Frame Sections for Highly Insulated Industrial Doors

Sofia Björnsson and Frida Sterner

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

ASSA ABLOY
Entrance Systems

Frame Sections for Highly Insulated Industrial Doors

Research and development of a new frame section for an overhead sectional door

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Supervisor: Per Kristav
Co-supervisor: Per-Erik Andersson
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Abstract

This Master Thesis, executed in collaboration with ASSA ABLOY Entrance Systems, aimed at developing a new frame section for industrial overhead sectional doors. The overhead sectional doors are a part of the existing product portfolio and exist in two different thicknesses, 42 and 82 *mm*. The doors are built up by either panel or frame sections, or a combination of both. The 82 *mm* thick door is used when there is a need for good insulation. The goal with the project was to finalise a design for a new frame section with the thickness of 82 *mm*, called OH1082FI, since these does not exist today. The main purpose of this project was to offer a frame section for the 82 *mm* door, with low heat transmission, also referred to as U-value.

The project has followed the steps in the product development process described by Ulrich and Eppinger freely. These steps included investigating customer needs, developing, and choosing concepts, as well as testing the concepts. Different designs and materials for the frame section have been investigated. The final concepts were compared and verified through FEA-simulations as well as U-value calculations.

The result is a new frame section, built up by aluminium profiles as well as thermal breaks in polyamide reinforced with glass fibre. The profiles are also filled with polyethylene foam, to insulate the profiles and achieve a low U-value.

In this project it is established that the new frame section is a possible addition to the company’s product portfolio and is specifically attractive for customers interested in improving their energy use as well as indoor climate.

Keywords: Product development, ASSA ABLOY, Frame section, Overhead sectional door, U-value

Sammanfattning

Detta examensarbete, utfört i samarbete med ASSA ABLOY Entrance Systems, syftar till att utveckla en ny ramsektion för industriella takskjutportar. Takskjutportarna är en del av den befintliga produktportföljen och finns i två olika tjocklekar, 42 och 82 *mm*. Dörrarna är uppbyggda av antingen panel- eller ramsektioner, eller en kombination av båda. Den 82 *mm* tjocka dörren används när det finns ett behov av bra isolering. Målet med projektet var att färdigställa en design för en ny ramsektion med tjockleken 82 *mm*, kallad OH1082FI, eftersom dessa inte finns idag. Huvudsyftet med detta projekt var att erbjuda en ramsektion för den 82 *mm* tjocka dörren, med låg värmeöverföring, även kallat U-värde.

Projektet har följt de steg i produktutvecklingsprocessen som presenteras av Ulrich och Eppinger relativt fritt. Dessa steg inkluderade en undersökning av kundernas behov, utveckling och val av koncept, samt test av koncepten. Olika konstruktioner och material för ramsektionen har undersökts. De slutliga koncepten jämfördes och verifierades genom FEA-simuleringar samt U-värdeberäkningar.

Resultatet är en ny ramsektion, uppbyggd av aluminiumprofiler samt isolerande profiler i polyamid förstärkt med glasfiber. Ramprofilerna är även fyllda med polyetenskum, för att isolera profilerna och uppnå ett lågt U-värde.

I detta projekt dras slutsatsen att den nya ramsektionen är ett möjligt tillskott till företagets produktportfölj och är speciellt attraktiv för kunder som är intresserade av att förbättra sin energianvändning samt inomhusklimat.

Nyckelord: Produktutveckling, ASSA ABLOY, Ramsektion, Takskjutsport, U-värde

Acknowledgments

We would like to express our gratitude to all people that has contributed to this project. Without all help and support it would not have been possible. Firstly, we would like to thank all employees at ASSA ABLOY Entrance Systems who have been involved in the project. Thank you for your insight and help; Marcel Ligthart, Kaj Søndergaard, Daniel Eliasson, Tom Brandhoff and Gerolt Kempen. We would also like to thank the other Master Thesis Workers at ASSA ABLOY Entrance Systems, Elin Elfström and Mattias Neumann, for their support and company throughout the project, like offering their expertise in 3D-printing.

A special thank you goes to our supervisor at ASSA ABLOY Entrance Systems, Anders Löfgren. He has been a great assistance to this project, as well as contributing to a great atmosphere in the Landskrona office.

We would also like to thank our supervisors at The Faculty of Engineering at Lund's University who have contributed to this Master Thesis. Thank you Per Kristav, Per-Erik Andersson and our examiner Jože Tavčar.

Lund, May 2022

Sofia Björnsson and Frida Sterner

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1 Introduction

This chapter introduces the Master Thesis and describes the project, its goals, research questions and delimitations.

1.1 Background

This report was written as a part of a Master Thesis project in Mechanical Engineering with a focus on product development. The project was conducted in collaboration with ASSA ABLOY Entrance Systems and the Department of Design Sciences at the Faculty of Engineering, Lund University. The project goal is to research, design and develop frame sections for highly insulated industrial doors that contributes to a better energy use and indoor climate.

1.2 Project description

ASSA ABLOY Entrance Systems is an industry that offers entrance solutions for different applications. This project concerns the industrial doors, more specifically the overhead sectional doors, which are build up by different sections. Today ASSA ABLOY's portfolio for the overhead sectional doors includes panel sections with a thickness of either 42 or 82 *mm*, see Figure 1.1. They are used in different areas, where those that are 82 *mm* are mainly used where insulation is important. Sometimes there is a demand for light intake as well as visibility through the door, and then a window can be integrated. Today there exist so called frame sections with a thickness of 42 *mm,* where a window can be integrated. These are offered in either an isolated version, or an uninsulated version. These frame sections do not exist for the 82 *mm* thick door today and the aim in this project was to develop this new frame section called OH1082FI.

The frame section that shall be developed should, except for being a more insulated alternative to the 42 *mm* frame section, focus on providing light and visibility by offering the possibility to integrate windows. To find the best design for the new frame section it will be investigated how the frame section would perform by looking at the thermal transmittance (U-value) as well as the resistance to wind load.

By looking at the thermal transmittance it can be determined how well isolated the door will be. The resistant to wind load is investigated to conclude the robustness of the design.

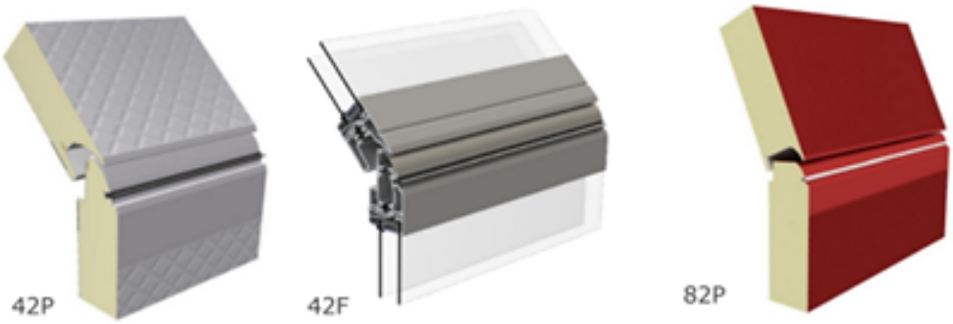

Figure 1.1 ASSA ABLOY Entrance Systems current panel and frame sections for the overhead sectional doors, where P indicates that it is a panel section and F that it is a frame section.

1.2.1 Goals and research questions

The main goal of the project is to research, design and develop prototypes of a frame section named OH1082FI for an overhead sectional door. The different concepts presented in the project will be evaluated by looking at parameters related to the U-value and the robustness. The goal is to offer a frame section with a U-value that is as low as possible to get a good insulation and is as robust as the existing overhead sectional doors in ASSA ABLOY's portfolio.

The research questions for the Master Thesis are as follows:

- What are the possible frame profile designs for the OH1082FI section?
- What parameters affects the U-value of the overhead sectional door?
- How does the number of windows affect the insulation of the door?

A fallback goal was set to ensure that the project will lead to a result. This goal will be accepted as the result if unforeseen delay may occur during the project. The fallback goal is to present at least one suggested design for the frame section OH1082FI. It is desirable to perform repeated tests of the prototypes and perform improvements of the design, but if the time is not enough only one test cycle will be performed.

1.2.2 Delimitations

The project will be time-limited with a duration of 20 weeks. Another delimitation is that the concepts only will be evaluated based on two specific parameters, in this case thermal transmittance and robustness. The tests are limited to these parameters since these are the most crucial for the overhead sectional door to provide the right insulation and safety. The industrial door should also be suitable for production, which limits the cost and the design. The cost should be consistent with the other industrial doors in ASSA ABLOY's portfolio. The testing and prototyping that will be carried out in the project will be limited by the possibilities given by ASSA ABLOY Entrance Systems.

1.3 Key People

The key people engaged in this project are listed in Table 1.1.

Table 1.1 Key people in this Master Thesis

Name	*Position*	*Role in project*
Sofia Björnsson and Frida Sterner	Master students in Mechanical Engineering with a focus on Product Development	Authors of the Master Thesis
Anders Löfgren	Senior Mechanical Engineer, ASSA ABLOY Entrance Systems, Landskrona Sweden	Supervisor, ASSA ABLOY Entrance Systems
Kaj Søndergaard	Product Manager Industrial Doors, ASSA ABLOY, Denmark	Expert on Industrial Doors at ASSA ABLOY
Marcel Ligthart	Senior Product Development Engineer, ASSA ABLOY Entrance Systems, Netherlands	Expert on frame and panel gates designed by ASSA ABLOY
Jože Tavčar	Senior Lecturer in Product Development	Examiner, Faculty of Engineering at Lund's University
Per Kristav	Lecturer in Product Development	Supervisor, Faculty of Engineering at Lund's University
Per-Erik Andersson	Lecturer in Product Development	Assistant supervisor

2 Company background

This chapter presents information focused on the company's background.

2.1 Presentation of ASSA ABLOY

ASSA ABLOY Group is a company focused on access solutions, with a background in lock construction. This Master Thesis is conducted together with ASSA ABLOY Entrance Systems, one of the foremost leaders in door opening solutions. The products offered by ASSA ABLOY Entrance Systems are divided into different departments. In this project the focus will be on industrial overhead sectional doors, a solution primarily intended for businesses with warehouses.

2.1.1 Overhead sectional doors

The overhead sectional doors offered by ASSA ABLOY Entrance systems consists of sections. These sections are offered in different thicknesses and can either be a panel or a frame. Some examples of the overhead sectional doors can be seen in Figure 2.1 to Figure 2.3.

Figure 2.1 Overhead sectional door with panel sections.

Figure 2.2 Overhead sectional door with frame sections.

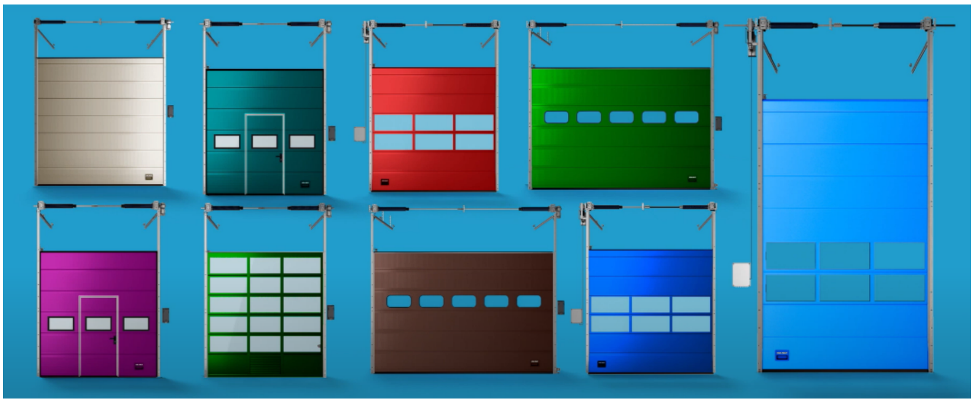

Figure 2.3 Different layouts for overhead sectional doors.

2.2 Presentation of existing industrial doors

Within the ASSA ABLOY Entrance Systems portfolio, a few types of industrial doors relevant to this project can be found. The doors are named systematically after their type and thickness. The doors relevant for this project are OH1042 and OH1082. The beginning of the product name OH1 indicates that it is an overhead sectional door, the zero is a generation mark and the last two numbers in the product names indicates the thickness of the door in millimetres. There are four door sections for the overhead sectional door, relevant to this project. A panel section for the 82 *mm* door, a panel for the 42 *mm* door and two different frame sections for the 42 *mm* door. These are called OH1082P, OH1042P, OH1042F, and OH1042FI. The P indicates that it is a panel section, F that it is a frame section and FI indicates that it is an insulated frame section with a so-called thermal break. In Table 2.1 the existing doors the most relevant to this project are presented. In the table key values regarding the thermal transmittance according to the standard EN 12428 and the class to withstand wind load from the standard EN 12424 are presented. The frame sections consist of two so called horizontal stiles and two or more vertical stiles.

Table 2.1 Existing overhead sectional doors.

Product	*Thickness [mm]*	*Type of panel/frame*	*Thermal transmittance [W/(K·m^2)]*	*Resistance to wind load*
OH1082P[a]	82	Full panel	0.46	Class 3
OH1042P[b]	42	Full panel (Steel)	1	Class 3
OH1042P[b]	42	Full panel (Aluminium)	1.1	Class 3
OH1042F[c]	44	Triple acrylic glazing	3.1	Class 3/2
OH1042F[c]	44	Double acrylic glazing	3.6	Class 3/2
OH1042F[c]	44	Single acrylic glazing	6.2	Class 3/2
OH1042FI[d]	42	Triple acrylic glazing	2.6	Class 3/2
OH1042FI[d]	42	Double acrylic glazing	3.1	Class 3/2
OH1042FI[d]	42	Single acrylic glazing	2.2	Class 3/2

Note: Classes named Class 3/2 is either Class 3 or Class 2, but it depends on the value of DLW (Daylight Width, the width of a glazed opening which admits light).

[a] (ASSA ABLOY Entrance Systems, 2021a)

[b] (ASSA ABLOY Entrance Systems, 2018)

[c] (ASSA ABLOY Entrance Systems, 2021b)

[d] (ASSA ABLOY Entrance Systems, 2021c)

2.3 Industry standards

ASSA ABLOY Entrance Systems follows several European standards regarding industrial doors when manufacturing their products. In this project, the standards EN 13241, EN 12604, EN12428, EN 12424 as well as EN 12444 have been looked at. These are further presented in Appendix A.

3 Methodology

This chapter aims to present the different methods in product development used during the project. This chapter describes the framework methods along with how the development methods are implemented in various parts of the process. The research- and development methods are then presented in more detail in the order that they are implemented.

3.1 Planning

The developed project plan for this project can be seen in Appendix B. The thesis work will be carried out during a period of 20 weeks. The work plan is mostly based on the steps described in the product development process methodology presented by Ulrich and Eppinger.

3.2 Product development process

This project is primarily based on the product development process presented by Ulrich and Eppinger. This process, illustrated in Figure 3.1, involves six phases where the planning phase is described as phase zero. According to this methodology the planning phase begins with opportunity identification and results in a mission statement that specifies the target market, business goals, key assumptions, and constraints for the product (Ulrich & Eppinger, 2012).

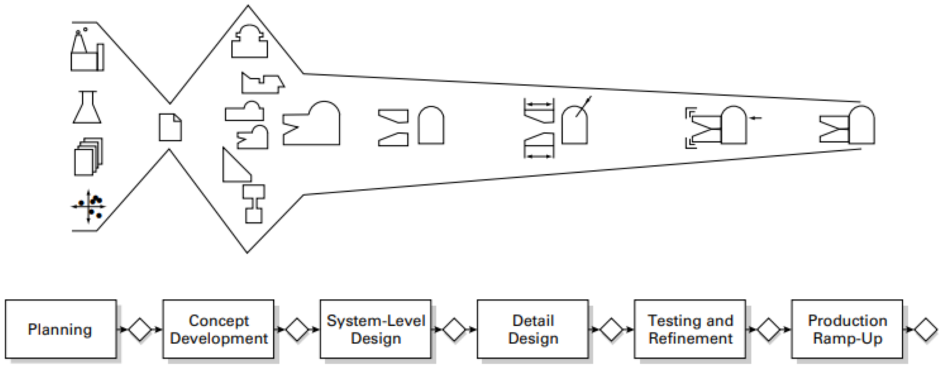

Figure 3.1 Product development process. (Ulrich & Eppinger, 2012, p. 14).

After the planning, the first phase of the product development process is the concept development process. This phase involves multiple steps that are connected to each other through an iterative process described in Figure 3.2. In this process the needs of the target market are identified, and the product concepts are generated. The concepts are then evaluated, and one or more concepts are selected for further development and testing. The second phase in the process is the system-level design phase where the products architecture, decomposition of the products subsystems and components as well as the design of the key components are investigated. The detail design phase is the third step in the product development process. This phase involves the complete specification of the geometry, materials, and tolerances of all unique parts in the product and the identification of all the standard parts to be purchased from suppliers. The fourth phase is the testing and refinement. The testing and refinement phase concerns the construction and evaluation of multiple preproduction versions of the product. The prototypes are tested, and the goal is to answer questions about performance and reliability to identify necessary engineering changes for the final product. The testing and refinement should not be exclusively performed in the end of the project but should be conducted iteratively towards the end of the process. Production ramp-up is the last phase of the product development process. The purpose of this phase is to train the workforce and to work out any remaining problems in the production processes. (Ulrich & Eppinger, 2012)

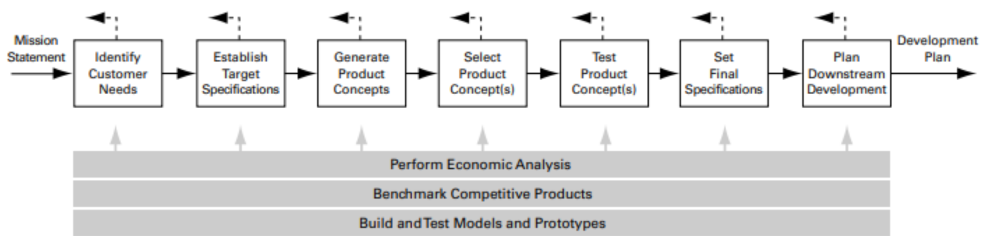

Figure 3.2 Concept development process. (Ulrich & Eppinger, 2012, p. 16)

3.3 Method applied in project

This project will follow the Ulrich and Eppinger product development process methodology, with some minor alterations. The method used is illustrated in Figure 3.3. The process will be more iterative than described by Ulrich and Eppinger, where multiple test and refinements of the product will be performed. This project will only go as far as finalising a prototype, and there will be no production ramp-up since that part of the project depends on ASSA ABLOY Entrance Systems. Instead, there will be a post-project review where the project will be discussed. The steps added to the process are described in sections 3.3.1 *Theory* - 3.3.4 *Post-project review*. Throughout this report, each step in the product development phase is further described in the beginning of each section.

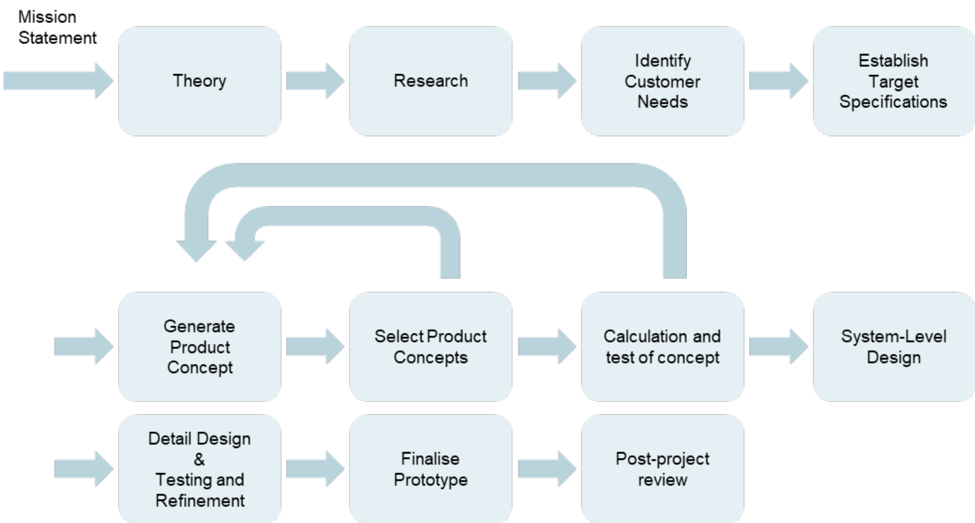

Figure 3.3 The product development process followed throughout this project.

3.3.1 Theory

To get a deeper understanding of the parameters that are to be tested for the frame sections, more information was gathered. Theory useful for this project is presented in chapter 4 *Theory*.

3.3.2 Research

A more in-depth investigation regarding the advantages and disadvantages of the existing designs was performed in chapter 5 *Research* to get a better understanding of the existing overhead sectional doors at ASSA ABLOY Entrance Systems.

3.3.3 Calculations and test of concepts

A phase that will be an extended part of the concept selection phase, where the different concepts will be tested regarding wind load and U-value to choose a final concept, will be performed. This phase replaces the concept testing phase in the product development process presented by Ulrich and Eppinger, since the product is an extension of an already existing product in ASSA ABLOY Entrance Systems portfolio.

3.3.4 Post-project review

In 15.3 *Post-project* review a shorter evaluation of the finished prototype with a simpler economic review can be found. Possible future development will also be described in this phase.

3.4 Mission statement

The mission statement, that describes the project and the goals, is shown in Table 3.1.

Table 3.1 Mission statement for the Master Thesis

Mission statement: Frame Sections for Highly Insulated Industrial Doors	
Product Description	Frame sections for highly insulated industrial doors.
Benefit Proposition	Designing a frame with increased thickness with a low U-value that contributes to better energy use and indoor climate.
Key Business Goals	• Produce a prototype. • Investigate parameters in the frame section affecting U-value and resistance to wind load.
Primary Market	Companies in need of overhead sectional doors with good insulation that offers light and visibility.
Secondary Markets	Businesses located in places in need of light, visibility, and good insulation.
Assumptions and Constraints	• Cost consistent with other overhead sectional doors in ASSA ABLOY's portfolio. • High manufacturability. • Compatible with ASSA ABLOY's overhead sectional doors standard parts. • Aesthetically compatible with ASSA ABLOY's overhead sectional doors.
Stakeholders	• Purchasers and users. • Manufacturing operators. • Service operators. • Distributors and resellers.

4 Theory

This chapter explains the theory used in this project, which includes the basics regarding heat transfer, thermal transmittance, and wind load.

4.1 Heat transfer

Heat transfer is the transport of heat from one gas or liquid to another through a heat exchanging surface or wall.

The heat flow in a material is determined by the temperature difference between the liquids or gases, their properties, motions, and the properties of the heat exchanging surface or wall.

The heat effect is determined as shown in Equation 4.1, where T_1 and T_2 are the temperature on each side of the heat exchanging surface and *A* is the area of the surface. *U* is the heat transfer coefficient (SI unit $W/(K \cdot m^2)$), which summarizes the heat transfer at the two sides of the heat exchanging surface and the heat conduction through the surface, see Equation 4.2. This is also referred to as thermal transmission.

$$\Phi = U \cdot A \cdot (T_1 - T_2) \tag{4.1}$$

$$\frac{1}{U} = \frac{1}{\alpha_1} + \sum 1^n \left(\frac{\delta_i}{\lambda_i}\right) + \frac{1}{\alpha_2} \tag{4.2}$$

α_1 and α_2 are the heat transfer coefficients (SI unit $W/(K \cdot m^2)$) on either side of the heat exchanging surface, δ is the layer thickness (*m*) of each layer, if the surface is composed of several layers, and λ is the thermal conductivity coefficient ($W/(K \cdot m)$) of the material in the respective layer. (NE Nationalencyklopedin AB)

4.2 Heat transfer in buildings

Thermal performance is an important contributing factor to buildings' environmental performance. The energy management is often driven by the heating or cooling requirements, where a minimization of heating or cooling loss is desired.

The heat or cool loss often takes place at various locations of the building, like walls, doors, or windows.

The thermal performance is measured in terms of heat loss, often expressed as U-value or R-value. Evaluating the thermal performance of building elements is crucial for efficient energy management operations. (Sadhukhan, et al., 2020)

The U-value of a door, window or assembly is commonly calculated as a function of the thermal transmittance of the components and their geometrical characteristics, plus the thermal interactions between the components.

U_f refers to the U-value of the frame and U_g the U-value of the glazing. These exclude the thermal interaction between the frame and the glazing (or opaque panel). To take this thermal interaction into account, the linear transmittance, ψ_g and/or ψ_p, must be either calculated or obtained from tables existing in standards. (Swedish Standards Institute, 2017)

4.3 Thermal bridge

A thermal bridge, also referred to as a cold bridge, is a component or area with higher thermal conductivity than the surrounding material creating a path for heat transfer. A thermal break, or broken cold bridge, is defined as a material with low thermal conductivity placed in a profile to reduce heat transfer. This is also referred to as an insulating profile in the report.

4.4 Wind load

Wind loads is a crucial factor to consider when designing an industrial door. The load arises from the differential pressure caused by the wind hitting a fully closed-door leaf. The wind load can depend on the angle that the wind strikes the structure as well as the structures shape (Extension Foundation, 2021).

5 Research

This chapter presents additional research about the existing products that was mentioned briefly in chapter 2 Company background. This is to get a deeper understanding of the existing overhead sectional doors to gather useful information regarding their advantages and disadvantages.

5.1 OH1082P

OH1082P is the first generation of the 82 *mm* panel section that exist at ASSA ABLOY Entrance Systems. This industrial door section is designed for an industrial environment with high temperature difference between the outside and the inside. It is designed to save both money and energy, by reducing the energy loss that can occur with high temperature differences. The OH1082P is to be used in an overhead sectional door when energy savings are relevant. It is however not recommended when the opening speed is important, when there are many daily openings, since it is heavier than the thinner version. The OH1082P panel is filled with PUR-foam, making it a well-insulated section.

The OH1082P is the only overhead sectional door option that is offered by the company with a thickness of 82 *mm,* and as for now there are no frame sections of that thickness. With these panels the lowest U-value within the company for overhead sectional doors can be achieved. A disadvantage with the OH1082P is that it is only compatible with one type of window, which is a window with four layers called FARP. These windows do not provide a sufficient clarity, and they are significantly smaller than the windows that can be integrated in a frame section. The windows can be added to the panel section by cutting out a section of the panel and then installing the window into the panel. Another disadvantage with the OH1082P is that it does not provide the safety feature to prevent the user from clamping their finger. A frame section solution that works in combination with OH1082P does not exist for the overhead sectional door. The window options that exist for the OH1082P are illustrated in Figure 5.1. (Søndergaard, 2022)

Figure 5.1 Different configurations of OH1082P.

5.2 OH1042F and OH1042FI

OH1042F and OH1042FI are two different frame sections that exists in ASSA ABLOY Entrance Systems' portfolio, where the main difference is that OH1042FI is insulated by thermal separation. This thermal separation is also referred to as a broken cold bridge. There is no visible difference between the options, the difference is inside the frames. OH1042F is commonly used in normal industrial environments with a need for daylight ingress and OH1042FI is used in the same situation where there is also a need for insulation. Both frame sections can be combined with the panel section OH1042P to create different designs of the overhead sectional door. Some examples can be seen Figure 5.2. (Søndergaard, 2022)

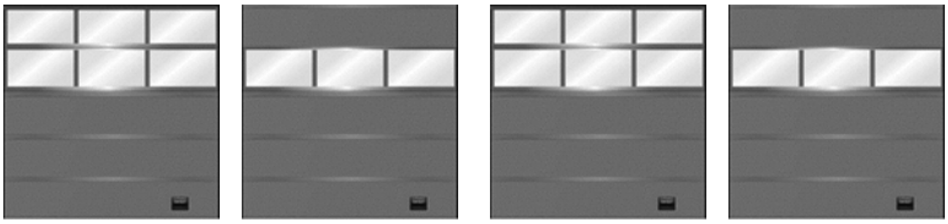

Figure 5.2 Combinations of OH1042P, OH1042F (left) and OH1042FI (right). As can be seen, there is no visual difference between OH1042FI and OH1042F.

The advantages with the OH1042FI compared to the OH1042F is the thermal separation of the profiles which drastically improves the insulation properties. The risk of ice-formation and condensation on the inside of the windows are also reduced. The frame sections have multiple window options. The OH1042F has six different window options and OH1042FI has ten. These windows are single, double, and even triple layered windows and exist in materials like acrylic and hardened glass. These materials can also have a scratch resistant coating applied. (Søndergaard, 2022)

5.3 Manufacturing

ASSA ABLOY Entrance Systems manufactures every industrial door themselves. Some standard parts are purchased and undergo strict quality controls. Some other parts are specifically designed and manufactured by the company. The portfolio offered by the company to the customers gives the possibility to customize each door for the customer's specific industry. The manufacturing process therefore involves customization, and a lot of various products are produced.

When it comes to the frame sections of the overhead sectional doors, the frame profiles are manufactured by a supplier. The stiles are made up of aluminium profiles and so-called thermal breaks made of polyamide reinforced with glass fibre. The aluminium profiles are manufactured by extrusion and is bought by length, and the thermal breaks are bought as a standard part from a supplier. These parts are then rolled together to build the stiles that makes up the frame, see Figure 5.3. ASSA ABLOY Entrance Systems main role is to assemble the frames and perform the post processing of the frames, as drilling holes and cutting lengths. The cutting is done by automatic cutting and the holes are drilled for the vertical stiles and made with a CNC machine for the horizontal stiles. Cut outs are made with a milling machine.

