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Calculations of embodied and operational carbon of double and triple glazed windows

To achieve the EU's goal to reduce overall carbon emissions, one route pursued by EU authorities is to move towards zero-emission buildings[i]. It means that the CO_2 emitted for heating and cooling the building throughout its lifetime, i.e., the operational carbon, needs to be minimised. Equally, CO_2 emitted for the building's construction, including the manufacturing of building materials, i.e., the embodied carbon, also needs to be minimised.

Both double glazed and triple glazed windows, when equipped with coated glass[ii], are high-performance products that help in reducing the energy consumption and the CO_2 emissions of a building. Yet, manufacturing triple glazed windows generates more CO_2 than manufacturing double glazed windows due to the CO_2 embodied in an extra sheet of glass and a heavier frame. Besides, since triple glazed windows are generally heavier than double glazed ones, the transport of triple glazed windows generates more CO_2[iii]. It is thus necessary to evaluate if using high-performance triple glazed windows generates a reduction of buildings' CO_2 emissions that is higher than when using a high-performance double glazed window[iv]. (And, if yes, in which conditions).

Glass for Europe has run calculations based on public data and energy performance models used by and developed for the European Commission (see Annex on methodology and calculations). This paper presents the results of these calculations. It must be noted that the calculations are strictly limited to carbon savings and carbon payback times according to the referenced energy performance models and parameters. For instance, the model is limited to residential buildings only. With these calculations, Glass for Europe does not intend to recommend any specific glass or window type for any building.

The following can be concluded from these calculations:

- ✓ Across Europe, **using Low-Emissivity (Low-E) triple glazed windows in buildings generally offers more CO_2 savings during the operational phase of a building than the incremental CO_2 that was emitted for its production**, when compared to Low-E double glazed windows. Depending on the exact model used, Low-E triple glazed windows may not always offer the most CO_2 savings in southern climates.
- ✓ The CO_2 payback time between Low-E double glazed windows versus Low-E triple glazed windows is highly dependent on the climate, the CO_2 efficiency of the heating or cooling system and the energy conversion factor. **This payback time varies between 14 to 17 years across central and northern Europe.**
- ✓ **The carbon payback time of Low-E triple glazed windows is the shortest, i.e., +/- 14 years, in northern European climates**, where these windows offer the most energy savings and comfort for building occupants.
- ✓ In southern European climates, the windows offering the most CO_2 savings during the operational phase of a building are windows equipped with solar control glass, rather than those equipped with Low-E glass. **Solar control double glazed windows offer a CO_2 payback time shorter than Low-E double or triple glazed windows in southern European climates.**

Depending on the models, solar control triple glazed windows may even be more efficient.

- ✓ While buildings become increasingly better insulated and the energy mix used to heat and cool buildings is gradually decarbonised, the payback times may become longer. Yet considering the lifetime[v] of a glazing product and the reduction in CO_2 emissions from glass manufacturing, **triple glazed windows are likely to continue generating more CO_2 savings throughout their lifetime in the coming decades**.

These findings show that high-performance triple glazed windows offer benefits in terms of reduced operational CO_2 emissions that outweigh the incremental embodied CO_2 emissions compared to high-performance double glazed windows in most situations.

When appropriate in a building considering the region's climate, expected energy savings, thermal comfort considerations, etc., high-performance triple glazed windows will contribute to reduced CO_2 emissions throughout the life cycles of both windows and buildings.

While the above is taken from the calculations realised by Glass for Europe based on the methodology and parameters presented on the next pages, it must be noted that the findings are generally consistent with numerous other pieces of work on the topic[vi].

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Glass for Europe is the trade association for Europe's flat glass sector. Flat glass is the material that goes into a variety of end products, primarily in windows and facades for buildings, windscreens and windows for automotive and transport as well as solar energy equipment, furniture and appliances. Glass for Europe brings together multinational firms and thousands of SMEs across Europe, to represent the entire building glass value-chain. It is composed of flat glass manufacturers, AGC Glass Europe, Guardian, NSG-Group and Saint-Gobain Glass Industry, and works in association with national partners gathering thousands of building glass processors and transformers all over Europe.

