

# **DOUBLE SKIN FAÇADES: LIFE CYCLE STUDY OF A VERSATILE TECHNOLOGY FOR THE SUSTAINABLE REFURBISHMENT OF NON-DOMESTIC BUILDINGS**

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## **Abstract**

Nearly half of the non-domestic building stock in central Europe was constructed between 1961–1990. Partly due to the technical lifespan of façades and building components, most of these buildings are characterised by high energy consumption and thermal discomfort. The sustainable renovation of the non-domestic stock is therefore arguably one of the great opportunities, and challenges, for all stakeholders in the built environment. Unlike domestic buildings, non-domestic buildings can vary greatly in scope, purpose, and built form, and solutions well-suited to a specific building type may not work in different contexts. In this respect, the flexibility offered by double skin façade (DSF) technologies represents an interesting approach with potential broad application. DSFs are capable of significant reduction of both the heating and cooling loads of the building they are applied to whilst providing good levels of indoor comfort. However, while the operational behaviour of DSFs is fairly well studied, there is limited knowledge of the whole life cycle. This paper reports on the life cycle impacts of DSFs when used in non-domestic refurbishments as an alternative to a more traditional single skin refurbishment approach. It focuses on embodied energy and carbon, two of the impact categories assessed throughout the life cycle stages by the recently developed standard EN 15978. The results show that DSFs can outperform their single skin counterparts for non-domestic refurbishments from a life cycle perspective, thus truly representing a low-carbon technology.

**Keywords:** *sustainable renovation, double skin façade, non-domestic buildings, embodied energy, embodied carbon*

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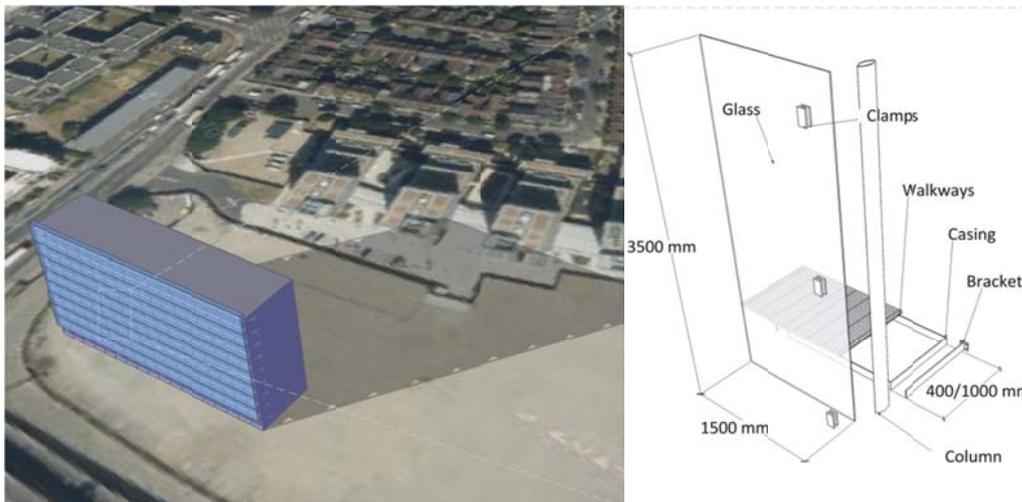
## **1 Introduction**

Nearly half of the non-domestic building stock in central Europe was constructed between 1961-1990 [1]. It is expected that by 2050, 75%-90% of the existing buildings will still be standing and their upkeep is one of the major challenges to achieve the carbon reduction targets [2]. For such reasons, the existing building stock is where the greatest opportunities for improvement lie, and reducing energy demand through retrofitting deserves to become a priority [3]. Unlike domestic buildings, non-domestic buildings can vary greatly in scope, purpose, and built form, and solutions well-suited to a specific building type may not work in different contexts. In this respect, the flexibility offered by double skin façade (DSF) technologies represents an interesting approach with potential broad application. DSFs are among the best façade technologies to reduce energy consumption and GHG-emissions, while