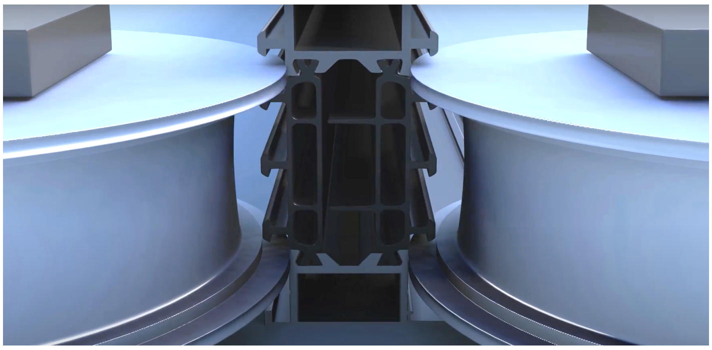

Figure 5.3 Image illustrating the process when the thermal breaks (dark grey parts) are rolled into aluminium profiles (Reynaers Aluminium, 2017).

The assembling of the frames begins by applying a butyl seal to the front part of the frame. The seal has unbroken corners, to prevent water leaks. The window is then mounted in place, followed by a glazing list. The glazing list is pushed in place from the back and is fastened by a connection in the front part of the frame section. The reason for this action is based on ASSA ABLOY Entrance Systems supply chain, this way the backside of the frame can lay still and the only part that needs to be moved is the front part. This is performed by hand, but the other actions are performed by machines. The window can easily be removed if it needs to be replaced. The co-extruded glazing list with the rubber lip against the window is the part that facilitates this action. The rubber lip can be removed and then the glazing list can be moved so that the connection will be disassembled, and a new window can be mounted. (Søndergaard, 2022)

6 Customer needs

This chapter presents the process of identifying customer needs according to Ulrich and Eppinger's product development process and how the method is implemented in this project.

6.1 Methodology and implementation in project

Identifying the customer needs is the first phase in the concept development process after the mission statement has been settled. The goal is to ensure that the product is focused on customer needs, to provide a fact base for justifying product specifications and develop a common understanding of the customer needs among the members of the development team. The needs that are identified in this process are not specific to a concept. Specifications that are later set depend on the final concept and what is technically and economically feasible, what competitors offer in the marketplace as well as on the customer needs. (Ulrich & Eppinger, 2012, pp. 73-90)

6.1.1 Gathering of raw data

The first part of establishing the customer needs is to gather raw data from customers. In advance to starting this Master Thesis ASSA ABLOY Entrance System had already established a need for this kind of product in the market, since the market demands doors with better U-values. The industrial door OH1082P that exists today is considered to have good insulation properties but does not offer sufficient daylight and visibility.

The methods intended to use to gather raw data information were interviews and observation, which are methods commonly used in the Ulrich and Eppinger methodology (Ulrich & Eppinger, 2012, pp. 76-77). Due to the Covid-19 pandemic increase in Sweden during the beginning of this project, the observation process was difficult to perform since the work was to be carried out from home. Therefore, the initial observation was performed online.

To gain information regarding issues with the existing industrial doors, as well as getting a deeper knowledge, it was decided to interview an expert on industrial doors. Kaj Søndergaard is a product manager for industrial doors at ASSA ABLOY Entrance Systems and is the expert that was interviewed regarding the company's industrial doors. Questions about the reason behind developing this kind of product, the advantage and disadvantages that exists with similar industrial doors was asked. All questions and answers can be seen in Appendix C. An additional information meeting with Kaj Søndergaard was also performed to gather more knowledge regarding the overhead sectional doors and the most important information from this meeting is presented in Appendix D.

6.1.2 Interpretion of raw data

The next step was to interpret the raw data gathered during the interview with Kaj Søndergaard. From the statements in the interview a few so-called needs for the product could be interpreted, these can be seen in Table 6.1. The table divides the statements and needs in relation to their topic.

Table 6.1 Interpret Raw Data from Interview

Topic	*Statement*	*Interpreted Need*
Reasoning for developing insulated frame section	We expect the market to change into better insulated doors as standard and since a lot of customers also demand daylight ingress.	The OH1082FI give a better insulation standard.
	Same as above.	The OH1082FI offers daylight ingress.
	With more insulation and to be able to offer these doors with windows, we need 82 *mm* frame sections with thermal separation in the profiles.	The OH1082FI has thermal separation in the profiles.
Potential problems	Risks like cost/price, difficulties in manufacturing, weight coursing balancing issues for the complete door.	The OH1082FI has a comparable price to existing industrial doors at ASSA ABLOY Entrance System.
	Same as above.	The OH1082FI is easy to manufacture.
	Same as above.	The OH1082FI shall not interfere with the weight coursing balance.
	Keeping the design and other details the same.	The OH1082FI is compatible with standard parts used in ASSA ABLOY Entrance Systems portfolio.
Disadvantages in existing industrial doors	For the OH1082P we lack the opportunity to offer big windows.	The OH1082FI allows the industrial door to have big windows.
	For the OH1042F and OH1042FI we do not meet the insulation (U-value) requirements demanded from the customer/authorities.	The OH1082FI has thermal separation in the profiles.
Standards	The complete door should fulfil all demands in EN 13241 and all underlying standards like EN 12424 and EN 12444 etc.	The OH1082FI respect the norms.

6.1.3 Organizing of needs

After the raw data was interpreted into needs the third phase of organizing the needs into a hierarchy was performed. According to Ulrich and Eppinger about 50 to 300 needs statements should be collected (Ulrich & Eppinger, 2012, p. 83), but in this case there were not that many needs. As earlier mentioned, some specifications for OH1082FI were already set by ASSA ABLOY Entrance Systems, and therefore not many needs were identified. This will be discussed further in chapter 7 *Target specifications.*

The needs that were interpreted in Table 6.1 was sorted into a list of primary and secondary needs. From the primary needs a few additional secondary needs were identified by the team, which are so called latent needs. This resulted in the list of primary and secondary customer needs seen in Table 6.2.

The needs were also ranked according to their importance, corresponding to the fourth step in the process of identifying customer needs. The ranking of the needs' importance is demonstrated in Table 6.2 by the number of *'s, with *** denoting critically important needs and the latent needs are denoted by !.

Table 6.2 List of primary and secondary customer needs

No.	*Primary Customer Needs*		*Secondary Customer Needs*
1	The OH1082FI provides a better insulation standard.	***	The OH1082FI has thermal separation in the profiles.
2	The OH1082FI provides daylight ingress.	***	The OH1082FI allows the industrial door to have big windows.
3	Same as above.	!	The OH1082FI offers a variety of windows.
4	The OH1082FI is easy to manufacture.	*	The OH1082FI is compatible with standard parts used in ASSA ABLOY Entrance Systems portfolio.
5	Same as above.	**	The OH1082FI is compatible with manufacturing methods used at ASSA ABLOY Entrance Systems.
6	The OH1082FI has a comparable price to existing industrial doors at ASSA ABLOY Entrance System.	*!	The OH1082FI has a simple design to keep the costs down.
7	The OH1082FI shall not interfere with the weight coursing balance.	*!	The OH1082FI is not too heavy, the weight is just right.
8	The OH1082FI respect the norms.	***!	The OH1082FI is safe.
9	Same as above.	**!	The OH1082FI has a robust design.
10	Same as above.	***!	The OH1082FI can resist heavy wind loads.

7 Target specifications

This chapter presents the methodology for creating specifications for the product according to Ulrich and Eppinger's design methodology as well as presenting the method used throughout this project.

7.1 Methodology and implementation in project

The activity following identifying customer needs in the concept development phase is to establish target specifications. A product specification, also called product requirements or engineering characteristics, provides engineers and designers with information about the attributes that the product needs to attain to meet the customer needs. The information given in the product specification should be detailed and measurable, meaning it must include one metric and a value corresponding to that metric.

Ideally, one product specification is established once early in the development process. Although, for high technology, that is often impossible. Instead, a target specification is established directly after the identification of customer needs and later when the final concept has been selected and refined, the final product specification can be set.

The target specification is set according to what the design team wishes that the product will meet, while the final product specification is revised to what seems possible after selecting the final concept. The target specification can be revised throughout the concept development process, depending on the concepts that have derived. (Ulrich & Eppinger, 2012, pp. 91-116)

7.1.1 List of metrics

In this project, a list of metrics was created from the customer needs that was presented in Table 6.2. This was the first step in the process of establishing the target specifications for the OH1082FI. The list is presented in Table 7.1, where the importance of the metric is based on the previous ranking of the customer needs. The thickness, which is a metric that derives from both need number four and five, is of high importance because the thickness has a set value from the beginning and must be fulfilled.

Table 7.1 List of metrics

Metric No.	*Need Nos.*	*Metric*	*Importance*	*Units*
1	8, 9, 10	Resistant to wind load	1	*Pa*
2	7	As low total mass as possible	5	Binary
3	1	Thermal transmittance (U-value)	1	$W/(m^2 \cdot K)$
4	4, 5	Thickness	1	*mm*
5	6	As low total cost as possible	7	Binary
6	2, 3	Window present	1	Binary
7	4	Compatible with standard parts	5	Binary
8	5	Compatible with standard manufacturing methods	5	Binary

Note: The importance has been ranked from 1 to 10, where 1 is especially important.

7.1.2 Benchmarking

The second step in this process was to investigate comparable products that exist on the market by performing a benchmarking session.

When performing the benchmarking session, it was found that that highly insulated frames sections were not common. Usually, overhead sectional doors used in industries have windows similar to the ones offered for OH1082P at ASSA ABLOY Entrance Systems. However, it was found that a large variety of window shapes was used by other companies. Completely round windows could be found as well as rectangular windows with both rounded and sharp corners. Some examples of these different windows shapes and placements can be seen in Figure 7.1 and Figure 7.2. It should be mentioned that some of these doors are intended as garage doors for private use. The opportunity to choose among a variety of window shapes might be more prioritised because of that reason in comparison to industrial doors.

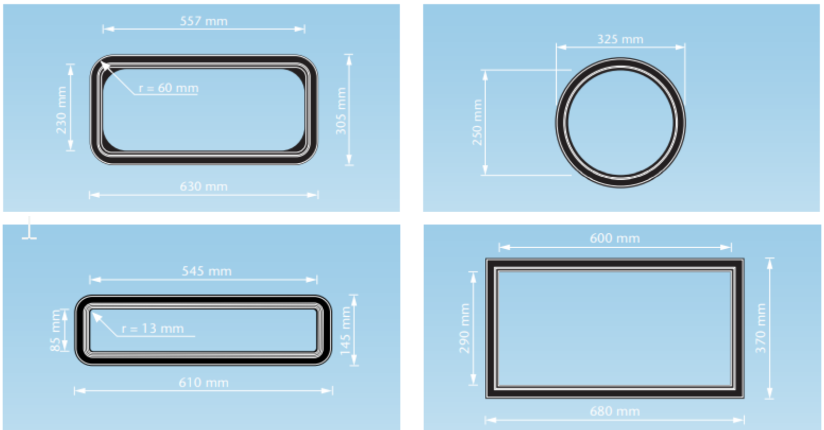

Figure 7.1 Different shapes of windows in industrial doors. (KONE Corporation, 2016, p. 9)

Figure 7.2 Unusual placement of windows. (KONE Corporation, 2016, p. 7)

During the benchmarking session few companies was found to have frame sections with a thickness that was greater than 42 *mm*. Only one of these companies offered information about their frame sections regarding thermal transmittance and resistance to wind load, the other companies did not share these values. In Table 7.2 the parameters for competitors' industrial doors are displayed.

Table 7.2 Other existing overhead sectional doors on the market (Hörmann, 2021, p. 100)

Product	***Thickness [mm]***	***Type of panel/frame***	***Thermal transmittance [W/(K·m²)]***	***Resistance to wind load***
APU 67 Thermo	67	Triple plastic glazing	2.1	Class 4/3
APU 67 Thermo	67	Quadruple plastic glazing	1.8	Class 4/3
APU 67 Thermo	67	Special climate double glazing	1.6	Class 4/3
APU 67 Thermo	67	Double glass glazing	2.6	Class 4/3
ALR 67 Thermo	67	Triple plastic glazing	2.2	Class 4/3
ALR 67 Thermo	67	Quadruple plastic glazing	1.9	Class 4/3
ALR 67 Thermo	67	Special climate double glazing	1.7	Class 4/3
ALR 67 Thermo	67	Double glass glazing	2.7	Class 4/3

Note: Classes named Class 4/3 is either Class 4 or Class 3, but it depends on the value of DLW (Daylight Width, the width of a glazed opening which admits light).

7.1.3 Establishing of target specifications

The third step of the process of establishing target specifications, to set ideal and marginally acceptable target values, was not followed completely according to Ulrich and Eppinger's methodology. The reason being that the project had already started at the company and some specifications for OH1082FI had already been set. Some of the specifications were the same as the ones that were established in the list of metrics. However, the list of metrics that was created resulted in a few new specifications. The target specification can be seen in Table 7.3.

Table 7.3 Target specifications with ideal and marginally target values

Metric No.	*Need Nos.*	*Metric*	*Imp.*	*Units*	*Marginal Value*	*Ideal Value*
1	8, 9, 10	Resistant to wind load	1	*Pa*	≥700 (≥450)	700 (450)
2	7	As low total mass as possible	5	Binary	Yes	Yes
3	1	Thermal transmittance (U-value)	1	$W/(K{\cdot}m^2)$	<2.7	1.8
4	4, 5	Thickness	1	*mm*	82	82
5	6	As low total cost as possible	7	Binary	Yes	Yes
6	2, 3	Window present	1	Binary	Yes	Yes
7	4	Compatible with standard parts	5	Binary	Yes	Yes
8	5	Compatible with standard manufacturing methods	3	Binary	Yes	Yes
9[a]		Broken Cold bridge	1	Binary	Yes	Yes
10[a]		Recognizable with ASSA ABLOY Entrance Systems portfolio	5	Binary	Yes	Yes
11[a]		Compatible with OH1082P panels	1	Binary	Yes	Yes
12[a]		Section profile assembly must be watertight	1	Binary	Yes	Yes
13[a]		Easily replaceable windows from inside	2	Binary	Yes	Yes
14[a]		Top seal	2	Subj.	Double seal	Double seal

Note: The importance has been ranked from 1 to 10, where 1 is very important. "Subj." is an abbreviation indicating that a metric is subjective. The value without the parentheses is for a door with a daylight width (The width of a glazed opening which admits light) that is smaller or equal to 4250 *mm* and the value in the parentheses is for a door wider than 4250 *mm*.

[a] Specifications that are already set by the ASSA ABLOY Entrance Systems.

The different values displayed in Table 7.3 are decided either by estimation, according to standards or are values given by ASSA ABLOY Entrance Systems. The values for the first metric, the resistance to wind load, were decided based on what the other industrial doors at ASSA ABLOY Entrance systems can resist. These can resist wind loads up to class 2 and 3 described in the standards. The values for these pressures were gathered from standard EN 12424 that is presented in Appendix A.

The second metric, the total mass, is a binary value since it is hard to specify a value when the overhead sectional doors exist in many different combinations and sizes. The desire is instead to have a weight that is as low as possible that still can fulfil the other requirements regarding, for instance, wind load. The weight also affects the balancing of the door and should not be too far from the weight of the panel sections.

The ideal value for the thermal transmittance was given in the specification from ASSA ABLOY Entrance Systems. The value should not exceed 1.8 $W/(K \cdot m^2)$ for a 5×5 m door. The marginal value was estimated by the group by comparing the difference in percent for the U-value between OH1042P and OH1082P. The U-value for OH1082P was 86 % of the value for the OH1042P. Therefore, the marginal value was estimated to be 86 % of the U-value for the OH1042FI with double acrylic glazing, which was 2.7 $W/(K \cdot m^2)$. These values are highly approximated because the U-value depends on multiple factors. Today there are countries and customers that demands a U-value of 1.4 $W/(K \cdot m^2)$ or less, but this is in relation to a specific door configuration depending on size and number of windows (Søndergaard, 2022). The focus in this project is to get the lowest U-value possible, but 1.8 $W/(K \cdot m^2)$ is set as a goal.

The fourth metric, the thickness of the frame, is a set value that must be fulfilled to be able to combine the frame section OH1082FI with the panel section OH1082P.

It was decided to have a binary value and not a specific ideal value for the cost after meeting with Kaj Søndergaard. ASSA ABLOY Entrance Systems does not have a focus on low prices, instead they strive to have the best solutions and not necessarily the cheapest. According to Søndergaard the OH1082FI will be a premium option compared to the existing frame sections in the company's portfolio because of the intended better characteristics regarding insulation, light, and visibility, therefore the option might be more expensive.

The sixth requirement, that the frame section must provide a window, derives from the customers wishes. Many customers desires daylight in their premises or visibility through the doors.

The seventh requirement is that it should be possible to use the same type of standard parts in the design as for the frame sections OH1042FI. This is to minimise the number of different components that will be used by the company and is a way of saving money as well as time. Another reason is also to keep the product catalogue smaller.

The ninth requirement, that the design should have a broken cold bridge, was not definitive. If an aluminium profile is to be designed, a thermal break is necessary. If another material is used, a thermal break might not be needed.

It is desired to keep the manufacturing similar to the method for the existing frame section OH1042FI. This will facilitate the reuse of standard parts and no new manufacturing methods will have to be implemented. This is the reason for the eighth metric value. Keeping this distinguished process in the company is desired.

The other requirements are related to the specification given by ASSA ABLOY Entrance Systems.

8 Concept generation

This chapter presents the methodology for generating concepts according to Ulrich and Eppinger's product development process as well as the method used throughout this project.

8.1 Methodology and implementation in project

When the target specification is set, the next phase according to Ulrich and Eppinger is the concept generation phase. The goal is to generate a set of concepts which later will be evaluated. One or several concepts will be selected for further development. The concept generation phase consists of five steps, and these can be seen in Table 8.1. In this project the four first steps were performed. (Ulrich & Eppinger, 2012, pp. 117-142)

Table 8.1 Process of concept generation (Ulrich & Eppinger, 2012, p. 120)

Step 1	Clarify the problem
Step 2	Search externally
Step 3	Search internally
Step 4	Explore systematically
Step 5	Reflect on the solutions and the process

8.1.1 Clarifying of problem

The main problem of designing a window frame section with a thickness of 82 *mm* was divided into two subproblems. Designing the window and designing the profiles for the 82 *mm* frame section.

To clarify the problem, Ulrich and Eppinger suggest that a function diagram is created. In this case a simple function means tree was created instead, since it was believed to suit the project better. In a function means tree the function describes the 'what', which is the individual operations that contributes to the performance of a system and the mean describes the ‘how’, which is the solution that delivers the function (Ahlqvist & Ahlström, 2021). The function means tree that was created for OH1082FI can be seen in Figure 8.1. This includes the main functions that the OH1082FI shall provide like insulation and visibility, and the means that delivers these functions. The different functions in the function means tree are gathered from chapter 7 Target specifications. The function means tree has different branches depending on if there is an option between the means or if both means are needed to solve the function. The branches seen beneath the function to provide visibility is showcasing that both means are necessary to achieve the function. Below the function ‘compatible with ASSA ABLOY products’ the branches instead show two different options and only one of the means is needed to solve the function.

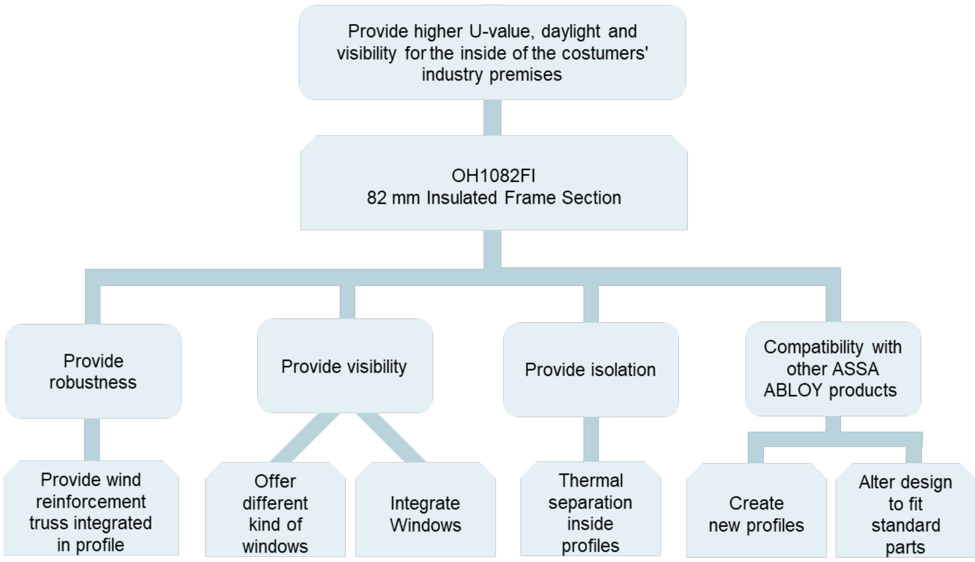

Figure 8.1 Function means tree for OH1082FI.

8.1.2 External and internal search

After clarifying the problem, the next step was to perform an external search. Approaches to search externally according to Ulrich and Eppinger can be to consult an expert, search patents, interview lead users, search published literature and benchmarking. Two of these actions has already been performed to some extent in the customer needs and target specifications phase, consulting an expert and benchmarking. Additional benchmarking was made in this step to get an even better understanding of competitors frame sections.

As previously noticed during the benchmarking, a frame section as thick as 82 *mm* does not exist among the competitors that has been investigated. The thermal break used among competitors is similar to the one used at ASSA ABLOY Entrance Systems.

In this benchmarking session it was observed how competitors profiles differed between different thicknesses, how the design was altered to make a thicker frame. The focus was on profiles with broken cold bridges since that is needed to achieve a low U-value, which is the focus of this project.

At Hörmann, who sells both garage doors and industrial doors, the design of their thicker frame profiles differs from the thinner version for their industrial doors. Both the profile parts and the thermal breaks are different. Almost every part is different compared to the thinner frame section. Panel sections and frame sections with different thicknesses from Hörmann's portfolio can be seen in Figure 8.2. The section in the figure referred to as number 1 and 4 display the different panel sections and 2, 3 and 5 showcase the frame sections. Hörmann also states that the aesthetics of the thicker frame is the exact same as the thinner one (Hörmann, 2021). The thermal break is not centred but placed in the front of the frame. The added thickness of the frame is on the backside.

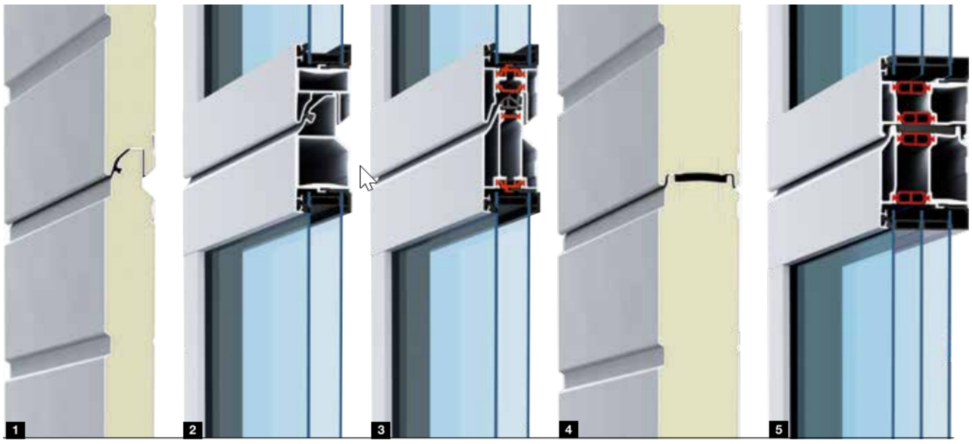

Figure 8.2 Panel and frame sections in Hörmann's portfolio, showing broken cold bridge. (Hörmann, 2021)

Novoferm, who sells garage doors, uses several types of plastic details to create their broken cold bridge in their different designs. These can be seen in Figure 8.3, where the black parts in section 1 and 2 display one type of thermal break and the blue part in section 3 and 4 showcase another. These parts are placed in the middle of the frame in difference to Hörmann.

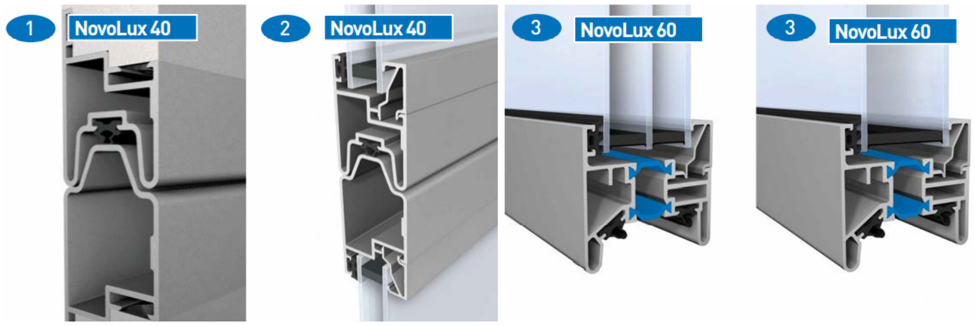

Figure 8.3 Panel and frame section in Novoferm's portfolio. (Novoferm, 2020)

The part creating the broken cold bridge in ASSA ABLOY Entrance Systems' frames today are from Ensinger, who makes the Insulbar® insulating bars. These are made of PA6.6GF25, which is a polyamide reinforced with 25 % glass fibre. Insulbar® comes in a few different designs and sizes. The one used in OH1042FI has a length of 14.8 *mm*. Insulbar® has a range of insulating profiles with lengths from 10 *mm* to 54 *mm* (Ensinger, 2021).

An additional note is that ASSA ABLOY Entrance Systems are satisfied with their design for the existing frame sections and want a similar design for the OH1082FI. In that way, the doors offered by ASSA ABLOY Entrance systems have similar aesthetics which creates a better overall impression when integrating several doors from ASSA ABLOY in a building.

In the search of patents performed in the Swedish patent database (PRV), it was first investigated if ASSA ABLOY Entrance System had any active patens involving the frame section, which they did not. The same search was carried out for Hörmann, Novoferm and KONE. Hörmann and KONE did not have any active patents involving frame sections. Novoferm had some active patents, but none that was relevant to this project.

8.1.3 Systematic exploration

The team started with generating concepts for the frame profiles since those are more important to begin with than the windows. The concepts for the windows will not be generated, but several existing alternatives will be investigated. In the end multiple windows should fit the frames. To generate concepts for the frame profiles a brainstorming session was performed while looking at the existing CAD-model of OH1042FI. This resulted in seven concepts. When looking for solutions, solutions for the middle section frames were primarily looked at since these are the most important when combining OH1082FI with the OH1082P panel. The different section types of an existing frame sections can be seen in Figure 8.4. At this stage, all suggestions were assumed to be in the same material used in the OH1042FI, in order to keep the design.

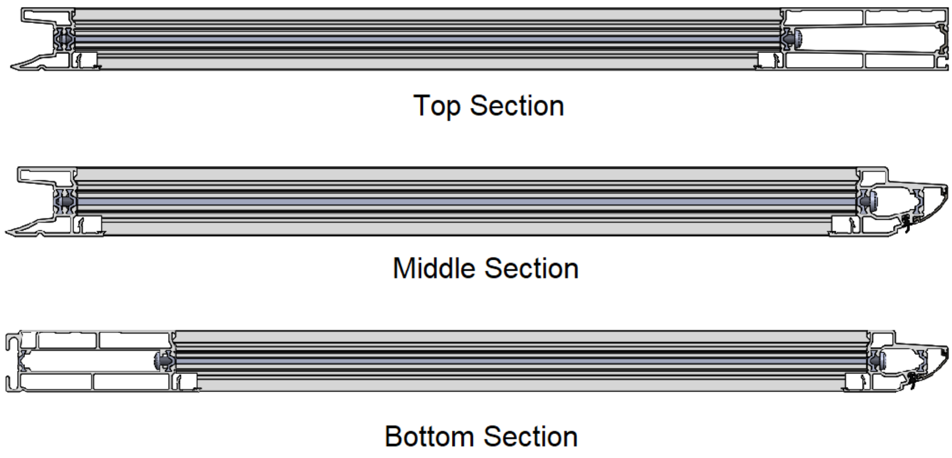

Figure 8.4 Schematic image depicting different sections in the overhead sectional door.

For the windows, a session to investigate different windows solutions that can be used in combinations with the concepts for the frame sections was conducted. These concepts are presented in section 8.2.2 *Window concepts*. The concepts are both window types that exist in ASSA ABLOY Entrance Systems portfolio as well as suggestions suggested by Anders Löfgren. Since the 82 *mm* frame section is mainly to be used in doors where good isolation is needed, it is mostly interesting to look at options that are well insulated, preferably multiple layer window options.

8.2 Generated concepts

In this part the different generated concepts for both the window and the profiles are presented. These solutions can be combined to create different kinds of frame sections. This resulted in a great number of different concepts that will be considered in the next phase, concept selection.