ANNEX – Methodology and Calculations

Embodied and operational carbon of double and triple glazed windows

To compare the CO_2 balance of double and triple glazed windows throughout their lifetime, several parameters have to be taken into account: the type of double or triple glazed windows that are used (type of coating, thickness of glass, type of frame, carbon intensity of the manufacturing), the type of building and climatic zone in which the products are used, the carbon intensity of the heating/cooling, and the emissions generated by the transports of the windows.

VHK, VITO, and ift Rosenheim have partnered to offer guidance on Ecodesign of Window Products (studies conducted for the European Commission). Their work[vii] was used to determine and compare window products' energy performance in residential buildings, according to two models, the single room and the single family house, in three different climates, northern, central, and southern Europe. Using both models showed consistency in results, which help confirm the outcome of the calculations. In this Annex, we present only the results of the single home model, which is found to be more representative of reality and easier to grasp for the lay reader. Yet, the results for the single room model are still provided in endnotes, to ensure transparency.

PRIMES data (EU Reference Scenario 2020)[viii] were then used by Glass for Europe to convert the energy consumed by a building into a quantity of CO_2 emissions per year. The energy conversion factors for residential consumption are established by EU Member State. Glass for Europe calculated an average conversion factor per climate by doing the average of the conversion factors of each country within a specific climatic zone[ix] weighted according to their population.

Based on these data and models, Glass for Europe ran calculations for Low-E double and triple glazed windows. To define the characteristics of the windows, we looked at the values of window products from various suppliers and correlated them with the ones of the standard windows given by the Ecodesign guidance. The following values have therefore been used:

Low-E double glazed window:
Structure: 4-16-4 with one Low-E coated glass sheet.
Corresponding window type in the guidance on Ecodesign of Window Products: 4a
Thermal transmittance of the window [W/(m²K)]: $U_W = 1.3$
Transmittance caused by infiltration [W/(m²K)]: $H_{ve,\,w} = 0.16$
Solar energy transmittance of the transparent part of the window [-]: g = 0.6
Frame fraction of the window [-]: $F_F = 0.3$
Weight of the window per m² [kg/m²]: $m_{double} = 39.5\ kg/m^2$
Embodied CO_2 *emissions: 113.3* $kgCO_2eq/m^2$

Low-E triple glazed window:
Structure: 4-16-4-16-4 with two Low-E coated glass sheet(s).
Corresponding window type in the guidance on Ecodesign of Window Products: 5a
Thermal transmittance of the window [W/(m²K)]: $U_W = 1.0$
Transmittance caused by infiltration [W/(m²K)]: $H_{ve,\,w} = 0.16$
Solar energy transmittance of the transparent part of the window [-]: g = 0.55
Frame fraction of the window [-]: $F_F = 0.3$
Weight of the window per m² [kg/m²]: $m_{triple} = 51.2\ kg/m^2$
Embodied CO_2 *emissions: 140.4* $kgCO_2eq/m^2$

To define the embodied CO_2 emissions and the weight of the windows, Environmental Product Declarations (EPDs) for the above-mentioned types of products have been considered. To ensure the representativeness of the values, we have selected the numbers given by various manufacturers and used mean values[x]. To evaluate the emissions linked to transportation, we considered a scenario where the windows would be transported on 800km with a carbon intensity of transportation of 60 gCO_2/tkm[xi].

PERFORMANCE LOW-E GLASS

		North	Centre	South
Energy consumption 30 years [MWh]	Double Low-E	66.9	41.0	53.4
	Triple Low-E	43.8	25.9	44.6
CO_2 emissions 30 years [$kgCO_2$]*	Double Low-E	9022	8246	8920
	Triple Low-E	8092	7481	8965
Cumulated emissions Triple Low-E < Double Low-E:		177 months	194 months	379 months

*This includes the windows embodied CO_2 emissions, the building emissions over 30 years, and the transport of the windows

If taking as a model a single family home[xii] with a floor surface of 162 m^2 and a window area of 32.4 m^2, the following can be calculated:

- When Low-E triple glazed windows are used over 30 years, the energy consumption per building can be cut by 23.1 MWh in northern climates, 15.1 MWh in central climates, and 8.8 MWh in southern climates.
- This results in cutting emissions by 930 $kgCO_2$ in northern climates and 765 $kgCO_2$ in central climates.
- In southern climates, the emission cuts generated over 30 years would not be enough to compensate for the triple glazed windows embodied CO_2 (19 months more would be needed)[xiii].

