EMBODIED ENERGY ANALYSIS OF ALUMINIUM-CLAD WINDOWS

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ABSTRACT

This article provides an overview of energy loads associated with the application of powder coated aluminium profiles on the exterior wooden surface of the double glazed windows. The entire powder coating process has been analysed to measure its energy and environmental contribution towards window cladding. Materials involved in aluminium clad windows have been analysed for their energy impacts. The energy embodied in a standard double glazed 1.2 m × 1.2 m aluminium clad window has been calculated, and is quantified as 1459 MJ, 1967 MJ, and 5.96 GJ respectively for Argon, Krypton and Xenon infill gases. The energy consumed in powder coating the window cladding has been estimated to be 27 MJ and the total embodied energy of adding aluminium cladding to the window has been evaluated as 724 MJ.

Keywords: *Life cycle analysis, environmental impact, embodied energy, aluminium cladding, powder coating.*

1.0. INTRODUCTION

In the last decade of the twentieth century and with the advent of twenty-first century there is an increased concern that mankind must utilise natural resources in a sustainable way in order to secure the future of our offsprings. To achieve this, it is necessary to use these resources wisely and in responsible way. Life Cycle Analysis (LCA) is a very helpful tool in this regard, providing a material and energy balance over the entire life of a material, product or service, determining its interaction with its environment and assessing its impact on the environment. Fig.1 shows the four main interactive steps for a complete Life Cycle Analysis.

Energy characterisation is fundamental to a LCA in that energy utilisation, in addition to being a significant resource requirement, contributes significantly to environmental burdens across the entire life cycle. Consequently one common measure of environmental burden is energy use itself. The energy requirement does not in itself measure environmental impact; it is however useful as a proxy for the level of stress that energy use may cause in the environment. Each form of commercial energy whether utilised as direct fuel, as electricity or in transportation, exhibits a life cycle of its own and includes mining, refining, conversion and distribution.

This article presents the findings of a study undertaken to determine the embodied energy of aluminium clad windows. The data and information presented here were acquired during a survey of the studied windows production plant and the powder coating unit used for coating the aluminium profiles.

2.0. ALUMINIUM CLADDING ON WINDOWS

Aluminium cladding is the covering of the exterior surface of the frame and sash of a window with aluminium profiles, for better protection against weathering effects. Aluminium profiles used are powder coated or anodised, but normally powder coated aluminium is applied.

2.1. ALUMINIUM

The aluminium used for profiles on the clad windows is the 6063 series aluminium alloy, and its good corrosion resistance qualities ensure wide use in architectural extrusions, buildings and construction applications. Normally the aluminium used is primary as well as recycled.

The production of primary aluminium can be divided into four main stages: mining of raw bauxite, Bayer refining, primary smelting and metal finishing. All these four processes are very important in the Life Cycle Analysis of aluminium for the energy and materials involved in them. The production processes of both primary and secondary aluminium are shown in Figure 2(a) and 2(b) respectively[1].

2.2. POWDER COATING ON ALUMINIUM CLADDING

Aluminium cladding profiles are powder coated, also called dry painting, to improve protection against corrosion and weathering effects. Aluminium profiles are first taken to a pre-coating treatment process, because proper surface cleaning and treatment is essential for good coating adhesion. The most common pre-treatment in powder coating involves the application of zinc phosphate conversion coatings with the phosphates acting to form a coating of metal phosphate crystals on the metal surface. These crystals are porous, allowing powder to soak in and produce an exceptionally good bond. In addition, the phosphate layer acts to insulate a variety of “electrochemical corrosion cells” present in the metal, and formed by peaks and valleys in the metal surface and by stress. Insulating these cells with a metal phosphate contributes significantly to corrosion resistance [2,3].

The aluminium profiles are painted in a powder coating chamber, where an 80-90 μm thick layer of powder is introduced over them through electrostatic spraying operation. Profiles are then taken to a furnace that melts the powder and produces a tough corrosion resistant coating fused onto the surface.

3.0. ENERGY ANALYSIS OF POWDER COATING

The main area of concern in the powder coating unit, relevant to this research work, is the analysis of energy involved in powering the process and in the powder used to paint the aluminium profiles. Different chemicals are used in pretreatment of the profiles. These chemicals are used in very small amounts and since the energy contents of these chemicals are of no significance when considering the whole picture of energy analysis of the window cladding, therefore this article does not address the embodied energy of chemicals. The embodied energy of the powder consumed in painting the aluminium profiles has been estimated. The energy involved in the form of power consumed in the entire coating process is calculated. The estimated energy consumption in powder coating the profiles for a standard window has been shown in Table 1.

Energy contents of the powder used are less than 1% of the energy consumed during powder coating. Furthermore, the estimated energy consumed in the whole powder coating process is less than 4% of the total embodied energy of aluminium cladding. Therefore the embodied energy of chemicals consumed is of minimal importance when considering the entire window.

3.1. TOTAL ENERGY INVOLVED IN CLADDING

The energy involved in aluminium cladding can be categorised into three main areas: embodied energy of aluminium metal used, energy associated with powder coating on aluminium profiles and energy consumed during profile cutting in the windows assembly unit.