8.2.1 Frame concepts

In Table 8.2 the different concepts generated for the frame profiles are presented. The concepts imagined for the frame profiles can be seen in Figure 8.5, Figure 8.6 and Figure 8.7. Only the three first concepts were sketched since the other concepts are variations of those concepts.

Table 8.2 Concepts for the frame profile

Concept	*Description*
1	Adding thickness to the parts in the back of the profile with 40 *mm*.
2	Increase length of thermal break.
3	Increase the thickness of the parts in the front of the profile with 20 *mm* and the back with 20 *mm*.
4	Increase the thickness of the parts in the front of the profile with 40 *mm*.
5	Like concept 2 but the screws would be replaced by a bigger size compared to the screws used in the 42 *mm* frame.
6	Change the look of the thermal break to a similar appearance to Hörmann's solution. Both increased in length and changed appearance (thicker).
7	Change the look of the standard thermal break to another one in the supplier's portfolio that is increased in length. This concept is similar to concept 2, where the thermal break is elongated.

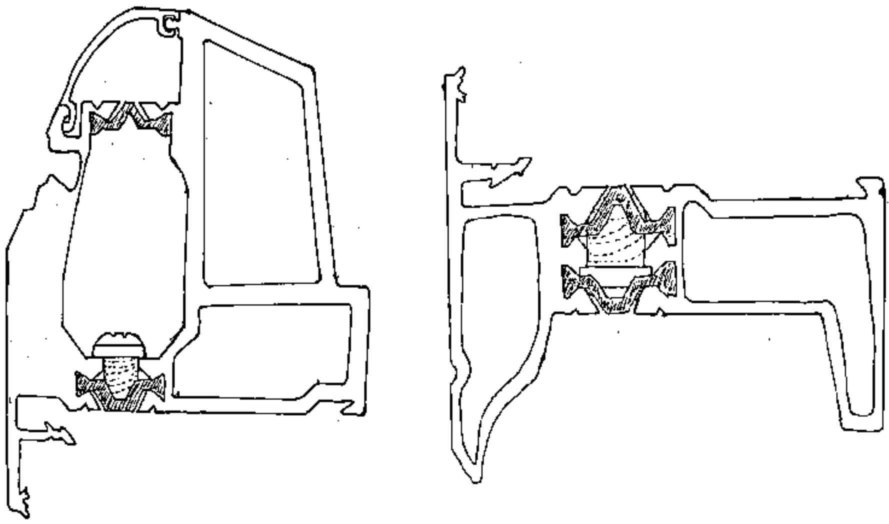

Figure 8.5 Sketch of concept 1.

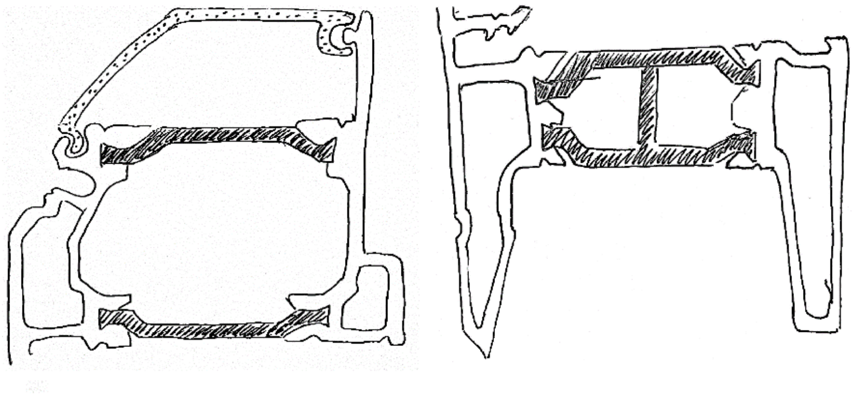

Figure 8.6 Sketch of concept 2.

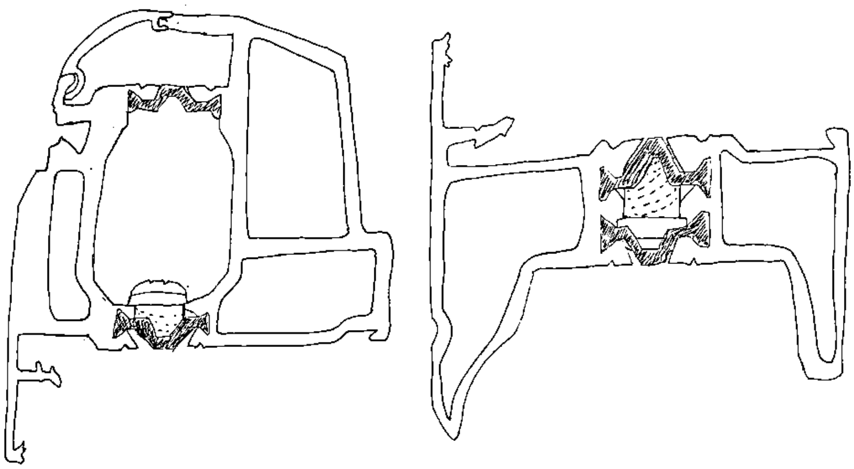

Figure 8.7 Sketch of concept 3.

8.2.2 Window concepts

Some possible solutions for different window alternatives for the frame section are either solutions that already exist at ASSA ABLOY Entrance Systems or new concepts. These alternatives can be seen in the following list, and the new concepts are indicated by *.

- Double Acrylic SAN with "scratch resistant" coating, double sealed (DAS).
- Double Acrylic SAN, double sealed (DSD).
- Triple Acrylic SAN with "scratch resistant" coating, double sealed (TAD).
- Triple Acrylic SAN, double sealed (TSD).
- Double glazed, doubled sealed, made with two 4 *mm* hardened energy glass, filled with argon (DE4D).

- Double glazed, doubled sealed, made with two 6 *mm* hardened energy glass, filled with argon (DE6D).
- The thickness of each layer in the window is increased by 40 *mm* divided by the number of layers.*
- The space between each layer in the window is increased by 40 *mm* divided by the number of layers.*
- Lightweight energy glass.*

9 Concept selection

This chapter presents the process of selecting concepts according to Ulrich and Eppinger's product development process and how the method is implemented in this project.

9.1 Methodology and implementation in project

After the concept generation phase, it is time to select concept according to Ulrich and Eppinger's product development methodology. The selection process can be done according to several different methods, but they vary in their effectiveness.

A two-stage concept selection methodology is suggested, where the first step is concept screening and the second is concept scoring. It is a structured method, but the team is encouraged to improve and combine concepts if possible.

During the screening step, where a few viable alternative concepts are produced, the rough initial concepts are evaluated according to a screening matrix. The concept scoring step is a more detailed analysis, and a finer quantitative evaluation is considered when creating a selection matrix. (Ulrich & Eppinger, 2012)

In this project, different concepts will be prototyped and tested. To limit the number of concepts a decision matrix was created for both the window options and the frame profiles.

9.1.1 Screening matrix

For the screening of the frame concepts the following criteria was chosen, which was inspired by the customer needs and the target specification.

- **Compatibility with OH1082P**: The frames must fit with the 82 *mm* panels, so that the frames can be combined with panel sections.
- **Aesthetical compatibility:** The 82 *mm* frames must be aesthetically compatible with ASSA ABLOY's other existing products.
- **Cost:** The potential cost should be within a reasonable price range.
- **Use of standard parts:** How many parts needs to be altered?

- **Ease of manufacturing:** The manufacturing should be equally demanding as the already existing manufacturing methods used.

For the screening of the concepts for the windows, the following criteria was chosen based on the customer needs and target specifications.

- **U-value:** The windows should have a low U-value.
- **Mass/*m*^{2}:** The windows should be lightweight in order to not disturb the balancing of the door.
- **Visibility:** The visibility through the window should be clear.
- **Light transmission:** The window should allow light to be transmitted into the building.
- **Cost:** The cost should be within a reasonable price range.

The ranking of the concepts for the frame sections profiles can be seen in Table 9.1.

Table 9.1 Concept-screening matrix for the frame profiles

	Concepts						
Selection Criteria	***1***	***2***	***3 (Reference)***	***4***	***5***	***6***	***7***
Compatibility with OH1082P	0	-	0	0	-	-	-
Aesthetical compatibility	0	0	0	-	0	0	0
Cost	+	0	0	+	-	-	+
Use of standard parts	+	0	0	+	-	0	+
Ease of manufacturing	0	-	0	0	-	-	0
Sum +'s	2	0	0	2	0	0	2
Sum 0's	3	1	6	2	1	2	2
Sum – 's	0	2	0	1	4	3	1
Net Score	2	-2	0	1	-4	-3	1
Rank	1	4	3	2	6	5	2
Continue?	Yes	No	Yes	Yes	No	No	Yes

For the scoring matrix, concept 3 was chosen as the reference. All the other concepts were then giving a '+', '- 'or '0' in each criterion depending on if they were better, worse, or equal to the reference concept. When it comes to rating the compatibility with the OH1082P, the concepts where the insulating part is altered was considered to be harder to adjust to fit the OH1082P. That piece can be more restrictive in design because it can be difficult to manufacture. Regarding the aesthetical compatibility, the score was given depending on how much the frame would look like the 42 *mm* frame. For example, if the window would be placed at the same "depth" in the frame as in the 42 *mm* frame.

The alternatives that got a lower score than the reference regarding cost are the ones where the insulating profile made of PA6.6GF25 are changed, which would require an extra tool, except for the ones for the aluminium frames. Creating a custom-made insulating profile is very expensive, because of the costly tools, and an insulating profile from the standard assortment should be preferred. The concepts where the number of changed parts were less got a better score.

For the use of standard parts, the concepts that are considered to keep more standard parts than the reference got a higher score. A lower score was given to the options where many new parts must be bought or changed. Regarding the manufacturing method the '0' score is given if the method is similar and '-' if a new tool has to be bought in combination with a more complex manufacturing method.

The ranking of the concepts for the windows is presented in Table 9.2. For the U-values and mass/m^2, the values in Appendix E were used to rate the different window options. The visibility was scored based on the windows material and the number of layers. Windows made by glass got a higher score compared to the windows made of plastic. The light transmission was 80 % for the DE4D according to documentation provided by ASSA ABLOY Entrance systems and according to AGC the energy glass provided the same transmission. The acrylic-based window got a similar score because there is not a major difference in this area. The cost of a glass window is higher than an acrylic. The DAS/DSD was not a concept that was considered due to the high U-value.

Table 9.2 Concept-screening for the windows

	Concepts						
Selection Criteria	***DAS/DSD***	***TAD/TSD (Reference)***	***DE4D***	***DE6D***	***Increased layer thickness***	***Increased space***	***Energy glass***
U-value	-	0	+	+	0	0	+
Mass/m^2	+	0	-	-	-	0	0
Visibility	+	0	+	+	-	0	+
Light transmission	0	0	0	0	-	0	0
Cost	+	0	-	-	-	-	-
Sum +'s	3	0	2	2	0	0	2
Sum 0's	1	0	1	1	1	4	2
Sum –'s	1	0	2	2	4	1	1
Net Score	2	0	0	0	-4	-1	1
Rank	1	3	3	3	5	4	2
Continue?	No	Yes	Yes	Yes	No	No	Yes

The concepts that were selected are later tested with digital prototypes. The frame profiles are tested regarding resistance to wind load and U-value.

10 Calculations and test of concepts

This chapter presents the methodology for testing concepts as an additional part of the concept selection phase and the method used throughout this project.

10.1 Method and implementation in project

The next part in the product development is according to Ulrich and Eppinger concept testing, meaning for example creating surveys that would be sent to customers (Ulrich & Eppinger, 2012, pp. 165-182). Since this product is a further development of an already existing product, that step was considered unnecessary. Instead, the next step in this project will be an extension of the concept selection. To decide which concept to continue with, the U-value and rigidity of the different concepts must be investigated.

To investigate the performance of the concepts, rapid prototypes were created. The resistance to wind load will be tested by using the simulation tool in the program Solidworks and the U-value will be calculated with the program Flixo. These first tests will be done with very basic prototypes, without reinforcements to handle wind load or other details. Different windows will be tested when a final concept is chosen. After the first tests, some concepts may be ruled out and the remaining will be further developed. After further developing, new tests will be performed.

10.2 Prototypes

The rapid protypes created for the initial tests of the concepts can be seen in Figure 10.1 to Figure 10.4. As mentioned earlier, these prototypes are very simple, to compare the different frame concepts. At this point the concepts are not designed for manufacturing and changes will later be needed in the project. The frame profile parts are made in aluminium and the insulating thermal breaks are made of PA6.6GF25.

Figure 10.1 Concept 1, top-, middle and bottom section.

Figure 10.2 Concept 3, top- middle- and bottom section.

Figure 10.3 Concept 4, top-, middle- and bottom section.

Figure 10.4 Concept 7, top-, middle- and bottom section.

In concept 1, 3 and 4 it is mainly the aluminium frames that are altered, and in concept 7 the thermal breaks are changed. The new insulating profile in concept 7 is a profile that already exists in Insulbar®'s standard assortment. The one used in OH1042FI is 14.8 *mm* long and has the article number 3388. The most interesting articles offered by Ensinger to investigate were the products with article numbers 3339 and 3311, which can be seen in Figure 10.5 and Figure 10.6. The team have been in contact with Ensinger to ensure that the "foot" geometry of 3311, 3339 and 3388 are the same, so the new alternatives could fit the same mounting. Article 3339 is 54 *mm* long, but after further investigation it was realised that it was hard to integrate because of its shape. Instead, it was chosen to continue with 3311 which is 50 *mm* long, since it was more equivalent to the shorter insulating profile already used in OH1042FI.

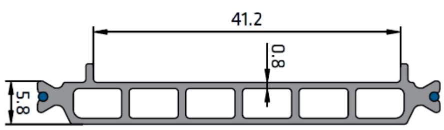

Figure 10.5 Thermal break 3339 (Ensinger, 2021).

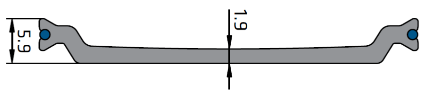

Figure 10.6 Thermal break 3311 (Ensinger, 2021).

10.3 Resistance to wind load tests

The tests regarding wind load on frames at ASSA ABLOY Entrance Systems have previously been performed with physical tests. In this project, the concepts will be evaluated by performing FEA simulations in Solidworks. Since these are quite time consuming, it was decided to only do simple calculations to compare the different concepts at this early stage of the project.

The horizontal profiles are the most interesting to compare, since these parts will bend the most when affected by the wind. It was decided to compare the upper and lower horizontal profiles of each concept to evaluate the designs.

The calculations were performed as described in the standards EN 12444, EN 12604 and EN 12424. The evenly distributed load arising from the wind was calculated with a safety factor according to the standards. The equation for the distributed load without the safety factors can be seen in Equation 10.1. In this case the dynamic pressure is the same as the pressure for the wind load classes. The safety factor for EN 12604 is 1.1 and for EN 12424 it is 1.25. The area is the area where the wind will hit the profile in a normal direction to the surface. The length for the profiles was set to the assumed maximum length of 7 250 mm since this is the worst-case scenario. The maximum bending moment can be calculated according to Equation 10.2 for the load case seen in Figure 10.7 (Swedish Standards Institute, 2001).

$$Q_{wind} = p_d \cdot A \tag{10.1}$$

$$M_b = \frac{Q_{wind} \cdot L}{8} \tag{10.2}$$

, were

Q_{wind} = wind load [N]

p_d = dynamic pressure [Pa]

A = surface area [m^2]

M_b = bending moment [Nm]

L = length of profile [m]

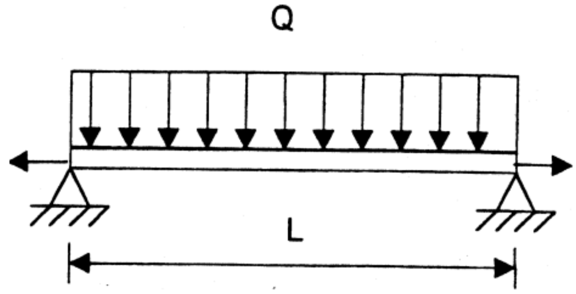

Figure 10.7 The load case presented for a uniformity distributed load in EN 12444.

For each horizontal upper and lower profile, the bending resistance can be calculated according to Equation 10.3. The z-axis is assumed to go through the cross section and the yz-plane is the bending plane. (Broberg, et al., 2018)

$$W_b = \frac{I_x}{|y_{max}|} \tag{10.3}$$

, were

W_b = bending resistance $[m^3]$

I_x = moments of inertia $[m^4]$

y_{max} = maximum length from centre of gravity to end point in y-direction $[m]$

The values for inertia and centre of gravity coordinates were taken from information calculated by Solidworks. With the help of the bending resistance the maximum stress could be calculated, see Equation 10.4. In Figure 10.8 a load case for a beam is illustrated. From this load case the deformation of the beam can be determined by Equation 10.5. Equation 10.6 describes the deformation at the middle of the beam and was used to approximate the deformation of the horizontal profiles (Broberg, et al., 2018). This was used even though the profiles are not beams and the material is not homogeneous. The calculations for each concept can be seen in Appendix F.

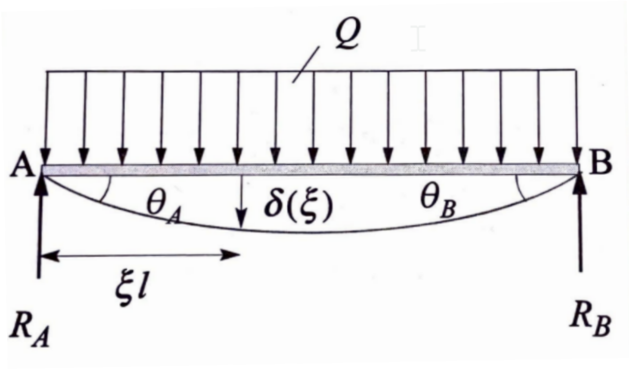

Figure 10.8 Load case for beam (Broberg, et al., 2018).

$$\sigma_{max} = \frac{M_b}{W_b} \quad (10.4)$$

$$\delta(\xi) = \frac{Q_{wind} \cdot L^3}{24 \cdot E \cdot I_x}(\xi - 2\xi^3 + \xi^4) \quad (10.5)$$

$$\delta\left(\frac{1}{2}\right) = \frac{5}{384} \cdot \frac{Q_{wind} \cdot L^3}{E \cdot I_x} \quad (10.6)$$

, were

σ_{max} = maximum stress [*N/m*^{2}]

δ = deformation [m]

ξ = scale of length of beam, see Figure 10.8

E = elastic modulus [*N/m*^{2}]

The results are presented in Table 10.1. It should be noted that the profiles are mock-up prototypes and lack features like reinforcements. Therefore, the deformations are quite large. They are simply calculated to compare the sturdiness of the concepts.

Table 10.1 Results calculation of maximum stress and deformation for the horizontal profiles

Concept		***Max. stress class 2[MPa]***	***Max. stress class 3[MPa]***	***Deformation, class 2 [mm]***	***Deformation, class 3[mm]***
1	***Upper horizontal stile***	18.9	29.4	39.2	61.0
	Lower horizontal stile	46.2	71.9	117.6	182.9
3	***Upper horizontal stile***	17.5	27.3	34.6	53.8
	Lower horizontal stile	45.6	70.9	114.5	178.2
4	***Upper horizontal stile***	27.2	42.2	56.4	87.7
	Lower horizontal stile	44.9	69.8	111.6	173.5
7	***Upper horizontal stile***	16.7	26.0	31.9	49.6
	Lower horizontal stile	45.6	70.9	116.9	181.9

Concept 1 was eliminated since the result was the worst in total. Concept 4 was also eliminated due to the bad values for the upper profile. The two concepts that will be further evaluated is concept 3 and 7.

10.4 U_f-value tests

To test the thermal performance of the different concepts for the frames, U-value calculations were performed. These were performed in a software called Flixo, where the mock-up prototypes of concepts 3 and 7 were tested. The reports from the calculations can be seen in Appendix F. The calculations followed instructions given during an education in the software taught by Heinrich Kopp from the company CAD-PLAN. In these tests the U-values for the frame profiles were calculated, U_f, in order to compare the two concepts. The U-values are perhaps not completely accurate, at least not representative of how the final concept will be, but they were calculated in the same way for both concepts so that they can be compared.

In Flixo, the U-values for sections can be calculated. The ψ-values of the joints can also be calculated. These U- and ψ-values can later be used when a U-value for a complete door is to be calculated. The U-values can only be calculated in one direction and therefore only on horizontal or vertical profiles, no corner profiles, can be tested.

To calculate the U-value of the frame profiles, U_f, the standard EN ISO 10077-2 was used. This standard has been used in previous tests calculating the U-value at ASSA ABLOY Entrance Systems. According to this standard, the calculations of the U_f-value should be performed with panels with a thermal conductivity, known as λ-value, of 0.035 $W/(K \cdot m)$. The interior temperature should be 20°C and the exterior temperature 0°C. The U-value is calculated in Flixo according to Equation 10.7 and a schematic picture that illustrates the model that is used in Flixo can be seen in Figure 10.9. Further information regarding the model is presented in Appendix F. Concept 3 had a U_f-value of 5.78 $W/(K \cdot m^2)$ and 4.06 $W/(K \cdot m^2)$ for concept 7. The team decided to continue the work with concept 7, since it had the lower U_f-value. This is probably due to the longer thermal break, increasing the distance between the aluminium profiles that have a high heat transmission.

$$U_{f\ A-B} = \frac{\frac{\phi}{\Delta T} - U_{p1} \cdot b_{p1} - U_{p2} \cdot b_{p2}}{b_f} \tag{10.7}$$

, were

U_{p1}= the U-value for panel 1 [$W/(K \cdot m^2)$]

U_{p2}= the U-value for panel 2 [$W/(K \cdot m^2)$]

b_{p1}= the length of panel 1 [m]

b_{p1}= the length of panel 2 [m]

ΔT= temperature difference interior and exterior [K]

Φ= heat flow through the frame [W/m]

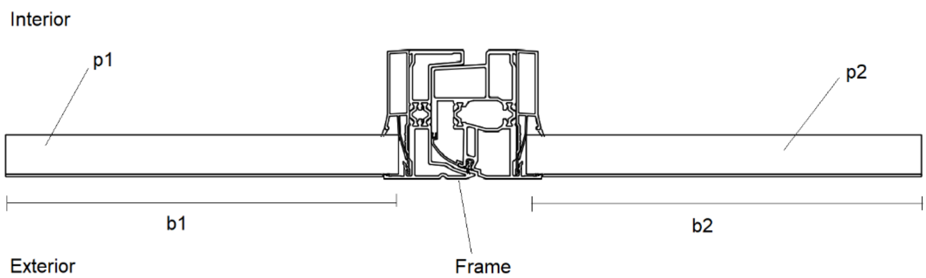

Figure 10.9 Schematic figure of the frame and profiles in the U-value calculations.

11 System-Level design

This chapter presents the process of system-level design according to Ulrich and Eppinger's product development process and how the method is implemented in this project.

11.1 Methodology and implementation in project

The next step in the product development process after the concept development phase is the system-level design phase. This phase includes the definition of the product's architecture, decomposition of the product into subsystems and components, as well as design of key components. Initial plans for the production system and the final assembly are usually defined in this phase. A geometric layout of the product, a functional specification of each of the product's subsystems and a preliminary process flow diagram for the final assembly process is generally the output in this step. (Ulrich & Eppinger, 2012, p. 15)

The first step is to establish the products architecture, but this was dismissed since the product is a part of a subsystem of an overhead sectional door. Instead, only the decomposition of the product into subsystems and components was performed. The preliminary design of key components was looked at in this system-level design phase. An investigation of possible materials was also performed, as well as tests looking at the U-value and wind load resistance. The initial plan for the production was also set.

11.1.1 Subsystems

The frame section can be divided into multiple subsystems and a few of them have different versions of the subsystem. These subsystems, their versions, and the components that each subsystem consist of can be seen in Appendix G. These subsystems are illustrated in Figure 11.1.

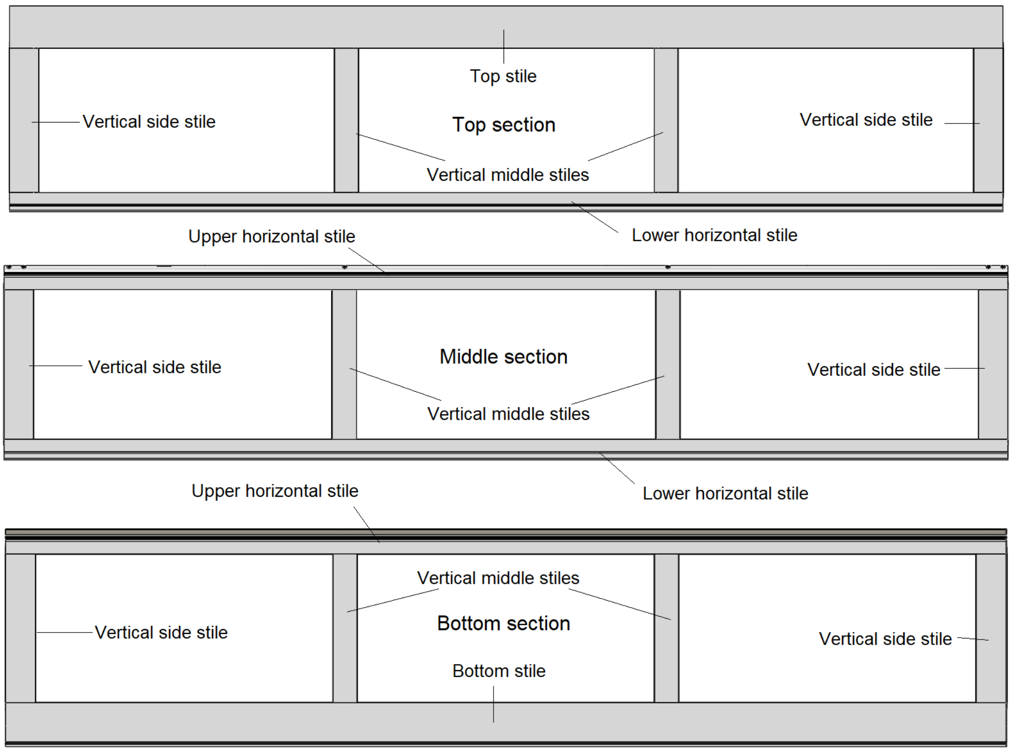

Figure 11.1 Schematic figure of parts in the top, middle and bottom frame section.

11.1.2 Key components

Three components in the frame section were identified as key components. The first key component is the thermal break, which affects the U_f-value greatly. This component also faces challenges if it is to be changed, since custom designed profiles like these can be expensive. Therefore, other standard parts should be considered. Another key component is the screws that holds the frame together. It must be investigated if the screws can hold the new design together, if the placement or number of screws must change, or if the screw needs to be changed to another type. More regarding the investigations of the screws can be seen in section 11.1.5.3 *Screws*. The last key component is the window type which affects the design of the infill profile, but most importantly the U-value of the frame section. Windows comes in a variety of U-value and weights. The weight of the window affects the frame section's total weight greatly, which make this component extremely important, since the weight affects the balancing of the door. The subsystem involving the window does not affect the frame in that sense that the subsystems can be designed separately. Therefore, this subsystem will be further investigated in chapter 12 *Detail design*.

11.1.3 Design of key components

After looking at the subsystems and key components the selected concept was further developed. The finger protection that exists on the OH1042FI was removed in the OH1082FI, since it does not have a function in this thicker frame. Removing this part resulted in changing the insulating profile with article number 3311 to a different one with an appropriate length. The new one used was the 2655 that exist within Insulbar®'s standard assortment. In the 42 *mm* frame, the insulating profile is not placed at the top of the profile, instead there is another plastic part that acts as a finger protection. Concept 7 earlier looked more like the 42 *mm* frame profiles, with the screw placed in the middle and a finger protecting part present. This earlier version can be seen in Figure 11.2. A few additional changes were made to the profile to fit the new length and width perfectly. The screw position was altered, to enable manufacturing and since the U-value probably will be improved by changing the position of the screws. The screws lead heat and can therefore increase the U-value, a greater distance between the screws should therefore be beneficial. The new appearance of the parts can be seen in Figure 11.3.

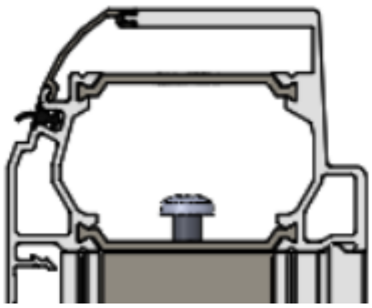

Figure 11.2 Earlier design of concept 7, with plastic part acting as finger protection and screw placed in the middle.