PERFORMANCE SOLAR CONTROL GLASS

Thus, in southern climates, using Low-E triple glazed triple windows is not necessarily advantageous. There, using solar control glass may be of interest to increase CO_2 emissions reduction. A comparison between windows with solar control glass[xiv] and the Low-E windows used until now has thus been done:

		South
Energy consumption 30 years [MWh]	Double Low-E	53.4
	Double Solar Control	34.2
	Triple Low-E	44.6
	Triple Solar Control	23.8
CO_2 emissions 30 years [$kgCO_2$]*	Double Low-E	8920
	Double Solar Control	7054
	Triple Low-E	8965
	Triple Solar Control	6938

*This includes the windows embodied CO_2 emissions, the building emissions over 30 years, and the transport of the windows

In southern climates, if, instead of Low-E double glazed windows, double glazed windows with solar control glass are used, the energy consumption over 30 years for a single family home can be cut by 19.2 MWh. This represents a reduction of 1866 $kgCO_2$[xv] over 30 years.

In case triple glazed windows with solar control glass would be used, instead of double glazed windows with solar control glass, the resulting energy consumption would be even lower and result in an additional cut of 116 $kgCO_2$[xvi] over 30 years (for southern climates with the single family home model). Solar control triple glazed windows can therefore be more adapted, depending on the model[xvii].

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[i] As defined in the EC proposal for a revised Energy Performance of Buildings Directive. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0802&qid=1641802763889

[ii] Main types of coated glass considered in this paper are Low-Emissivity coated glass (Low-E) and solar control coated glass, which is meant to increase energy performance by reducing heat losses and either maximising or minimising solar heat gains.

[iii] This assumption is based on available EPDs for windows (see endnote x for the weblink to these EPDs). This statement is valid if the glass sheets composing the respective windows have a comparable thickness and if the frames are made of similar materials.

[iv] See the annex for the detailed product specifications. Only windows equipped with coated glass are computed, be they double glazed or triple glazed. In northern and central climates, Low-E coated glass is used while solar control glass is also computed for southern climates.

[v] The lifetime is equivalent to how long it stays in a building. For the sake of this work, a period of at least 30 years is computed, knowing that it is not uncommon for windows to remain installed in a building for 50 years or more in the residential sector.

[vi] Culp, T. (2022, January 18). *Triple Glazing and Embodied Energy: Yes, the juice is worth the squeeze*. National Glass Association. https://www.glass.org/triple glazed-and-embodied-energy-yes-juice-worth-squeeze

Ménard, R., & Souviron, J. (2020). Passive solar heating through glazing: The limits and potential for climate change mitigation in the European building stock. *Energy and Buildings*, *228*, 110400. https://doi.org/10.1016/j.enbuild.2020.110400

Feehan, A., Nagpal, H., Marvuglia, A., & Gallagher, J. (2021). Adopting an integrated building energy simulation and life cycle assessment framework for the optimisation of facades and fenestration in building envelopes. *Journal of Building Engineering*, *43*, 103138. https://doi.org/10.1016/j.jobe.2021.103138

[vii] *LOT 32 / Ecodesign of Window Products TASK 7 – Policy Options & Scenarios* https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/window-products/task7-lot32-windows-consolidated.pdf

[viii] *EU Reference Scenario 2020 - main results on energy, transport and GHG emissions* https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

[ix] This calculation resulted in the following conversion factors:

- Northern climate: 0.92 tCO_2/toe = 79.1 $kgCO_2$/MWh
- Central climate: 1.28 tCO_2/toe = 110.1 $kgCO_2$/MWh
- Southern climate: 1.13 tCO_2/toe = 97.2 $kgCO_2$/MWh

