Embodied energy of windows in buildings: impact of architectural and technical choices part 1

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Abstract: - Embodied energy, observed today by pioneers in the field, will soon become part of the basic energy requirements of all projects. In this publication, the relationship that exists between embodied energy of building components and the global energy efficiency of building has been quantified. First, the embodied energy of multiple windows based on their typology has been compared. The aim was to evaluate the embodied energy and additional costs required for a triple glazing window, with the gain in energy consumption that its integration generates for a building. The study was performed on an existing case. Energy consumptions were obtained by in situ measurements and reinforced by building modeling using dynamic thermal simulation software. These allowed us to estimate the return on investment in terms of the embodied energy of building elements. It is a reasoning process expressing overall energy costs that will be presented in part 2 of this publication.

Key-Words: - Embodied energy, triple and double glazed window, operational performance; return on investment

1 Introduction

Faced with the challenges of global warming, energy efficiency has become one of the key topics in all areas of activity including the residential and commercial building sector. So, complementing efforts to reduce operating energy consumption, efforts are also being made to reduce environmental impact.

Today, is an achieved knowledge how to construct comfortable, healthy and energy-efficient buildings. We constantly talk about reducing the energy needs of the buildings themselves, but the issue of energy expended before the completion of construction is often neglected. Until now this indirect energy consumption has accounted for a minority of the consumption compared to the building itself, but this area has become increasingly significant due to the emergence of more and more efficient buildings. Thus, to complement efforts to reduce operating energy consumption, born approaches of reducing environmental impacts.

If in many industrial fields, eco-design has become essential and we systematically apply the life-cycle analysis (LCA), in the construction domain, it is far from being the case. Indeed, the LCA methods, as advanced multi-criteria and global approaches are difficult to be applied in the construction sector since building consists of an assembly of a very different and significant number of elements. Therefore accurately quantify the environmental impact of a building proves to be complex [1].

In order to realise a global study of the environmental impact of a building or product, this must be done on its entire lifecycle. Therefore, we can consider the life of a building "from cradle to grave" as shown in Fig. 1, or in another approach "from cradle to gate".

For building sector, the steps of transport, implementation, operating life and end of life are difficult to take into account with precision, and therefore sometimes inaccurate.

The environmental impact of buildings is a vast subject which takes into account a high number of variables that makes a synthetic approach to be a difficult task [2].

Our study will focus on the impact of embodied energy of some building components only. The concept of embodied or "grey" energy represents the energy enrolled into the construction of a building, for its maintenance, up to the end of life of the building. The term "grey" indicates that this energy is generally hidden or forgotten behind the operating energy consumption in our buildings.

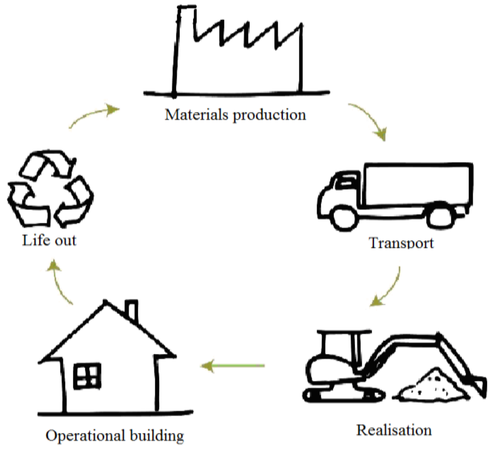


Fig. 1 Life cycle of building elements "from cradle to grave"

This indicator of "grey energy" is also significant in the construction field because it can be connected and compared with the well-known "operating energy" or "consumption energy" in buildings [3].

The investment payback on embodied energy of building elements is considered by evaluating the report that exists between the energy performance and their embodied energy. That is introducing the analysis in overall energy cost [4].

Professionals of construction sector are required to acquire new knowledge and to evaluate and include the terms of embodied energy in the future projects [5]. Soon, it will be necessary to integrate energy efficiency at the design stage and being able to quantify the environmental impacts arising from architectural and technical choices made early at this stage. Thus, project management teams, companies and manufacturers must work together.