The amount of aluminium cladding fixed to one window is equal to 3.62 Kg and allowing for a wastage of 8% during profile cutting process, the total aluminium used can be estimated to be 3.91Kg. The embodied energy of aluminium is 225 MJ/Kg for primary aluminium and 50 MJ/Kg for secondary aluminium[4]. It is estimated that about 27% of world's total aluminium production comes as secondary aluminium from recycling of aluminium[5]. This provides a total embodied energy of 695 MJ for aluminium profiles used in cladding the standard window. Considering the respective energy consumption of 27 MJ and 2 MJ in powder coating and profile assembly process, the total embodied energy of aluminium cladding amounts to 724 MJ, as shown in Table 2.

Aluminium strips are used as a boundary shield around glazing and are also fitted along the bottom edge of the sash to protect the timber from water penetration. In the presence of cladding these outer protections are not required. The mass of aluminium used as outer protection is 1.45Kg, which is not needed in the presence of aluminium cladding. Therefore in cladding a window, the extra amount of aluminium used is in fact 2.46 Kg, that contains embodied energy of 437 MJ. Taking into account the energy consumption in powder coating and profile assembly process, the extra energy associated with cladding is 466 MJ.

3.2. ENERGY ANALYSIS OF THE STANDARD DOUBLE GLAZED ALUMINIUM-CLAD WINDOW

All the major energy consumption factors are studied that contribute towards the gross embodied energy of the windows. These include the energy contents of any inert infill gases in the cavity between the glazing. These gases are Argon, Krypton and Xenon that themselves have enormously different embodied energy. For the studied window, the estimated embodied energy for Argon, Krypton and Xenon is 11.85 MJ, 508.2 MJ and 4.50 GJ respectively[6,7]. Other main energy consuming parts include the glazing itself, timber, aluminium profiles, powder coating process, and aluminium used in the form of other parts such as the glazing unit spacer, ventilation mechanism and window adjustment mechanism. Table 3 provides the estimated energy contents of these aluminium parts used. Energy consumed in manufacturing and assembling the windows is also taken into account, and all these estimated values are given in Table 4 and Table 5 respectively. The energy content of timber and glass is extracted from reference[8]. The energy embodied in a standard double glazed aluminium clad window has been quantified as 1459 MJ, 1967 MJ, and 5.96 GJ respectively for Argon, Krypton and Xenon infill gases. As discussed in previous section, the 466 MJ of extra energy associated with cladding, brings an additional 46.9 %, 31 % and 8.5 % of embodied energy respectively for Argon, Krypton and Xenon filled double glazed windows, as shown in Fig 3.

4.0. CONCLUSIONS

Aluminium cladding is a relatively new technique for windows, and currently there is no exact information available for the Life Cycle Assessment of cladding. This article provides an overview of the major energy contents in a clad window and also reports the embodied energy of a standard double glazed clad window. The findings of this study can be concluded as follows:

- The main energy consuming factors in aluminium clad windows include aluminium metal, powder coating on aluminium profiles, timber, glazing, infill gases and energy used in manufacturing and assembling of windows.

- The aluminium cladding brings an additional 46.9%, 31% and 8.5% of embodied energy respectively for Argon, Krypton and Xenon filled double glazed windows.

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- Aluminium has good resisting qualities against corrosion and weathering effects, that protects the window frame and sash. Powder coating further helps to improve these qualities providing an extra shield against the weathering impacts.

- An added advantage associated with aluminium cladding is that, towards the end of its life, it can be recycled, thus helping reduce the energy and environmental burdens.

This article has focused on the embodied energy of windows but in order to study the entire Life Cycle Analysis of aluminium clad windows, various other aspects should be approached such as environmental impacts, effective service life, energy balance during life time, and maintenance cost. It is also recommended herein to compare the life time performance of aluminium clad windows (frame) with other windows, i.e., normal wooden and PVC frames.

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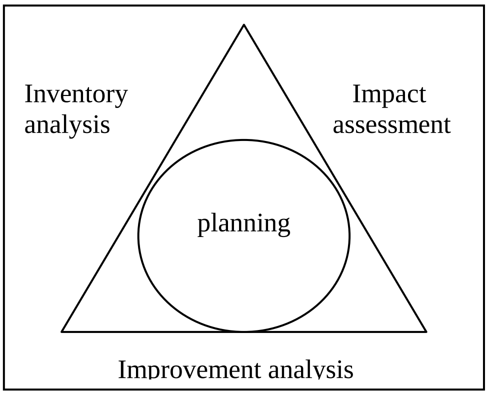
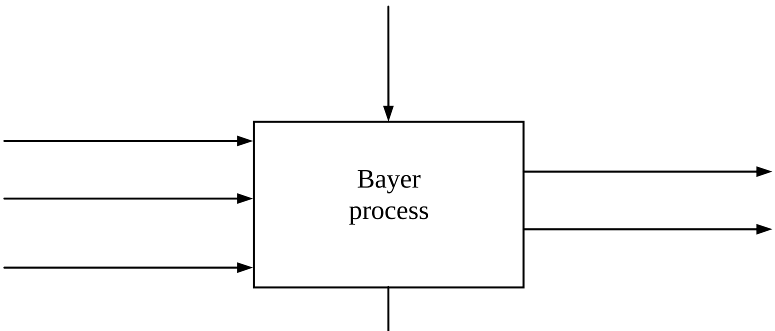