helping provide comfortable conditions to the occupied spaces [4]. In refurbishments, a DSF consists of a second, glazed skin installed in front of the existing building façade, which creates an air space that acts either as a thermal buffer or a ventilation channel or a combination of both. Operational behaviour of the DSF has been widely studied and, in temperate climates, this technology promises significant reductions of 30% -60% in heating and cooling loads [e.g. 5, 6]. A recent broad systematic review of existing literature has concluded that, on average, DSFs in temperate climates can reduce heating and cooling loads by as much as 33% and 28% respectively [7]. To the contrary, existing knowledge is extremely limited about DSF embodied energy (EE) and embodied carbon (EC), with just a handful of studies which have investigated it [8-12]. This research sets out to address such gap through a comparative life cycle assessment of DSFs and single skin refurbishments solutions. The additional processes, assemblies, and impacts that the DSF bears are compared against its operational energy and carbon savings to answer the following research question: can DSFs be considered as a low-carbon refurbishment solution? Cumulative Energy Demand (CED) and Global Warming Potential (GWP) are used as calculation methods for the embodied energy and embodied carbon assessment respectively, which has been carried out by means of primary data collection and the use of SimaPro and Ecoinvent.

## 2 Material and methods

For this research, a cradle-to-grave LCA has been conducted based on the TC350 standards [13]. The non-domestic building model used for this research and representation of the façade module used as functional unit (FU) are shown in **Fig. 1**.



**Fig. 1** Building model (left) and representation of the FU (right)

The FU totals 5.25 m<sup>2</sup> of façade area and it is the result of consultations with façade engineers to have realistic values for the assessment. The building model is a generic yet representative type with a slender built form, which is very common in Europe and also has the characteristics generally found in DSF refurbishments [14]. The building consists of 9 floors of 66.6 m x 16 m, totalling 9590 m<sup>2</sup> of treated floor area (TFA) and is naturally ventilated as the majority of existing offices in Europe. The façade service life is assumed at 25 years in line with studies specifically focused on building façades in the Europe [15]. The DSF is equipped with a basic form of Building Management System (BMS) that opens the bottom

and the top of the cavity when either outside air temperature exceeds 20 °C or cavity temperature exceeds 15 °C. These values are the result of an optimisation process aimed at minimising overheating of the indoor spaces in summer. The inventory of the components for the façade module are given in **Tab 1**.