Finally, the embodied energy consumption has to be addressed systematically in projects because it plays a significant role in solving the energy, economic and environmental problems encountered within the framework of the sustainable development objective.

This study is wedged on a project realized by the agency Nunc Architects: for the building named "Maison du Pays de la Zorn" in Hochfelden in the region of Alsace in France.

2 Life-cycle assessment and window embodied energy

A life-cycle analysis process has four main steps [6]. These steps are: defining the objectives and scope of the study; making inventory data; realising impact analysis on consumptions and finally interpretation of the results. This last step aims to check the reliability of the results and to conclude the study, explaining the limits and providing recommendations.

In this publication the transparent areas as windows in buildings have been defined as main entity of study, since most contemporary buildings have extremely large glazed areas. For this, the embodied energy values of the windows are calculated using KBoB database [7].

Among the existing databases, the KBoB database stands on Ecoinvent documents that include figures related to the construction sector (materials, equipment, and energy).

Thus in Table 1, we have assembled the representative values of embodied energy of a triple glazed window and a double-glazed window that are assembled in a wooden frame.

Table 1
Embodied energy values considered for double-glazed and triple-glazed window with wood frame.

Product	Embodied Energy	Description of the data
Wood Frame	608 kWh/m² [7]	The data takes into account all processes and inputs required for one m² of wooden window frame (carpentry, woodworking as solvents and paints), iron and frame assembly, transportation of raw materials, and disposal of waste paint. Note: 1 m² of frame has a mass of 80.2 kg.
Glass of triple glazed window	230 kWh/m² [7]	The data takes into account all processes and inputs required for one m² of visible glass, including the elimination of production waste. Note: 1 m² of triple glass has a mass of 30 kg.
Glass of double glazed window	120 kWh/m² [7]	The data takes into account all processes and inputs required for one m² of visible glass, including the elimination of production waste. Note: 1m² of double glass has a mass of 20 kg.

Ecoinvent database is today regarded as the world leader in environmental impact databases. It was prepared by Zürich Federal Institute of Technology in collaboration with other laboratories [8]. This Swiss database that is sweeping many industries, including construction.
Ecoinvent is particularly appreciated for its transparency regarding the origin of the data, their method of production, evaluation and integration in the calculations. Indeed, the data sources are made by experts as: Federal Laboratories for Materials Science and Technology (EMPA), the Institute of Technology in Lausanne (EPFL), Federal Institute of Technology in Zurich, and the Confederation's center of excellence for agricultural research. The registration of these data is based on industrial data compilations accomplished by international well-known research institutes. Data are assembled on the concept of "process unit" which makes of Ecoinvent a very flexible database. It can also be imported into the environmental quality of the building software.

2.1 Embodied energy of a double glazed window and of a triple glazed window

Today, in the field of construction, we focus on increasing the energy performance of buildings. For this, new materials and high performance construction elements are implemented. But what is the environmental impact of these high-performance components? This study targeted the answer for the windows.

A comparative study of embodied energy consumed to produce a triple-glazed window (TGW) and a double glazed window (DGW) has been made and shown in Table 2.
Both studied windows have a wooden joinery and both have the same dimension: (1.70 * 1.00) m^2.

Table 2
Characteristics and Embodied energy of a double glazed window and of a triple glazed window

	Triple glazed window	**Double glazed window**
	Windows characteristics	
Window Dimension [m] Height and Width	1.70	1.70
	1.00	1.00
Percentage area of gazing [%]	73	77
Percentage area of frame [%]	27	23
Glazing Area [m²]	1.25	1.30
Wood frame Area [m²]	0.45	0.40
Description	Glazing : 4-12-4-12-4 Frame section : 90*90 mm^2	Glazing : 4-16-4 Frame section : 78*78 mm^2
	GLAZING *[KBoB 2014]*	
Unitary Embodied Energy [kWh/m²]	230	120
Embodied Energy of Window [kWh]	287	156
Energy additional costs related to TGW for one Window [kWh]	131	
	FRAME *[KBoB 2014]*	
Unitary Embodied Energy [kWh/m²]	608	608
Embodied Energy of Window [kWh]	276	241
Energy additional costs related to TGW for one window [kWh]	35	
	EMBODIED ENERGY	
Embodied Energy of Window [kWh]	562	398
Energy additional costs related to TGW for one window [kWh]	165	