Northern climate value includes the conversion factor of the following countries:
Estonia, Finland, Latvia, Lithuania, Sweden, and half of the population of Denmark, Ireland, and Poland. These three last countries do not seem fully situated in northern climates in the Ecodesign guidance maps, therefore we considered that half of their population would live in northern climate's buildings.
Central climate value includes the conversion factor of the following countries:
Austria, Belgium, Bulgaria, Croatia, Czech Rep., Germany, France, Hungary, Luxemburg, the Netherlands, Romania, Slovenia, Slovakia, and half of the populations of Denmark, Ireland, and Poland (see explanation above).
Southern climate value includes the conversion factor of the following countries:
Cyprus, Greece, Italy, Malta, Portugal, and Spain

[x] For each type of window (double and triple), mean values for the embodied CO_2 emissions were obtained from the EPDs of four different products (two with frames in Aluminum and two with frames in PVC).
PVC frame – Double glazed window:
https://www.deceuninck.com/en/EPD-files.aspx
http://materiales.gbce.es/wp-content/uploads/2020/02/DAP_REHAU_window_double_glazing.pdf
PVC frame – Triple glazed window:
https://www.deceuninck.com/en/EPD-files.aspx
http://materiales.gbce.es/wp-content/uploads/2020/02/DAP_REHAU_window_-triple_glazing.pdf
Aluminum frame – Triple glazed window & Double glazed window:
https://european-aluminium.eu/resource-hub/building-products-epd-programme/
https://european-aluminium.eu/media/3543/16-10-25-epd-3-reynaers-windows-masterline-8-windows-r01.pdf
https://european-aluminium.eu/media/2029/epd-3-alumil-window-s67-2017-signed.pdf
https://european-aluminium.eu/media/2031/epd-5-alumil-window-s91-2017-signed.pdf

[xi] Value evaluated with the following report:
Easy Ride: Why the EU Truck CO2 Targets are unfit for the 2020s https://www.transportenvironment.org/wp-content/uploads/2021/10/202108_truck_CO2_report_final.pdf

[xii] These parameters are defined by the Ecodesign guidance, for both building models. The area of windows (20%) is rather high in comparison to typical European buildings. Yet, since the Ecodesign guidance values used to do the calculation have been determined using this ratio, we chose to stick with it.

[xiii] If we consider the single room model (see endnote vii), which has a floor surface of 19.8 m^2 and a window area of around 4 m^2, the studied Low-E triple glazed windows are more advantageous than Low-E double glazed windows in all climates. According to this model, the energy consumption of the building can be cut by 2.6 MWh in northern climates, 1.7 MWh in central climates, and 1.6 MWh in southern climates (over 30 years). According to the 2020's conversion factor for residential energy consumption in the EU (see endnote viii), this would result in cutting emissions by 95 $kgCO_2$ in northern climates, 82 $kgCO_2$ in central climates, and 44 $kgCO_2$ in southern climates.

[xiv] The parameters for the solar control double glazed window are identical to the Low-E double glazed window used until now, except for the following number:
Solar energy transmittance of the transparent part of the window [-]: g = 0.35
The parameters for solar control triple glazed windows are identical to the Low-E triple glazed window used until now, except for the following characteristics:
Thermal transmittance of the window [W/(m²K)]: $U_W = 0.8$
Solar energy transmittance of the transparent part of the window [-]: g = 0.35

[xv] For a single room, the energy consumption can be cut by 8.8 MWh if using solar control glass in place of Low-E glass (in a double glazed window). This represents a reduction of 856 kgCO_2.

[xvi] With the single family home model, it would take 319 months (=26.6 years) for the cumulated CO_2 emissions of a solar control triple glazed window to be lower than the ones of a solar control double glazed window.

[xvii] With the single room model, it would take 1942 months (=162 years) for the cumulated CO_2 emissions of a solar control triple glazed window to be lower than the ones of a solar control double glazed window. The CO_2 emissions over 30 years would therefore be higher than when using solar control double glazed window