**Tab. 1** Inventory of the main components for the FU

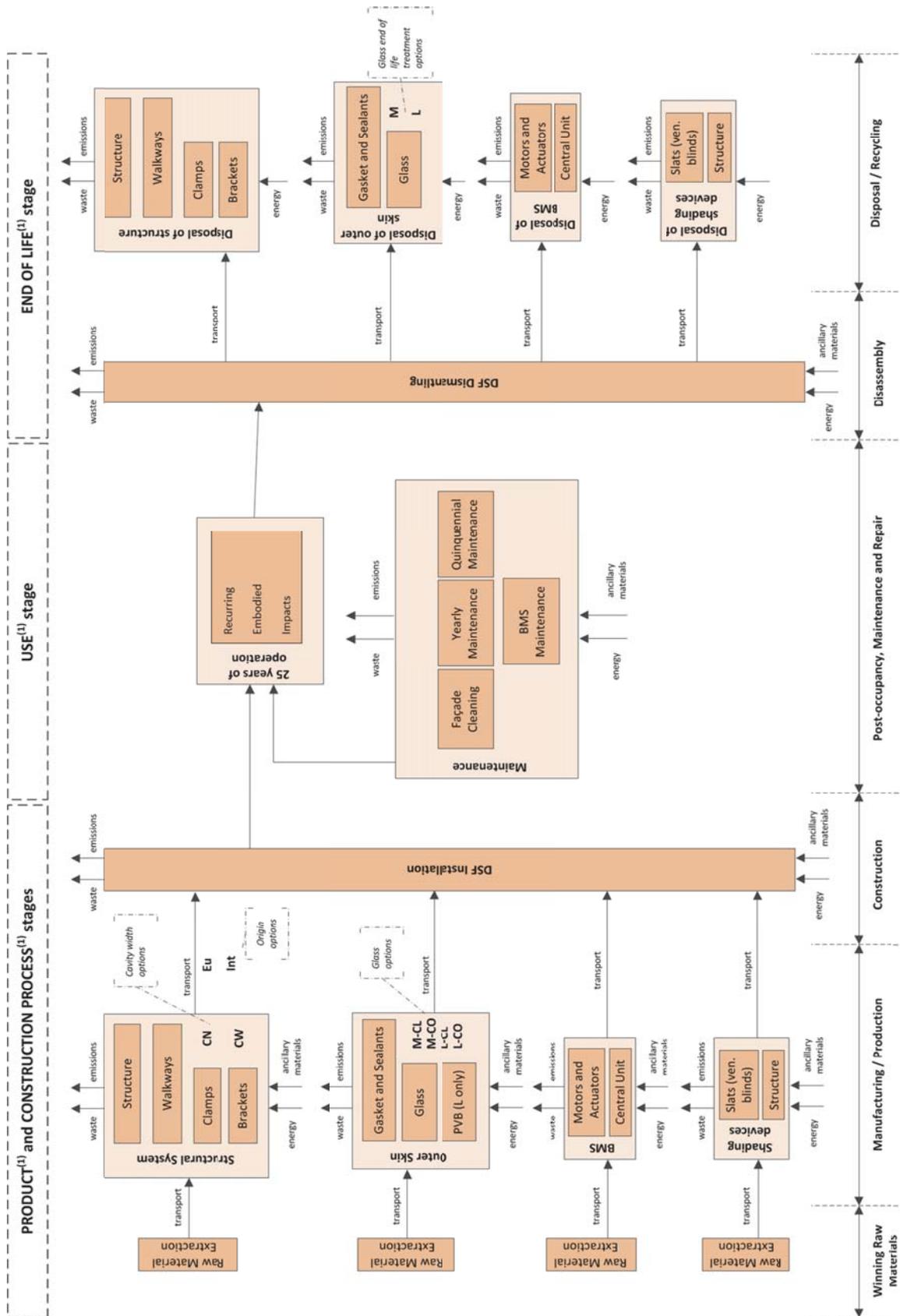
<b>Inventory (Bill of Materials)</b>			
<b>Quantity</b>	<b>Description</b>	<b>Total</b>	<b>Unit</b>
3	clamps (actual product Art. No.*)	8.1	kg
3.5	m profile (actual product Art. No.*)	19.25	kg
1.5	m <sup>2</sup> of aluminium for walkways* (wide option)	12.447	kg
0.6	m <sup>2</sup> of aluminium for walkways* (narrow option)	4.979	kg
0.0011	m <sup>3</sup> of steel for bracket* (wide option)	8.855	kg
0.00484	m <sup>3</sup> of steel for walkways casing* (wide option)	38.962	kg
0.0005	m <sup>3</sup> of steel for bracket* (narrow option)	4.025	kg
0.00354	m <sup>3</sup> of steel for walkways casing* (narrow option)	29.302	kg
5.25	m <sup>2</sup> of 12 mm thermally toughened glass (monolithic option)	157.5	kg
10.5	m <sup>2</sup> of 8 mm glass (laminated option)	210	kg
1.52	mm of plastic layer (laminated option)	3.96	kg
5	m of structural sealant	0.515	kg
5	m of PVC sealing gasket	0.3475	kg

\* = sensitive information related to manufacturer/data provider

**Tab. 1** details the first-level inventory for the FU. Second, third, etc. levels such as the processing to cut-to-measure the glass panes, their tempering, the processing on the aluminium profile or zinc coating of the brackets are not shown in the table to avoid data overload, but they have all been considered in the analysis. DSFs are defined by several parameters, including the geometry of the cavity and its width. The configuration chosen here is multi-story, consisting of a cavity with no horizontal or vertical partitions. Regarding cavity width, narrow and wide categories are widely acknowledged and both are considered. Geometry of the building, data collected from visits to construction glass manufacturing facilities, interviews with a leading façade engineering and manufacturing company, and the construction specifications, all helped choose the parameters, leading to the options in **Tab. 2**. The flowchart for the system boundaries of the assessment are instead shown in **Fig. 2**.

**Tab. 2** Realised and assessed options

<b>Parameter</b>	<b>Options assessed</b>	<b>Code(s)</b>	<b>No.</b>	<b>Details</b>
Cavity	Narrow	CN	2	40 cm cavity width
	Wide	CW		100 cm cavity width
Glass composition	Monolithic	M	2	12mm tempered
	Laminated	L		8mm+8mm+1.52mmPVB laminated
Glass coating	Clear	CL	2	Clear glazing system
	Coated	CO		Solar control glazing system
Structure Manufacture	Central Europe	Eu	2	Lorry Euro 4 – 500 km
	China	Int		Oceanic Ship – 20070 km /Train – 140 km/Lorry Euro 4 – 120 km



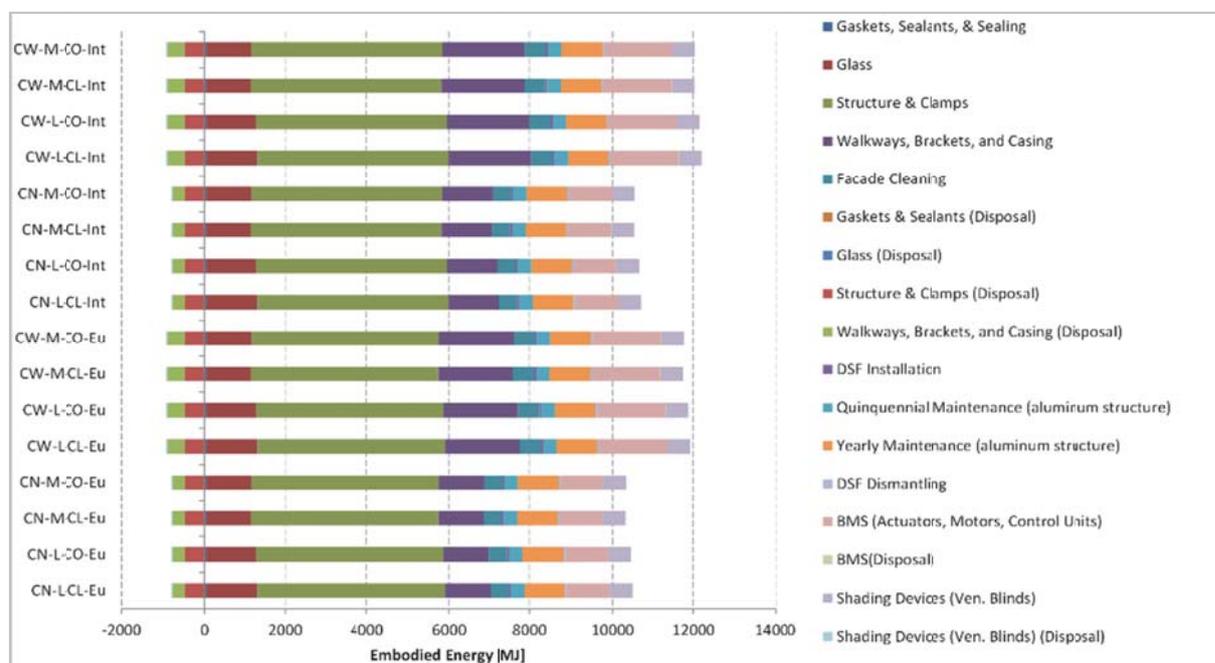
<sup>(1)</sup> Terminology from current European standards for the assessment of environmental performance of buildings (BS EN 15978:2011)

Fig. 2 Flowchart for the system boundaries considered in the assessment

Data collection has been approached systematically starting from the macro-assemblies in **Fig. 2** through a process-based analysis that refers to a mix of processes, products, and location-specific data to calculate and establish the environmental impact of a product system. In LCAs of buildings and their components a process-based approach appears to be the most reasonable and detailed choice [16]; it is also suggested by the TC350 standards. As explained, embodied energy has been calculated through the Cumulative Energy Demand (CED) calculation method, whereas Embodied carbon is based on the GWP over 100 years method developed by the Intergovernmental Panel on Climate Change (IPCC).