First, we note that the frame area of a double glazed window, DGW (78*78) mm^2 is inferior to the frame area of a TGW, triple glazed window (90*90) mm^2.
This implies that the proportion of the frame is more important in a TGW than in a DGW. But, the

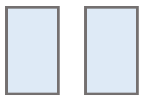
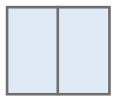
embodied energy of one m² of a wooden frame is greater than the one of one m² of glazing.
In addition, a triple-glazed window has a supplementary pane, spacer and additional seals comparative to a double glazed window.
It is obvious that grey energy needed to manufacture a triple glazing window exceeds the one of double glazing. Thus, there is a grey energy extra cost for the manufacture of a triple-glazed window with respect to a double glazed window.
To the extent that, the study is wedged on a control building where triple glazed windows have been implemented, and also because the use of triple glazing is becoming more widespread, we decided to deepen the analysis of triple glazing windows in the next paragraph.

2.2. Embodied energy of a window based on its type and shape

2.2.1. Embodied energy of a window function of its typology

We studied the evolution of grey energy of a triple glazing depending on the typology of the window.
Thus, for the three types of comparative windows format, the opening area in the wall is the same, as one may see in Table 3.
However, the difference in type causes difference in the proportions frame / glazing, which can in turn affect the architectural appearance of the building concerned.

Table 3
Embodied energy of triple glazed window function of its type

	TRIPLE GLAZING WINDOW		
	A	**B**	**C**
	Two windows	One double window	One large window
	Windows characteristics		
Format			
Width [m]	2*1.00	2.00	2.00
Height [m]	1.70	1.70	1.70
Percentage area of glazing	73	77	81
Percentage area of frame	27	23	19
Glazing Area [m²]	2.49	2.60	2.77
Wood Frame Area [m²]	0.91	0.80	0.63
Section frame [m²]	0.09	0.09	0.09
Glazing thickness [mm]	4-12-4-12-4	4-12-4-12-4	4-12-4-12-4
	GLAZING *[KBoB 2014 Glazing IV]*		
Unitary embodied energy [kWh/m²]	230	230	230
Embodied energy glazing [kWh]	573	599	636
	FRAME [*KBoB 2014 Wood Frame]*		
Unitary embodied energy [kWh/m²]	608	608	608
Frame embodied energy [kWh]	552	485	385
	EMBODIED ENERGY		
Embodied energy [kWh]	1 125	1 083	1 022
Embodied energy [kWh/m²]	331	319	300
Percentage of embodied energy of glazing [%]	51%	55%	62%
Percentage of embodied energy of frame [%]	49%	45%	38%

The large window (C in Table 3) has a glass area greater than that of two small windows for the same opening area in the wall (Figure 2). That means more daylight surface benefits for the occupants inside the building.

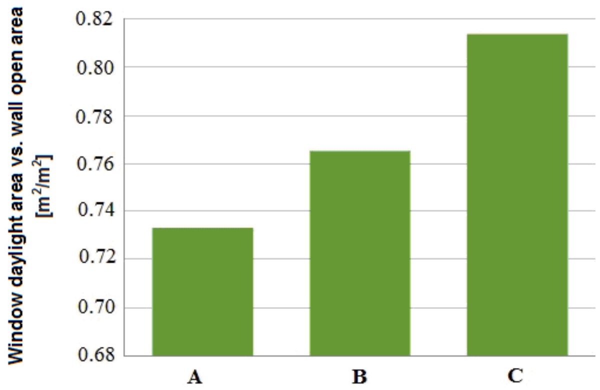


Fig. 2 Ratio: daylight surface of the window glass compared with corresponding surface opening area in the wall [m^2/m^2]

The proportion frame/glazing affect energy expenditure required for the production of the window. Indeed, the production of the wood frame is more energy intensive than the glass production (Figure 3). Therefore, for one square meter of wall opening, reducing the percentage of the frame surface allows the reducing of embodied energy overall costs of window.
Finally, the establishment of a large window rather than several small windows presents a number of advantages as:

- Reduce the grey energy costs for the production of the window,
- Allows having a higher surface for the transparent part of the window.