Fig. 1. Four main interactive steps for a complete Life Cycle Analysis



Bauxite(Al(OH)$_3$)
4.750 Kg

Water 9.500Kg

Water 9.307 Kg

NaOH 0.215 Kg

Lime (CaO) 0.086 Kg

Red mud 3.344 g

Alumina (Al_2O_3)
1.900 Kg

Carbon anode 0.400 Kg

CO_2 1.230 Kg

Aluminium fluoride 0.018 Kg

Flue gas 0.025 Kg

Cryolite (Na3AlF6) 0.007 Kg

Waste 0.70 Kg

Aluminium 1.00 Kg

Fig.2(a). Primary aluminium production from raw material

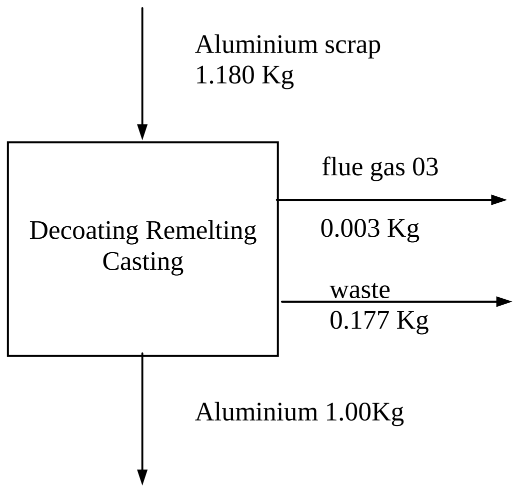


Fig.2(b). Recycled aluminium production

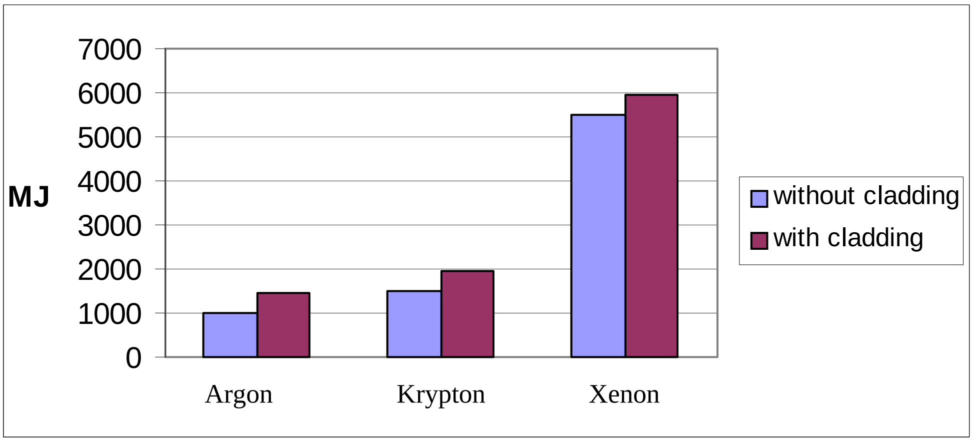


Fig 3. Embodied energy of simple and aluminium clad windows for the three infill gases, Argon, Krypton and Xenon.

Table 1 Energy consumption for powder coating of 3.91 kg of aluminium profiles, to clad one window.

Entity /Function	Energy (MJ)
Power consumed	26.92
Powder	0.135
Total	27

Table 2 Summary of energy contents of cladding a window with powder coated aluminium profiles

Entity/Function	Energy (MJ)
Embodied energy of aluminium metal	695
Powder coating	27
Manufacturing /cutting of profiles	2.36
Total	724.4

Table 3 Estimated aluminium mass used on the aluminium clad standard Nor-Dan 1.2 m by 1.2 m window

Window component	Aluminium mass (Kg)	Waste %	Total aluminium mass (Kg)
Glazing unit spacer	0.241	3	0.248
Frame ventilation	0.159	17	0.186
Window mechanism	0.174	17	0.204
Total	0.574		0.638

Table 4 Summary of energy content for manufacturing processes [6, 7, 8]

Function	Energy requirement per window (MJ)
Timber sash and frame	33.2
Sealed glass unit	6.0
Aluminium processing	2.362
Lighting and factory services	97.7
Total	139.3

Table 5 Summary of energy contents for raw material and manufacturing processes

Window entity/function	Embodied energy of Argon filled window (MJ)	Embodied energy of Krypton filled window (MJ)	Embodied energy of Xenon filled window (MJ)
Inert infill gas	0.01	508.2	4500
Timber	195.3	195.3	195.3
Aluminium profiles	695	695	695
Powder coating	27	27	27
Aluminium parts	113.4	113.4	113.4
Glass	289.4	289.4	289.4
Manufacture	139.3	139.3	139.3
Total	**1459**	**1967**	**5959**

LIST OF FIGURES: