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Eco-design/Sustainable Product Development principles - Analysis and application on industry

Panagiotis Stefanidis

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Student Name: Panagiotis Stefanidis

SID: 1106170026

Supervisor: Prof. Dimitris Karalekas

I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

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Abstract

This dissertation was written as part of the MSc in Strategic Product Design at the International Hellenic University and the selected field of review was selected due to the increasing debate about sustainability.

Elevators industry is a supplier for the buildings construction sector, which is becoming more and more concerned about environmental issues with the course of time. Taller buildings, increasing population in urban metropolitan areas and crowded public places make the design of a sustainable, eco-friendly lift and at the same time capable to service buildings with high traffic to seem as a great challenge and a great opportunity for the related companies to innovate and acquire competitive advantage with. That is also the main purpose of the current dissertation, to review some related issues, some practices already being followed by lifts organizations, which have brought considerable improvements and also present some thoughts and ideas that would further favor a sustainability approach in lifts industry.

At this moment I would like to thank Professor Dimitrios Karalekas who apart from supervising me and coaching me throughout this effort, he was the one who gave me the idea to work on this interesting topic. Moreover, I would like to thank my wife, my family and my friends who supported me during the challenge of conducting this dissertation. Last but not least, I feel very grateful for company Kleemann S.A., which provided me with much useful information and specially Dr. Ioanna Sfampa the Innovation Researcher of the company, Mr. Dimitris Kominis – R&D Cabins Team Leader and Mr. Theodoros Kokovidis – Cabins Engineering Department, for giving me necessary guidance.

Keywords: Elevators, Eco-Design, Sustainable Product Development

Panagiotis Stefanidis

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Contents

Introduction

Resulting initially from the increase of the world's total population over the decades and thus the subsequent increase of consumption of products and services, the need to design the production and the service sector in accordance with sustainability principles is becoming more and more imperative. So much debate has already been made regarding the depletion of the world's resources reservoir, the impact of gases emissions and the waste of the everyday human activity, that nowadays is considered as the best momentum to let all this scientific knowledge be the base for a holistic redesign of the activities, which are considered to be more harmful for the environment and thus are going to be exponentially more harmful in the future. Population rises, the urban area able to host him is limited and thus becomes denser, so there is a trend towards vertical instead of lateral building. This fact implies the big importance and potential to design eco-friendly future elevators.

At the beginning, some first thoughts combined with a literature review are presented. The reader is introduced into the notion of eco-design, the companies' perception towards sustainability strategies, what the barriers are that prevent the organizations from integrating eco-design principles into their processes, what kind of mechanisms exist, in order to promote the adoption of such practices and which short and long term initiatives could be given to the corporations, in order to accelerate the transition to sustainable product development. Afterwards, the review becomes more specific and presents the elevators industry. There is an argumentation about the importance to construct sustainable buildings, which are serviced by eco-designed elevators and why this practice has a great potential to contribute to a more sustainable world. Also, there is a literature review about some materials that are widely used in the sector, which are considered bad for the environment. Before going further to the case study, there is a benchmarking session, where the main elevators companies are presented and there is an overview of what kind of practices they have already adopted, in order to acquire competitive advantage through innovating and through the development of green products. Next, there is the main part of the current thesis, where some solutions are presented which could have a positive environmental impact and finally there is a simulation of a lifts cabin in Solidworks. A typical cabin is modeled and some improvement scenarios are discussed. Finally, the concluding ideas of the text are presented, followed by some thoughts for future elaboration.

1. Literature Review

The literature signifies the importance to integrate the eco design principles from the very beginning of the product development process [1]. In these early stages the designers have freedom to experiment between various concepts and given that they are equipped with the necessary tools, they can decide which concept is eco-friendlier. Moreover, when creating a sustainable product, the whole development procedure should take into consideration all the life cycle phases, from the raw materials selection till the product's end of life disposal [2]. There is also sometimes some misconception among the companies that following a Sustainable Product Development results solely from the need to protect the environment or to promote an eco-friendly profile to the market. That is however not true, because when a company adjusts all its processes according to sustainability principles, then it will become easier to innovate, to gain competitive advantage among the competitors and hence to enjoy positive financial outcomes [3]. Much discussion has also been made about the barriers that an effort towards Sustainable Design often encounters, pointing out that although there are many tools in the hands of the designers, these are not always incorporating all the sustainability dimensions or the data used might be of bad quality, leading to unreliable results. Also, the product development being an interdisciplinary process, it should be supported by tools that consider all the company's departments being involved into it [4].

1.1. Eco-design drivers

Seeking the definition of eco-design, we find out that there are various terms that are used to express the base similar notion, like *Sustainable Design, Eco-Design, Design for Environment (DfE)* etc. A comprehensive definition for all the above terms would be: The design of products under systematic consideration of design performance with respect to environmental, health, safety and sustainability objectives over the full product and process life-cycle [5]. The sustainability feature is crucial, as it designates the importance of designing a product, which satisfies some particular needs-requirements of a target group, without however burdening the fulfillment of the future generation needs.

It is widely well-known that the economic activities of our generation are material and energy intense and given that the earth population is constantly increasing, the required processes input is going to follow an upward trend for the years to come. The sustainability issues and the environmental impacts behind the intense human activity has been studied during the past 2-3 decades more thoroughly, however the stance of the economy operators would be described passive. This means that to a very big extend, whichever effort towards sustainable products has been made, the incentive behind this effort was an environmental regulation that imposed a change in the operation, in order to meet specific objectives by the end of a deadline. Also, a common trend since the beginning of 21st century has been the labeling of the product or service as green, meaning that the companies followed specific procedures that were defined in detail by certifying organizations, in order to get this label and use it for marketing purposes. These actions certainly steer the companies towards the sustainability direction, since they mitigate some of the factors that could have a negative environmental impact, but are not enough to make us hope for a sustainable future.

As it happens in human beings, the organizations tend to remain in a 'business as usual' state, if no reason for a change exists. As soon as their operations are successfully being executed and their products/services are delivered on time to the customers keeping them satisfied, there is no need to invest money to make changes. So the most important driver that would force the companies to alter their processes and products in an eco-efficient manner is creating a framework, which would be based upon existing regulations, but would create clear incentives for the companies to invest in their sustainable future. Trying to comply with regulations and implement what studies elaborate on, about the harmful human activities, the subsequent waste and emissions and the huge amounts of materials and energy used, is not a direct and short term incentive for the shareholders to fund a process reengineering.

Consequently, the aforementioned framework should consist of two types of incentives. The ones that may influence the short term performance of the corporation and the ones affecting the long term company's operations, which are considered the strategic ones. The former consist mostly of tangible drivers, meaning mainly the economic benefits for the shareholders. These include the reduction of the energy consumption and materials costs through a sustainable reengineering of the processes. Also the differentiation among its competitors could give the corporation a more instant access into the market, because the simplification of the product development reduces the time –to –market of a product and therefore contributes to making a quick market intrusion, leading to business growth. Another short term initiative could be the strict regulations, which if the companies are not conformed to, could impose penalties and therefore would increase the costs.

However, the biggest driver towards Design for Environment tactics is the acquisition of long term value, which should be regarded as the only way to survive in the future. The long term value is mainly connected to intangible benefits, as analyzed in the next lines. The first and very important is the added value on the brand equity. This factor is considered of big importance and weighs a lot in the mix of the total shareholders' assets. It depicts the reputation of the firm globally and can of course affect the market share, the synergies and networking between the company and the various stakeholders (employees, suppliers, NGOs, regulators etc.). In addition, there is a long term benefit for the organization's human capital, both for the managerial positions and for the other employees. By following strategic DfE the Management acquires corresponding skills, such as being proactive and able to make strategic decisions, becomes more sensitive about the company's sustainability and adopts transparent disclosure methods. The employees become more devoted towards the fulfillment of the main strategic target, they improve also themselves in terms of hard and soft skills and the company is considered as a magnet for new graduate talents to come on board. This fact can build strong relationships with universities and as a further benefit could be the formation of consortiums between academics and the companies, in order to promote innovation and help R&D operations. As an output of the R&Ds innovation activities, the technology and the knowhow will remain up to date in the future. A very efficient trigger point for DfE may be also the so called sustainable financing, which means that the organizations could be rated according to their sustainability strategies and depending on this criterion they could gain access to funds, in order to finance their future operations (5).

1.2. Eco-design in Elevators sector

Elevators is the means for vertical transportation between the buildings floors. Over the last century there has been a huge population migration from countryside to the urban areas, which has caused the rapid expansion of the cities. In most cases, due to lack of sufficient area, the construction of buildings of 2-3 floors up to skyscrapers is favored, in order to be able to accommodate dense populations, expanding the cities vertically. Consequently, the elevators market has thrived in these areas over these years, with the trend being always upcoming specially in the developing countries like Brazil, India, China etc. Therefore, the call for eco-friendly lifts is more imperative than ever before.

Elaborating further on this, since the beginning of 1990s' there have been discussions about the climate change and specifically the increase of the earth's average temperature due to human activities and namely because of the greenhouse gases emissions. The Kyoto Protocol and the Paris Agreement both deal with the mitigation of the greenhouse emissions. The building sector, including the operation of the lifts, account for about 40% of the total contribution to the global warming [6]. As such there are some European directives with the scope of mitigating the environmental impact of the building sector. For example, there is the Energy Performance of Buildings Directive 2010/31/EU (EPBD), which gives guidance towards buildings with better environmental performance, however it does not include the eco design of lifts. Furthermore, there is the Directive 2009/125/EC (ErP directive), which deals with the sustainability of energy related products. Although the products list is updated every three years, with new entries being assessed, lifts have not yet been included [6]. There are also some buildings rating systems, like BREEAM in the UK, which consider among others the energy performance of the lifts, in order to give a rating to a building under study. They do not consider though the life cycle impact of them. Finally, a good effort to depict the environmental impact of the whole life-cycle is the Environmental Product Declaration (EPD), a document issued by the International EPD system [7]. However, it is acquired voluntarily, so two different alternative products cannot be compared based on that, as the one not accompanied with EPD might be eco-friendlier.

Based on the LCA analysis performed for KONE Corporation and published in 2002 [8], the materials inventory consisted mainly of metals (~93%), with the rest 7% being complemented by plastics, rubber, glass and others. This case study was a traction lift, serving a 5 floor residential building, with a speed of 1m/sec and a rated load of 630kg. Taking into account all the life-cycle stages, it was found that about 81% of the environmental impact results from the use phase, while 11% from the raw materials production and about 8% from the manufacturing process. Therefore, an efficient assessmentwould suggest, that in order to redesign the elevator in an ecofriendly way, much effort should be given on mitigating the energy use during its operation.

Several components in the lifts industry are made of steel, a material with high recyclability, machinability and which offers exquisite mechanical properties. Some of these components are cabin and landing doors, some interior cabin materials like cabin walls, handrail and ceiling, the floor platform etc. Steel without any kind of coating's protection is though susceptible to corrosion due to its iron content, which oxidizes in contact with the atmospheric air and rust is created. There are several coating methods to make steel corrosion resistant, by providing it with a coating layer. Let us take a closer look in some of them, to review how they work and what is the environmental aspect of them:

- Galvanized steel
- Painted steel
- Stainless steel

1.2.1. Galvanized VS painted steel

The most common galvanizing method is the Hot-dip galvanizing. At the beginning of the process, the steel part passes through some cleaning baths, in order to get prepared for the galvanizing bath. The latter is a kettle containing about 98% molten zinc at around 450ºC.

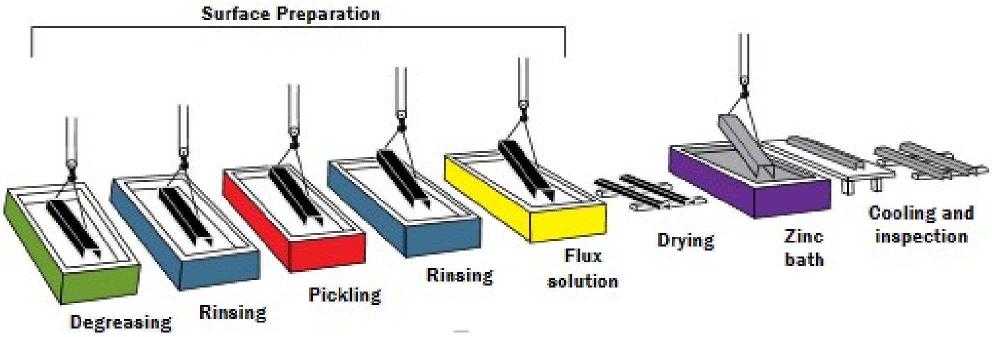


Figure 1: Hot-dip galvanizing galvanizing process (25)

While immersed into the molten zinc the iron content of steel forms metallurgical bonds with zinc, creating a multi-layer coating of Zinc-Iron alloy and an external pure zinc coating. The intermetallic layering, which is strongly bonded with the steel substrate, acts like a barrier between atmosphere and steel and protects it from corrosion. It is also abrasion-resistant, because the hardness of the zinc-iron layer is bigger that the steel's. Apart from a physical barrier, the zinc coating offers a cathodic protection, meaning that it reacts with atmosphere's oxygen and carbon dioxide to form zinc carbonate, thus playing a sacrificial role for the protection of steel.

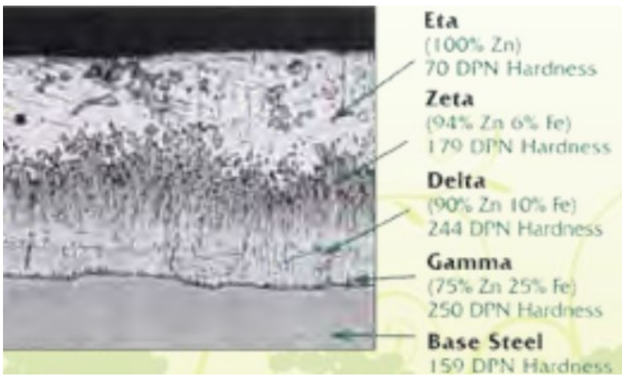


Figure 2: Intermetallic layer creation through Hot dip galvanizing (25)

This kind of corrosion protection offers many benefits. As mentioned above, there are several parameters that make this kind of coating of high quality, namely it is strongly bonded to the steel underneath and with an abrasion-resistant surface. Moreover, as the steel part is fully dipped into the bath, even the internal and the hollow surfaces are zinc coated. Another quality indicator is the layer thickness on edges and corners, which is equal to that of the flat surfaces.

From an environmental and resource efficiency point of view, the inputs are the steel parts, zinc, various chemicals which are used as cleaning agents, such as hydrochloric acid and water. Water use is relatively small in relation to other coating techniques and is usually recycled and reused. The two main materials zinc and steel enter the process from various streams. Steel is the most recycled construction material with almost 40% of the world steel production deriving from steel scrap. Already galvanized steel components that are discharged, can go back to the plant, get re-galvanized and be reused. Moreover, galvanized products can enter also the steel scrap stream, be processed through the Electric Arc Furnace, where the zinc content volatilizes and can enter the zinc stream. Zinc, except for zinc ores of course, can also be acquired from zinc-made used parts like gutters and from the galvanizing process itself. During the latter there is zinc ash and dross accumulated at the bottom of the kettle, which can be collected and brought back to the beginning. Regarding the energy use, it depends mainly on the heat consumed for keeping the molten zinc in the proper temperature, regularly deriving from natural gas and in fewer cases from electricity. In respect of the by-products of each process stage, during the cleaning preparation there are water vapor, acid fumes which are captured and spent acids/liquids which are reused. During galvanizing in the zinc kettle, some particulate emissions are filtered before released to the atmosphere, while generated zinc ash and dross enters the zing stream as presented above.

Apart from the recycling loops mentioned above and which are included in the galvanizing's plant processes, the sector has improved also the energy efficiency of its operation, mainly through improving the efficiency of natural gas burners and through exploiting wasted heat by using it in the preparation phase baths.

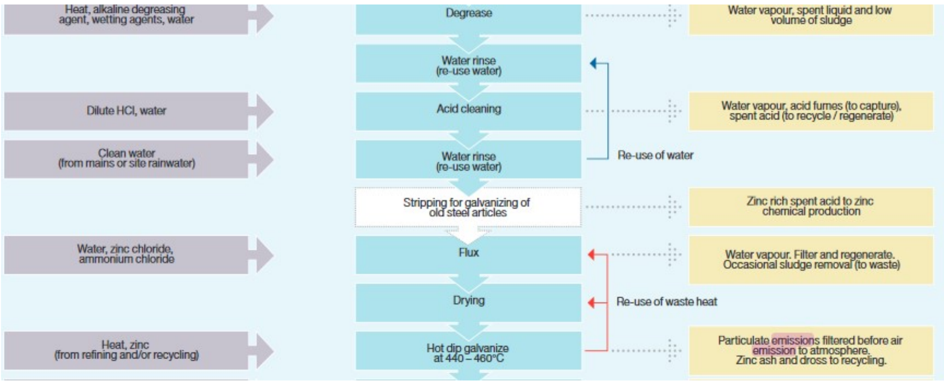


Figure 3: Inputs, emissions, wastes and recycling flows of galvanizing process (27)

More detailed facts about the life cycle behavior of various corrosion protective coatings can be retrieved from numerous case studies. A famous one, comparing the galvanizing zinc and the painting coating is the study for a balcony system called Product Balcony Structure. This assessment was carried out in April 2004, by VTT Technical Research Centre of Finland for the International Zinc Association (25). The corrosion rate of various coatings depends to a huge extend on the environmental conditions. In this study, assuming the Finnish environment as the baseline, the corrosion rate of a galvanized part is 0.5-1μm/year, meaning that a 100μm zinc alloyed coating would have a 60-year life cycle without the need for maintenance. The other corrosion protective coatings that were assessed is the standard painting layer of zinc-rich epoxy (40μm DFT[1])/epoxy primer (2x80μm DFT)/polyurethane (40μm DFT) and a water borne low VOC paint system. Under the convention that a paint coating requires maintenance re-painting every 15 years more or less and assuming that the maintenance painting has the same quality like the initial one, the following results have been extracted. It is evident that the choice of the coating significantly affects the life cycle environmental result, presenting the galvanizing method as eco-friendlier than painting, regarding each

[1] Dry film thickness (DFT) is the thickness of a coating as measured above the substrate. This can consist of a single layer or multiple layers. DFT is measured for cured coatings (after the coating dries) (sourced from www.corrosionpedia.com (26)

individual impact category. Much of this result is attributed to the longevity of galvanized steel, with a life time of +60 years without the need of any maintenance.

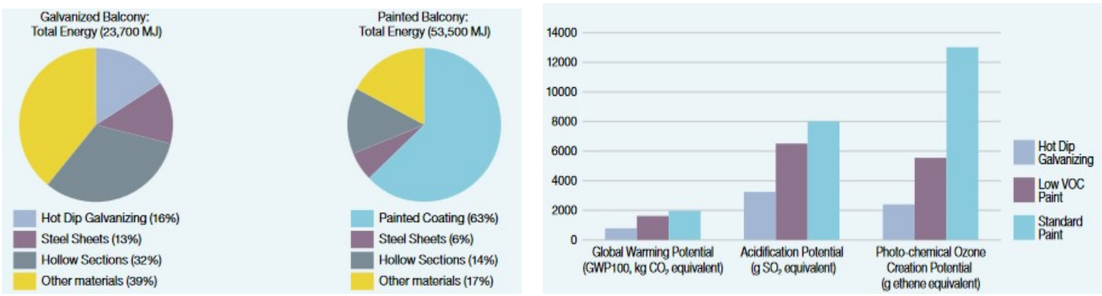


Figure 4: Life cycle energy demand and environmental categories impact between galvanizing and painting coating (25)

Table 1: Comparison Galvanizing VS Painting (Source: American Galvanizers Assosiation YouTube channel)

	HOT-DIP GALVANIZING	PAINT
Life Cycle Cost	Initial Cost Only	Initial Cost + Maintenance Costs
Barrier & Cathodic Corrosion Protection	Yes	No
Bond Strength to Steel	~3600 psi	~400 psi
Abrasion Resistant	Yes	No
Edge & Corner Protection	Yes	No
Int. & Ext. Coating Coverage on Hollow Structures	Yes	No
100% Recyclable	Yes	No

1.2.2. Galvanized VS Stainless steel

An also very widely used method for protecting steel against oxidation is Stainless Steel or INOX. It is a typical material found in many applications like construction, cookware, electrical appliances etc., offering protection also in regions near the sea, where the air composition is saltier. Stainless steel credits its corrosion resistance to the chromium content, which is added into the molten steel at a percentage above 10%. Increasing this proportion and adding also some nickel can add up more on its protection against corrosion.

In general, st/st is stronger than galvanized steel, which is more ductile and easier to work with. However, the latter cannot sufficiently withstand salty marine environments.

Regarding the cost, galvanized steel is much cheaper than its counterpart and can be found at one quarter or one fifth the price of stainless steel. In terms of eco-friendliness, it is as sustainable as galvanized, service also for a long life time with high durability, no need for maintenance and with a high scrap value, when it fulfills its operation. It is fully recyclable and due to the fact that consists of metals with big demand, it has also high reclamation rate (28).

Trying to reach a conclusion about which method is more sustainable between galvanizing, stainless steel and painting, the former two are for sure regarded as the main competitors. Painting, although it serves its purpose during the first usage years, it starts decaying after 5-10 years, requiring maintenance and overall painting after more years. Also, when the product reaches the end of its life, the paint material is not recyclable. All these facts rate painting as not a sustainable option for a long term use. Regarding the first two options, both offer a long term corrosion protection, leaving high valued products at the end of their life, with big recyclability and reclamation rates. Therefore, one has to examine other parameters, when a selection between these two has to be made, like cost effectiveness, robustness and appearance.

1.2.3. MDF (Middle Density Fiberboard)

Medium Density Fiberboard is an engineered product of the wood panel industry like particleboard and OSB (Oriented Standard Board). It consists of about 80-85% of hardwood and softwood chips, around 10% formaldehyde resin and 5-10% water and paraffin wax. During the production process, the wood is sheared to fibers, then mixed with the adhesive agents which are the resin and the wax, together with water. Afterwards, temperature and pressure is applied on this mix, in order to form the final product, a dense wooden plate. Its advantageous properties make it ideal for use in furniture manufacturing and also in the construction sector. It is cheap, strong enough to withstand pressure and strains, yet quite formable enough.

However, there are nowadays some challenges that have to be tackled by the wooden plate sector, the right handling of which is critical to all three sustainability aspects of the product, that is sustainability, economic, social and environmental. Firstly, during the last years the use of wood biomass for energy production has increased, creating concerns about a possible shortage of raw material for the MDF industry. Some alternatives, such as straw, miscanthus and rice husk, are still at the testing phase with many being skeptical about whether the logistics of these crops would be sufficient to cover the demands of the wood panel sector. An additional challenge is to efficiently adopt MDF recycling, a technology that is still not mature, allowing tones of MDF material to end up to landfills. The issue with recycling lies on the fact that separating the wood fibers from the adhesives is not an easy task.

During the early 2000s a collaboration initiative was formed by Bio-Composites Center, the UK's Furniture Industry Research Association (FIRA) and C-Tech Innovation (29). This very first attempt to harvest the value of waste MDF panels was made using the microwaves technology, with a process names Micro-Release. The microwaves release the wood fibers from the adhesives and recover it for reuse. This technology is not yet commercialized and its development has been paused in 2008 due to market pressure.

However, the utilization of wood resources for energy generation has been increasing and this fact created a supply shortage for the wood panels sector. Moreover, the cost for some furniture companies to send waste MDF to landfill was sometimes close to 10% of their turnover. Consequently, the incentive to invest money for the sake of MDF recycling technologies became even bigger and led to the foundation of MDF Recovery Ltd company, whose main purpose was to develop and commercialize MDF recycling technology. With the help of its partner C-Tech Innovation, they worked on developing ohmic heating technology for MDF recovery. The notion behind is to shred the MDF panel into little pieces-chips, then soak them in water and let electric current pass through the soaked bulk. Due to the embodied resistance, the electricity causes the temperature to rise up to almost 100^{o}C and the resin bonds break, releasing the MDF fibers and making them available for recovery and reuse in newly manufactured panels (29).

Except for the economic sustainability issues that the increased use of wood products for energy generation imposed, there are also concerns about how social sustainable the wood panels are and in particular the MDF panels, studied in this section. These discussions have arisen since the 1970s', when the energy crisis happened and the indoor air quality was questioned. It was noticed that in many houses with MDF panels used in furniture, there were increased amounts of formaldehyde emissions. As already aforementioned the usual binding agent used in MDF and in other composite wood panels is formaldehyde resins and most of the times urea based formaldehyde. This is a polymer substance found also in other adhesives, like some glues, which low cost, effective use in the manufacturing process and provides good adhesion to the wood fibers for indoor environments. The skepticism appears due to the fact that the bonds between urea and formaldehyde are such that allow a portion of the latter to be emitted to the air. Research on the consequences of formaldehyde inhalation by humans have shown that if the exposure is prolonged and the emission levels are high, it may cause respiratory problems, eyes irritation and in a long term scale even cancer. The last fact has been also acknowledged by the International Agency for Research on Cancer (IARC) a body belonging to WHO, that has characterized formaldehyde as a possible carcinogenic, however the research is not finished yet (30).

European Union, North America, Japan and some other countries have imposed strict thresholds on formaldehyde emission levels of the wood panels produced in their territories. In EU for example, there are three classifications E0, E1 and E2 that correspond to formaldehyde content of <3 mg/100 g of glue, <9/100 g of glue and <30 g/100 g of glue, respectively. Some countries like Germany, Austria, Denmark and Sweden have adopted the E1 level as the permitted threshold for the manufactured wood panels and the rest have the E2 classification (31).

All the stakeholders of the wood panels industry argue that if these standards are strictly followed by them, then there is no risk for human exposure to such minimum levels of formaldehyde. In addition, the industry is trying to find more sustainable solution under the pressure of the regulations. There are some other alternatives for example, that could substitute Urea-Formaldehyde resins, in order to eliminate the formaldehyde emissions. For example, there is the PF resin, which uses Phenol instead or Urea. This provides strong adhesion of the wood materials, strong bonds between Phenol and Formaldehyde, thus lowering the risk of the latter to be emitted. These resins are also capable for outer spaces due to water resistance, but not preferred for furniture due to their dark (14). Another option is to add melamine to the resin and make MF resins, which have stronger bonds also. The cost of melamine is though such, that does not make it a sustainable solution to be commercialized at the moment.

1.2.4. Forest Stewardship Council

In relation to the above paragraph and concerning also the whole range of raw materials deriving from forests, either it is wood or composite wood, there is an important aspect of a company's sustainability profile that deals with the wide-spread concerns, whether the products that are made through forest management activities.

The international organization called Forest Stewardship Council was founded in 1993 with the aim of assuring that the worldwide economic activity does not compromise the survival of the forests (32). The main principles on which all the provided certificates are based have to do with all aspects of sustainability, namely environmental, social and economic. More specific, the acquisition of a raw material or a product which originates from forest exploitation must not be the outcome of an activity that:

- Puts at risk the biodiversity, the survival of rare species and leads to the degradation of the forest
- Does not respect the rights of the indigenous populations and their interests. Violates human and worker rights (social aspect)

In order to promote sustainable forest exploitation FSC has authorized third party institutions to release FSC certificates under its principles and its custody. An accredited company which trades forest-originating products or uses wood or composite wood material in its products can improve its eco-friendly profile and market these products with a competitive advantage. Products that are labelled with FSC certificates have the advantage that they are characterized by a tracking method, from the forest till the end user, which ensures that they have been produced through a sustainable forest exploitation activity.

2. Benchmarking of sector's sustainability approach

Table 2: Benchmarking table (10,11,12,13)

Features	KLEEMANN	KONE	ORONA**	OTIS	SCHINDLER	THYSSENKRUPP
ECO PROJECT		SPARCS project	Net0Energy	Way to Green	Not found	Urban Hub, Cooperation with Ecova
EcoProduct series	Atlas RPH R		ORONA 3G X	Gen2 (e.g. Switch battery-powered elevator), SpecECO	Schindler 3300 AP/Schindler 7000 (HRS)	TWIN, ACCEL, MULTI
Followed standard	ISO 14001, ISO 14006, ISO 14025 (EPD), VDI 4707	VDI 4707, ISO 14001	ISO 14006/14001,VDI 4707	VDI 4707 (class A for Gen2 Switch)	VDI 4707*	EPDs for MRLs /ISO 14006 for Walkways/ ISO 14001/ISO 50001
Other features		Carbon fiber ultra rope (Jeddah Tower)		Closed-Loop Door Operator, Water glycol hydraulic fluid for SpecECO, flat belts	Energy Control Option (ECO), Production of Regen Drives	Gear to Gearless upgrades, First company ever retrofitting an existing lift to net-zero
* External consultants make complementary assessments according to ISO 14004, ISO 14043*						
** First company in lift sector to be certified forEcoDesign						

2.1. ORONA

Orona is the first company ever certified for its eco design practices, acquiring the ISO 14006 standard in 2008. Following this assessment, all the product development procedure has been being executed accordingly and the result is the product series Orona 3G X. These models are MRL (Machine Room Less) solutions, with gearless motors, using efficient shaft and cabin lighting and sometimes being accompanied with a Regenerative Drive unit. In regard to the end of product's life cycle, Orona is responsible for the waste material, in order to actually transform it from waste to useful resources. As seen in Table below, some components are directly recycled, while some others undergo some special treatment first. For example, lamps and lighting are sent to specialized companies. The same happens also for electronic board components, which are treated in order to reenter the market as secondary raw materials, so that the most possible embedded value is exploited. The same also for oils which are regenerated under 2008/98/CE. Those materials that cannot be reused/recycled etc. are sent to waste management companies, in order to be disposed through the proper way. Moreover, Orona is certified with ISO 14001 for its facilities in Spain and finally it is member of the Consortium-Project of Net0Energy, which is formed by universities and other corporations of the related sectors (e.g. architectures).

Table 3: Waste management by Orona (Eco Design data brochure by Orona)

Material	Waste / Recycled
Steel, iron and sheet metal	Recycled
Other metals: Cu, Al	
Plastics	
Wood	
Glass	
Oils (HW)	Treatment that leads to recovery, recycling etc.
Lighting (Fluorescents, LEDs) (HW)	
Electronic boards (HW)	
Batteries (HW)	

2.2. OTIS

Otis participates in the Way to Green project, which focuses on executing all its operations in an environmentally better way. They have also developed energy efficient product series, the Gen2 models and the hydraulic lift SpecECO. The innovation of the latter is that instead of using oil as a lifting agent in the elevator cylinder, it is substituted with a Water-Glycol fluid, which is more environmental friendly. The Gen2 model is characterized also by the use of flexible polyurethane coated steel belts, instead of the conventional ropes, which has multiple advantages. They are lighter with bigger life span than ropes and they have a smaller bend angle potential, which favors the use of more compact motors. Also, Otis offers the Closed-Loop Door operator, a technology that makes the operation of the automatic doors less energy consuming and also decreases the amount of required lubricants, as it encompasses compact sealed bearings mechanism.

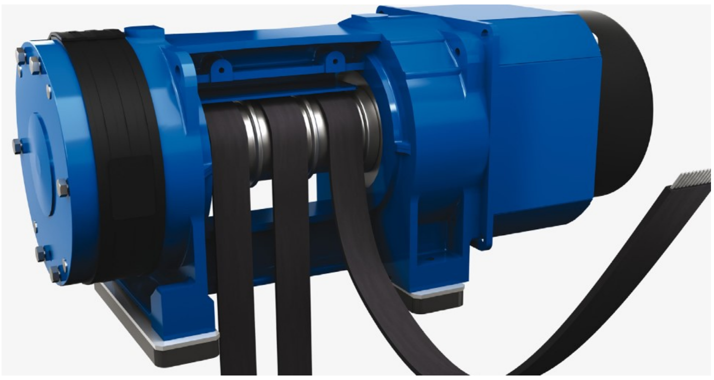


Figure 5 : Polyurethane coated steel belts (Source www.otis.com, accessed on 12/12/20)

Moreover, as a member of the Gen2 series there is the Gen2 Switch lift that operates on single-phase 220V – 50Hz, thus being able to be plugged in like any other electrical appliance. It is also equipped with a battery and a regenerative drive module and when the cabin moves just with the force of gravity, the battery is recharged through the regen. Its battery capacity makes it also fully capable to get connected to renewable energy systems, such as photovoltaics or wind generators. It requires only 500W power to function and is considered to be 75% more efficient than traditional elevators (10).

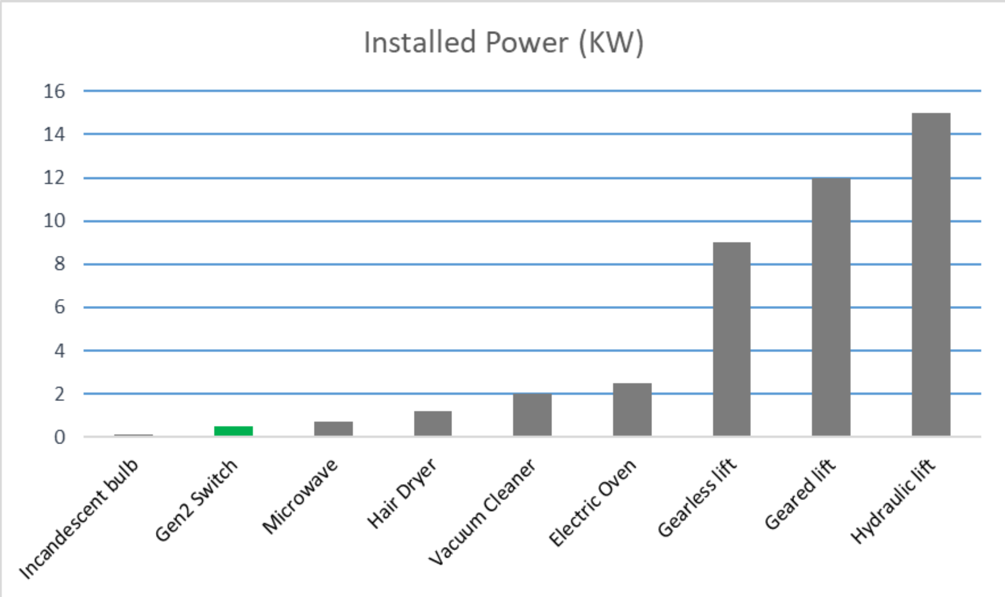


Figure 6 : Operation power for several appliances (19)

As already said the electricity consumption of an elevator during its idle state is not negligible. In an attempt to tackle this problem Otis has developed a sophisticated electronic system, which dispatches the passengers in an efficient way and realizes also the traffic conditions. In cases of very low traffic, when most of the building's elevator stay idle, it deactivates them. This system is called CompassPlus Destination Dispatching.

2.3. KONE

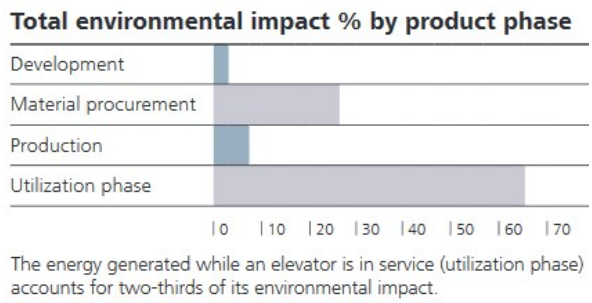
The first to introduce the MRL technology in 1996 saving 70% energy compared to hydraulic lifts. KONE's EcoSpace MRL product uses a gearless low friction machine, which reduces energy consumption for an about 50% in comparison with a geared machine. KONE is aligned with ISO 14001, indicating the importance of getting aligned with environmental management directives and issues also the Publish Environmental Product Declaration that reflects the environmental impact during the whole life cycle of the products. Moreover, in 2019 the company achieved an introduction in the so called CDP's prestigious A List, asserting them as the only elevators company following a strategy towards the climate change mitigation. KONE corporation has initiated strategic partnerships with various stakeholders, having as a common goal to reduce the harmful materials that flow into the value chain and also take the most out of the value of the materials, deriving from its products end-phase.

Regarding the specific products innovation, the company was licensed by its strategic partner Toshiba to introduce the first high rise double-deck elevator for the Broadgate Tower project in London. These elevators are able to travel with a speed of about 10 meters per second, reaching to a 660 meters' height. The advantage of such systems is that they have the capacity to service buildings with high traffic, mitigating the waiting time, because two cabins, one on top of the other, can transfer the passengers up to the desired floors, allocating them accordingly with a destination control system (18). Another innovating technology is the Ultra Rope, a hoisting means for really high rises up to 1km. This is also the roping system used in the Jeddah Tower elevator. The Ultra Rope consists of a carbon fiber core, surrounded by high-fiction coating, which is resistant to wear and does not require lubrication. It weighs 5 times less than the conventional ropes, which means that in a tall building of 100 floors the moving mass can be reduced from about 27tn to 13tn. This in turn induces a significant reduction of the energy consumption, proportional to the rise of the building. For buidings of 500 m and 800 m travel height the energy reduction can reach about 15% and 40%, respectively. Lastly, the company participates strategically into projects that include eco-efficient buildings, thus promoting its environmental sensitivity through these reference eco – projects.

2.4. SCHINDLER

Accordingly, Schindler have deployed the Schindler 3300 AP model and the Schindler 7000 for high raise speeds. The official assessment method is according to VDI 4707 certificate, however it has also made partnerships with external consultants, who conduct LCAs on behalf of them under ISO 14004 and 14043. The contribution to innovation is highlighted by the Energy Control Option (ECO) and the production of Regenerative Drives. Schindler, instead of conventional steel wire ropes, uses in its 3300 series a Suspension Traction Media comprised of 6 surface-coated wire ropes, encased in a light synthetic rubber called EPDM.

Table 4: % Enviromental impact (www.schindler.com)



2.5. THYSSEN KRUPP

Thyssen Krupp has been also trying during the last decades to adopt a sustainable mindset, to acquire environmental certifications and to implement green ISO standards in all its plants. Regarding the latter, the target of the company is to implement the Environmental Management System ISO 14001 at all its plants. By today this has been achieved for 90% of its manufacturing sites. Moreover, TK participates in a global Carbon Disclosure Project CDP, which is a platform where companies from all over the world disclose information regarding their activities in relation to greenhouse gas emissions, water management strategies and protection of the forests. For the year 2020 CDP has recognized the efforts of TK to reduce materials, wastes, carbon footprint etc. by listing it among the top companies in its prestigious A list. In 2017 it was the first elevators company to receive an Environmental Product Declaration for its MRL products. Furthermore, TK has issued a Supplier Code of Conduct, which obliges its partner to follow a series of principles related to all aspects of sustainability, gives the right to TK to perform regular assessments and to request disclosure of relevant information, whereas if a repeated violation of these regulations is noticed, TK reserves the right to cancel the contract. Finally regarding targets for the future, TK aims to reduce GHG emissions by 25% and 50%, by 2030 and 2040 respectively.

2.6. KLEEMANN

Since 2012 Kleemann has been implementing environmental management system for its processes (offices and factories) under the certification ISO 14001. The company is also the first Greek corporation to follow ISO 14006 for its product developing processes, aiming to improve the energy efficiency of its products, reduce the quantity of raw materials, paints and solvents used. Finally, related to the use phase of the lift, the company aspires to the reduction of the total lift weight, in order to mitigate the electricity consumption. Moreover, it follows several assessment and disclosure methods like energy analysis through BREEAM and LEED, energy efficiency studies according to VDI 4707, while it provides Environmental Product Declaration for four products, according to ISO 14025. Concerning the disposal of its products, Kleemann takes over the recycling of its products, if the customer is able to transfer the lift to the manufacturing plant.

3. Eco-design solutions for elevators

As already mentioned, the biggest environmental impact derives from the elevators use phase. It is the electricity needed for the operation of the systems the most important factor that contributes to burdening the environment. Therefore, most of the recommended solutions found in the literature and adopted by various competitors in the industry relate themselves with the efficient use of the lifts, through which the electricity consumption is reduces as much as possible (15).

3.1. MRL Technology

Initially introduced by KONE in the mid-1990s it was a breakthrough advancement in the elevators technology, which induced a great improvement of the lifts energy consumption. Instead of using a machine room above the shaft, which was the conventional approach up till that time, the new solution gave the opportunity to place the hoisting apparatus in the shaft, close to the shaft’s ceiling and right above the guide rails. This, accompanied by the use of a gearless machine, resulted in a reduction of energy consumption of about 70-80% compared to the hydraulic lifts .

3.2. Regenerative Drives

There are occasions during a traction lift's operation, when instead of using electrical energy to move the cabin, energy is generated and dissipated in form of heat. Such is the case when for example a fully loaded cabin is going to move downwards or vice versa a totally empty cabin shall move upwards. In conventional systems this excess energy generation is transferred by the machine to a breaking resistor and released to the environment in the form of heat. Taking into consideration the fact that in many modern buildings of heavy duty the elevators might be numerous or the floors to be serviced might be many, the energy loss is enormous. The solution to this is the regenerative drive, which is an electronic device installed next to the inverter and that in cases of energy generation, it attributes this energy to the building's grid and if stored, it can be used for other purposes like in HVAC systems or for hot water. In addition, this alternative eliminates the need for installing a cooling system for the machine (16).

In the following example, retrieved from a company's brochure, we can notice the difference in terms of energy consumption, between using and not using a regenerative unit. In the first case, the nominal annual electricity consumption is bigger, resulting in an energy class B. If a regen drive is deployed, then a 30% reduction in energy consumption and in the CO_2 emissions is achieved, awarding the elevator with the energy class A according to the certification VDI 4707. However, the first column representing the stand-by power demand indicates that there is a 14% increase due to the use of regen unit. This emphasizes the need to assert each single situation, in order to judge whether such an installation is worth in terms of capital investment and regarding the total energy consumption.

Example

Nominal load: 1600kg
Nominal speed: 1.6 m/sec
Travel height: 25m
Operating days per year:

365

Table 5: Case study with and without Regenerative Drive (Source 17: Ziehl Abegg Bochure)

Use of Regen	Stand-by demand (W)	Spec. travel demand (mWh/kg*m)	Nominal annual demand (KWh)(enegy class)	CO_2 emissions (kg)
Without Regen	73 (class B)	0.78 (class B)	5418 (class B)	3121
With Regen	83 (class B)	0.51 (class A)	3778 (class A)	2176

3.3. Control features

Especially in much populated buildings, it is important to regulate the elevators traffic in such a way that reduces or even eliminates the empty car routes. The main target of these software is the efficient operation of the lifts through the traffic control, the minimize of passengers queuing time and the idling of the systems, when the lift is not in use. Moreover, a very efficient practice is the so-called standby mode, which turns off the electronic equipment that is not necessary, when then lift remains idle for a long time. This brings a significant decrease in energy consumption, because idle hours may be many.

3.4. Use of PVs

Either when the shafts are made of cement or when metallic structured shafts are utilized, one possible solution to mitigate the environmental impact is to provide the lift with electricity deriving from renewable energy sources, e.g. photovoltaics. The shaft could be constructed with an inclined rooftop, so that the required room to store the necessary electrical equipment can be underneath the rooftop. If that is not possible, then the necessary components can be housed in the machine room. If the required electricity per day is more than the amount that the PVs installed power can provide, the supplementary supply of the buildings electrical grid can be used additionally.

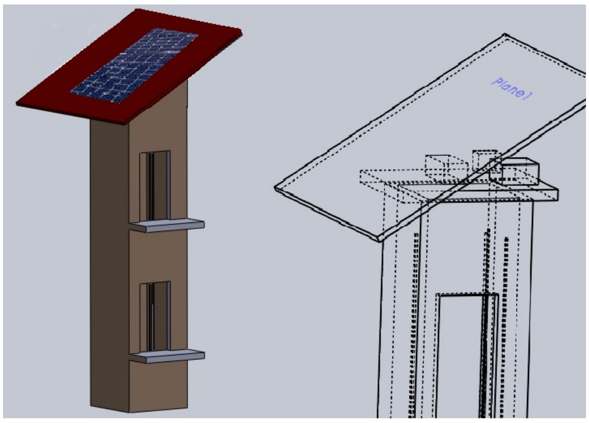


Figure 7 : An illustration of a possible PV system implementaion

3.5. Eco-friendly materials in cabin

As already mentioned, it is more efficient to make design changes during the conceptual phase of the product development. During this phase the information is abstract, not allowing the designer to make precise calculations about the environmental impact that each design concept is going to induce. Therefore, instead of initiating a detailed and time consuming LCA analysis under the instructions of the ISO standards, it would be more proper to use a simplified LCA approach. Of course, this implies the need to make omissions, which in turn makes the final results and reports inappropriate for official external use. However, these results can be of great value for the product development phase. This generic approach can be found in the literature under various terms, like Screening-Level LCA, Conceptual LCA or Simplified LCA (20).

It can be feasible through the Sustainability module of Solidworks CAD Software. This feature enables the designer to evaluate individual design concepts and decisions regarding the materials in real time. Each component of an assembly has to be assigned with a specific material, which is linked with a materials database and manufacturing processes. When all necessary inputs are given, the software calculates the environmental impact of the assembly across its entire life cycle, namely the Materials acquisition, Manufacturing, Transportation, Use and End of life. The impacts of each of these stages are assessed in terms of Carbon Footprint, Energy Consumption, Air Acidification and Water Eutrophication.

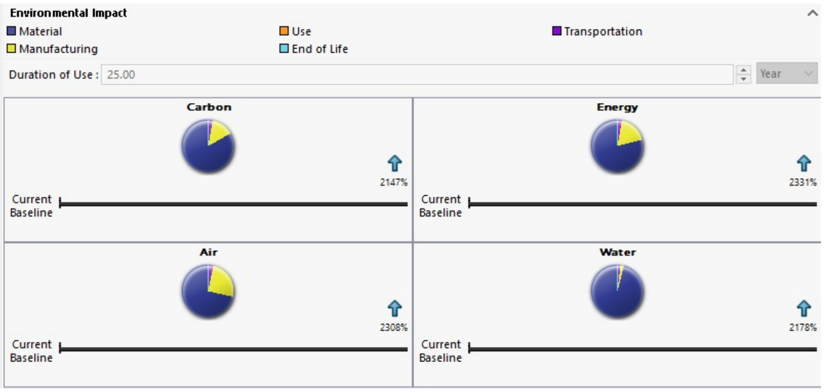


Figure 8: Environmental impacts results in Solidworks

In order to improve these results, the software enables the designer to choose between similar materials, in order to mitigate the burden of a 'hot spot' of the assembly and find the proper material mix with the less impact. Another option, which should be however implemented in connection with the Finite Element Analysis module, enables the designer to lessen the material amount of a component, in case the Factor of Safety advocates such a decision.

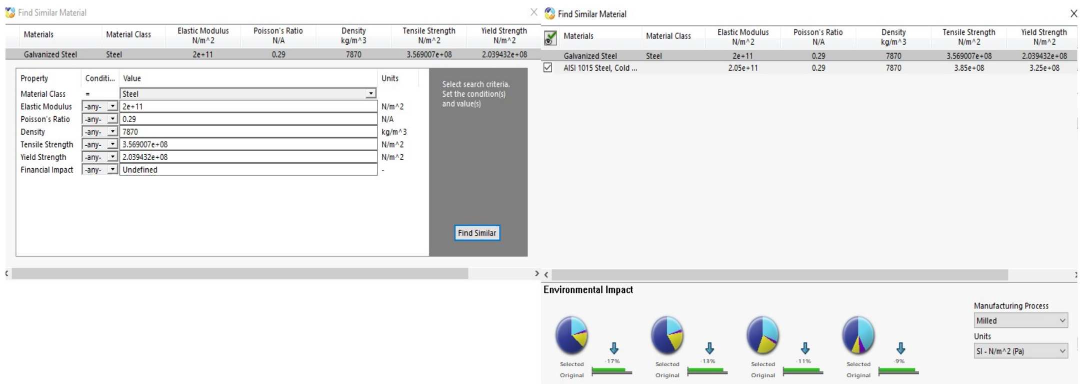


Figure 9: Choosing between alternative materials

Under the scope of this project, one of the most popular cabin types of an elevators company was selected to be modeled in Solidworks, in order to examine how eco-friendly it is and evaluate possible improvement suggestions. The cabin comprises the following components:

3.5.1. The floor components

Starting from the very bottom of the cabin, usually with a UPN or a square hollow cross section, there is the platform made of galvanized steel, a component that receives all the cabin loads and therefore should be of robust construction. There is also another type of platform which is made of bended steel metal, but in this example the former case is going to modelled. Right above the platform there is the MDF piece, with a common thickness of 16mm, which the final floor inside the cabin will apply on, like a rubber for example, with the desired anti slip properties or techno granite etc.

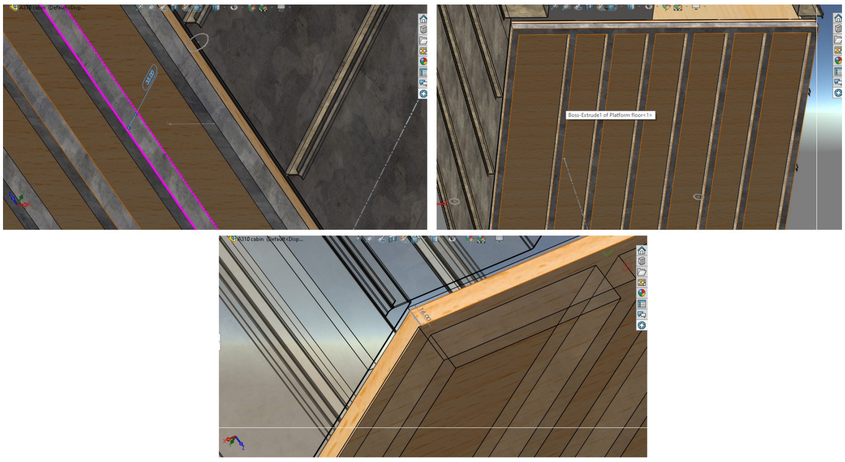


Figure 10: Floor MDF and platform

3.5.2. Cabin walls and corners

Installed across the perimeter of the cabin, cabin walls and corners form the cabin shell. The cabin walls are formed sheet metal pieces, with 325mm length each, that have been galvanized to withstand the corrosive environment and have been screwed together to fully enclose the cabin interior, with the help also of the Corners. The corners are made of stainless steel, in order to be corrosion resistant and at the same time contribute to the aesthetics of the cabin interior (Figure 11).

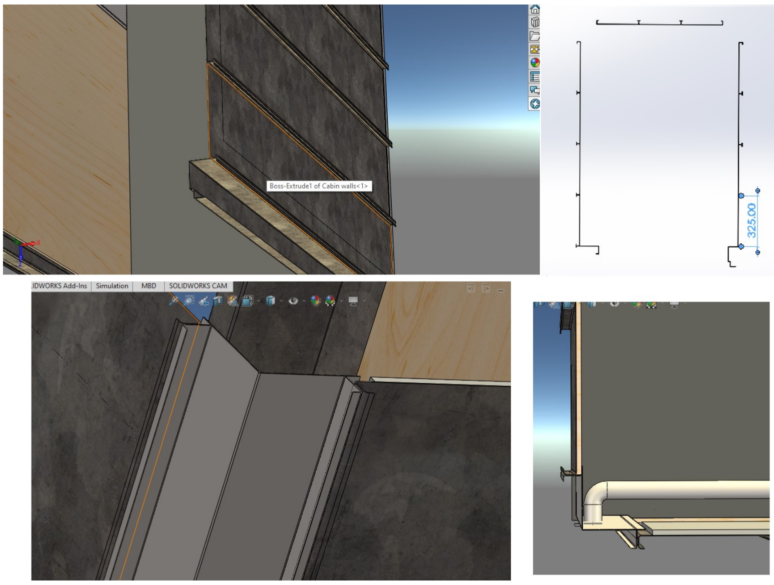


Figure 11: Galvanized steel walls and INOX corners

3.5.3. Handrail and Mirror

Regarding the cabin interior, on the rear side of the cabin there is the handrail and the mirror. Of course mirror is assigned with glass material and the handrail is made of a ϕ38mm inox tube, manufactured through extrusion. Right below the mirror there is an Inox strip, that separates the former from the below part of the rear side (Figure 12).

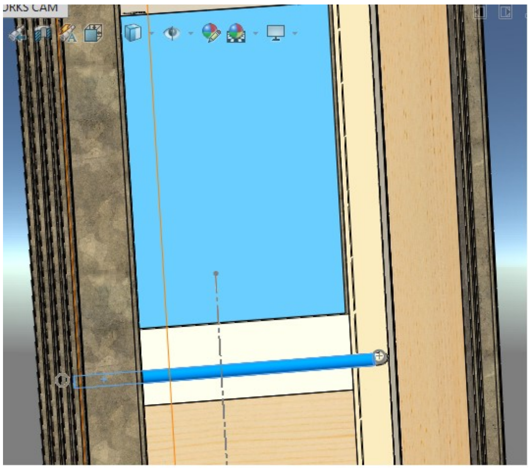


Figure 12: Mirror and handrail

3.5.4. Laminate sides and ceiling

The major appearance characteristics of this particular cabin are given by its side walls interior and the below part of the rear wall. They all consist of MDF 6 mm cladded with a formica / laminate film in order to have a pleasant look from inside. The ceiling is an Inox sheet metal that serves two purposes, first it creates the necessary room to house the cabin lightning and second contributes to the aesthetics of the interior, hiding the upper part of the cabin deck. In Figure 13 the final rendered view of the cabin is visible.