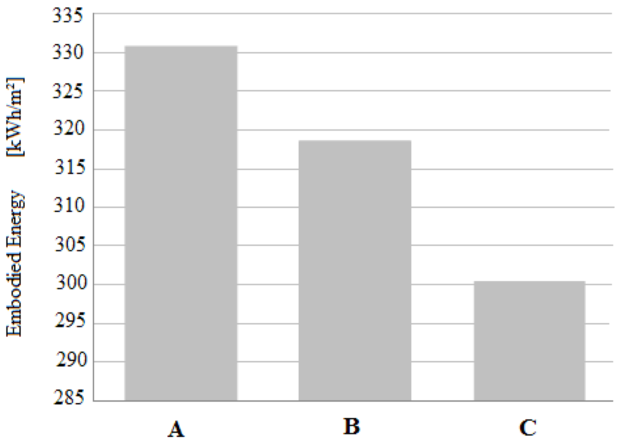


Fig. 3 Embodied energy ratio of a window function of its type

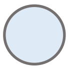
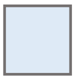
2.2.2 Embodied energy of a triple glazed window function of its shape

In the Table 4 we compare the embodied energy required to produce a round window (D), a square window (E) and a rectangular window (F).
For the same opening area, the perimeter of the circular window is the smallest followed by the square window and by the rectangular window perimeter.
This induces a greater frame proportion for a rectangular window as for a square window as for circular window.

Table 4
Embodied energy function of the geometrical characteristics of a triple glazed window.

	TRIPLE GLAZED WINDOW		
	D	**E**	**F**
	Circle	Square	Rectangle
WINDOWS CHARACTERISTICS			
Format			
Dimensions [m]	Ø	1.00	0.50
	0.56	1.00	2.00
Percentage area of glazing	71%	67%	58%
Percentage area of frame	29%	33%	42%
Glazing Area [m²]	0.71	0.67	0.58
Wood frame Area [m²]	0.29	0.33	0.42
Section Frame [m^2]	0.09	0.09	0.09
Glazing thickness [mm]	4-12-4-12-4	4-12-4-12-4	4-12-4-12-4

Table 4 (next)
Embodied energy function of the geometrical characteristics of a triple glazed window.

	TRIPLE GLAZED WINDOW		
	D	**E**	**F**
	Circle	Square	Rectangle
Format			
WINDOWS GLAZING CHARACTERISTICS			
Embodied energy per square unit [7]	230 [kWh/m²]	230 [kWh/m²]	230 [kWh/m²]
Embodied energy of glazing	162 [kWh]	155 [kWh]	134 [kWh]
	FRAME		
Unitary embodied energy [7]	608[kWh/m²]	608 [kWh/m²]	608 [kWh/m²]
Frame embodied energy	178 [kWh]	199 [kWh]	254 [kWh]
	EMBODIED ENERGY		
Embodied Energy [kWh/m²]	341	354	388
Percentage of embodied energy of glazing [%]	48	44	35
Percentage of embodied energy of frame [%]	52	56	65

The greater the frame area, the lower the glazing area is. Thus, for the dimensions of the study, the square window has a glazed area of 10% greater than the rectangular, for the same opening area in the wall.
In addition, the frame / glazing proportion affects the energy expenditure required for the production of the window. Indeed, the production of the wood frame is more energy intensive than the glass production.
As shown in Table 4, for 1 m² of window in this study, there is an embodied energy overcharge of 34 kWh/m², which means 9% plus, to produce a rectangular window over a square one.
Finally, the establishment of a round window rather than square rather than rectangular one has several advantages:
- Reduce the embodied energy expenditure for the overall production of the window
- Allows having a higher surface for the transparent part of the window.

2.2.3 Discussion

Considering the results obtained on the typology and on the geometry of windows, it is noted that the reduction of window frame areas can reduce the embodied energy costs required to manufacture the window and the same time may increase the daylight area of windows and of walls.

For architects and designers, it follows two arguments for reducing energy expenditure required for the production of the window:

- For the same glass area, choose a large window rather than two smaller ones.
- Moving towards a form whose perimeter is reduced; for example, choose a square rather than a rectangular window.

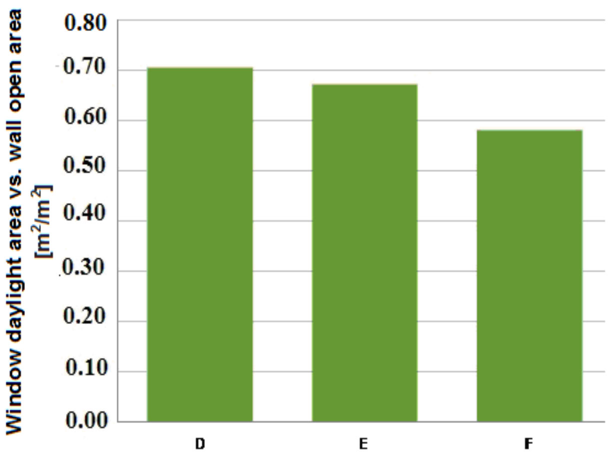


Fig. 4 Ratio: daylight surface of the window glass compared with corresponding surface opening area in the wall [m^2/m^2].

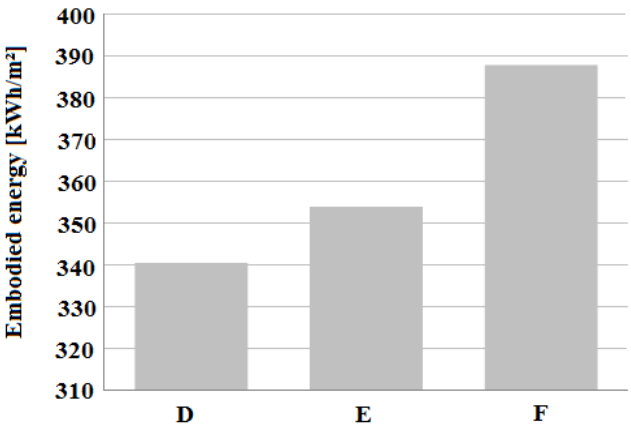


Fig. 5 Embodied energy ratio of a triple glazed window function of its geometrical form.

The observation of the geometry of windows is thus a method of reducing embodied energy expenditures for construction. Certainly, for a unit, the gain is low, but in a building where the number of windows is important, the savings can be substantial.
However, a decision on the geometry of openings has an important impact on the aesthetics and the architectural results.

3 Conclusion – part 1

The aim of this publication was to demonstrate and to quantify the correlation between the embodied energy of building components and energy consumption of a building in operation. In this study, we focused on embodied energy of the transparent elements of buildings. Thus, for the specific window component, several alternatives with different energy performance we have been analysed.
Considering the results obtained in the study on the typology and the geometry of the window, one can see that the reduction of window-frame surfaces can reduce the embodied (or "grey") energy costs required to manufacture the window, and, at the same time, increase daylight surface and improve the thermal performance of the inner surface.

As far as designers are concerned, studies of window geometry have produced two arguments for reducing energy expenditure required in their production:
- For the same glass surface, choose one large window rather than two smaller ones.
- Start moving towards a window shape with a reduced perimeter: a square rather than an oblong, for example.

So, looking at the geometry of windows can be seen as a way of reducing expenditure on the grey energy of buildings.
However, addressing the geometry of apertures would obviously have an impact on the aesthetic and architectural aspect of a building.

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