### 3 Results and discussion

**Fig. 3** and **Fig. 4** show respectively embodied energy and embodied carbon results for the assessed scenarios.



**Fig. 3** Embodied Energy Results

Results in **Fig. 3** and **Fig. 4** are given for each of the 16 unique combinations of DSF parameters that have been considered (**Tab. 2**). Embodied energy results are in the range of 9513–11271 MJ/FU which translates into 1812–2147 MJ/m<sup>2</sup> of façade. Embodied energy results are in line with the only existing figures on the EE of DSFs found in the literature, i.e. 2120 MJ/m<sup>2</sup> [8] and 2273.08 MJ/m<sup>2</sup> [9].

Similarly, embodied carbon results range from 1463–2063 kgCO<sub>2e</sub>/FU which correspond to 278–393 kgCO<sub>2e</sub>/m<sup>2</sup> when normalised to the area unit of the façade. Comparatively, embodied carbon values found in this research are significantly higher than the only EC value available in literature for DSFs, which is 178.64 kgCO<sub>2e</sub>/m<sup>2</sup> [9]. A possible reason for such a big difference between the two figures lies in the significant amount of primary data collected from manufacturers for this study, which allowed the assessment of embodied figures with less uncertainty and fewer assumptions.

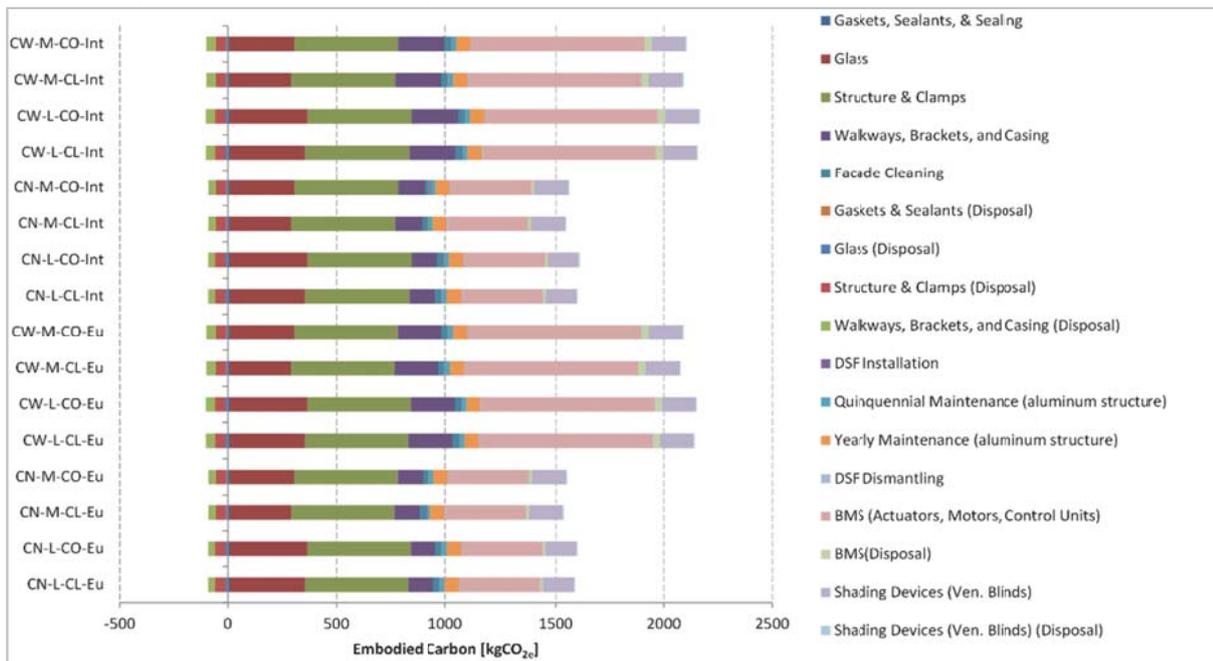


Fig. 4 Embodied Carbon Results

Due to the scarcity of existing studies on DSFs, an attempt was made at a comparison of embodied carbon figures with LCAs of curtain-wall façades, which have some commonalities in terms of materials and processes. The lower bound of the EC range is reasonably in line with one of the existing studies on curtain-wall systems undertaken by Kim [17] who reported values in the range of 255–269 kgCO<sub>2e</sub>/m<sup>2</sup>. However, another study by Taborianski and Prado [18] found much lower EC values, in the range of 97–122 kgCO<sub>2e</sub>/m<sup>2</sup>. Anyhow, even the upper bound of the range reported by Kim [17] is nearly 50% lower than the maximum embodied carbon found in this research. These discrepancies show how important it is to have reliable and good quality data to conduct an assessment. Indeed, if we were to use available figures in existing literature the embodied carbon values would have been greatly underestimated.