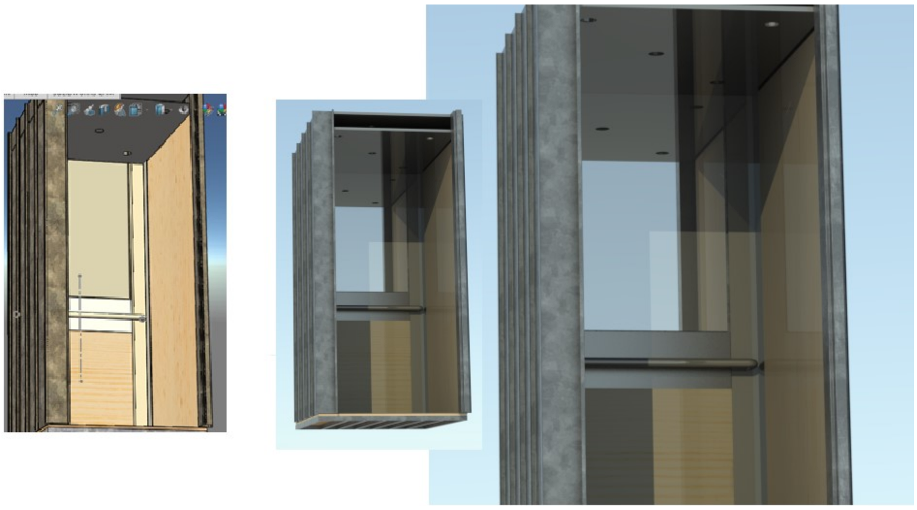


Figure 13: Laminate sides and final cabin rendering in Solidworks

3.6. Assessment results

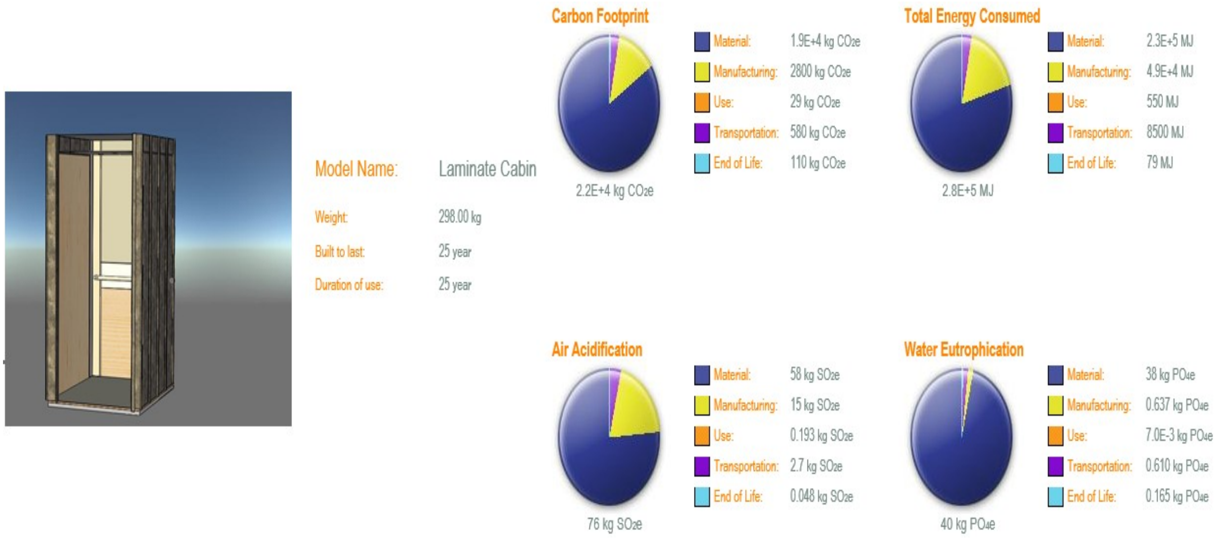


Figure 14 : Assessment results on every impact caterogy (baseline case)

The generated report shows the total cabin weight, which is about 300kg, and also some pie charts regarding the environmental impact of each individual stage of the cabin's life cycle in terms of Carbon Footprint, Total Energy Consumption, Air Acidification and Water eutrophication. In the charts, it can be observed that the blue and yellow colours represent the biggest burdens in every impact category, namely it is the Raw Materials acquisition and the Manufacturing process that affect mostly the results. This outcome is of course expected since during the use stage, the cabin as a single component of the whole elevator system, consumes only a little energy, the energy needed to give sufficient lighting to the cabin interior. Most of lifts installations nowadays use led spot lights that are very efficient and thus reduce the electricity consumption significantly.

Going further in detail, Solidworks enables the designer to investigate each component and visualize its impact share in relation to the rest of the assembly components. If the results were not normalized to the mass, then the most massive parts (Cabin Walls, Platform and Ceiling) would be the main contributors to all categories, which is self-explanatory (Figure 15). The only exception can be noticed in Water Eutrophication where the ceiling, the handrail and the inox part behind the handrail are the main determinants, most probably because all these components are made of stainless steel.

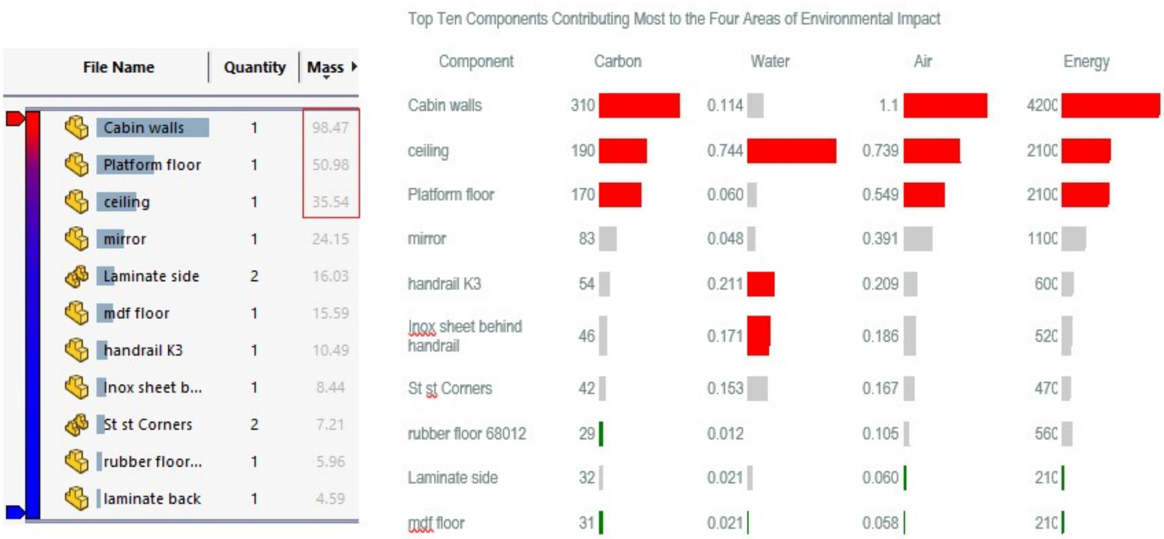


Figure 15: List with the main contributors (baseline case)

Apart from being the heaviest parts of the cabin assembly, another common characteristic of the Cabin Walls and the Platform Floor is that they are both made of galvanized steel. From this fact arises the idea to try an alternative way to transfuse these parts with anti-corrosion properties. For example, instead of galvanizing them, another option would be to paint them both or to construct the whole cabin walls from stainless steel. These alternatives are going to be tested later in this chapter.

However, except for the absolute impacts, we are interested also in values that have been normalized to the mass, for example specific energy consumption, in order to examine each material no matter the size of it. The list below informs us that the parts with the biggest Specific Energy Consumption (MJ/kg) are the PVC / rubber floor interior part with a value of about 94MJ/kg (Figure 16) . Modelling the floor with an alternative material like tiles or techno granite would be an alternative to compare with. The parts of the model with the biggest Specific Energy Consumption are represented with red color in the corresponding picture (Figure 16). Furthermore, another material that should be investigated is MDF panels, which are incorporated in the cabin sides and in the floor substrate. Although the simulation does not present these features as 'hotspots', the literature draws though the attention to the recyclability of MDF panels and also to some substances that are considered carcinogenic (see section 1.2.3 about MDF panels).

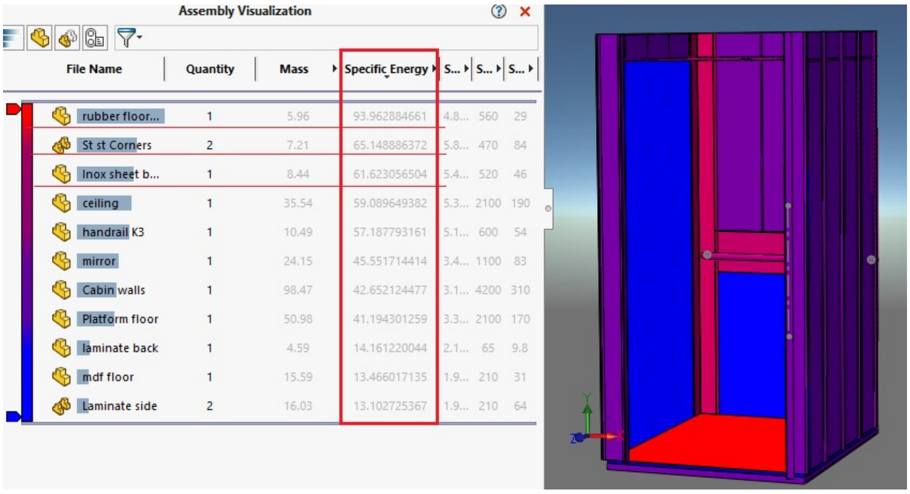


Figure 16: Specific energy consumption list

3.6.1. 1st improvement scenario

As already mentioned above, the first scenario will be to use an alternative material for the cabin walls and platform, instead of galvanized steel. After searching within the solidworks list of similar materials, the one that seems more capable to accommodate is the AISI 1020 Cold Rolled, which is a commonly used carbon steel, appropriate to be machined and welded (22). The SolidW. comparison window in Figure 17 reveals that it is a material with same density as galvanized steel and with bigger tensile and yield strength. In the same window it is visible also that this change will bring a positive effect on all the environmental impact categories (carbon ftp, energy consumption, etc.). It is important to add of course, that in order for this material to acquire anti-corrosion property like galvanized steel, it is inevitable to undergo further coating treatment, like the addition of nickel- or chromium-plate or the powder coating. In this scenario the latter is used.

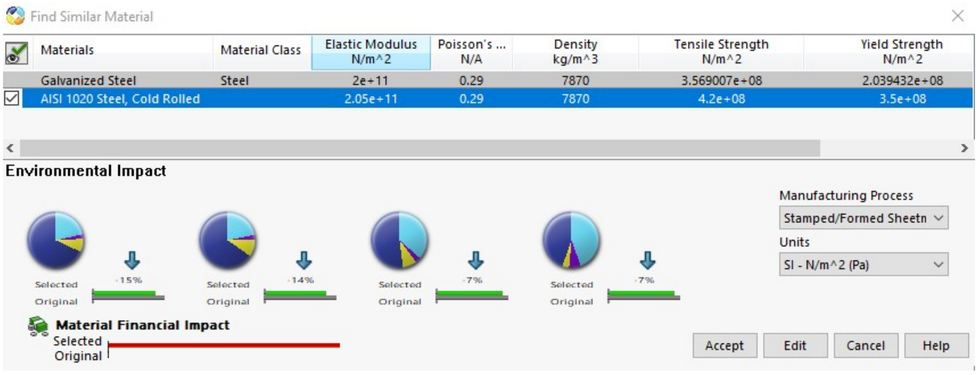


Figure 17: Comparison between Galvanized Steel and AISI 1020 cold rolled Steel

Apart from air acidification, there is a positive impact of this substitution, as observed in Figure 18. The Carbon Footprint and the Energy Consumption decrease by 3% and 7% respectively, while the water eutrophication remains unchanged.

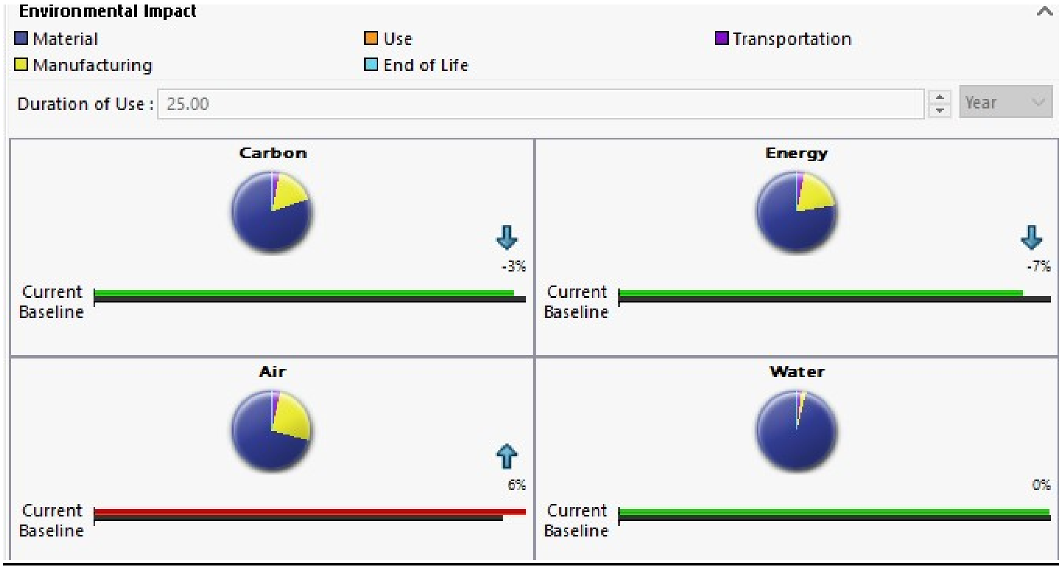


Figure 18: Improvements with AISI 1020 cold rolled

Looking into each category in more detail in Figure 19, the comparison between the base and the 1st improvement scenario is illustrated, using a black reference line which represents the results for the base scenario. A first conclusion is that the manufacturing impact is worse than the base case in every single category, which is shown with the red bar. However, the biggest improvements are attributed to the material itself, which was changed from galvanized steel to AISI 1020 cold rolled steel (painted). Namely the new results show a reduction of 5% kg CO_2, 9% MJ and about 2% kg SO_2 in categories Carbon Footprint, Energy Consumption and Air Acidification, respectively (see Table 6: Scenarios comparison table).

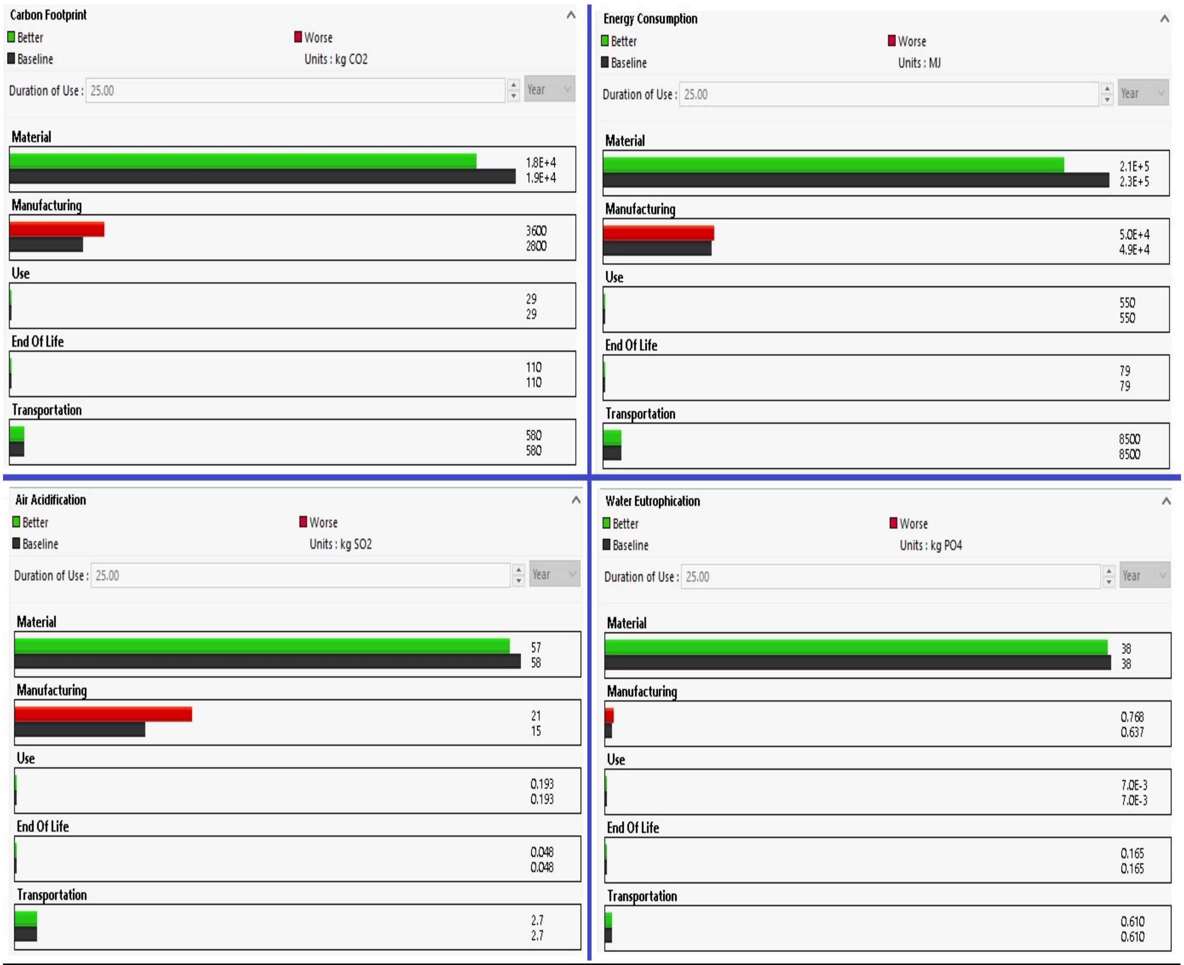


Figure 19: Impact categories analysis with AISI 1020 Cold Rolled

3.6.2. 2nd improvement scenario

When examining the specific energy consumption a couple of pages above, it was mentioned that this value is quite high for the PVC material of the interior floor, which is a rubber-like anti slip pad attached on the MDF substrate. An alternative floor modeled in the 2nd improvement scenario is the ceramic porcelain tiles. They offer many benefits such as their hardness, which makes them difficult to be scratched, their low weight compared to other flooring materials like granite or mosaic floors and their strength which is almost 2.5 times higher than the latter. During their manufacturing process they consume large amounts of thermal energy, coming from natural gas and being utilized during various drying processes. Thermal energy accounts for about 90% of total energy consumption, the rest is electricity (23). However, by looking in the following

Figure 20, it can be realized that ceramic tiles have a specific energy consumption of about 9,6 MJ/kg, nearly 10 times lower than PVC floor.

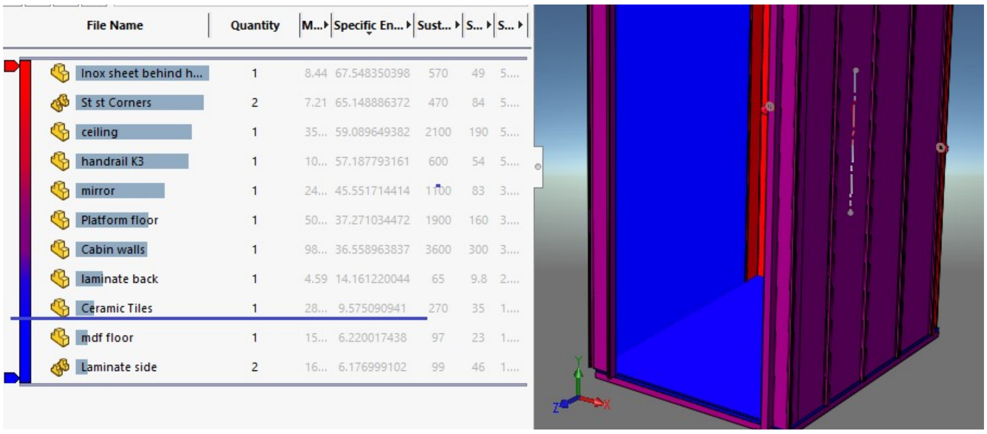


Figure 20: Specific energy consumption of Ceramic Tiles

An additional result of this flooring alternative is the increase of the total cabin weight for about 23kg. The environmental impact of this is not visible in this simulation, however it can be assumed that increasing the weight that the elevator is expected to lift, will consequentially increase the energy consumption of the whole elevator system.

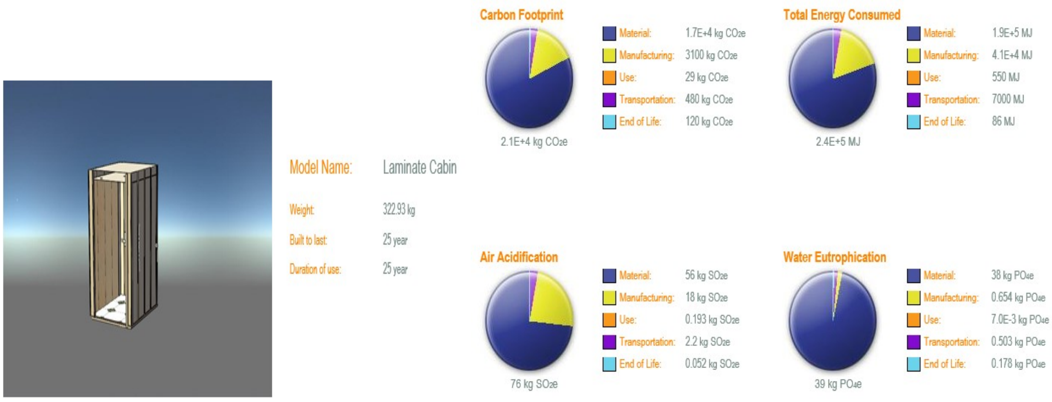


Figure 21: 2nd improvement scenario (1020 cold rolled+ceramic tiles)

4. Conclusions

The approach of the present dissertation on the life-cycle environmental impacts of an elevator was not under the strict principles of a Life Cycle Analysis, firstly due to the fact that such a comprehensive analysis has already been conducted and secondly because it would require more time than what was available. Therefore, it was decided to make first a literature review, in order to spot the main challenges and trends in the lift industry. Afterwards, there was a benchmarking comparison between the companies of the sector, in order to get a sense of how each one of them try to adopt some eco-friendly practices in order to gain competitive advantage and hence ensure that they will continue growing in the future. Furthermore, some suspicious materials have been further discussed in order to judge whether they contribute or not to the total environmental burden and next some good to follow practices were highlighted. In the last section of the text, Solidworks software has been deployed in order to model an elevator cabin and then evaluate its environmental consequences with the help of Sustainability tool.

Based upon the literature review, a first point that has to be emphasized is that, if an organization wants to successfully implement environmental and sustainable development principles, it should first acknowledge the strategic incentives that lie beneath such decisions. The expected benefits and returns on investment can be regarded both as short and long-term outcomes. Apart from the fear of being penalized, if not complying with environmental related policies, the most crucial motivation for a company towards sustainability has to be survival and successfully continue growing in accordance with all sustainability aspects, namely social, economic and environmental. Transforming into a green corporation does not mean only emitting less pollutants or creating less waste, but also producing the same output with less energy and materials, meaning being more efficient and also being able to respond quicker to market requirements than the competitors. The latter combined with strategic innovation management increase the possibility that the company will remain flexible and will be able to adapt to market changes and new policies establishment. In order to do this successfully the company, as a whole organization and with all departments being involved, shall integrate sustainability indicators within its everyday processes and shall embed these indicators in the year's targets, so that it is guaranteed that they are tightly followed. Afterwards, two very common materials used in the elevators industry are presented, namely Medium Density Fiberboard (MDF) and Galvanized Steel. The reason is that there has been extensive discussions and literature entries have been found that argue on whether these materials are eco-friendly and if not, if they can be substituted or in any way managed differently to mitigate their impacts.

Regarding MDF, it is a very efficient material, meaning that It is quite cheap and its mechanical properties make it ideal for the purposes it is being used. All these plus an already established supply chain make it fulfill the economic sustainability criteria. The challenge is therefore that some actions will be widely adopted, in order to ensure that MDF will remain socially and environmentally sustainable in the future. First of all, the skepticism over the health issues that might be caused has to be seen as a springboard for imposing strict limits to the permitted formaldehyde content of the resin, as USA, European Union and some other countries have already done. Moreover, research on finding alternative chemicals to be bonded with formaldehyde instead of urea has to be more intensive, because stronger bonds will result in lower emission levels. Lastly, with the purpose of improving its eco-friendly profile, MDF industry should massively adopt recycling processes, like the one mentioned as ohmic heating, a technology that was developed by MDF Recovery Ltd and C-Tech Innovation. This process will give the opportunity to recover used MDF panels and will also relieve its supply chain, which receives upstream pressure because of the fact that there is a simultaneous demand of the raw materials, creating competition between different markets. Additionally, MDF and other products coming from forests exploitation should be labelled with FSC certificates, in order to assure that the companies involved to carry them from their initial source to the customer have followed sustainable forest management processes and have made partnerships with suppliers and other stakeholders that share the same mindset.

Concerning Galvanized Steel, it is also a material very often encountered at elevator systems, which many components are made of. The discussion is whether such a kind of corrosion protection coating is eco-friendlier than painting or than Stainless Steel. Relying on various case studies on this topic, it can be deduced that it is a material with a very efficient supply chain, it is relatively cheap and offers a long term corrosion resistance, sometimes over a 60-years period. During this period, it requires no maintenance and therefore its life cycle impact is constrained mainly to the upstream stages of raw materials processing and manufacturing. The high quality corrosion and abrasion resistance offered by its intermetallic coating layer make it ideal for applications, where the object appearance is not of high importance and in areas not close to sea, because salty air might be harmful. Stainless steel on the contrary is rated better in terms of appearance, it is applicable also in areas nearby the sea, while both st/st and galvanized steel have big residual value at the end of their life cycle and can be fully recycled. Painting coating on the contrary requires regular maintenance after some years of exposure and its recycling is problematic.

In the benchmarking section, it is noticed that the biggest companies of elevators industry invest lots of funds in innovating, in order to be able to follow the trends and become more sustainable. They conduct a lot of research on finding ways to efficiently service the buildings of the future, the height of which is going to increase further. Their main concern is to reduce the mass of the components that have to be lifted, to provide components with long expected life and with the least possible maintenance, to utilize premium electronic components and traffic management systems, that can allocate passengers and manage a complex of many lifts etc. Another practice followed by some of the lifts corporations is to participate in projects or initiate partnerships with construction companies, sharing the same target with them, which is to create buildings that consume as little energy as possible.

In the last chapter, a Screening-Level LCA or else a simplified kind of LCA approach is presented. This generic kind of environmental impact assessment is useful during the product development phase, when there is not enough information available regarding the final materials and manufacturing processes and therefore a by the book LCA would be inefficient. In fact, it gives a good estimation regarding the impacts of every design concept decision, however it is not proper to be used officially, because it entails some necessary simplifications, which may compromise though the precision of the final results. This analysis is performed with the Sustainability tool of Solidworks and more specific a very common cabin type of the lifts industry is modelled and assessed. Once this product is simulated and some first results are produced, it is deduced that the biggest part on the environmental effects pie charts are occupied by blue and yellow color, which means that raw materials production and acquisition and manufacturing are the major contributors. This outcome has to be considered separately from the result that would have been produced, if the elevator as a whole system had been modeled, because in the latter case the use phase energy consumption would be the main burden factor. Since cabins, except for lighting which is very efficient, do not consume any energy during use phase, these results are reasonably justified.

In an attempt to improve the firstly produced results, two intervention scenarios are carried out next. The first one represents the substitution of cabin walls galvanized steel with another material with similar mechanic properties, which however needs to be painted to acquire corrosion resistance, this is the AISI 1020 cold rolled steel. The second improvement scenario relates to the flooring material, which instead of PVC in the baseline simulation, here the alternative of ceramic tiles is preferred, in order to check whether it will prompt any improvements. Additionally, apart from the aforementioned improvement scenarios, the assessment of another cabin type is included in the very right column of the comparison table (see Appendix). This is also a very commonly used cabin, consisted totally of stainless steel parts, which is also the interior appearance and therefore no galvanization is needed (see Appendix - Figure 28). Of course the environmental impact of this cabin is predefined and expected to be much lower, so the only reason to present its results is to stress the importance of a possible marketing or sales decision about which kind of product to promote. If we exclude this obviously best scenario, comparing the other 3 assessments by looking at the appendix charts and comparison table, it is noticed that the major improvements are achieved in the Carbon Footprint and Energy Consumption categories, however the maximum percentage is only 13%, referring to the reduction of energy use. Therefore, the most preferable option would be the base scenario, since galvanized walls require no maintenance through their life time, unlike the AISI 1020 cold rolled ones, that would require repainting. Also, regarding ceramic tiles flooring, it would add extra weight that the machine would be called to lift, so the electricity consumption would increase. Therefore, it is suggested to acquire PVC flooring through circular economy market, which is based on a patented recycling process developed by the Fraunhofer Institute for Process Engineering and Packaging IVV (33).

Trying to reach some final concluding points as a summary of the current project about how to design eco-friendly elevators, these would be:

- Adopt specific environmental indicators for each company department and include them in every year targets of it
- R&D department's innovation efforts should be in accordance and combined with ISO 14006 principles, meaning that every design decision during product development should consider also the environmental impact of it. Intensify the research on finding sustainable solutions for high rises lifts, since extremely tall buildings are going to be constructed more often in the future.
- Enter partnerships and synergies with companies that share a sustainability mindset. Develop a supply chain that is favorable to complying with sustainability principles through the whole product's life-cycle. Induce specific criteria, according to which the upstream and downstream participants-stakeholders of the supply chain are chosen.
- Create or enter existing circular economy markets. As mentioned in previous chapters, there are materials the use of which causes skepticism and is criticized. For example, galvanized steel, MDF panels, PVC flooring in elevator cabins etc. Since these materials comply with the economic and social aspect of sustainability, for the reasons already presented, the challenge is to create a circular economy market for these materials. Every participant of such a market has the interest to acquire and exploit the most of the remaining value at every stage of a materials life, while reuse and recycling remain the main drivers

- Promote products designed with simplicity like the stainless steel cabin mentioned in the last section. If this is not always applicable, find solutions through circular economy. For example, galvanized cabin walls and MDF materials of the cabins modelled with Solidworks could be supplied through a recycling stream.

Appendix (Simulation charts)

BASELINE CASE

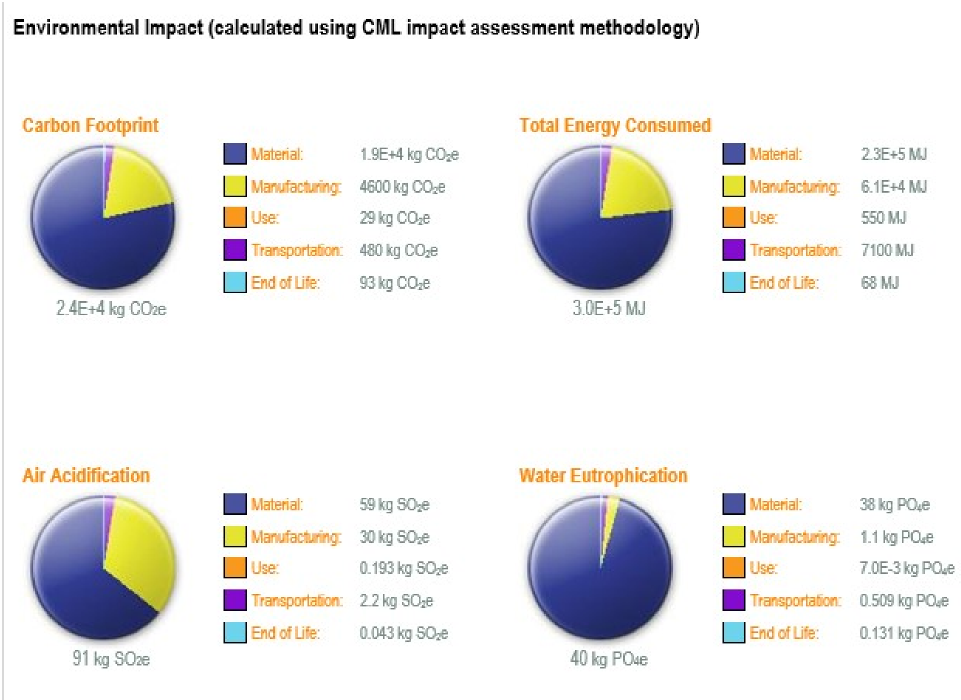


Figure 22: Baseline pie charts

Figure 23: : List with the main contributors (baseline case)

1st IMPROVEMENT SCENARIO (AISI 1020 cold rolled)

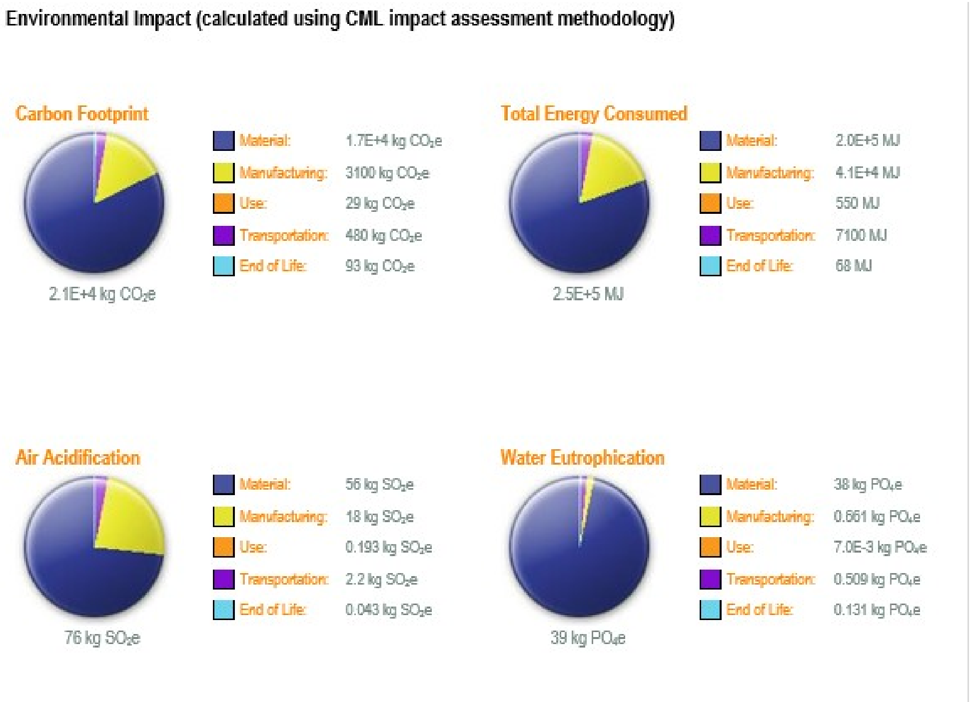


Figure 24: 1st improvement scenario pie charts

Top Ten Components Contributing Most to the Four Areas of Environmental Impact

Component	Carbon	Water	Air	Energy
ceiling	190	0.744	0.739	2100
mirror	83	0.048	0.391	1100
handrail K3	54	0.211	0.209	600
Inox sheet behind handrail	49	0.172	0.207	570
St st Corners	42	0.153	0.167	470
rubber floor 68012	29	0.012	0.105	560
Laminate side	23	0.014	0.027	110
mdf floor	23	0.014	0.027	100
laminate back	9.8	6.4E-3	0.018	65
Platform floor	0.00	0.00	0.00	0.00

Figure 25: List with the main contributors (1st scenario)

2nd IMRPOVEMENT SCENARIO (AISI 1020 cold rolled+ceramic tiles)

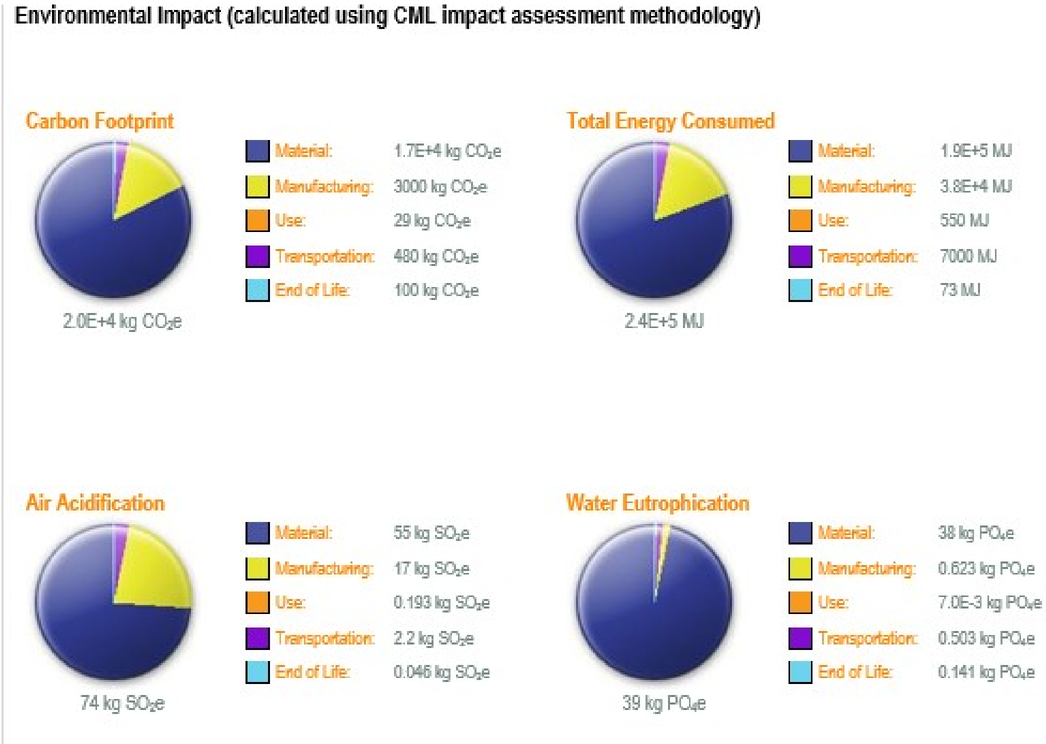


Figure 26: 2nd improvement scenario pie charts

Top Ten Components Contributing Most to the Four Areas of Environmental Impact

Component	Carbon	Water	Air	Energy
Cabin walls	280	0.109	1.2	3400
ceiling	190	0.744	0.739	2100
Platform floor	150	0.057	0.538	1800
mirror	83	0.048	0.391	1100
handrail K3	54	0.211	0.209	600
Inox sheet behind handrail	49	0.172	0.207	570
St st Corners	42	0.153	0.167	470
Ceramic Tiles	35	0.036	0.112	270
Laminate side	23	0.014	0.027	110
mdf floor	23	0.014	0.027	100

Figure 27: : List with the main contributors (2nd scenario)

STAINLESS STEEL CABIN

Figure 28: Stainless steel cabin

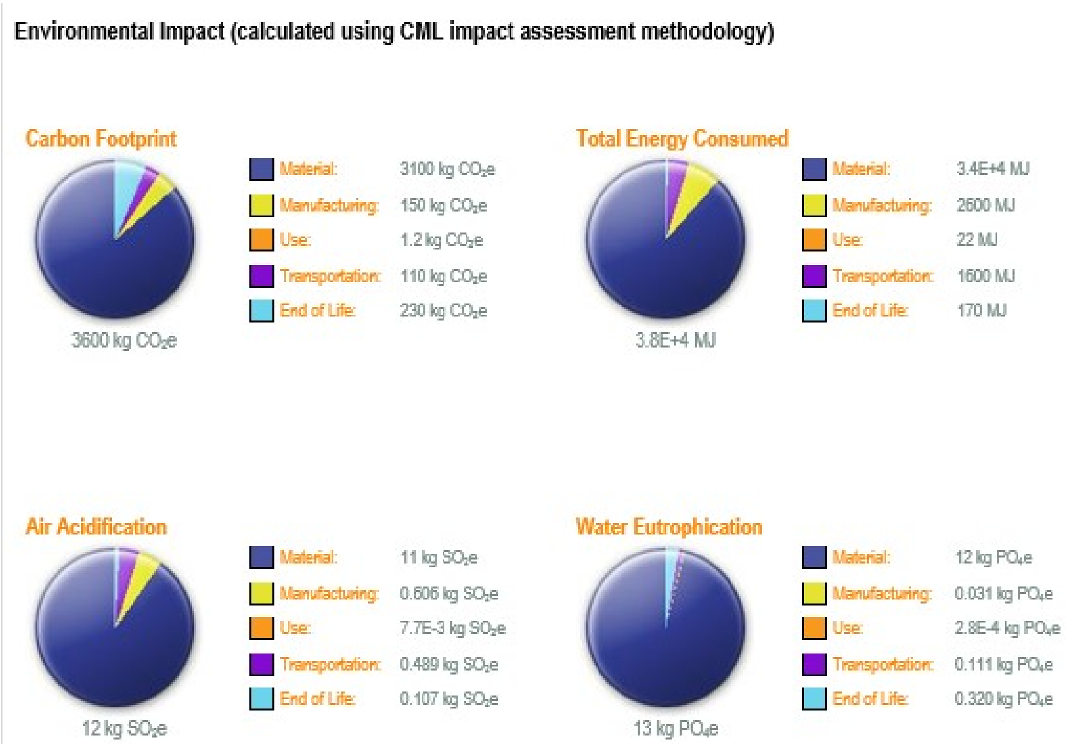


Figure 29: Stainless steel cabin pie charts

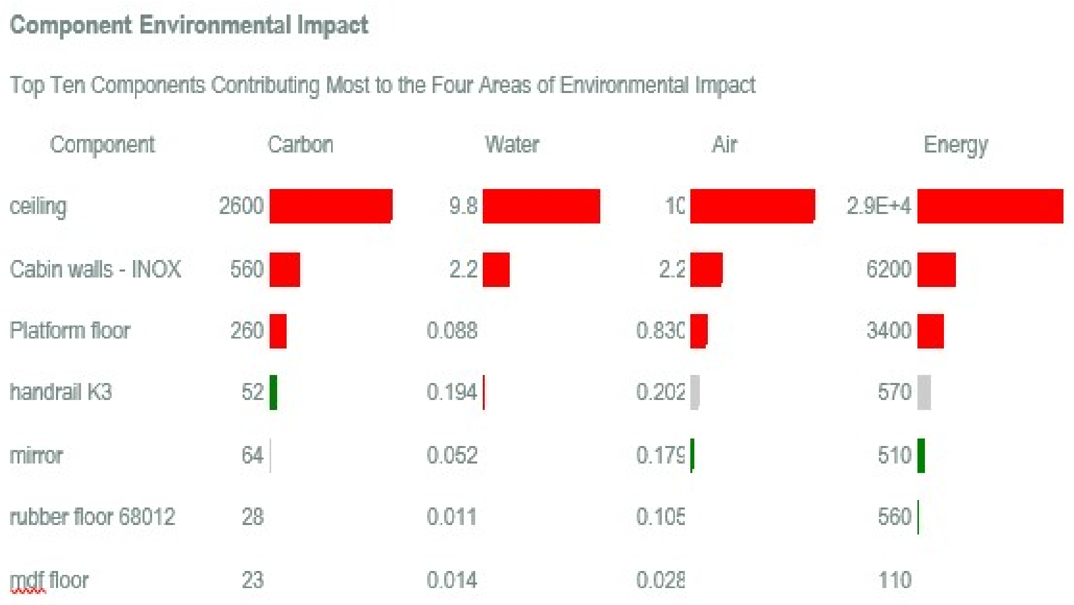


Figure 30: List of main contibutors (stainless steel cabin)

Table 6: Scenarios comparison table

	Baseline	1st improvement	2nd improvement	St/st cabin
Carbon Footprint (kg CO_2e)				
Material	19000	17000	17000	3100
Manufacturing	3300	3100	3000	150
Use	29	29	29	29
Transportation	480	480	480	110
End of life	93	93	100	180
Total	22902	20702	20609	3550
Total Energy Consumed (MJ)				
Material	220000	200000	190000	34000
Manufacturing	42000	41000	38000	2600
Use	550	550	550	550
Transportation	7100	7100	7000	1600
End of life	68	68	73	170
Total	269718	248718	235623	38392
Air Acidification (kg SO_2e)				
Material	57	56	55	11
Manufacturing	19	18	17	0.606
Use	0.193	0.193	0.193	0.007
Transportation	2.2	2.2	2.2	0.489
End of life	0.043	0.043	0.046	0.107
Total	78.43	76.43	74.43	12.2
Water Eutrophication (kg PO_4e)				
Material	38	38	38	12
Manufacturing	0.711	0.661	0.0623	0.031

Use	0.007	0.007	0.007	0.001
Transportation	0.509	0.509	0.503	0.111
End of life	0.131	0.131	0.141	0.32
Total	39.35	39.3	38.71	12.47

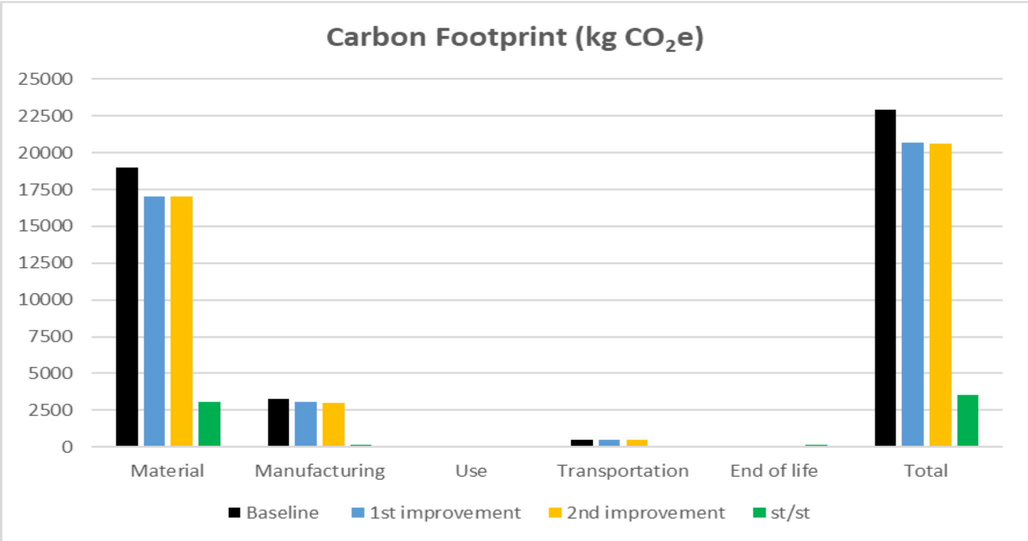


Figure 31: List of main contibutors (stainless steel cabin)

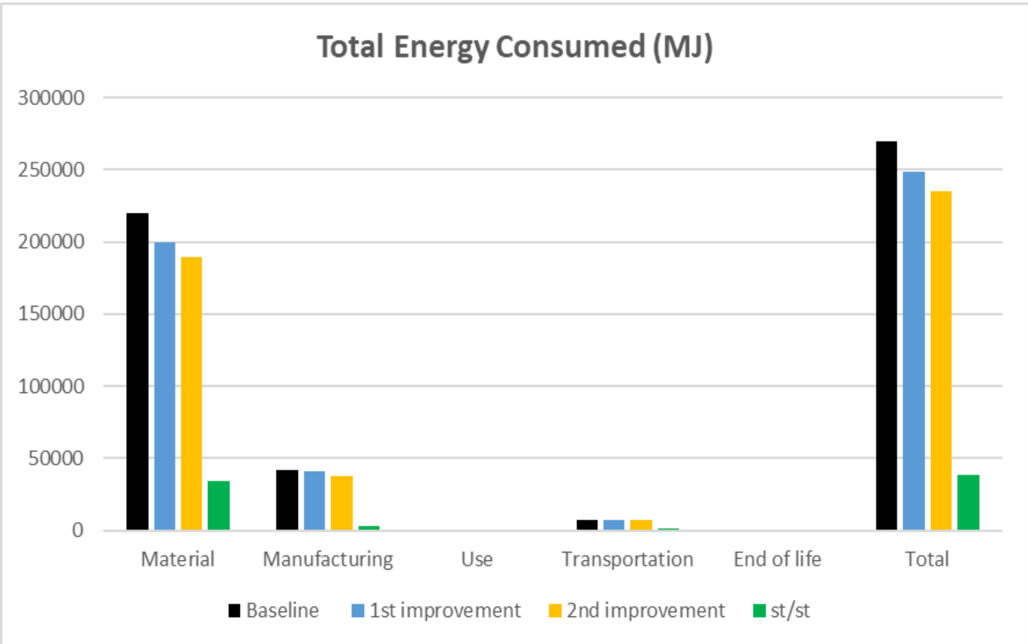


Figure 32: List of main contibutors (stainless steel cabin)

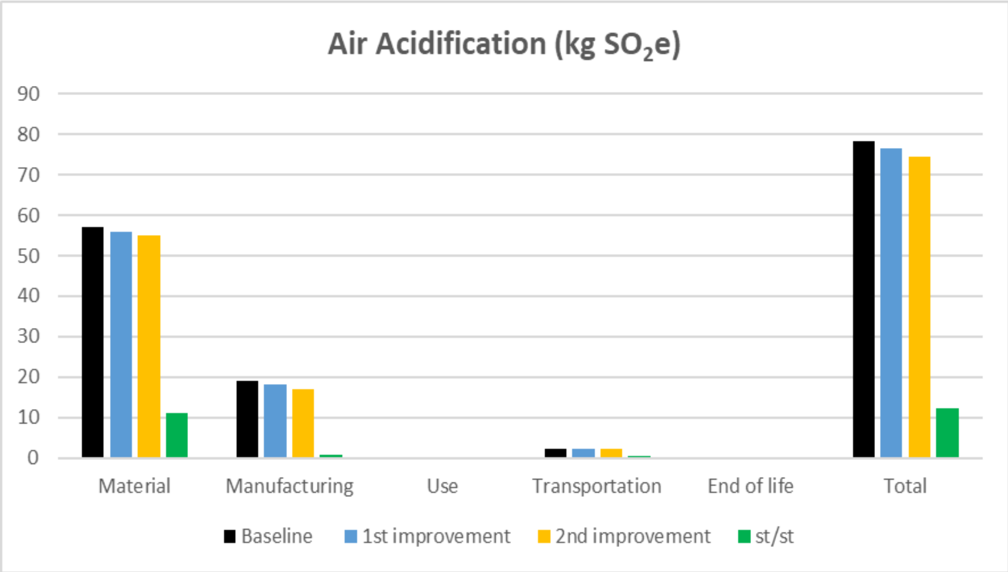


Figure 33: List of main contibutors (stainless steel cabin)

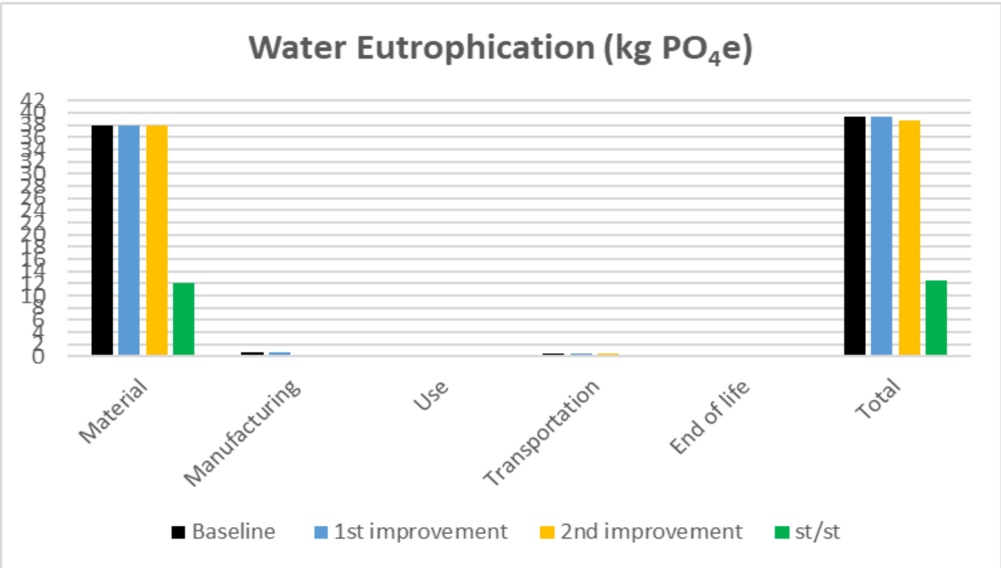


Figure 34: List of main contibutors (stainless steel cabin)

Glossary (Source https://www.solidworks.com)

Air Acidification: Burning fuels creates sulfur dioxide, nitrous oxides, and other acidic air emissions. This causes an increase in the acidity of rainwater, which in turn acidifies lakes and soil. These acids can make the land and water toxic for plants and aquatic life. Acid rain can also slowly dissolve man-made building materials such as concrete. This impact is typically measured in units of kg sulfur dioxide equivalent (SO_2) (34).

Carbon Footprint: Carbon dioxide and other gasses resulting from burning fossil fuels accumulate in the atmosphere, which in turn increases the earth's average temperature. Also known as Global Warming Potential (GWP), carbon footprint is measured in units of carbon dioxide equivalent (CO_2e). Scientists, politicians, and others blame global warming for problems like loss of glaciers, extinction of species, and more extreme weather, among others) (34)..

Downstream procedures: These are procedures related to the product, after the product is dispatched from the company. They comprise of transportation of the product to the customer, the use and maintenance phase and finally the disposal of the product at its end of life cycle.

Total Energy Consumed: This is a measure of the non-renewable energy sources associated with the part's lifecycle in units of mega joules (MJ). This impact includes not only the electricity or fuels used during the product's lifecycle, but also the upstream energy required to obtain and process these fuels, and the embodied energy of materials that would be released if burned. Total energy consumed represents the net calorific value of primary energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are also factors (34).

Upstream procedures: Procedures that take place before the raw materials reach the manufacturing unit. These procedures relate to the raw materials extraction, transport, processing etc., until the materials reach the plant and are ready for being used in manufacturing

Water Eutrophication: Eutrophication occurs when an overabundance of nutrients are added to a water ecosystem. Nitrogen and phosphorous from wastewater and agricultural fertilizers cause an overabundance of algae to bloom, which then depletes the water of oxygen and results in the death of both plant and animal life. This impact is typically measured in either kg phosphate equivalent (PO_4) or kg nitrogen (N) equivalent (34).

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