathering performance that makes them more durable and have a longer life-time than timber windows. The results also support the fact that aluminium-clad timber windows require less maintenance than the timber ones.

It is therefore concluded that the 'air-filled triple-glazed aluminium-clad timber window' is the value engineered window design since it is durable, long-life and the most economical of all.

6 Conclusions

The air-filled triple-glazed aluminium-clad timber window has been found to be the value engineered choice amongst the range of window designs studied — it is the most cost effective when employed with gas for

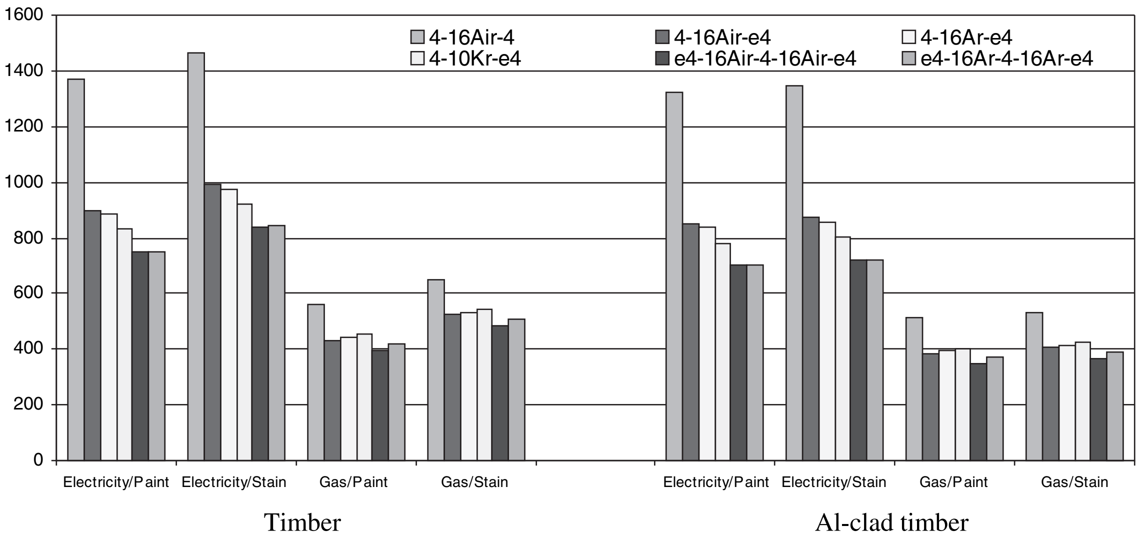

Figure 5 Life-cycle cost comparison of the studied window designs in domestic applications (ignoring the cleaning cost) at an Edinburgh location shows that an aluminium-clad timber window with gas heating and paint maintenance options is the optimum choice.

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space heating and paint for maintenance purposes.

Results show that running cost is vital in terms of life-cycle costing. It is seen that windows with better functional characteristics are more expensive in capital costing but their lower running cost makes them the more economical choice over the life-cycle.

In terms of frame choice, aluminium-clad windows are more expensive than timber windows due to the additional cost of aluminium cladding involved. Aluminium-clad windows are cheaper than timber windows in terms of running cost, due to reduced painting/staining requirements associated with the former. Analysis has shown that despite being more expensive by £28, aluminium-clad timber windows are more economical over the lifetime by £48–£118 than timber windows.

Heat loss through the windows can be reduced by up to 60% by employing low U-value glazing units that involve multiple glazing, insulation gas and low-e coating. Reduction in heat loss accordingly cuts down the energy cost of the window. Using gas for the space heating instead of electricity can further reduce energy cost. Analysis shows that for an air-filled double-glazed window life-cycle cost can be reduced by 59% by using gas as the heating medium rather than electricity.

Findings from the survey and accelerated tests carried out have indicated that aluminium-clad timber windows are more durable and have a longer life than timber ones.

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