Once embodied impacts are known, it is possible to calculate pay back periods (PBP) for both embodied energy and embodied carbon of the 16 configurations examined. To do so, operational energy savings – and consequently carbon – must be evaluated first. As a reference it can be assumed a consumption of 120 kWh/m<sup>2</sup><sub>TFA</sub> for single skin office buildings, which represents a suitable benchmark figure for heating loads [1, 19]. Considering the 33% reduction mentioned before due to the use of DSFs, the heating load of a DSF building would turn out at 80.4 kWh/m<sup>2</sup><sub>TFA</sub>. This allows to calculate the total energy saved over the 25-year service life and compare it with the embodied energy figures. For what concerns carbon PBP, the energy savings must first be converted into CO<sub>2e</sub> savings. A very conservative GHG conversion factors for Europe is 0.184 kgCO<sub>2e</sub> for each kWh<sub>GAS</sub> [20]. In terms of end-of-life scenario, it has been used the waste scenario for England available in the EcoInvent database with figures developed by the Department for Environment, Food & Rural Affairs (DEFRA).

Results of the PBPs for both embodied energy and embodied carbon are presented in **Tab. 3**, where values have been rounded up.

**Tab. 3** *PBPs for both embodied energy and embodied carbon*

	<b>EE PBP [years]</b>	<b>EC PBP [years]</b>
CN-L-CL-Eu	2.5	7.7
CN-L-CO-Eu	2.5	7.8
CN-M-CL-Eu	2.5	7.4
CN-M-CO-Eu	2.5	7.5
CW-L-CL-Eu	2.9	10.4
CW-L-CO-Eu	2.8	10.5
CW-M-CL-Eu	2.8	10.1
CW-M-CO-Eu	2.8	10.2
CN-L-CL-Int	2.6	7.8
CN-L-CO-Int	2.6	7.8
CN-M-CL-Int	2.5	7.5
CN-M-CO-Int	2.5	7.5
CW-L-CL-Int	2.9	10.5
CW-L-CO-Int	2.9	10.5
CW-M-CL-Int	2.9	10.2
CW-M-CO-Int	2.9	10.2

It can be seen that although very different from one another both embodied energy and embodied carbon are amply paid back within the 25 years of service life of the façade. For embodied energy, PBPs vary between two and a half and nearly three years, whereas for embodied carbon between seven and a half and ten and a half years. This means that, in the worst cases, the DSF pays back its embodied carbon in 10 years and 6 months, a time after which it continues to save carbon for nearly 15 more years with an evident beneficial effect on GHG emissions in comparison to a single skin façade.

## **4 Conclusions**

Most European non-domestic buildings are in need of refurbishments and Double Skin Façade (DSF) technologies represent an interesting and versatile approach to address their renovation.

This study has shown, through a detailed life cycle assessment, that the DSF configurations examined perform better than a traditional single skin approach for the refurbishment of non-domestic buildings. The combined use of life cycle energy and carbon assessments not only showed how significant the energy reduction potential is but also how important is to consider the carbon density of the energy carrier. Indeed, when the focus switches to carbon, thus taking into account the specific type of energy that is being saved, PBPs become three times as great although they remain safely below the assumed façade service life. Results have also shown how significant the impacts of different assemblies and processes are and this represent an interesting outcome. By focussing on those processes and assemblies it is possible to further reduce DSF's embodied energy and carbon. The assessment of one specific building model and structure can be seen as limitations of this study and as such they surely represent important and interesting future avenues of research. Additionally, LCA should be coupled with life cycle costing (LCC) to assess the financial viability of DSFs as a refurbishment option in Europe and this aspect is also surely worth of further investigation.

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