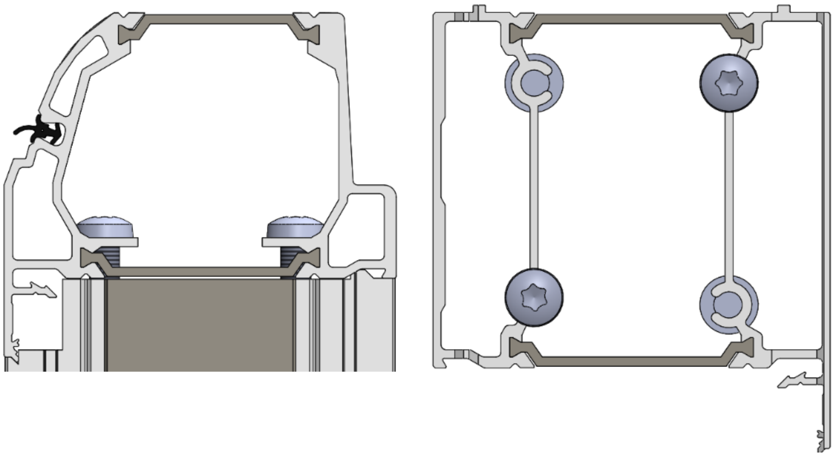

Figure 11.3 New designed stiles for concept 7, profile and overview.

This new design was further developed by looking at possible materials that could be used to fill the profile, to isolate it and improve the U-value. It was also investigated if other materials could be possible for the frame profiles, see section 11.1.4 *Material research.* These options were later tested regarding the U-value and the robustness of the design, see section 11.1.5 *Testing.*

Multiple secondary systems exist for the frame section, like mounting systems and sealings. These parts already exist for the panel section OH1082P and should fit the frame section as well. The same parts will be used for OH1082P as in OH1082FI and therefore does not require any investigation. A secondary subsystem for the frame section is the 82 *mm* panel section since the frame and panel section should be compatible with each other. To test that the panel and frame is compatible with each other, the outline of the frame and panel section was compared to ensure they are exactly same. It was identified that there was an angle on the horizontal upper stile in OH1082P as seen in Figure 11.4, so the new design was not consistent with the 82 *mm* panel. This angle was incorporated and resulted in a new design of the upper stile, see Figure 11.5.

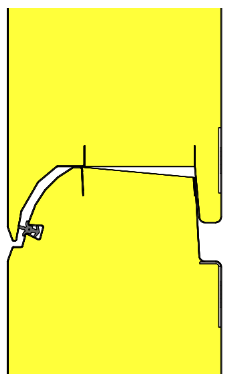

Figure 11.4 Middle part panel OH1082P.

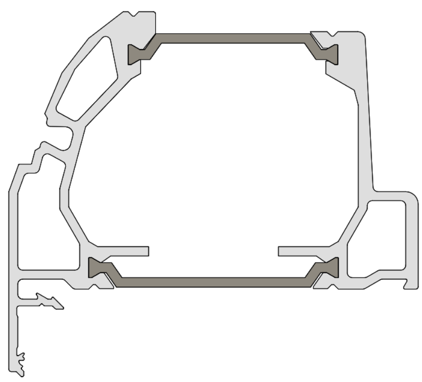

Figure 11.5 Redesign of upper stile.

According to the so-called rulebook for OH1042FI all windows that are going to be investigated use the same type of infill profile. These windows vary in thickness from 25 to 27 *mm*, but the same profile can be used for the energy glass that has a thickness of 26 *mm*.

During a meeting with Anders Löfgren and Marcel Ligthart where the design of the profile was evaluated, it was noticed that the load distribution in the new design had a load flow from the aluminium profile to the insulating part made in PA6.6GF25. The profile can probably not hold this load and therefore the lower profile is redesigned as seen in Figure 11.6 to ensure that the load flow goes from aluminium-to-aluminium. The load point can be seen in Figure 11.7.

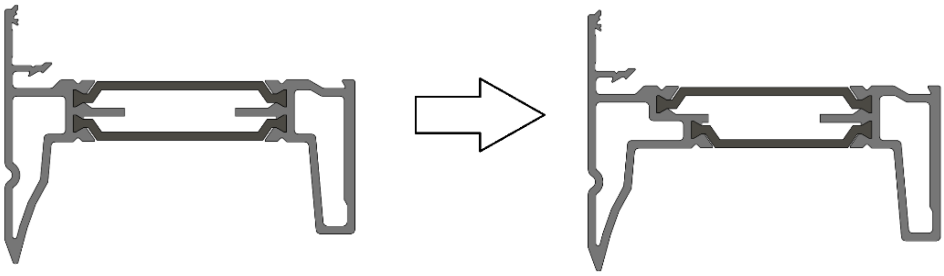

Figure 11.6 Redesign of lower stile.

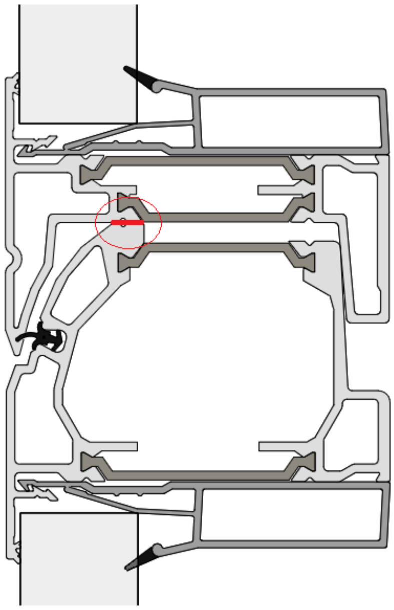

Figure 11.7 Load point is indicated by red line.

The next step after testing the concept was to investigate the production method for the components to define the manufacturing. This is discussed in 11.1.6 *Production methods.* The assembly for the frame sections is referred to in Appendix G and is based on an aluminium design.

11.1.4 Material research

When it comes to the material of the frame, it should be robust and lightweight, as well as having a low thermal conductivity. In order to try to improve the U-value of the frame, as well as decreasing the weight, different options for materials will be looked at. The first concept generation only included solutions with thermal breaks, but now other alternatives will be investigated as well. In Figure 11.8 a chart displaying the thermal conductivity for different materials can be seen. It is desirable that the material has a low thermal conductivity. One possibility is, as mentioned earlier, to fill the aluminium frame profiles with for example foam, to improve the U-value. Another possibility could be to use wood in the middle of the profiles with aluminium on the outside as seen in Figure 11.9, since wood also has a low thermal conductivity.

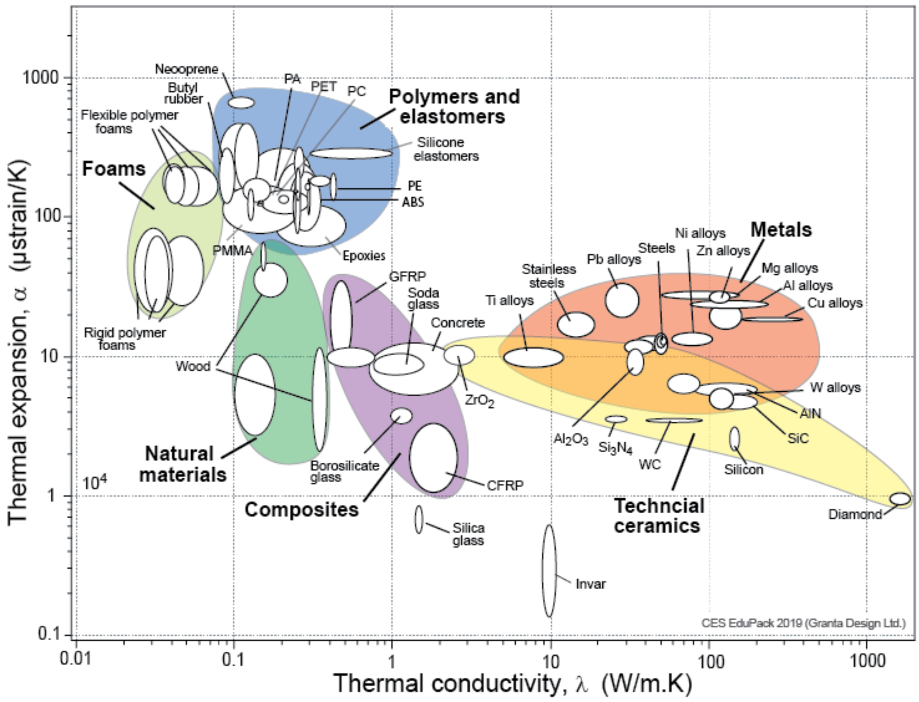

Figure 11.8 Material property chart, thermal expansion vs thermal conductivity. Chart created using CES EduPack 2019, ANSYS Granta © 2020 Granta Design. (Ansys Granta, 2022)

Figure 11.9 Idea for the wood concept.

Aluminium that is used today is interesting since it is both durable and lightweight, and wood is as mentioned interesting as it has a low thermal conductivity and is still rather lightweight. A third alternative could be to change the profiles aluminium parts into polymer or polymer composite.

The aluminium that is used today is EN AW 6060-T66 with the mechanical properties displayed in

Table 11.1. In Figure 11.10 a chart displaying the density and strength of different materials can be seen. The materials mentioned above was considered since they show similar properties as aluminium. Polymers have a much lower thermal transmission and density than aluminium, which makes it an interesting option. The insulating profile acting as a broken cold bridge would not be needed, and the concept could then be one solid profile, see Figure 11.11. A commonly used material in window frames today is PVC, but this is probably not robust enough. There are also negative health aspects with PVC. A regular polymer would probably not be rigid enough, looking at the chart in Figure 11.10. Therefore, it was decided only to look at reinforced polymers, polymer composites, instead of regular polymers.

Table 11.1 Mechanical properties for aluminium, collected from information in Solidworks.

Material	*Density [g/cm^3]*	*Young's modulus [GPa]*	*Tensile strength [MPa]*	*Yield Strength [MPa]*
EN AW 6060-T66	2.755	69	215	160

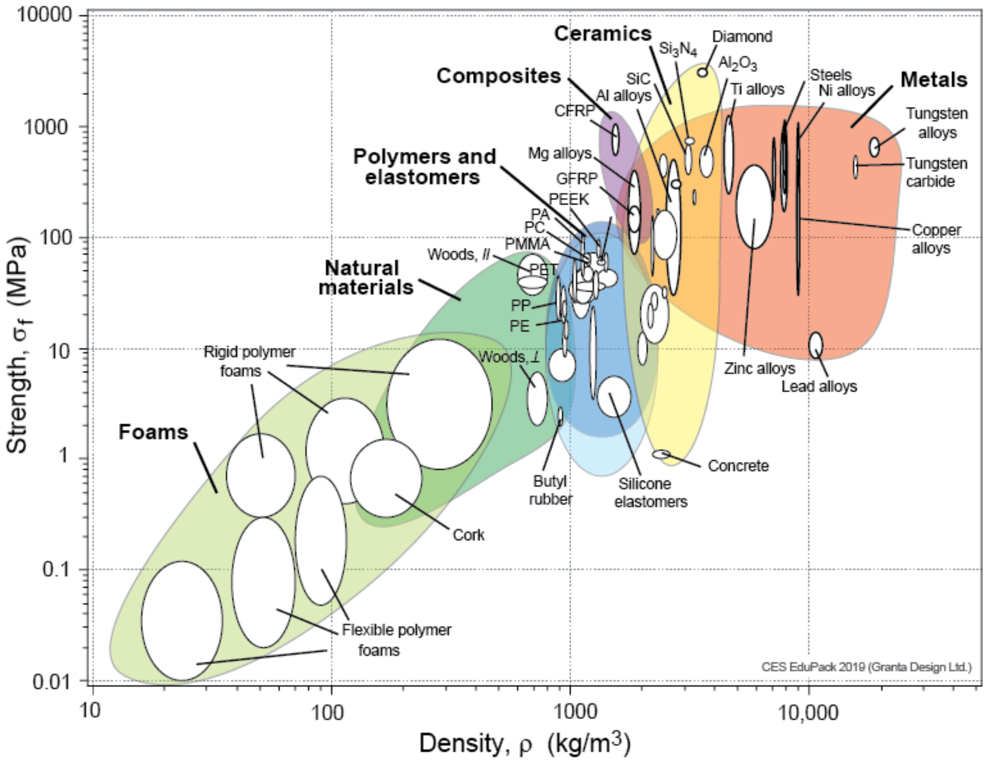

Figure 11.10 Material property chart, strength vs density. Chart created using CES EduPack 2019, ANSYS Granta © 2020 Granta Design. (Ansys Granta, 2022)

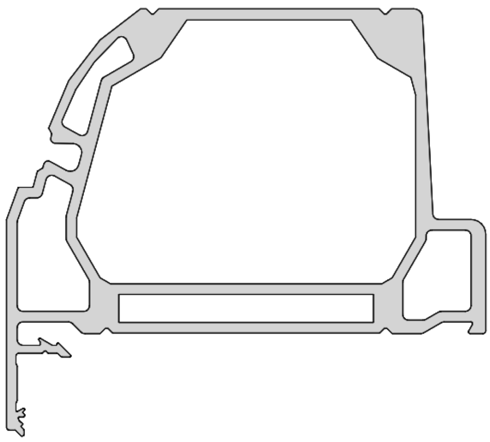

Figure 11.11 Potential design of a profile in a polymer composite.

When looking at possible polymer composites, the fibres were investigated first. Seven possible fibres will be considered, these are carbon, glass, aramid, basalt, boron, polyethylene, and natural fibres.

Carbon fibre is a fibre with a low density, high fatigue strength and elastic modulus, but it requires high energy to produce which makes it expensive. Glass fibres have high strength, good resistance to water and a low cost. It is also the fibre that is most generally applied in construction industry. Aramid fibres are expensive compared to glass fibres. However, they have a low density, high tensile strength, high elastic modulus and sufficient stiffness. Basalt fibres have a high tensile strength and a good durability but has a limited application in civil construction. The properties of these fibres are illustrated in Table 11.2. (Abbood, Odaa, Hasan, & Jasim, 2020)

Table 11.2 Fibres mechanical properties

Fibre	*Density [g/cm^3]*	*Young's modulus [GPa]*	*Tensile strength [MPa]*
Carbon fibre	1.50-2.10	37-784	600-3920
Glass fibre	1.25-2.50	35-86	483-4580
Aramid fibre	1.25-1.45	41-175	1720-3620
Basalt fibre	1.90-2.10	50-60	600-1500

Boron fibres have a high tensile strength and are very stiff but are only suitable for prepreg tape production (Hasan, 2020). Polyethylene fibres have a low density and are commonly produced by melt extrusion but are generally developed as a textile fibre (Mather, 2017).

Regarding natural fibres, wood fibres are the most interesting since they display higher mechanical properties than the other natural fibres. They also display excellent characteristics of low thermal conductivity. It is also a more climate conscious option. Natural fibres are however poorly compatible with polymers, and they lose mechanical properties upon atmospheric moisture absorption. The mechanical properties can be improved by various modifications. The drawback is the moisture absorption. In Table 11.3 mechanical properties for wood fibres made of softwood and hardwood is displayed. (Dai & Fan, 2014)

Table 11.3 Wood fibres mechanical properties

Fibre	*Density [g/cm^3]*	*Young's modulus [GPa]*	*Tensile strength [MPa]*
Softwood	1.5	18-40	600-1020
Hardwood	1.2	37.9	-

Glass fibres were chosen as the most interesting fibres in this project due to the low cost and good mechanical properties. They also have similar mechanical properties as aluminium. Carbon fibre as well as aramid fibre is dismissed because of their high cost. Glass fibre also has a significantly lower thermal conductivity than carbon fibre, which is desired in this case. Basalt fibres are not interesting due to its limited applications and boron fibre is eliminated because of its production. The polyethylene fibre is not considered because it is not suited for this project. The natural fibres are dismissed because of their poor properties.

The next step was to decide on a matrix material that will be combined with the glass fibre. It was decided to use short fibres that are randomly oriented throughout the tests to simplify the simulations, seen in 11.1.5.2 *Wind load simulations*. The different properties for some polymers that can be used as matrix for creating a fibre reinforced polymer can be seen in Table 11.4.

Table 11.4 Properties of polymers (Joladarashi, Kulkarni, & Mahesh, 2021)

Polymer	*Density [g/cm³]*	*Young's modulus [GPa]*	*Tensile strength [MPa]*	*Cost [USD/kg]*	*Flexibility on a scale of 1-12*
PP	0.91	1.6	40	1	8
PE	0.95	0.5	45	0.95	11
HDPE	0.97	1.1	40	1.26	10
PS	1.05	3.5	60	1.92	6
PVC	1.38	3	53	1.15	7
Polyester	1.5	4.5	90	1.28	3
Epoxy	1.6	6	100	6.41	1
Vinyl ester	1.4	3.8	86	4.64	4
Phenolic	1.29	4.8	62	2.56	2
PEEK	1.32	3.6	95	102.52	5
PU	1.12	1.31	40	10.25	9
Rubber	0.92	0.0025	32	0.9	12
PA6.6[a]	1.15	3.1	85	4.12[b]	-

Note: The material with the highest flexibility has the rank 1.
[a] (Ensinger, 2022)
[b] (Elner-Haglund, 2021)

When choosing matrix material, it is desired to have a polymer with a high tensile strength, but none of the alternative offer a tensile strength as high as aluminium. With this requirement only five alternatives exist, which are polyester, epoxy, vinyl ester, PEEK and PA6.6. PEEK is ruled out due to its high cost. The density of the four remaining options is very similar. Unsaturated polyester (UP) is chosen to be an alternative for the matrix since it is the cheapest alternative and has a high young's modulus. PA6.6 is also chosen to be looked at because of its good mechanical properties.

11.1.5 Testing

11.1.5.1 U-value simulations

To compare the different material options for the frame profiles their U_f-value was tested in a program called Flixo. The different options can be seen in Figure 11.12 to Figure 11.18, and the materials are described in Figure 11.19. The tests were performed with models based on the protype designed for the aluminium version. Only the material was changed, not the design. Two of the options were based on adding foam inside the profiles to improve the U-value. Another option was to add wood on the inside. A frame profile made of steel, which has a lower heat transmission than aluminium, was also tested to compare how the material affects the U_f-value. The frames made in polymer composite are either a polyester or polyamide matrix with glass fibre. For the polyester version, the polymer composite material is set to regular polyester since that is the only option that exists in the Flixo material database. It is also assumed that the glass fibre does not have a major impact on the U_f-value, which was confirmed by comparing the U_f-value for a profile with polyamide and for a profile with polyamide with glass fibre. The difference was only 0.06 $W/(K \cdot m^2)$, so it was concluded that the glass fibres did not have a major impact on the U-value. The simulations resulted in the U_f-values seen in Table 11.5. The U_f-value for the existing frame section was also tested to compare it with the new designs.

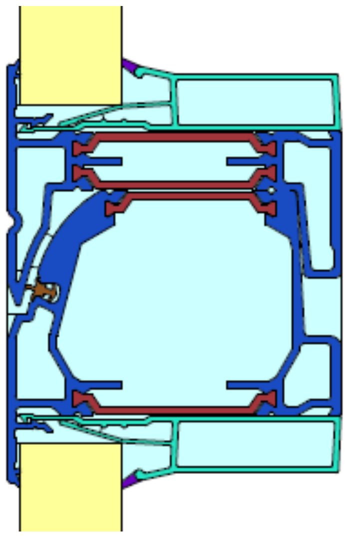

Figure 11.12 Option 1, no added insulation with aluminium frame.

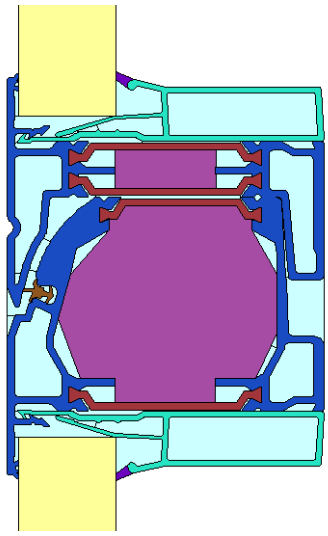

Figure 11.13 Option 2, added polyethylene foam with aluminium frame.

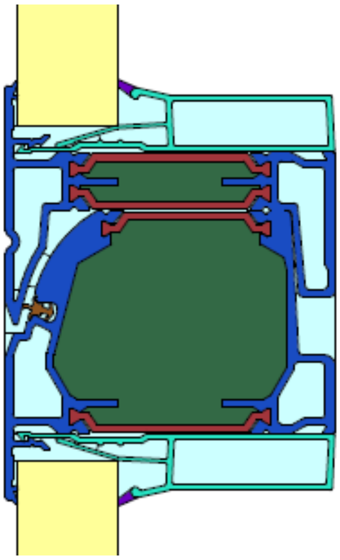

Figure 11.14 Option 3, added expanding elastic foam in both parts, aluminium frame.

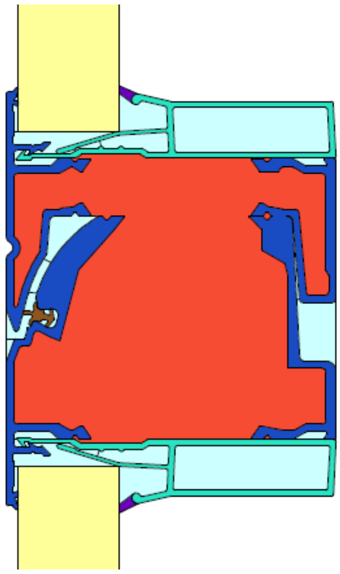

Figure 11.15 Option 4, added wood, aluminium on the outside.

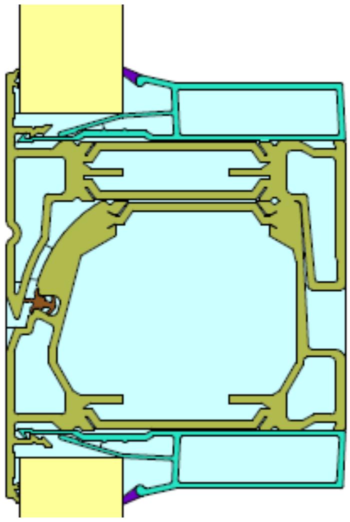

Figure 11.16 Option 5, frame in polyester and glass fibre composite.

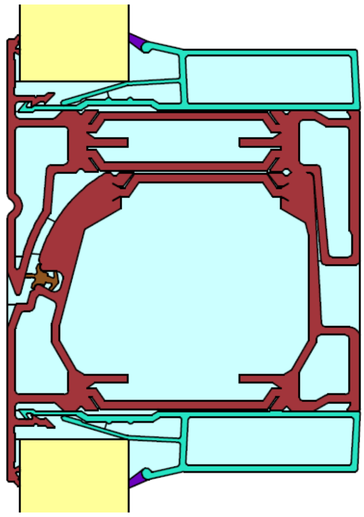

Figure 11.17 Option 6, frame in composite made of PA6.6GF25.

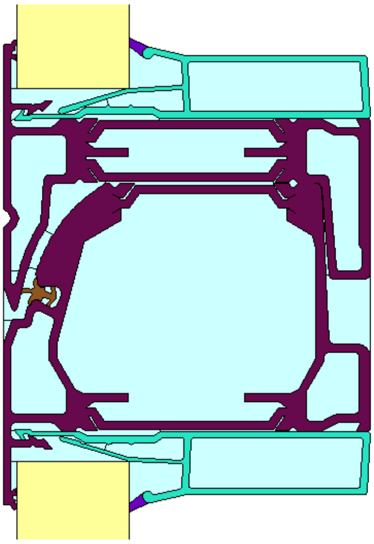

Figure 11.18 Option 7, steel frame.

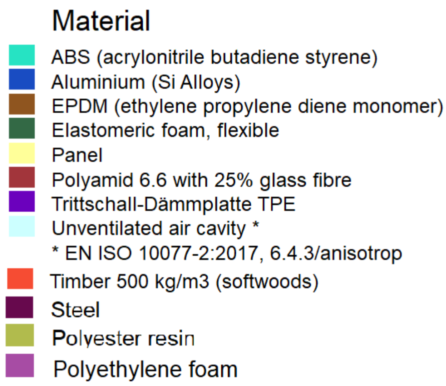

Figure 11.19 List of materials used in Flixo.

Table 11.5 U_f-values for middle section frames

Frame tested	***U_f-value [W/(K·m^2)]***
OH1042FI	3.3
Option 1	2.96
Option 2	1.86
Option 3	1.87
Option 4	2.15
Option 5	1.53
Option 6	1.67
Option 7	5.66

The options with the lowest U_f-values were option 5 and 6. Both options are made in a polymer composite material. The third lowest U_f-value was option 2, which was the aluminium frame filled with polyethylene foam (PE-foam). To be noted is that these calculations are not completely accurate, for example the placement of the foam is roughly estimated. The polymer composite version should probably have a different design from the profiles in aluminium, since there is no need for a thermal break, but here the material is just applied to the aluminium model. Some changes might be made to the design depending on which material that is chosen. The profile made entirely by steel has a much higher U_f-value compared to the option with the profiles in aluminium with thermal breaks. This really shows the importance of the thermal break since steel has a significantly lower heat transmission than aluminium.

11.1.5.2 Wind load simulations

Not only the U_f-value of the profiles is of importance when selecting the material, but also the robustness. The different profiles robustness was tested by FEA-simulations carried out in Solidworks. In these tests the individual stiles of the frame were tested for their worst-case scenarios. The worst case is experienced when the parts are at their maximum length. For the horizontal parts that is 7 250 *mm* and for the vertical parts the length is set to 475 *mm,* since the frame sections usual standard height is 545 *mm*. The tests were carried out on the 42 *mm* OH1042FI frame profiles as well as on the design alternatives for the 82 *mm* frame profiles. The results were then compared. Since the design of the OH1042FI is robust enough, the comparison should give an indication of how the future design of OH1082FI would behave. The boundary conditions used in the tests, as well as the load application can be seen in Appendix H. The pressure that is applied represent the wind load for class 2 and 3 with the safety factors that was used in the earlier calculations in section 10.3 *Resistance to wind* load. The results are presented in Table 11.6 where the profiles are assumed to be made from the same materials as OH1042FI, which is aluminium EN AW 6060-T66 and PA6.6GF25. The tests were also carried out on the parts reinforced with wind trusses, that are intended to handle higher wind load. The polymer composite version was also tested later.

Table 11.6 Simulation results regarding wind load (Aluminium and PA6.6GF25)

Part	*Wind load class*	*Stress [MPa]*	*Deformation [mm]*
Upper stile 42 *mm*	Class 2	32.95	28.01
	Class 3	51.26	43.56
Upper stile 82 *mm*	Class 2	10.13	4.44
	Class 3	15.76	6.91
Upper stile with short truss 82 *mm*	Class 2	28.20	2.36
	Class 3	43.87	3.67
Upper stile with long truss 82 *mm*	Class 2	30.05	1.89
	Class 3	46.74	2.94
Lower stile 42 *mm*	Class 2	33.76	28.27
	Class 3	52.52	43.97
Lower stile 82 *mm*	Class 2	14.96	6.03
	Class 3	23.27	9.37
Side stile 42 *mm*	Class 2	3.26	$5.76 \cdot 10^{-3}$
	Class 3	5.08	$8.95 \cdot 10^{-3}$
Side stile 82 *mm*	Class 2	1.75	$4.28 \cdot 10^{-3}$
	Class 3	2.72	$6.66 \cdot 10^{-3}$
Vertical middle stile 42 *mm*	Class 2	2.23	$5.51 \cdot 10^{-3}$
	Class 3	3.47	$8.57 \cdot 10^{-3}$
Vertical middle stile 82 *mm*	Class 2	1.27	$3.33 \cdot 10^{-3}$
	Class 3	1.97	$5.17 \cdot 10^{-3}$

The OH1082FI stiles experienced less stress and deformation than the OH1042FI according to the test, which was expected. This indicates that the new aluminium design for the 82 *mm* design most likely will fulfil the classification regarding resistance to wind load according to class 2 and 3.

The polymer composite version was also tested regarding its robustness. The same load cases and boundary conditions were applied to the frame section with the parts made from polymer composite. This test was applied to unsaturated polyester with 15 % glass fibre composite and with 29% glass fibre, as well as a composite in polyamide with 25 % glass fibre and another with 50 % glass fibre. The material properties for these materials are presented in Table 11.7. One of the unsaturated polyester composites also had mineral powder added, since this was one material datasheet that was found, which showcased the mechanical properties needed. In Table 11.8 the stress and deformation for one part of the composite frame section is displayed for the different alternatives. The tests were only carried out on one part at this time since it would be quite time consuming to test all the parts. This should give an indication of how the polymer composite will perform, if compared with the previous tests.

Table 11.7 Material properties of composites

Material	*Density [g/cm³]*	*Young's modulus [GPa]*	*Tensile strength [MPa]*
PA6.6GF25[a]	1.12	2.62	90
UP+GF15+MD55[b]	2.05	12	55
PA6.6GF50[c]	1.61	9	115
UP-GF29[d]	1.85	4.028	47

[a] The materials mechanical properties are collected from Solidworks because other parts in this material already exist in the OH1042FI.

[b] (Matmatch GmbH, 2022)

[c] (Ensinger, 2022)

[d] (Findik, Misirlioglu, & Soy, 2002)

Table 11.8 Simulation results regarding wind load for the upper part made in composite

Part	*Wind load class*	*Stress [MPa]*	*Deformation [mm]*
Upper part - UP+GF15+MD55	Class 2	7.17	20.89
	Class 3	11.16	32.50
Upper part - PA6.6GF25	Class 2	8.05	95.92
	Class 3	12.52	149.2
Upper part - PA6.6GF50	Class 2	7.97	27.87
	Class 3	12.40	43.35
Upper part - UPGF29	Class 2	7.17	62.24
	Class 3	11.16	96.86

According to the results it can be determined that the composite with polyamide and 25 % glass fibre showed larger deformations than the OH1042FI frame and will therefore not be investigated further. The polyamide composite with 50 % glass fibre shows similar deformations as the upper stile in OH1042FI and is therefore considered to be robust enough. The polyester composite with 15 % glass fibre and mineral powder showcased lower deformation compared to the 42 *mm* frame section, however the density is rather high for this material. Since the intention of using a polymer composite was to lower the weight, as well as the U-value, this material was ruled out. The result for the polyester with 29 % glass fibre experience larger deformations than the polyamide with 50 % glass fibre, which according to these tests are the better option among the composite alternatives.

A meeting with Anders Löfgren, Daniel Eliasson and Marcel Ligthart at ASSA ABLOY Entrance Systems was held to discuss the different material options. It was determined that the most interesting materials were polyamide with 50 % glass fibre and the aluminium frame with PE-foam. The expandable elastic foam was ruled out since the manufacturing method was considered too complex to be used in the assembling. This resulted in two options for the design, either an aluminium frame with insulating profiles in PA6.6GF25 and PE-foam or an PA6.6GF50 composite frame.

Before deciding on the PA6.6GF50 it was investigated if a profile in this material would be possible to manufacture. The team therefore contacted Roger Seahorse at Polybase AB in Staffanstorp, which is a company that extrudes profiles made in plastic and polymer composites. According to them, it is not common to extrude profiles made with PA6.6 that has a glass fibre content higher than 30 %. The profile would then need a lot of post-processing.

It was decided to look at manufacturers that focus on producing fibre reinforced plastic profiles offering other manufacturing methods. The team chose to only contact companies located in Europe. The team got in contact with Röchling, a company that produces products in plastic and composite materials. Röchling is based in Germany and the team was in contact with was Lars Ameln, that is head of sales in the pultrusion sector. A rough sketch of the intended design for the upper part was sent and the answer was that the profile was possible to manufacture, but some modifications and simplifications must be made. It was assumed that a high fibre content is expensive, and therefore alternative ways of reinforcing the profiles were looked at. Then perhaps PA6.6GF25 could be used.

The first option was to add reinforcements in the same material as the profile, simply by changing the geometry of the inside of the profiles. In the first option the reinforcement was put horizontally since it is in that direction the load from the wind is applied. The second option that was looked at was reinforcing the profile with metal beams, in either aluminium or steel. These beams could be put into the frame profiles. These versions can be seen in Figure 11.20 and Figure 11.21.

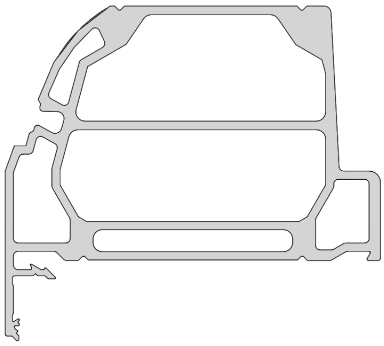

Figure 11.20 New design of upper part made in PA6.6GF25.

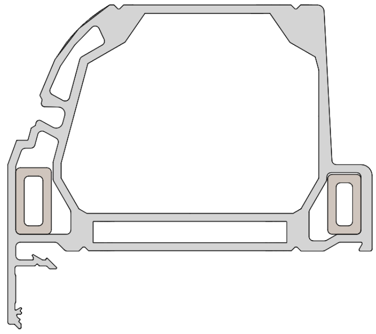

Figure 11.21 Upper composite part reinforced with metal beams.

The tests were set up in the same way as the previous test with fixed ends and pressure along the upper parts front side. The results from the test can be seen in Table 11.9.

Table 11.9 Wind load simulation for new PA6.6GF25 designs

Part	*Wind load class*	*Stress [MPa]*	*Deformation [mm]*
Upper part, new design – PA6.6GF25	Class 2	5.91	16.01
	Class 3	9.19	24.94
Upper part – PA6.6 reinforced with steel beams	Class 2	0.43	$2.99 \cdot 10^{-2}$
	Class 3	0.66	$4.65 \cdot 10^{-2}$
Upper part – PA6.6 reinforced with aluminium beams	Class 2	0.34	$7.91 \cdot 10^{-2}$
	Class 3	0.53	$1.23 \cdot 10^{-1}$

According to the results, the new design of the composite part will be able to withstand the wind load better than OH1042FI. This also applies to the upper part reinforced with steel beams, as well as the one reinforced with aluminium beams.

These additional concepts were also tested regarding their U-values, to verify that the new design did not affect the U-value in a negative way. These tests were performed in the same way as in section 11.1.5.1 *U-value simulations*. The lower part was not altered during these tests, only the upper part. The results are presented in Table 11.10.

Table 11.10 U-values for middle frames

Frame tested	*U-value [W/(K·m²)]*
New PA6.6GF25 design	1.61
PA6.6GF25 reinforced with steel beam	1.78
PA6.6GF25 reinforced with aluminium beam	1.78

The new design reinforced with an extra horizontal beam in the middle got the best U-value of the three options. This solution does not need additional parts, which makes this solution the most desirable. Since the alternative with no metal reinforcements was considered the best, other ways of reinforcing the profiles in composite was looked at as well, see Figure 11.22, to see if an even better or simpler result could be achieved.

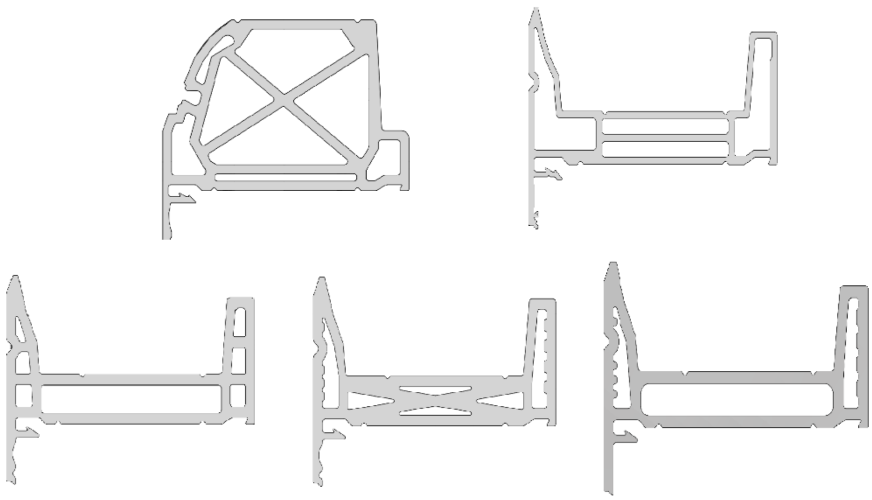

Figure 11.22 Different ways of reinforcing the polymer composite profiles.

A wind load study where a complete frame was tested was conducted to compare the designs. A 3 044 *mm* middle section was tested, which included two vertical middle parts. The sides were set to a fixed geometry, so the frame was fixed on each end. The pressure was applied to each part in the same fashion as in the earlier tests, but only for wind load class 3. The sturdiest design of the upper and lower profiles can be seen in Figure 11.23. Here the thickness of the walls is altered to 3 *mm* and some parts are simplified, according to requirements from Röchling.

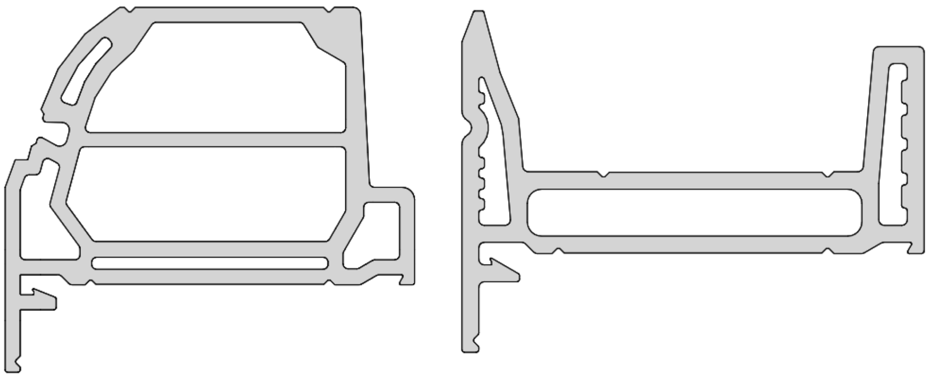

Figure 11.23 Sturdiest designs of upper and lower part.

11.1.5.3 Screws

The screws currently used in the 42 *mm* insulated frame are torx pan head tapping screw. These follow the standard ISO 14585, and the name of the screw is C-ST6.3×38. The screw is a self-tapping screw, meaning that there is no need for threads in the parts.

These screws have been used in different products at ASSA ABLOY for a long time. There are no strength calculations or alternative standards that have been considered for this screw in the OH1042FI. It has been indicated to the team that the same type of screws can be assumed to work if more screws are added to the design. However, with the placing and added screws as seen in Figure 11.24 a bending force will affect the flange, and this should be investigated.

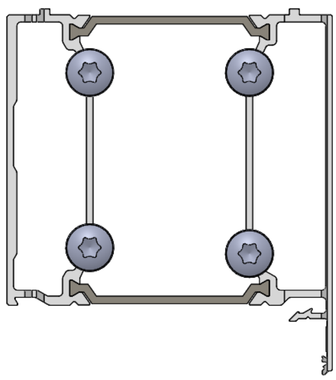

Figure 11.24 New screw placement.

After a meeting with Marcel Ligthart, Anders Löfgren and Daniel Eliasson it was determined that there are three possible screw solutions for the OH1082FI, which all involve self-tapping screws. The three possible solutions are the screw used in OH1042FI, a Taptite screw and a Nassau screw.

It was decided to first investigate if the existing screw could be used in the construction. The screws are not affected by any external loads, and only hold the frame together. To see how the screws affected the upper and lower stile of the frame was done by investigating how the tightening torque from the screws affects the flanges. The tightening torque for the specific screw could not be found and therefore a metric screw with similar dimensions was looked at, in this case M6. According to the standard ISO 898/1 it is stated that an M6 screw has a tightening torque between 7.7 to 11.3 *Nm* based on the friction, if the property class is 8.8 (BOSSARD, 2021). The property class 8.8 was chosen to look at since it is a class that has medium strength. In the standard ISO 2702 that applies for the existing screw it is stated that the maximum torque that can be applied to the screw is 13.6 Nm (Swedish Standards Institute, 2008). With this information the tightening torque for C-ST6.3×38 is approximated to 11 *Nm* in the tests performed in Solidworks.

The study was first performed for the upper and lower stile in aluminium and the results for the stresses and deformations can be seen in Appendix I. The screws were applied to one side of the profiles, and the deformation and stress were only looked at locally. In Solidworks a few boundary conditions were applied. All parts in the lower stile assembly were set to be in contact with each other, so the parts wound not penetrate each other. The screws were applied as a connection, as a bolt specified to be a counterbore screw. The measurements for the screws were taken from the standard ISO 14585 which was 12 *mm* for the head diameter and 6.3 *mm* as the nominal shank diameter (Swedish Standards Institute, 2011). The screw was determined to be rigid, the material set to a steel alloy and the torque was set to 11 *Nm*. In Figure 11.25 and Figure 11.26 the connections can be seen. The maximum stress that occurred was 62.08 *MPa*, which is below the yield strength of 160 *MPa* for the aluminium used. This indicates that the structure will hold, and the deformations are also extremely small in both the simulations for the upper and the lower stile.

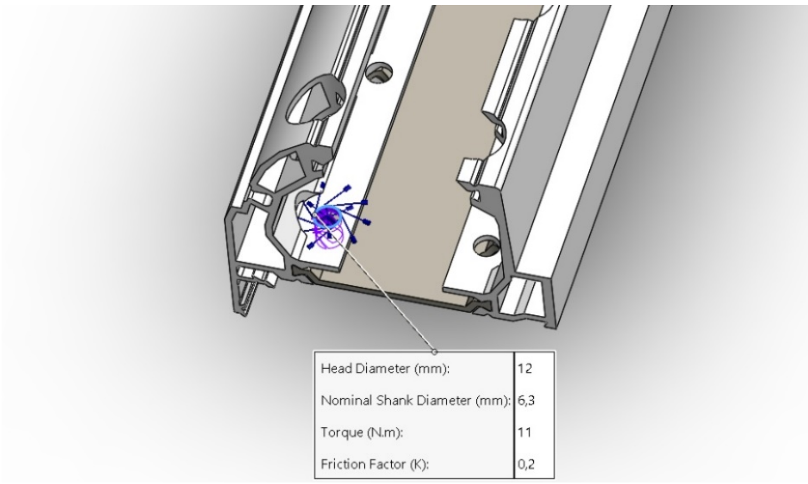

Figure 11.25 Connections applied in the upper stile's simulation.

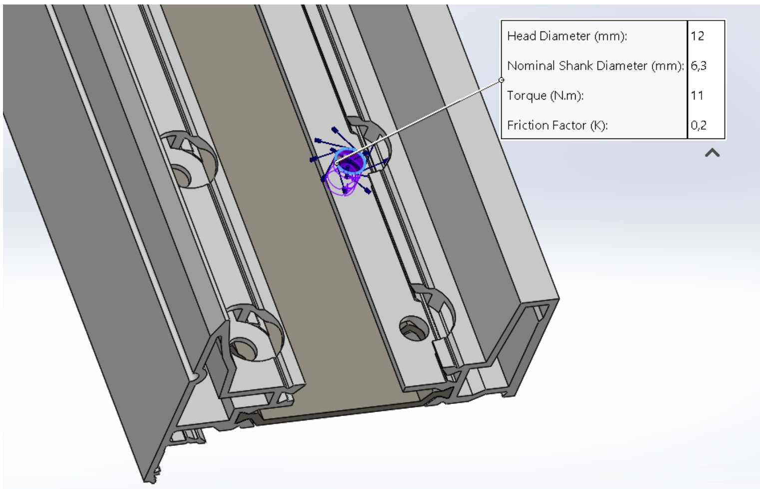

Figure 11.26 Connectors applied in the lower stile's simulation.

The same tests were performed for the composite version. The composite material PA6.6GF25 has a yield strength of 103.65 *MPa* according to the material in Solidworks. For this version, some simplifications were made to the model in these simulations since the design was too complex for the simulations and therefore very time consuming. The screws were applied to one side of the profiles, and the deformation and stresses were only looked at locally there. The small section that sticks out from both the upper and lower part that is in contact with the window was removed because of all the small details due to their complexity. The results from the simulations are presented in Appendix I. In this case the screw placement has been changed for the lower part and longer screws will be needed. C-ST6.3×45 and C-ST6.3×50 are longer screws that can be used instead of the existing C-ST6.3×38. In this placement they would get a similar engagement of the thread as the C-ST6.3×38. From the simulations it could be seen that the highest stress was in the lower part, and it was 2.76 *MPa*, which is below the yield strength and indicates that the part will be rigid enough.

From the tests it can be determined that the existing screws will be good enough for both alternative constructions. For the polymer composite version, the screws need to be of a longer version. Since the existing screw works with the construction, it was decided not to investigate the other options. It is also beneficial for ASSA ABLOY Entrance System to use the same kind of screws as in OH1041FI because the same supplier can be used, and the supplier will probably also have the screws in a longer model.

It should be noted that when using self-tapping screws in fiberglass the drilling tip of the screw can become dull quickly as it encounters the glass fibres, which could lead to cracking in the glass fibres and the gel coat. To avoid cracking proper installation techniques must be used, like drilling a pilot hole before screwing in the self-tapping screw. (RS Components Ltd, n.d.)

11.1.6 Production methods

To verify that the designs are manufacturable, the different possible methods will be discussed. The 42 *mm* insulated frame include pieces that are bought from different suppliers and is assembled at ASSA ABLOY Entrance Systems. The insulating profiles are bought from the standards assortment at Ensinger. The aluminium parts are bought from a supplier called BOAL, these parts are custom made, after ASSA ABLOY Entrance systems' design. The aluminium parts are produced by extrusion and if the 82 *mm* thick profiles are going to be produced in aluminium, the same method will be used.

Extrusion is a process where a screw pump with one or two rotating screws under high pressure push a machined mass forward in a cylinder and out through a nozzle. The design of the nozzle determines the final shape of the extruded profile (NE Nationalencyklopedin AB).

The team contacted BOAL to investigate the possibility to fill the profiles with foam, but this is not something they offer. The filling of the foam would then have to be made by ASSA ABLOY Entrance Systems. But as earlier mentioned, this is overly complex. An option could be to place a PE-foam profile in the stile. These PE-foam profiles can be bought in rectangular and cylindrical shapes by length and can be added in the existing assembling process.

If it is decided to continue with the composite profiles, then a new supplier must be found. The composite profiles would then be made by pultrusion, which is a continuous process for manufacturing composites with constant cross-sections or structural profiles having significantly long length (Joshi, 2012).

The infill profiles are made through extrusion as well. The parts are custom made and the new design of the infill profiles needs to be designed in consideration to this manufacturing method. The new infill is going to be assembled in the same way as in the OH1042FI design, but the frame profiles and infill profile will have a new design.

12 Detail design

This chapter presents the process detail design according to Ulrich and Eppinger's product development methodology and how the method is implemented in this project.

12.1 Methodology and implementation

In the detail design phase, the goal is to complete the specification of the geometry, materials, and tolerance of all unique parts in the product as well as identifying of all the standard parts that are to be acquired by suppliers.

Firstly, a process plan is to be established. Tooling is to be designed for each part that is to be produced. In the end of this step, drawings describing the geometry, production tooling, specifications, and the process plan for fabrication as well as assembling of the product should exist.

Three critical issues considered throughout the product development should be solved during this phase. Those are material selection, production cost and robust performance. These can be solved by working with design for Environment and design for Manufacturing for example. (Ulrich & Eppinger, 2012)

The first part in the detail design process is to determine the material for the frame section. This was a crucial phase because depending on the material the environmental impact, the manufacturing method and geometry would be different. More regarding the material selection can be seen in 12.2 *Material* selection.

After the material for the frame was decided, the frame's stiles were looked at again to see if further changes had to be made, see 12.3 *Further design of frame* profiles. The top and bottom stile were tested to see if they were robust enough or if the parts needed to be redesigned. These parts had not been tested earlier since the focus was on the middle section, due to the project's time limit. After the frames profiles have been designed further the next step involved the production of the profiles and how they could be designed for manufacturing. The last part in the detail design was to create drawings displaying the parts in the frame section assembly.

12.2 Material selection

When deciding between the aluminium and PE-foam design and the polymer composite design, different aspects must be considered. Both regarding the manufacturing of the material, the durability, as well as the environmental impact. The composite option was the most interesting alternative since it would result in the lowest U-value and weight. However, the composite version faces some challenges regarding manufacturing, especially when it comes to the tooling cost. The team contacted Röchling, who suggested a change to a polyester and glass fibre composite called Durostone® UPGMZ-LP. Röchling also provided an approximative cost for a pultruded profile in this material. For the upper profile, the price was estimated to 20.50 EUR/*m*, if over 5 000 meters of profiles would be bought. The price was based on the current cost of raw material, energy, and transportation. The tooling was estimated to be between 28 000 to 30 000 EUR for the upper part, according to Röchling. Together with the other parts, that results in a total tooling cost of 132 500 EUR. The estimated price for all composite parts, and the tooling cost, can be seen in Table 12.1 and Table 12.2.

Table 12.1 Price for polymer composite parts per meter

Part	*Price [EUR/m]*
Upper part	20.50
Lower part	23.00
Side part	29.25
Vertical middle part	25.35

Table 12.2 Tooling cost for polymer composite parts

Part	*Tooling cost [EUR]*
Upper part	28 000-30 000
Lower part	33 000-36 000
Side part	33 000-36 000
Vertical middle part	33 000-36 000

The cost per meter for the stiles in 42 *mm* frame section, can be seen in Table 12.3. The tooling cost is considered to not be included. The price for the new 82 *mm* aluminium profile would be more expensive due to higher raw material use and the addition of the PE-foam. On the other hand, PE-foam profiles in various shapes have a relatively low cost, between 1.5 to 3 EUR/*m* (Fogspecialisten, 2022).

Table 12.3 Price for OH1042FI parts per meter

Part	*Price [EUR/m]*
Upper stile	12.14
Upper stile with short truss	16.64
Upper stile with long truss	18.54
Lower stile	11.32
Side stile	15.59
Vertical middle stile	12.47
Top stile	20.19
Bottom stile	22.35

The price for the insulating profiles could not be provided by Ensinger because of long lead-times on PA6.6. The insulating profiles considered for the 82 *mm* frame are wider, and therefore the price is estimated to be higher than for the thermal break used in OH1042FI.

The tooling costs for the existing aluminium parts was provided by Marcel Ligthart as seen in Table 12.4. It can be concluded that the total tooling cost for the existing middle section including the two reinforced options is 14 425 EUR. The total tooling cost for all the aluminium parts is 23 325 EUR.

Table 12.4 Tooling cost for OH1042FI for aluminium parts

Part	*Tooling cost [EUR]*
Upper front part	1 450
Upper back part	1 450
Upper back part with short truss	1 850
Upper back part with long truss	1 850
Lower front part	1 450
Lower back part	1 450
Side front part	750
Side back part	1 275
Vertical middle front part	1 450
Vertical middle back part	1 450
Top front part	3 350
Top back part	1 850
Bottom front part	1 850
Bottom back part	1 850

The wind load tests were carried out again with these two remaining alternatives, the aluminium version and the polyester composite version. These tests were carried out on a frame section with the length of 3 044 *mm* and four vertical stiles. In Table 12.5 the results are presented, and the simulations can also be seen in Appendix J. As expected, the aluminium version experiences less deformation than the polyester composite version. The deformation in the polyester composite version is although considered to be acceptable since it is not too far away from the deformation in the 42 *mm* frame.

Table 12.5 Wind load testing on middle section

Material	*Wind load class*	*Stress [MPa]*	*Deformation [mm]*
Aluminium and PA6.6GF25 42 *mm*	Class 3	41.11	1.10
Aluminium and PA6.6GF25 82 *mm*	Class 3	10.14	0.31
Durostone® UPGMZ-LP	Class 3	12.13	1.55

The advantages with having a frame made from a polymer composite is as mentioned the good isolation properties offered as well as the low weight. The design would also only include one part per profile, instead of the three as in the aluminium version. The aluminium version on the other hand, offers an aesthetic more similar to the current frames in the portfolio at ASSA ABLOY. The aluminium version also displays less deformation. Another important aspect to look at is the environmental impact of the two different versions. In short, polymer composites display issues when it comes to recycling, where aluminium on the other hand functions well when it comes to recycling. The PE-foam that is supposed to be in the aluminium version can be recycled. So, for the composite version, the whole part shows difficulties in recycling, although the fibres can be recycled. For the aluminium version, the aluminium parts as well as the PE-foam shows no difficulties in recycling, but it also includes the thermal break in PA6.6GF25. This thermal break is not easy to recycle but it is needed for the insulation of the frame section.

According to a Life Cycle Assessment read by the team, ordered by a window company, the percentage of recycled aluminium used has a significant impact when comparing an aluminium window frame to a frame made from polyurethane with glass fibre. Also stated in this report is that the aluminium manufacturing is more energy consuming than the polymer composite one. In this report some breakeven points were established, that displays at what percentage of recycled aluminium the life cycle energy and impacts for aluminium and the polyurethane composite windows are equal. These breakeven points can be seen in Figure 12.1. What is not compared in the Life Cycle Assessment mentioned, is the U-value. Since the polyester composite version will have a lower U-value, providing better insulation, energy consumption in buildings in cold climates can be lowered. So, to summarize, the polyurethane composite had a lower cradle to grave energy consumption and climate change compared to aluminium. The aluminium could be as good if the aluminium is recycled. The recycling of composites faces challenges, in difference from aluminium. On the other hand, a polymer composite displays good isolation properties. It also should be considered that these door frames should have a long lifespan, 100 000 cycles as the existing OH1042FI.

The Break-even Point Analysis

(Recycled Aluminum Weight%)

Energy	Climate Change	Acidification	Eutrophication	Smog Creation
84%	80%	70%	12%	57%

Figure 12.1 Break-even points for aluminium and composite windows. (Covestro, 2015)

In Table 12.6 the advantages and disadvantages for the different material options are presented.

Table 12.6 Advantages and disadvantages for the material options

Material	*Pros*	*Cons*
Aluminium, PA6.6GF25 thermal breaks and PE-foam	• Same aesthetics as OH1042FI • Same manufacturer for profiles could be used • Better resistance to wind load • Lower tooling cost	• Heavy • Need for thermal break since aluminium has high heat transmission • Many moulds (8 moulds) • High energy consumption • Risk of condensation
Polymer composite (Durostone® UPGMZ-LP)	• Lightweight • Low U-value • No need for thermal break • One part for each profile • Fewer moulds (4 moulds)	• Recycling issues • Not same aesthetics as OH1042FI • Higher manufacturing cost • Complex method to implement screws • Not as rigid

To conclude, the composite material was superior regarding insulation, but was ruled out in the end because of the extremely high tooling cost. The work was therefore continued with the aluminium version.

12.2.1 Design for environment

The environmental effects for aluminium have been briefly discussed in the previous section. Something that should be considered is that the profiles currently purchased from BOAL are in average made from 30 % recycled aluminium, some profiles consist of more and some less. If the amount of recycled aluminium could be increased, the environmental impact of the aluminium frame could be improved. According to BOAL the amount of recycled aluminium can go up to 60 %, and the percentage does not affect the price. The properties can change slightly based on the mixture. A higher percentage of recycled aluminium would be interesting, and this can hopefully be achieved by demanding it from BOAL or changing supplier.

The polyethylene foam, which will be inside the profiles, is a material that is recyclable and can be reused. The composite PA6.6GF25, that the thermal breaks are made of, is not easy to recycle. The material is only partly recyclable and generally only the glass fibre can be recycled.

12.3 Further design of frame profiles

12.3.1 Design changes

To allow the insulating profiles to be rolled into the aluminium profile, a cut-out in the aluminium part must be present. In the current design the aluminium part does not allow the insertion of the insulating profile, therefore the design was altered, see Figure 12.2. The current design also has a lot of excess material, which was now decreased.

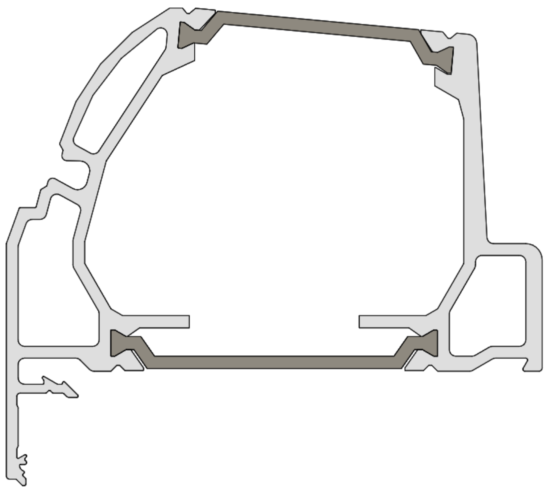

Figure 12.2 Updated design of upper profile in the middle section.

Another design change was to use PE-foam pipes instead of cylinders. The PE-foam pipes are easier to deform and therefore easier to fit into the profiles which will facilitate the manufacturing. However, this change affects the U-value slightly due to a small airgap in the middle of the profile, which makes the U-value moderately higher.

12.3.2 Robust performance remaining parts

So far, only the middle sections stiles have been tested regarding the resistance to wind load, and not the top and bottom sections stiles. Now, these stiles were tested at a length of 7 250 *mm* and the boundary conditions and loads were the same as in previous wind load tests. The stresses and deformation for the OH1042FI bottom and top profiles and for the OH1082FI are presented in Table 12.7. The 82 *mm* version for both the top and bottom stile achieves a lower deformation than the OH1042FI profiles and fulfils the requirements for the robustness regarding wind load.

Table 12.7 Wind load simulations of top and bottom part

Part	*Wind load class*	*Stress [MPa]*	*Deformation [mm]*
Top stile 42 *mm*	Class 2	41.28	36.22
	Class 3	64.21	56.35
Top stile 82 *mm*	Class 2	49.68	7.70
	Class 3	77.28	11.98
Bottom stile 42 *mm*	Class 2	35.37	31.85
	Class 3	55.02	49.54
Bottom stile *mm*	Class 2	72.26	5.58
	Class 3	112.40	8.68

These parts should be able to function, but after further investigation and discussion with the team, it was decided that the 82 *mm* frame section only will be designed as middle sections, no top or bottom section. Further reading can be done in 12.4.2 *Design for manufacturing.*

12.3.3 Vertical load

Up until this point, the profiles have only been tested on how they perform when affected by wind load. Now, tests exploring how they withstand the vertical load arising from the weight of other panel or frame sections in the door were performed. These tests were performed by assembling the upper and lower profiles of the middle section profiles and adding a load onto the lower profile. The upper stile is set to a fixed position, while the lower stile is allowed to move vertically. These boundary conditions can be seen in Figure 12.3. The length of the profiles is set to 1 *m.* A total load of 500 *kg* is applied on the areas seen in Figure 12.4, where the profile has contact with the imagined second upper profile. This weight was approximated by adding the weight of eight panels together and rounding that number. A safety factor of ten was also applied.

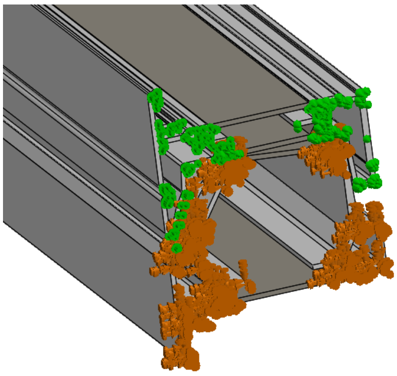

Figure 12.3 Boundary conditions for vertical load case. The green arrows indicate roller/slides fixtures, and the orange indicates fixed geometry.

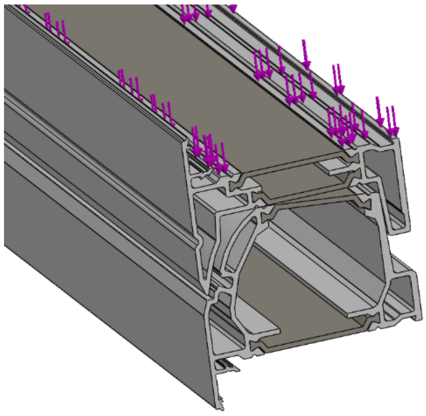

Figure 12.4 Areas where the 500 *kg* load is applied in the vertical load case.

The results from the first tests performed indicated that the current design would be able to withstand the load of 500 *kg*. The results showed a maximum stress of 134.6 *MPa* concentrated in the area seen in Figure 12.5. This was expected to be the most challenged area since this is where the force is transferred from the upper to the lower part. The maximum deformation occurs at the middle of the assembly, see Figure 12.6, where the deformation is $7.96 \cdot 10^{-1}$ *mm*.

A second test, with a greater load, will also be performed. In this test, the frame section was imagined to be in the bottom of a door made of other frame sections. These are heavier than the panels. The current weight of the 82 *mm* frame section without a window is 6.26 *kg* in the dimension 1 000×545 *mm*, compared to 6.08 *kg* for the panel section. Among the different window options for the 82 *mm* frame, the window type with the highest mass is the DE6D. That window has a weight of 31 *kg* per m^2, resulting in an approximated weight of 16 kg per frame section in the size mentioned earlier. A worst-case scenario with 30 frame sections was assumed, which is largely exaggerated. The weight of 30 frame sections is around 730 *kg*. The results of this test can be seen in Figure 12.7 and Figure 12.8. As can be seen the deformation could be considered to be acceptable, but the stress is higher than the yield strength. This is acceptable anyway since this is an extreme scenario.

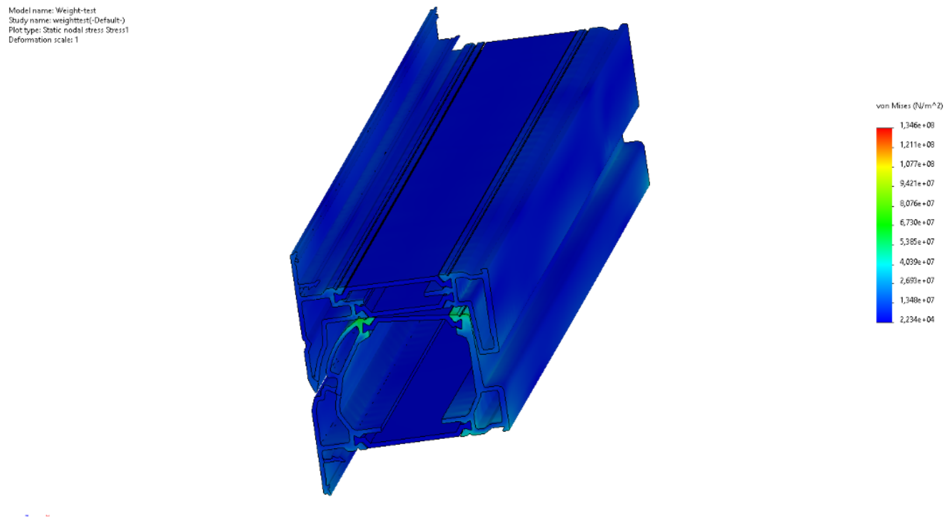

Figure 12.5 Stress that appears in the assembly when the vertical load of 500 *kg* is applied.

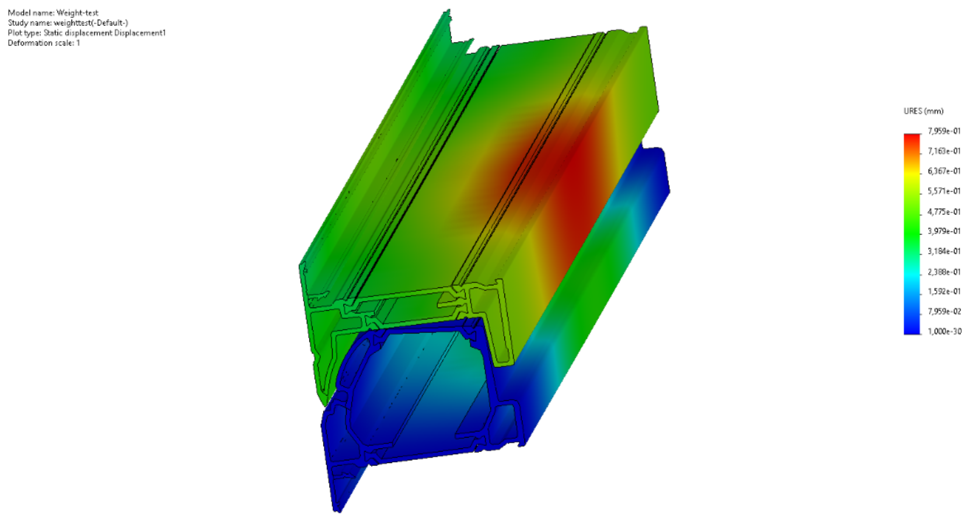

Figure 12.6 Deformation that appears in the assembly when the vertical load of 500 *kg* is applied.

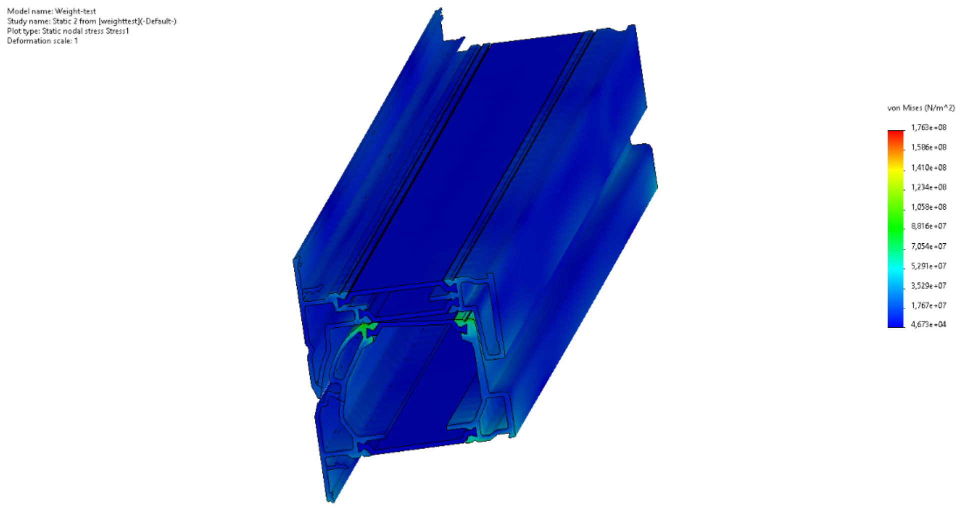

Figure 12.7 Stress appearing in the assembly when loaded with 730 *kg* vertically.

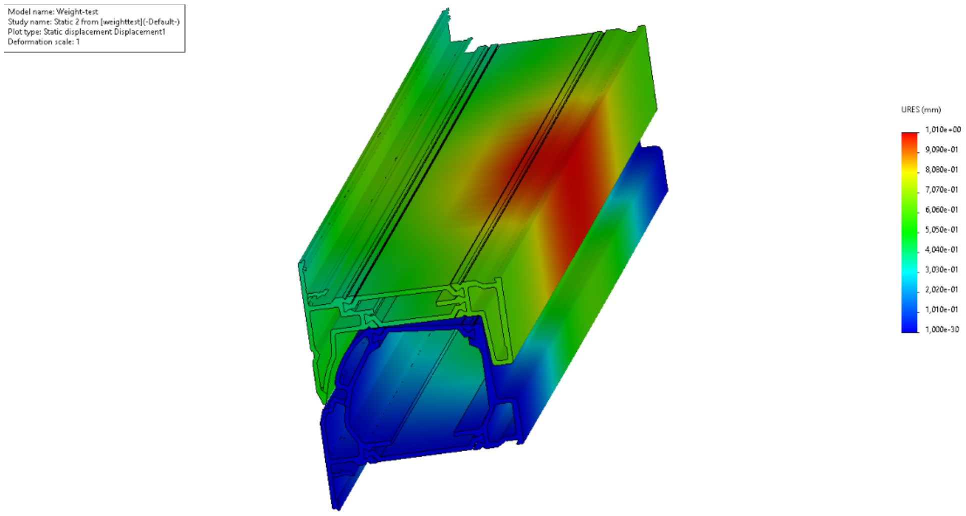

Figure 12.8 Deformation when the assembly is loaded with a vertical load of 730 *kg*.

12.3.4 PE-foam investigation

To verify the idea to place PE-foam tubes inside the profiles, different options were looked at. So called bottom lists would be a good option, and these exist in various sizes. The idea was to use tubes, since these would be easy to deform, in comparison to a solid shape. The ideal tube would be as large as possible, and with the smallest hole possible, since that would result in the best U-value. For the upper profile in the middle section a tube with a diameter of 50 *mm* was looked at and for the lower stile a tube with the diameter of 24 *mm*. The tubes looked at can be compromised to

2/3 of their original size and the inner diameter is 17 *mm* and 7 *mm* respectively for the 50- and 24-mm tubes according to Leif Arvidsson AB.

These options were tested by 3D-printing the upper and lower profiles in the middle section, see Figure 12.9. Tube isolations were then purchased in two different sizes, 50 *mm,* and 30 *mm.* These tubes were then inserted into the 3D-models to see how large tubes could be inserted into the profiles. The sizes were altered by cutting the tubes, and the inner diameter was altered by putting the smaller tube into the larger one. In Figure 12.10 the different tubes can be seen with their different measurements. The tubes inserted into the profiles can be seen in Figure 12.11. The 50 *mm* tube seemed to be a good option for the upper profile, and for the lower profile a 24 *mm* tube seemed to be a good fit. The deformation and placement of the foam will later be used in the U-value calculations since these images shows how the foam would likely be placed in the profiles.

Figure 12.9 Simplified 3D-models of upper and lower stile made in PETG.

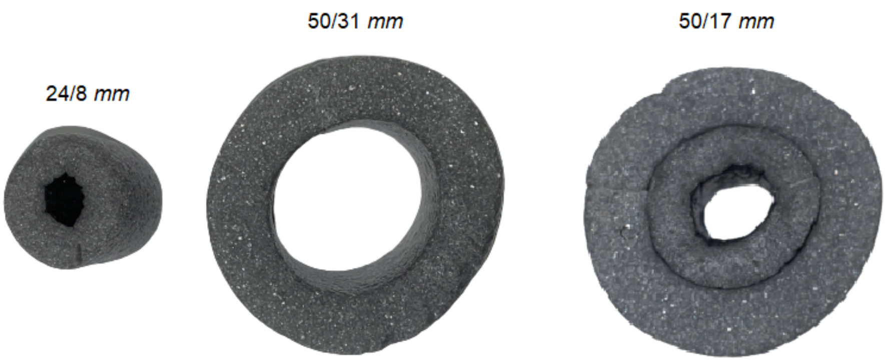

Figure 12.10 Pipe insulations used while testing foams behaviour in profiles.

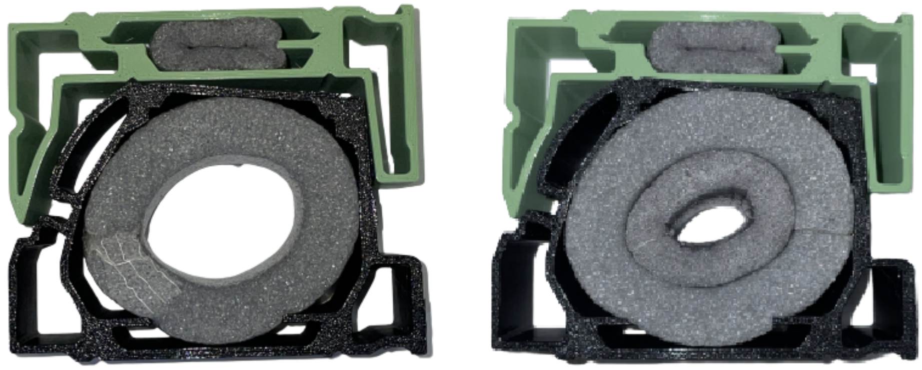

Figure 12.11 Pipe insulation inserted in the upper and lower spart.

The same procedure was applied to the vertical stiles, see Figure 12.12. In the middle vertical profile, a 40 *mm* tube was a good fit, and for the side vertical side two 40 *mm* tubes were inserted. According to the supplier these tubes have an inner diameter of 15 *mm,* but the ones used for the tests had a smaller hole than that.

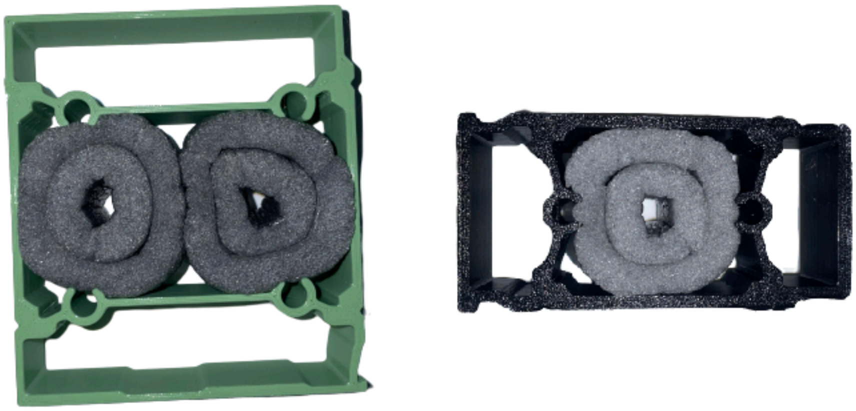

Figure 12.12 Pipe insulation tested in the side part (left) and the vertical middle part (right).

12.3.5 Window selection

From the selection matrix in section 9 *Concept selection*, the remaining alternatives for the opaque panel for OH1082FI was TAD/TSD, DE4D, DE6D and the low weight energy glass. To achieve a weight closer to the panel section's weight, the DE4D and DE6D option will now be excluded. To select window type, the linear thermal transmittance will be calculated for the two remaining options, see section 13.2 *U-value calculations*. The low weight energy glass has a lower U-value than the TAD/TSD and the weight is similar. The TAD/TSD option has a lower cost though.

12.3.6 Geometry check and conections to other parts

To check that the geometry of the parts was correct, a test to see if the parts fit together was performed with the 3D-models. The results were satisfying. A test to compare the 82 *mm* panel section and the frame section outer shape was also conducted to investigate that the new changes did not affect the connection between the two. By ensuring that the outer shape of the frame section is the same as the panel it can be concluded that the parts fit together. The result for the test is presented in Figure 12.13.

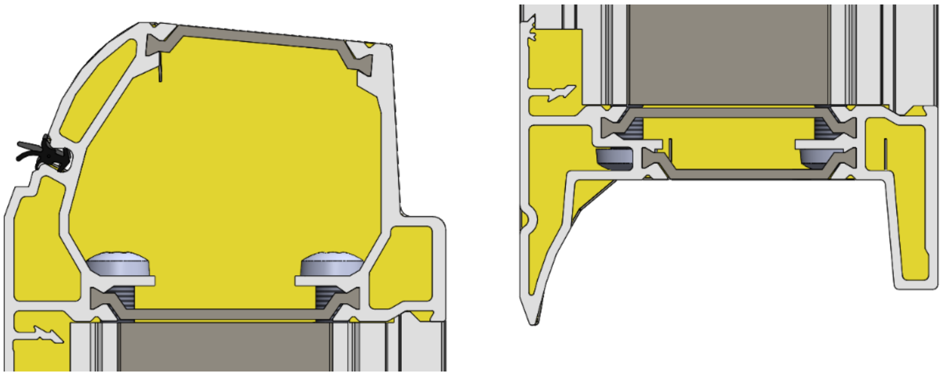

Figure 12.13 Test to compare panel and frame sections shape where the yellow shape is the panel section.

12.4 Production

12.4.1 Process plan

The process plan for the new profiles will be very similar to the existing 42 *mm* frame section. However, there will be an added step of putting the PE-foam inside the profile. This step will be performed simultaneously as the aluminium part will be rolled together with the thermal brakes. The PE-foam will be placed between the thermal brakes in this process. There are multiple advantages with this type of process. Firstly, as mentioned earlier, it is very similar to the existing process plan that exist at ASSA ABLOY Entrance System today, which means that it is easier for the operators to assemble the new frame. Another advantage with this process plan is that the same suppliers can be used as for the 42 *mm* frame section. The aluminium parts can be produced by BOAL, and they will develop the necessary tooling. The thermal breaks will be bought from Ensinger's standard assortment. However, the shortage of PA6.6 might lead to a change of the supplier for the thermal breaks. The insertion of the PE-foam will also have to be performed by the same company, since the profiles are to be rolled together. The team contacted a new manufacturer for the thermal breaks that ASSA ABLOY has been in contact with, to investigate the possibility to insert the PE-tubes into the profiles. This company is called Cortizo and was contacted instead of Ensinger, due to the shortage of the material PA6.6. The team was in contact with Pasko Saric, sales manager at Cortizo, who discussed the foam with the technical team. Today, they insert PE-foam as in Figure 12.14. The shape is rectangular, but since a round tube would allow the profile to be more filled with foam that would be more advantageous. Since the tube is easier to deform. The more filled the profile is with foam, the better is the U-value. Cortizo did not have experience with round shapes and mentioned that it could be difficult to integrate. However, a rectangular shape of the PE-foam would be possible for the lower, side, and middle profile. The upper profile might be more difficult because the thermal break at the top is angled, which makes it difficult to put in a rectangular shaped foam that covers the intended space.

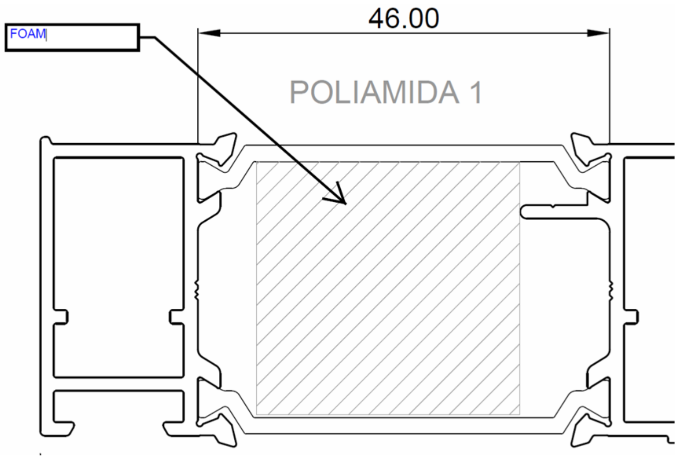

Figure 12.14: Suggestion of insertion of foam in profiles offered by the company Cortizo.

12.4.2 Design for manufacturing

The Ulrich and Eppinger method to design for manufacturing is divided into five steps that can be seen in Table 12.8. The steps mainly involve trying to reduce the cost and consider the impact of decisions that involves the manufacturing. This process has not been followed completely because of problems to retrieve accurate pricing. It has been decided to only estimate the cost based on the approximative costs per part or subassembly. This will be performed as the last step.

When designing for manufacturing it is also important to adjust the design to the intended manufacturing method. For the extrusion of the aluminium profiles, that means making sure that the overall thickness of the walls is similar and that corners have a correct radius adjusted for the process. The design should also be simple and unambiguous. This is something that the team have had in mind throughout the design process. The standard EN 12020-2 has also been studied, that describes tolerances and dimensions for aluminium extrusion.

Table 12.8 Design for Manufacturing process (Ulrich & Eppinger, 2012, p. 256)

Step 1	Estimate manufacturing costs.
Step 2	Reduce the cost of components.
Step 3	Reduce the cost of assembly.
Step 4	Reduce the cost of supporting production.
Step 5	Consider the impact of DFM decisions on other factors.

The OH1082 door’s main purpose is to offer good isolation, therefore configuring a door completely constructed of frame sections is contra productive. The panels still offer better isolation, so therefore having a thick door with only frame sections could be considered unnecessary. Therefore, only the middle frame section should be offered, and no top or bottom section. If windows are put in the door, they are mainly placed somewhere in the middle of the door, not in the top or the bottom. This limits the number of parts, which is cost effective.

Another reduction of the cost of the components was made early in the project by deciding to only use standard thermal breaks. There will be no added tooling cost, since the articles already exist in the supplier’s assortment. In the project it has also been determined to use the same supplier as for the OH1042FI. However, ASSA ABLOY Entrance Systems is now investigating to change some of the suppliers due to material shortage. This mean that this profile would also be affected by the change of supplier.

To reduce the cost of the assembling process it has been decided to use PE-foam pipes instead of cylinders. The tubes are easier to deform and speed up the assembling process.

To reduce the cost of supporting production, error proofing is considered. This has already been done by deciding to only use one type of screw for all fastenings in the frame section. It has also been taking into consideration choosing the number and sizes of PE-foam tubes. The same diameter of the PE-foam tubes has been selected as often as possible.

Regarding step five, consider the impact of DFM decisions on other factors, the PE-foam will add some difficulties in the assembling process because an extra step will be needed. By adding the PE-foam the U-value will decrease a great amount and without the foam the design would not even be considered.

The tooling price for the parts in the middle section for the OH1042FI is 14 425 EUR. The tooling price for the new design is estimated to be higher due to size of the tools, but also when considering inflation. The tooling cost is estimated to increase with 20 %, which results in a tooling cost of 17 310 EUR for the new parts. The amount of material used will also increase compared to the OH1042FI, leading to an increasement of the components price. In Appendix K the size increasement is presented, where the average increasement is 23 %. To consider the added foam parts as well as the higher price of PA6.6GF25 today, it is estimated that the prices increase with 50 %. The cost for the 82 *mm* frame stiles is presented in Table 12.9. The cost of the screws used to assemble the frame section is 0.0303 EUR per piece and was provided by ASSA ABLOY Entrance Systems.

Table 12.9 Cost of new designed parts per meter

Part	*Cost [EUR/m]*
Upper stile	18.21
Upper stile with short truss	24.96
Upper stile with long truss	27.81
Lower stile	16.98
Side stile	23.39
Vertical middle stile	18.71

The last step was to estimate the total cost of the middle section. The model used to calculate the cost of the middle frame section has a length of 3 044 *mm* and has two vertical middle stiles. This assembly uses 24 screws, and the vertical parts has a height of 475 *mm*. This results in a cost of 127.84 EUR, where the tooling and production cost is not considered. If the short truss is used the frame section cost 148.39 EUR and 157.07 EUR if the long truss is used.

12.5 Product scheme

An assembly drawing of the OH1082FI has been created to showcase the assembly for the frame section. The frame section can be customer made in different sizes. The assembly drawing can be seen in Appendix L, as well as drawings of the different profiles used to build up the middle section and the glazing list. It should be kept in mind that the drawings do not include the PE-foam, but the amount required is added in the BOM in the middle section drawing. The drawings of the stiles do not include the PE-foam at all. The upper stile has a 50 *mm* PE-foam tube, the lower a 24 *mm* tube, the middle stile a 40 *mm* tube, and the side stile have two 40 *mm* tubes.

13 Testing and refinement

This chapter presents the process testing and refinement according to Ulrich and Eppinger's product development methodology and how the method is implemented in this project.

13.1 Methodology and implementation

The testing and refinement phase involves the construction and evaluation of preproduction versions of the product. Early prototypes are usually not built for manufacturing and therefore they are tested and refined to evaluated whether the product works and if it satisfies the key customer needs. Later prototypes versions are usually built with parts that are intended for the production process. This later so-called beta prototypes are evaluated internally within the company and can be tested in the customers own use environment. The goal for the beta prototypes is usually to answer questions about performance and reliability to identify necessary engineering changes for the final product. (Ulrich & Eppinger, 2012, p. 15)

The testing and refinement have been implemented already in earlier phases of the project, where test of the overall performance, assessment of environmental impact and design changes has been applied. The assessment of the environmental impact has already been made in 12.2.1 *Design for environment*. This phase has been carried out at the same time as the detail design and therefore the design changes are presented in that section.

13.2 U-value calculations

Earlier U-value calculations at ASSA ABLOY Entrance Systems have been performed using an excel sheet to calculate the U-value of doors. In this document, different ψ- and U-values are added for different parts of the door, and the U-value is then calculated. The calculations needed for the calculation can be seen in Appendix M. The models used in these tests can be seen in Figure 13.1 to Figure 13.6. Firstly, the U_f-values are calculated for each configuration in Flixo. The ψ-values for the different areas in the door are then calculated with the previously calculated U-value for that configuration. The ψ-values are calculated with both the TAD/TSD window and the low energy glass. Flixo models for both window options are made with aluminium spacers, which separates the different layers of the window section. This was chosen since that is the worst-case scenario, since aluminium transfers heat well. The TAD/TSD version is created with air between the layers, and the low energy glass has a gas-filling in between. The energy glass is made of a laminated glass made of glass and polyvinyl butyral, and TAD/TSD is made of acrylic. The properties for the polyvinyl butyral did not exist in the Flixo material database, so the material was created with a density of 1.065 g/cm^3 and a thermal conductivity of 0.20 $W/(K\cdot m)$ (WMC GLASS, 2016). The models of the windows can be seen in Figure 13.7.

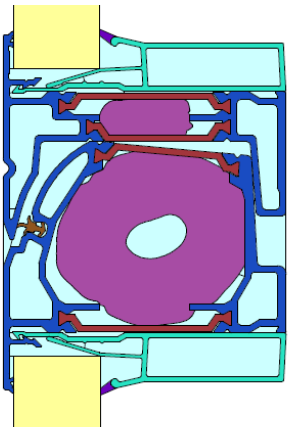

Figure 13.1 Model for U_f-value calculation for PSIJOINTCONTRUCTION frame-frame.

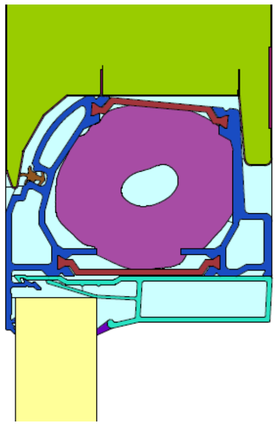

Figure 13.2 Model for U_f -value calculation for PSIJOINTCONTRUCTION frame-panel (above).

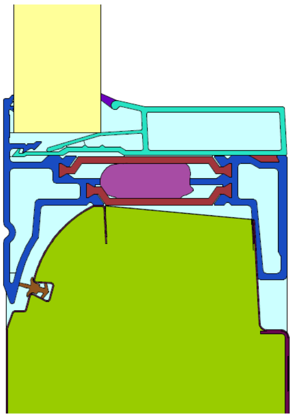

Figure 13.3 Model for U_f-value calculation PSIJOINTCONTRUCTION frame-panel (below).

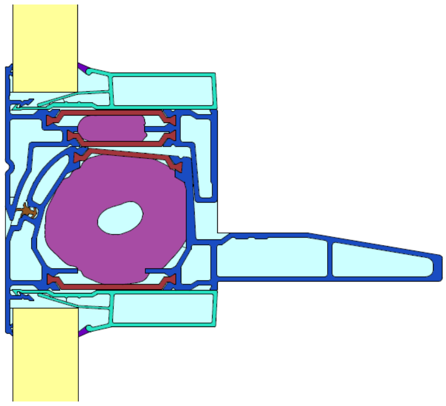

Figure 13.4 Model for U_f-value calculation PSIJOINTCONTRUCTION frame-frame with long truss.

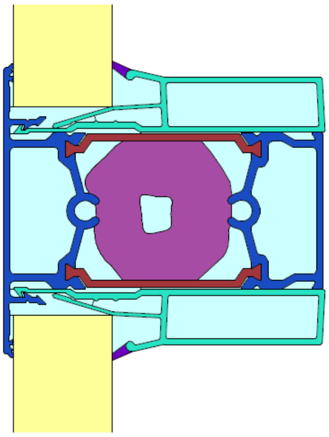

Figure 13.5 Model for U_f -value calculation for PSISTILEPROF.

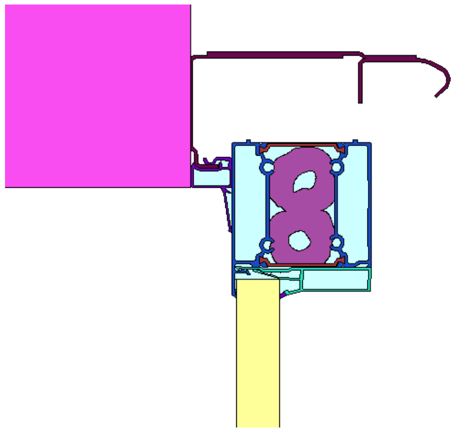

Figure 13.6 Model for U_f -value calculation PSISIDECONSTRUCTION.

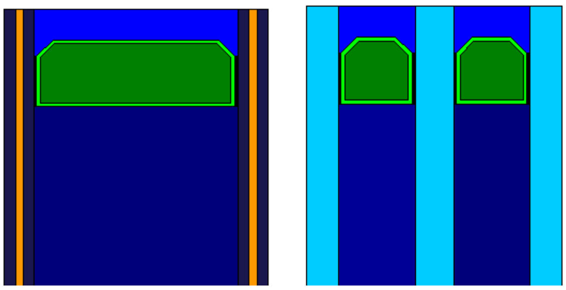

Figure 13.7 Windows used in the U-value simulations. The energy glass is to the left and TAD/TSD to the right.

A test of the U_f-value at the locations of the screws was also performed. This showed, as expected, that the U_f-value increases significantly at the location of the screws. This is an effect of adding material that has a high heat transmission. The model can be seen in Figure 13.8. The U_f-value was calculated to 7.53 $W/(m^2 \cdot K)$. The material of the screws was set to steel, from the material database in Flixo.

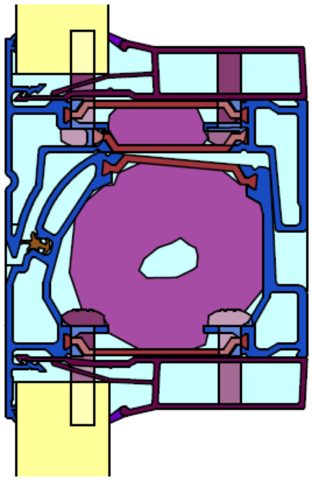

Figure 13.8 Model for U_f-value for frame with screws.

The properties for the other materials applied in the models were taken from previous tests performed by RISE for ASSA ABLOY Entrance Systems or from the material database in Flixo. Concrete, which was the material used for the wall in Figure 13.6, has the thermal conductivity 2.0 *W/(K·m)* (Swedish Standards Institute, 2008). For the construction involving the wall the standard EN ISO 6946 was used to calculate the ψ-value, since the standard EN ISO 10077-2 does not include walls but only frame structures. The outer temperature used in the calculations is -10°C according to EN ISO 6946. The results for the different test of the U- and ψ-values is presented in Table 13.1.

Table 13.1 U-value and PSI-values

Test	*U_f-value [W/(K·m²)]*	*ψ-value (TAD/TSD) [W/(K·m)]*	*ψ-value (Energy glass) [W/(K·m)]*
PSIJOINTCONSTRUCTION frame-frame	1.93	0.019	0.060
PSIJOINCONTRUCTION frame-panel (above)	0.465	0.018	0.067
PSIJOINCONTRUCTION frame-panel (below)	0.517	0.020	0.063
PSIJOINCONTRUCTION frame-frame with long truss	2.03	0.021	0.062
PSISTILEPROF	1.86	0.019	0.060
PSISIDECONSTRUCTION	1.52	1.080	1.118

With the calculated ψ-values, the U-value for a door of the size 5×5 *m* was calculated with the help of the already existing U-value for the windows. The top and bottom section was set to panel sections, and frame sections were placed in between. The frame sections can be custom made with different heights, but for this calculation the height was set to the same as the panel section, 545 *mm*. This resulted in a U-value of 1.67 $W/(K \cdot m^2)$ for the TAD/TSD version and 1.15 $W/(K \cdot m^2)$ for the energy glass version. This is the worst possible configuration regarding U-values, but both options still got good results.

Since both window options resulted in U-values below the target 1.8 $W/(K \cdot m^2)$, both alternatives could be considered. The low energy glass is more expensive but could perhaps be offered to customers willingly to pay more who also wishes to get an especially low U-value.

As mentioned earlier, the OH1082 door will perhaps only have one or two frame sections, and not be completely configurated with frame sections. Tests for both window options were performed to get the U-value for a 5×5 *m* overhead sectional door with one and two frame sections. The U-value for the option with the TAD/TSD window with one frame section was 0.61 $W/(K \cdot m^2)$ and 0.79 $W/(K \cdot m^2)$ with two sections. The energy glass option had a U-value of 0.54 $W/(K \cdot m^2)$ for one frame section and 0.64 $W/(K \cdot m^2)$ for two.

All U-values are below 1.8 $W/(K \cdot m^2)$, and the new design of the frame sections offers good insulation. From these tests it is implied that the number of frame sections affects the U-value. Fewer frame sections lead to a lower U-value, which is expected. The difference between integrating one or two frame sections in the door is an increasement of 29.5 % for the TAD/TSD option and 18.5 % for the energy glass option.

As mentioned, the results from the U-value calculations are good, but of course there is room for improvement. For example, the heat loss that takes place at the joint of between the wall and the side stiles could most likely be improved. Perhaps by looking at different seals. Also, different separators in the windows could be investigated. This will not be further investigated in this project since it is outside the scope of this project. Also, the placement and material of the screws could be investigated, so that the U_f-value at the location of the screws could be improved.

It might be difficult to use round PE-foam, which is mentioned in the process plan. Therefore, tests with rectangular PE-foam were performed to conclude how the U-value would be affected. One of the models with rectangular foam can be seen in Figure 13.9. The U- and ψ-values from these tests can be seen in Table 13.2.

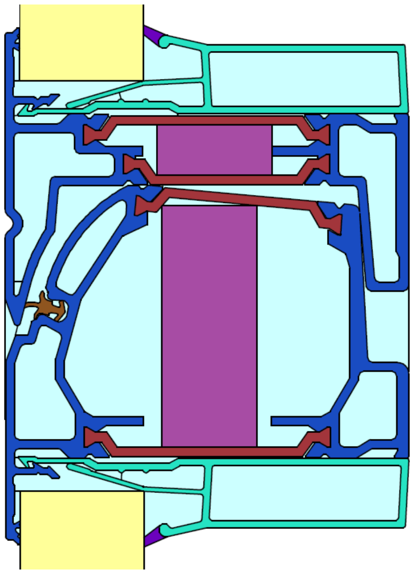

Figure 13.9 Flixo model with rectangular PE-foam.

Table 13.2 U-value and PSI-values with rectangular foam

Test	*U_f-value [W/(K·m²)]*	*ψ-value (TAD/TSD) [W/(K·m)]*	*ψ-value (Energy glass) [W/(K·m)]*
PSIJOINTCONSTRUCTION frame-frame	2.04	0.024	0.067
PSIJOINCONTRUCTION frame-panel (above)	0.499	0.035	0.082
PSIJOINCONTRUCTION frame-panel (below)	0.518	0.020	0.063
PSIJOINCONTRUCTION frame-frame with long truss	2.14	0.026	0.068
PSISTILEPROF	1.88	0.019	0.060
PSISIDECONSTRUCTION	1.50	1.080	1.118

The U-value for the worst configuration, with all frame sections except for the top and bottom section, was for the TAD/TSD version 1.67 *W/(K·m²)* and for the Energy glass 1.15 *W/(K·m²)*. The U-value for the TAD/TSD option with one frame section was 0.61 *W/(K·m²)* and 0.54 *W/(K·m²)* for the energy glass option. These values are the same as for the PE-foam tubes and the rectangular foam might be a better alternative if it is easier to manufacture. From the beginning it was assumed that tubes would be easier to use, since these would adjust in shape and since they can be bought from a supplier in a standard size. The rectangular foam will have to be bought and custom made but seems to be easier to use according to the manufacturer.

In the graph presented in Figure 13.10 the U-value for both the 42 and 82 *mm* frame are displayed. The difference between having a door made of only frame sections (except for the top and bottom section), the worst-case scenario, and only having one or two frame sections can be seen. As expected, the U-value increases with a higher number of frame sections. It can also be seen that the difference in the acrylic glass and the low energy glass is neglectable when only having one or two frame sections.

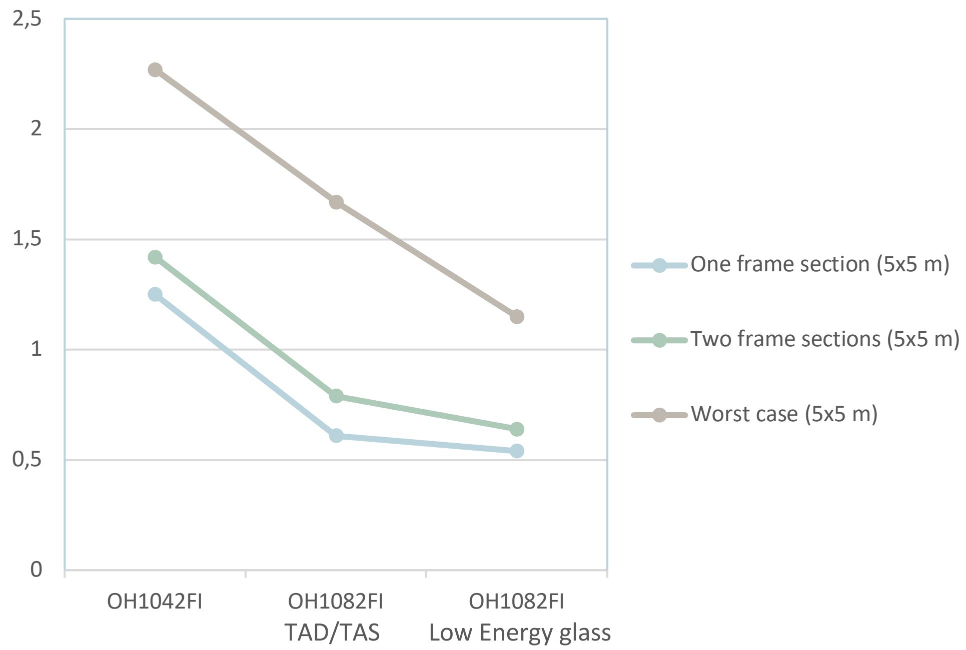

Figure 13.10 Graph displaying the number of frame sections effect on the U-value.

13.3 Weight and robustness

The tests regarding wind load are considered to be finished at this point in the project. Testing the complete frame with a window inserted is too time consuming and complicated for the scope of this project. Regarding the balancing of the door, it is important to look at the weight of the frame sections. The weight for the OH1042FI and OH1082FI, without windows, can be seen in Table 13.3. As can be seen, the OH1082FI is 23.69 % heavier than the OH1042FI. When comparing the OH1082 frame with the panel, the weight of the window must be included. If the heaviest window is considered the weight for the frame with the window is around 33 *kg*, making it almost twice as heavy as the panel. This could lead to problems balancing the door when it is lifted, since the weight is not balanced over the door. The weight is desired to be more evenly distributed over the door. The overhead sectional doors can be lifted either vertically, or first lifted vertically and then land in a horizontal position along the roof. The balancing of the door is more critical when the door is bent. The effect can be adjusted by altering the number of frame sections, depending on what lifting system will be used.

Table 13.3 Weight of frame and panel sections

Frame	***Mass [grams]***
OH1042FI with two vertical middle stiles, two side stiles (3 044 *mm*)	12 690.34
OH1082FI with two vertical middle stiles, two side stiles (3 044 *mm*)	15 696.97
OH1082P (3 044 *mm*)	18 515.87

13.4 Industry standards

In this project the focus has been to look at standard EN 12424, EN 12444 and EN 12428, which involves wind load and thermal transmittance. EN 13241, which is a summary of the standards used for industrial doors, has partly been looked at. This is a standard that refers to other standards, which are more specific regarding different areas of the industry door. EN 12604 has been used to some extent in this project, mostly to get a safety factor for the added loads when testing the prototypes. The standard EN 12489, which is about the industry door's resistance to water penetration, has not been investigated in this project. These tests are performed with a physical model and has therefore not been executed.

14 Result

This chapter presents the finalised design of the insulated frame section and the final specification.

The finalised design of the frame section OH1082FI includes aluminium profiles with thermal breaks made in PA6.6GF25 as well as PE-foam on the inside of the profiles. Renderings of the frame section can be seen in Figure 14.1 and Figure 14.2. The drawings for the finalised concept can be found in Appendix L. In the drawings the height and width of the frames are not included, which are variable options for the customer.

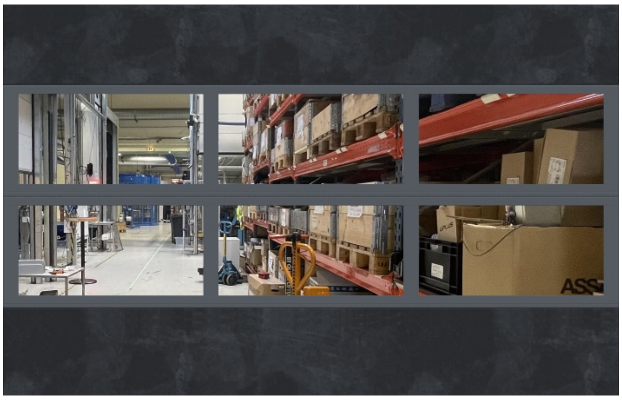

Figure 14.1 Rendering of OH1082FI between 82 *mm* panel sections.

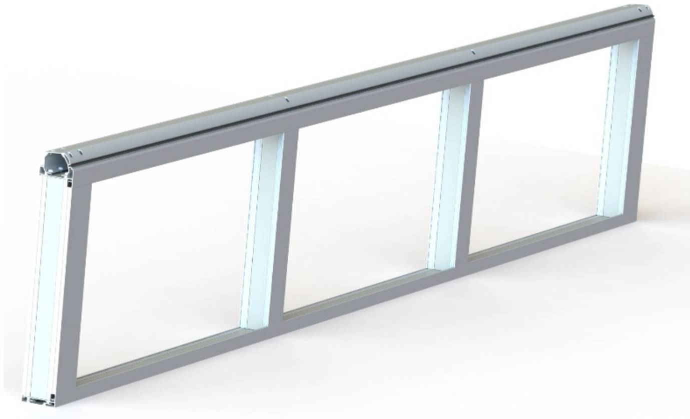

Figure 14.2 Rendering of OH1082FI (3 044 *mm*).

14.1 Final specification

The final specification for the OH1082FI is presented in Table 14.1. All the specifications fulfil the target specifications that was set in the beginning of the project. It should be noted that only a middle frame section will be developed and configurations with panel sections for the top and bottom sections in OH1082P will be used.

Table 14.1 Final specifications

Metric No.	***Metric***	***Units***	***Value***
1	Resistant to wind load	*Pa*	≥700 (≥450)
2	As low total mass as possible	Binary	Yes[a]
3	Thermal transmittance (U-value) 5×5 *m* door	*W/(K·m²)*	1.7/1.2[b]
4	Thickness	*mm*	82
5	As low total cost as possible	Binary	Yes
6	Window present	Binary	Yes
7	Compatible with standard parts	Binary	Yes
8	Compatible with standard manufacturing methods[c]	Binary	Yes
9	Broken Cold bridge	Binary	Yes
10	Recognizable with ASSA ABLOY Entrance Systems portfolio	Binary	Yes
11	Compatible with OH1082P panels	Binary	Yes
12	Section profile assembly must be watertight	Binary	Yes
13	Easily replaceable windows from inside	Binary	Yes
14	Top seal[d]	Binary	Yes

[a] The mass depends on the window type and options with low weight is used in OH1082FI.

[b] Different value depending on window selection. (TAD/ low energy glass)

[c] Different assembly method, but very similar.

[d] A frame top section does not exist in the 82 *mm* thickness. The top section will consist of a panel section.

15 Discussion

This chapter includes a discussion regarding the result, the following of methods and standards as well as the post project review.

15.1 Result

This Master Thesis has resulted in a finalised prototype of an 82 *mm* insulated frame section for the industrial overhead sectional door OH1082 produced by ASSA ABLOY Entrance Systems, consequently both the primary goal and fallback goal established in section 1.2.1 *Goals and research questions* has been fulfilled. The finalised design includes aluminium profiles with thermal breaks made in PA6.6GF25, the same materials used in the already existing insulated frame for the door OH1042FI. But in difference to the 42 *mm* frame, the new 82 *mm* frame also includes PE-foam inside the profiles.

Concerning the U-value for this door, it was found that the material affects the heat transmission greatly, which was expected. Also, the design of the frame, the wall thickness, and the space between the different sides of the frames affects the U-value. Thicker walls lead to less heat transmission and a greater distance between the sides had the same affect. The number of frame sections also affects the U-value of the door, the greater number of frames the higher U-value it gets. There is heat loss at every joint, and an increase of joints leads to a higher U-value. The difference of the window type. The energy glass offers better insulation compared to the TAD/TSD, but if only a few frame sections are used the difference is negligible. Therefore, the choice of window could be left for the customer depending on their desires. It was decided to only offer a middle section of the 82 *mm* frame, since the U-value increases with the number of frame sections in a door. The 82 *mm* thick door is mainly intended for customers who are looking for good insulation. Therefore, customers should be advised to have as few frame sections as possible. It is also important to look at how many times a day the door is opened, if the door is to be opened and closed often throughout the day, a door with a faster motor could be more energy saving than the 82 *mm* thick door. According to ASSA ABLOY Entrance Systems, the faster door OH1042S should be chosen if there are more than 20 daily openings. The placement of the door should also be considered, if the door is placed on the south side of a building, that could also be beneficial since the sun could improve the heat flow.

The project has also resulted in findings regarding the stiffness of the stiles in the frame. Different ways of reinforcing the structure were investigated. These alternatives have been tested in the wind load tests as well as the tests involving vertical loads. It resulted in a structure that fulfils the requirement to resist the wind load for the required classes. The structure can also carry a high vertical load.

15.2 Following of methodology

In the beginning of this report in section 3 *Methodology*, methodologies regarding product development were presented. Evaluating how these have been followed is important, to ascertain whether they have been followed and if anything has been overlooked or left out of the project.

The project followed the methodology described quite well. Some processes took longer than expected, and some steps were shorter. This is however not very surprising, since a product development process is iterative, and it is hard to predict how long a process will be. The detail design step was a long process, multiple things were looked at the same time. The material selection process was longer than expected, but also important since it affects the outcome of the OH1082FI greatly. Some factors that could not be affected also delayed some parts in the project, for example waiting for responses from manufacturers or suppliers. The initial time plan as well as the actual time plan can be seen in Appendix A.

15.3 Post-project review

Following this Master Thesis, ASSA ABLOY Entrance Systems have a good starting point for getting the new frame section OH1082FI out to the market. The existing prototype is satisfactory, although some more testing is necessary. New tooling will be needed to create the new parts and assemble the 82 *mm* frame section. The investment for the OH1082FI is slightly higher than the cost for OH1042FI but should be reasonable. The OH1082FI is slightly more expensive due to a higher material cost, but at the same time it offers much better insulation properties. By providing the same possibility to custom design highly insulating doors ASSA ABLOY Entrance Systems customer range increases as well. It has been determined through customer needs that this is a product that the market lacks, which makes this frame section a good investment.

Studies of an actual physical prototype or model should be conducted to verify the results of this Master Thesis. The material and drawings in this Master Thesis lay a good basis for how a physical prototype could be constructed. It is mainly the stability and rigidity of the frames that need physical testing. In the future it would also be desirable to perform impact tests on the complete door to see if it is rigid enough to handle unexpected loads. However, the OH1082FI is expected to perform as well as OH1042FI, if not even better, and for that reason it should hopefully perform well in these tests.

Except for more tests regarding the wind load and the U-value, to verify the values calculated, some tests regarding the manufacturing also must be performed. In this project it has been assumed that the insertion of the PE-foam tubes into the aluminium profiles will be possible. This is of course something that must be verified and tested. It might be that adjustments have to be done, but some solution is surely to be found. There are frames with insulation on the inside, made of different kinds of foam. Even if the tubes looked at in this project are not feasible in this project, there are other alternatives. Foams with a rectangular cross section should be a possible alternative according to companies that have been contacted. As mentioned in the testing and refinement phase, the U-value does not change significantly by using rectangular PE-foam. It should be mentioned though, that if rectangular PE-foam is to be used, they probably have to be manufactured according to a specific design.

Regarding the U-value of the door, it is satisfactory. However, some parts outside of the scope for this project could be studied, for example the side seal. This part of the construction has the highest U-value and by lowering this value, a lower U-value for the complete door can be achieved.

Another aspect to investigate is how the frame section handles water penetration. Due to the frame section's similarity to the OH1042FI frame, which meets the requirements in the standards, it is assumed that the new frame section will perform good as well.

It should also be investigated if the placement of the door influences the energy savings of a building. This information would be useful for potential customers.

16 Conclusion

This chapter summarises and concludes the Master Thesis project.

The scope of this Master Thesis has been to conduct a product development process, creating an insulated frame section for the 82 *mm* overhead sectional door currently sold by ASSA ABLOY. The main challenges of this project have been to determine the right material for the design, as well as achieving the lowest U-value possible with a reasonable cost. The limitation to keep the aesthetic similar to the OH1042FI frame has also been demanding. The design has also been restricted by the consideration of the compatibly with already existing components in the company's portfolio.

The result of this project is a new thicker frame section, enabling the configuration of a door with frame sections, with continued good U-value for customers. The product also fits into the desired aesthetic that exist in ASSA ABLOY Entrance System product portfolio. By finalising a thorough cost analysis and performing physical tests, this project lays a good foundation for future work with the OH1082FI frame sections at ASSA ABLOY Entrance Systems.

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Appendix A Industrial standards

This appendix presents the industrial standards that have been looked at in this project.

A.1 EN 13241 - Industrial, commercial, garage doors and gates – Product standard, performance characteristics

The European standard EN 13241 specifies the safety and performance requirements, except resistance to fire and smoke control characteristics. The standard applies for industrial, commercial, garage doors and gates and barriers, intended for installation in areas in the reach of people, and for which the main intended uses are giving safe access for goods and vehicles accompanied or driven by people in industrial, commercial, or residential premises. (Swedish Standards Institute, 2016)

This standard refers to other standards and can be seen as a summary of standards involving industrial, commercial and garage doors and gates. The information relevant to this project that was gathered form this standard is:

- All doors, manual and power operated, shall be planned, designed, and constructed in accordance with EN 12604.
- Resistance to water penetration shall be based upon test measurements carried out on completely assembled doors or individual representative parts in accordance with EN 12489.
- The resistance to wind load of a door is its capacity to withstand a specified differential wind pressure. Doors shall be designed to resist a specified differential wind pressure and shall be classified in accordance with the wind load classes specified in EN 12424.
- Resistance of a door to differential pressure shall be determined in accordance with the methods specified in EN 12444, by a full-scale test, or by a model test, or by a component part test and extrapolation, or by calculation.

- Different safety factors shall be used depending on whether test or calculation is the basis of the design. These factors, specified in EN 12604, EN 12444 and EN 12424.
- Thermal resistance for a completely assembled door shall be tested or calculated in accordance with EN 12428.
- Where specific product characteristics of thermal insulation, air permeability and resistance to water penetration shall be declared, the design features (including seals, hardware, and insulation material, where applicable) shall be included into the durability test in accordance with EN 12605:2000.

A.2 EN 12604 – Industrial, commercial and garage doors and gates – Mechanical aspects – Requirements and test methods

The standard EN 12604 involves safety requirements and protective measures for mechanical aspects of industrial, commercial and garage doors and gates used by vehicles accompanied or driven by people. (Swedish Standards Institute, 2020)

The information from standard EN 12604 relevant to this project is as follows:

- The minimum safety factors for calculation purposes to be used for stress due to all loads for the design of the door are a safety factor of 2 for yield stress and 3.5 for breaking stress. For components where testing is carried out instead of calculation the minimum safety factor before yield shall be 1.1.
- The guides shall be designed and constructed in such a way that unintentional disengagement or derailment are prevented during normal operation, or in case of contact with a stationary obstacle, or in case of failure of a suspension element. The movement of the door leaf shall be limited by end stops. Mechanical end stoppers in the terminal positions of the door movement shall withstand the energy developed by the possible impact of the door leaf.
- The door shall not be able to close uncontrolled if a component fails. The design of the door shall also ensure that in case of a single failure the resulting short-term transient loads will not cause secondary mechanical failures of other elements of the door. Elements of the suspension or balancing system which could fail during operation of a door are balancing springs, counterweights, steel wire ropes, pulley, drums, chains, straps, belts, and their attaching parts.

- In the event of a failure in the door suspension or balancing system, the main edge of the door leaf shall not move downwards more than 300 *mm* even in case of bouncing.
- The maximum out-of-balance of the door leaf static force occurring at the primary closing edge of the door does not exceed 200 *N* when there is a suspension or balancing component failure, and failed component is clearly visible or detectable during normal operation of the door.
- The door shall also be fitted with a device which avoids that the door leaf, during the opening or closing movement, can be lifted more than 50 % of the length of the pin of the hinges or any other supporting means (“anti-lifting” device).
- A door shall be able to open or close with a force not exceeding 150 *N* for doors for residential use and 260 *N* per person for industrial/commercial use, wind or other environmental factors not being considered. These forces can be exceeded to start the movement.
- Sharp edges shall be eliminated or safeguarded to avoid the risk of cutting when operating the door. Edges with radius of at least 2 *mm* and, for combined radius (sum of the 2 radii), of at least 6 *mm* (e.g., at least 2 *mm* + 4 *mm* or 3 *mm* + 3 *mm*) are considered to be safe.

A.3 EN 12428 – Industrial, commercial and garage doors – Thermal transmittance – Requierments for the calculation

The standard EN 12428 is used to evaluate the thermal transmittance aspects of industrial, commercial or garage doors. The doors are intended for installation in areas in the reach of people, for which the main intended uses are giving safe access for goods, vehicles, and people in industrial, commercial, or residential premises (Swedish Standards Institute, 2013).

The relevant information provided from this standard was:

- The calculation can include different types of glazing, frames with or without thermal breaks, and different types of opaque panels and thermal bridge effects at the edge of the panel or joint between the glazed area, the frame area, and the panel area.
- It is assumed that the principal heat flow in a section is perpendicular to a plane parallel to the external and internal surfaces. But at the perimeter of an industrial, commercial or garage door and between door sections the heat flow will be two or three dimensional. The heat flow can be conducted along components with high thermal conductivity around parts with high thermal

resistance, especially where metal parts connect (for instance internal surface sheet – end cap/edge profile – external surface sheet).

- The linear thermal transmittance of the connections between the door panel and surrounding construction or between panels is determined as the additional heat flow compared to the one-dimensional heat flow through the door panel.
- All components in the door or gate that affect the heat flow should be included in the thermal transmittance. This value is calculated as the total heat flow rate through the door, divided by the temperature difference (20 °C) and the partition wall aperture area (width × height).
- The surrounding walls and floor are regarded as adiabatic and consequently as having no influence on the thermal transmittance of the door.
- Input data (thermal properties) shall be evaluated by measurement, two- or three-dimensional finite element or finite difference software calculation or by tables or diagrams.

A.4 EN 12424 – Industrial, commercial and garage doors and gates – Resistance to wind load - Classification

The standard EN 12424 describes how to evaluate the design and mechanical aspects of industrial doors in a closed position. The doors are intended for installation in areas in the reach of people, for which the main intended uses are giving safe access for goods, vehicles, and people in industrial, commercial, or residential premises (Swedish Standards Institute, 2000).

The relevant information provided from this standard was:

- Wind load is understood as differential pressure of one side of the fully closed-door leaf to the other. A test specimen belongs to a specified class, if the results of a full-scale test, model test, component part test and/or calculations that show that the test specimen can withstand the reference wind load specified for that class.
- Tests or calculations shall also show that the door leaf will remain in position under a peak load 1.25 times greater than the reference wind load unless otherwise required. Permanent deformations of door components are allowed in this case.
- The classes shown in Table A.1 indicate positive pressure. Suction or reverse direction loads must be specified as a negative class i.e., a wind load of 300 *Pa* applied to the inside face of the door is shown as class -1.

Table A.1 Wind load classes

Class	*Reference wind load [Pa]*	*Specification*
0	-	No performance determined.
1	300	
2	450	
3	700	
4	1 000	
5	>1 000	Exceptional; Agreement between manufacturer and purchaser.

A.5 EN 12444 - Industrial, commercial and garage doors and gates – Resistance to wind load – Testing and calculation

The standard EN 12444 is used to evaluate the designs resistance to wind load for doors in a closed position. Just as in the standard EN 12424 the doors are intended for installation in areas in the reach of people, for which the main intended uses are giving safe access for goods, vehicles, and people in industrial, commercial, or residential premises (Swedish Standards Institute, 2001).

The information that was relevant for this Master Thesis that could be found in the standard was as follows:

- The principle of test is to apply a pressure differential across the test specimen, to determine failure. Full size specimen shall be tested. If it is impossible or uneconomical to achieve full scale testing, parts of door assemblies shall be tested for calculating a result for a full door calculation.
- An evenly distributed load or pressure may be applied to the surface. This can be achieved in various ways, for example, but not restricted to:
    - Air - pressurised chamber, in which case steps shall be taken to eliminate all air leakage on the product and its attachment to the supporting construction.
    - Bags filled with sand or water distributed over the surface of the test sample.
    - Air - pressurised bags applied across the whole surface between a fixed rigid surface, for example the floor and the surface of the test sample.

- Calculations shall be done in accordance with normal engineering practice. Calculations can be performed by using parameters which have been determined by preliminary tests on defined elements, such as finite -element methods.

Calculations shall be carried out to verify that the largest size of product to be manufactured can withstand the highest load (differential pressure) within the classification group according to EN 12424:2000 that the product is to perform.

Appendix B Work distribution and time plan

This appendix presents the work distribution of each student that has contributed to the Master Thesis. The appendix also presents the project plan and the actual outcome.

B.1 Work distribution

The same amount of time was put into the project by both Frida Sterner and Sofia Björnsson, but for some activities the amount of work was not divided equally for the team members. The work distribution for each activity can be seen in Table B.1.

Table B.1 Work distribution for each activity

Activity	*Percentage of work performed by Sofia Björnsson*	*Percentage of work performed by Frida Sterner*
Literature review	50	50
Concept generation	50	50
Prototyping	40	60
Material investigation	50	50
U-value simulations	60	40
Wind load simulations	50	50
Concept refining	50	50
Writing of report and presentation	50	50

B.2 Project plan and outcome

Figure B.1-B.3 shows the initial time plan for the project while Figure B.4-B.6 shows the actual time plan. The differences between the two are discussed in section 15.2 *Following of* methodology.

Master Thesis - "Frame Sections for High Insulated Industrial Doors"

Company name Assa Abloy

Project lead

Project Start Date: 2022-01-17

Scrolling Increment: 0

Legend: On track | Low risk | Med risk | High risk | Unassigned

Milestone description	Category	Assigned to	Progress	Start	Days
Start-up (Planning)	Low Risk		0%	2022-01-17	10
Prestudy	Med Risk		0%	2022-01-19	9
Write mission statement	High Risk		0%	2022-01-18	4
Concept development	High Risk		0%	2022-01-24	35
Select specifications	Milestone		0%	2022-02-02	1
Select product concepts	Milestone		0%	2022-02-15	1
Set final specifications	Milestone		0%	2022-02-21	1
Education in U-value caluclati	Med Risk		0%	2022-02-17	9
System Level Design	Med Risk		0%	2022-02-28	7
Detail Design	Med Risk		0%	2022-03-07	14
Testing and Refinement	Med Risk		0%	2022-03-21	47
Final prototype	Milestone		0%	2022-04-13	1
Post-project review			0%	2022-05-02	25
Economic review	Med Risk		0%	2022-05-02	5
Finished product development phase	Milestone		0%	2022-05-24	1
Conduct post-project review	Med Risk		0%	2022-05-24	3
Report and Presentation					
Write Report	High Risk		0%	2022-01-19	128
Critical review of other degree project	High Risk		0%	2022-05-30	5
Write scientific article	High Risk		0%	2022-05-27	4
Presentation	Low Risk		0%	2022-05-31	4

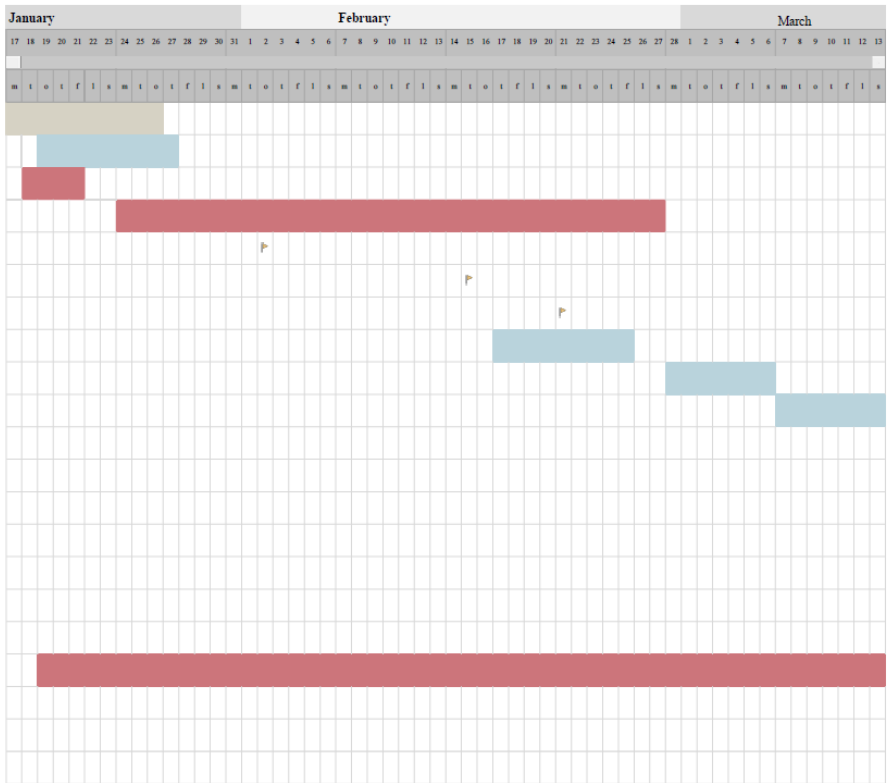


Figure B.1 Project plan page 1.

Master Thesis - "Frame Sections for High Insulated Industrial Doors"

Company name Assa Abloy

Project lead

Project Start Date: 2022-01-17

Scrolling Increment: 56

Legend: On track | Low risk | Med risk | High risk | Unassigned

Milestone description	Category	Assigned to	Progress	Start	Days
Start-up (Planning)	Low Risk		0%	2022-01-17	10
Prestudy	Med Risk		0%	2022-01-19	9
Write mission statement	High Risk		0%	2022-01-18	4
Concept development	High Risk		0%	2022-01-24	35
Select specifications	Milestone		0%	2022-02-02	1
Select product concepts	Milestone		0%	2022-02-15	1
Set final specifications	Milestone		0%	2022-02-21	1
Education in U-value caluclati	Med Risk		0%	2022-02-17	9
System Level Design	Med Risk		0%	2022-02-28	7
Detail Design	Med Risk		0%	2022-03-07	14
Testing and Refinement	Med Risk		0%	2022-03-21	47
Final prototype	Milestone		0%	2022-04-13	1
Post-project review			0%	2022-05-02	25
Economic review	Med Risk		0%	2022-05-02	5
Finished product development phase	Milestone		0%	2022-05-24	1
Conduct post-project review	Med Risk		0%	2022-05-24	3
Report and Presentation					
Write Report	High Risk		0%	2022-01-19	128
Critical review of other degree project	High Risk		0%	2022-05-30	5
Write scientific article	High Risk		0%	2022-05-27	4
Presentation	Low Risk		0%	2022-05-31	4

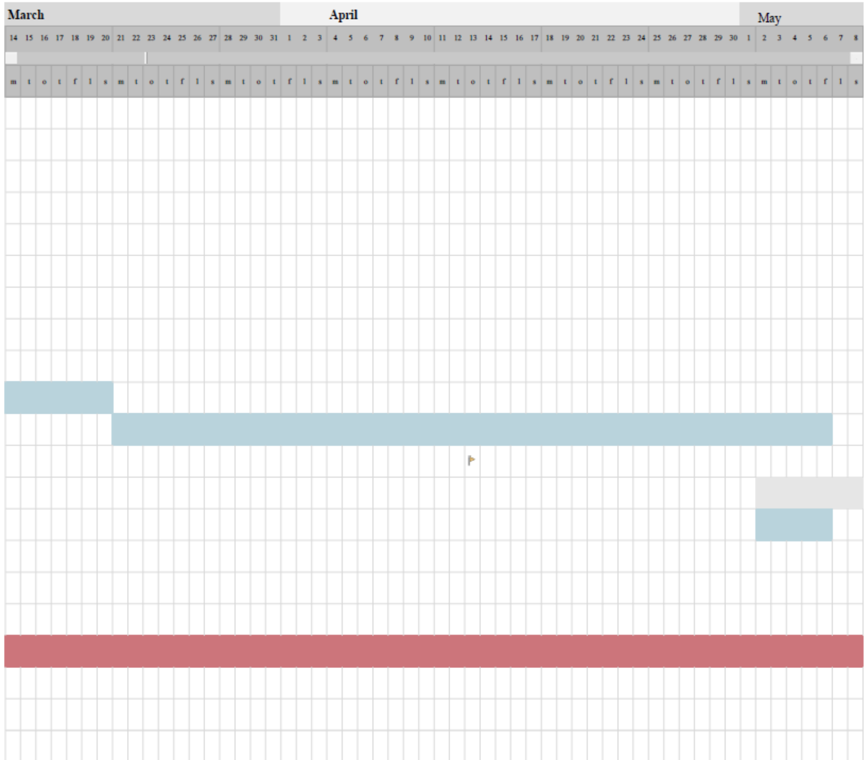
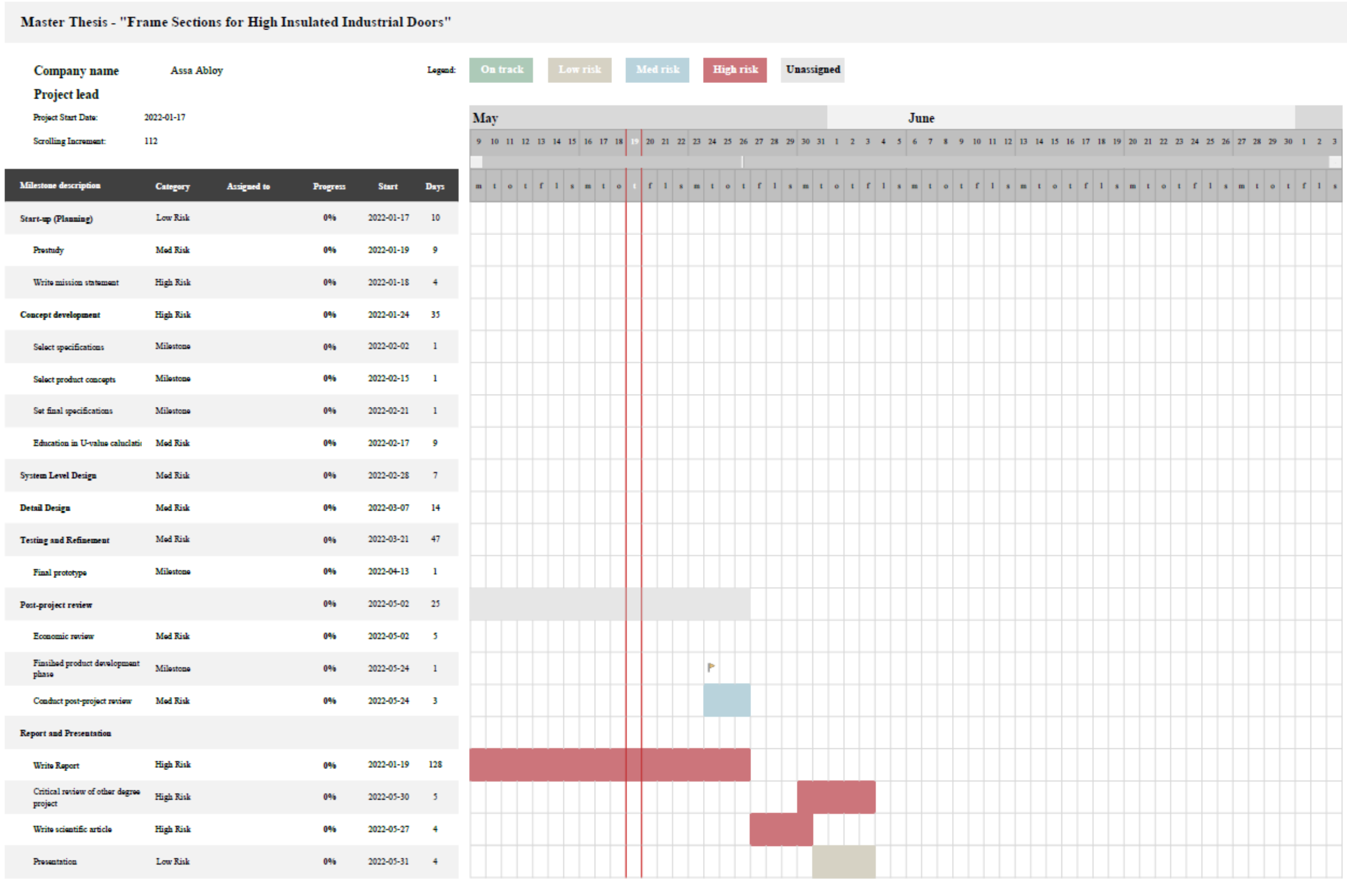


Figure B.2 Project plan page 2.



Master Thesis - "Frame Sections for High Insulated Industrial Doors"

Company name: Assa Abloy
Project lead
Project Start Date: 2022-01-17
Scrolling Increment: 112

Legend: On track, Low risk, Med risk, High risk, Unassigned

Milestone description	Category	Assigned to	Progress	Start	Days
Start-up (Planning)	Low Risk		0%	2022-01-17	10
Prestudy	Med Risk		0%	2022-01-19	9
Write mission statement	High Risk		0%	2022-01-18	4
Concept development	High Risk		0%	2022-01-24	35
Select specifications	Milestone		0%	2022-02-02	1
Select product concepts	Milestone		0%	2022-02-15	1
Set final specifications	Milestone		0%	2022-02-21	1
Education in U-value caluclati	Med Risk		0%	2022-02-17	9
System Level Design	Med Risk		0%	2022-02-28	7
Detail Design	Med Risk		0%	2022-03-07	14
Testing and Refinement	Med Risk		0%	2022-03-21	47
Final prototype	Milestone		0%	2022-04-13	1
Post-project review			0%	2022-05-02	25
Economic review	Med Risk		0%	2022-05-02	5
Finished product development phase	Milestone		0%	2022-05-24	1
Conduct post-project review	Med Risk		0%	2022-05-24	3
Report and Presentation					
Write Report	High Risk		0%	2022-01-19	128
Critical review of other degree project	High Risk		0%	2022-05-30	5
Write scientific article	High Risk		0%	2022-05-27	4
Presentation	Low Risk		0%	2022-05-31	4

Figure B.3 Project plan page 3.

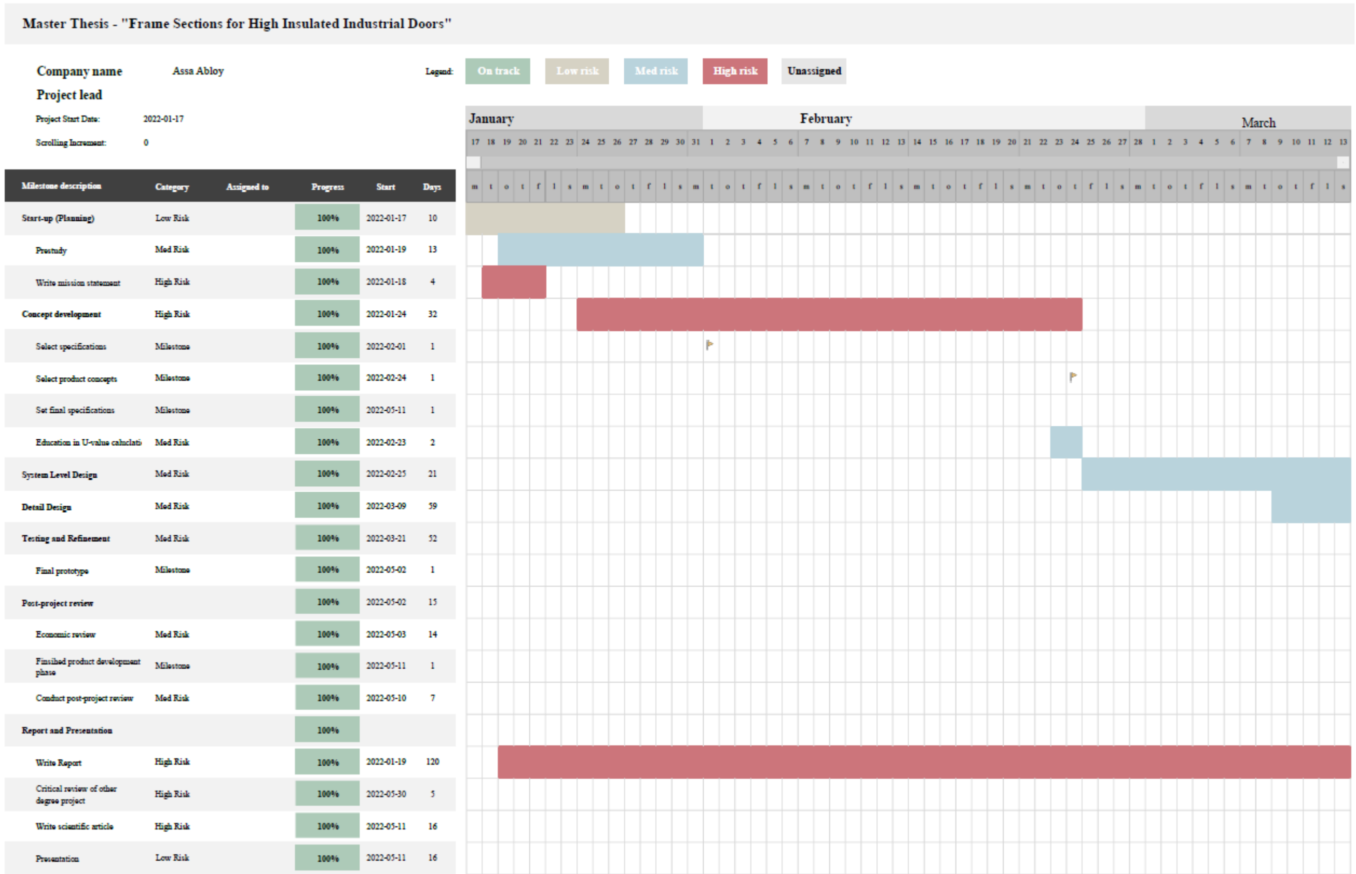


Figure B.4 Performed activities page 1.

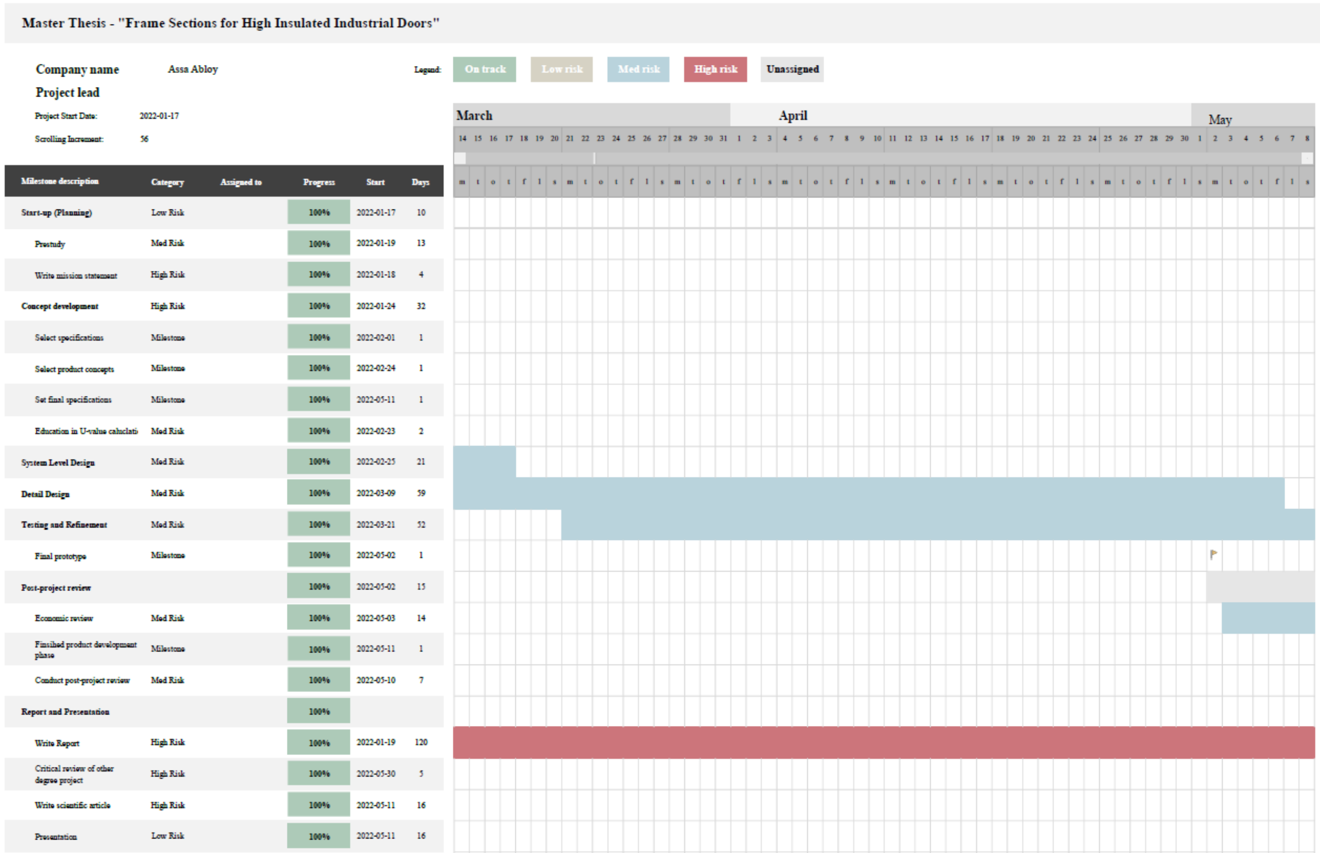


Figure B.5 Performed activities page 2.

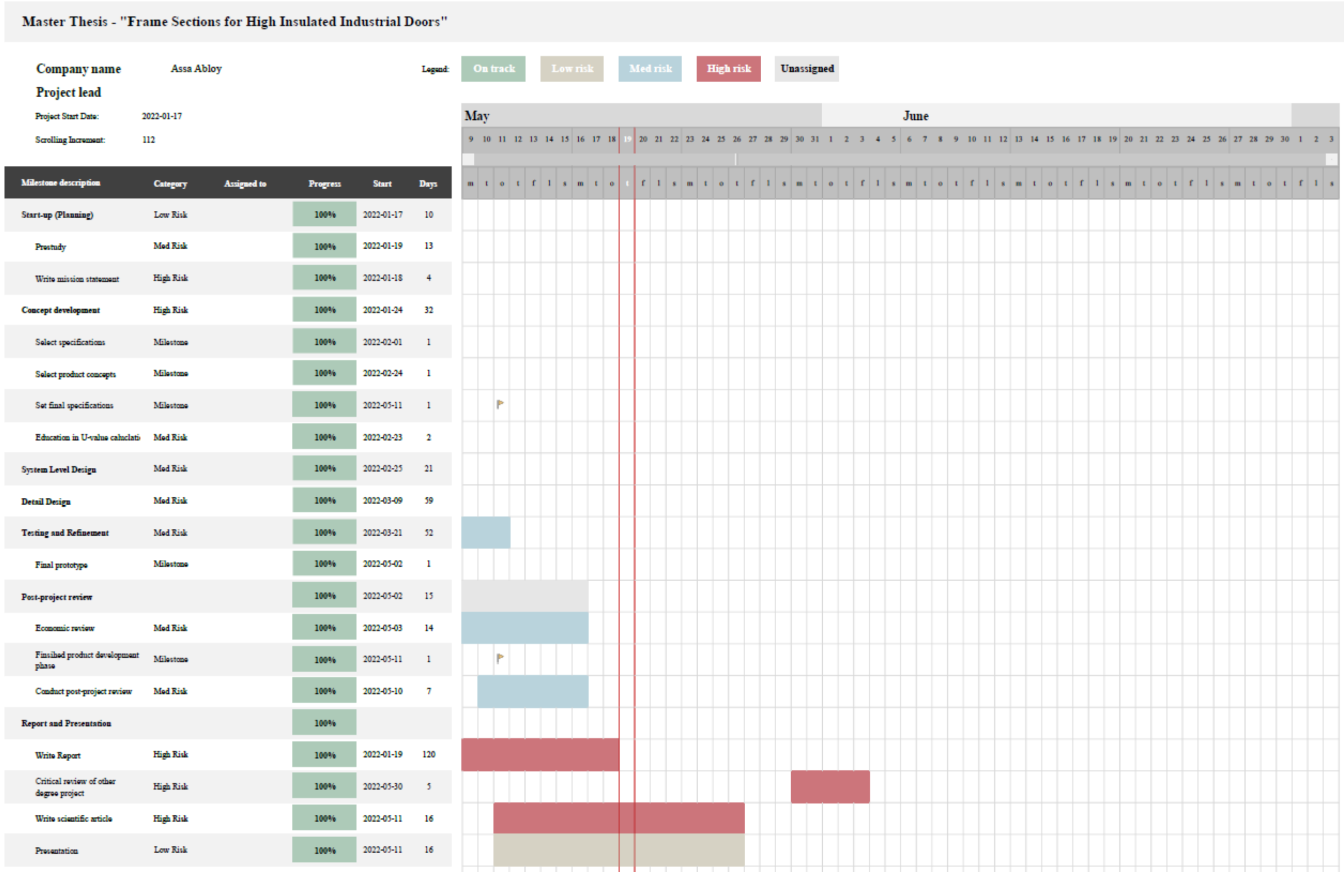


Figure B.6 Performed activities page 3.

Appendix C Interview

This appendix presents the interview questions that was used during the interview of gathering information for the customer needs. The appendix also presents the answers that was gathered from this interview that was received on the 26 of January 2022.

Do you know the reasoning behind the decision to make a frame section for OH1082FI?

Answer: We do not have frame sections for the 82 *mm* door (OH1082P). We expect the market to change into better insulated doors as standard and since a lot of customers also demand daylight ingress, the best way to combine both good insulation and daylight is thermal separated frame sections in the 82 *mm* panel door.

When and why would the OH1082FI be used instead of the existing overhead sectional doors?

Answer: In the future the standard will be "high insulated" doors meaning thicker with more insulation and to be able to offer these doors with windows we need 82 *mm* frame sections with thermal separation in the profiles.

What do you want to see in a future OH1082FI frame section?

Answer: I like to have a wide portfolio offering a basic door 42 *mm* in both panel and frame section and a mix of these and I also like to have the same opportunity in the high insulated (82 *mm*) door range.

Do you see any potential problems that could arise with an 82 mm frame section?

Answer: Not really, but there are always risks like cost/price, difficulties in manufacturing, weight coursing balancing issues for the complete door etc. But in my view, it is "just" a matter of making the 42 *mm* FI profiles 82 *mm* thick, keeping the design and other details the same.

Advantages and disadvantages with the existing overhead sectional doors that exist today (OH1082P, OH1042F and OH1042FI)?

Answer: For the OH1082P we lack the opportunity to offer big windows which the insulated frame sections offer. For the OH1042F and OH1042FI we do not meet the insulation (U-value) requirements demanded from the customer/authorities.

Is there a target specification for U-value, weight, and class for resistance to wind load and so on for the new OH1082FI?

Answer: Yes, a requirement specification document exists and is sent to you, when it comes to other mandated characteristic the complete door should fulfil all demands in EN 13241 and all underlying standards like EN 12424 and EN 12444 etc.

Appendix D Information meeting with Product Manager Industrial Doors

This appendix present important information from the PowerPoint presentation given by Kaj Søndergaard on the 28 of January 2022.

An informative meeting regarding the overhead sectional doors offered by ASSA ABLOY Entrance Systems was held with product manager Kaj Søndergaard. Some important information was noted and can be seen in the list below.

Information about core values at ASSA ABLOY Entrance Systems:

- A nice design is a nice feature, but quality and good features sell by itself.
- Quality is more important than a low price at ASSA ABLOY, strives to be the "best", not the cheapest.

Information about overhead sectional doors:

- Why do we use doors? To divide environments. Reasons: protection, indoor climate, security, dust, access, noise.
- Sales arguments regarding the overhead sectional doors: Close tight, when opened they are out of the way, offers custom design, easy to operate, highly insulated.
- 90 % of the overhead sectional doors are electrically operated.
- The biggest energy loss is when the door is opened. A highly insulated door makes sure that the insulation is good when the doors is closed. If a door is opened many times during a day, it might be better to invest in a door that open and closes faster to save energy.
- Panel sections are always 545 *mm* high; frame sections can be offered at different heights. The fixed height at 545 *mm* gives better running performance but is more expensive because more panels are needed.
- There are requirements regarding U-values on buildings, meaning ASSA ABLOY Entrance Systems are obliged to deliver a certain U-value.
- The glue used in the frame sections is butyl.
- The OH1082P has no finger protection.
- Competitors offer 80, 67 or 60 *mm* for panel sections, ASSA ABLOY offers the best U-value and thickest thickness.

- Manufacturing: pushed from the backside with a connection in the front, supply chain reason, the connection only affects the front, and the backside can stay flat. A robot put sealing on the inside of profile, unbroken corners, no water leaks in corners. Broken corners lead to water leaks as competitors.
- Material for frames is anodised aluminium.

Information about the future OH1082FI:

- Right now, ASSA ABLOY only offer OH1082P, there is no frame section so a door cannot be “mixed and matched”.
- The weight of the OH1082FI should be as light as possible but strong enough to meet the constrains regarding wind load etc.
- The window in OH1082FI will be bending due to wind load, and that is okay. It should move together with the door.
- If real glass windows, they must be safety glass to fulfil European stands.
- Mostly acrylic windows are used.
- When designing the OH1082FI, it is not necessary to have the pass door in mind, but that is why it is important that the frame sections are 82 *mm* thick exactly.
- The appearance of the frame sections must be the same. Customers should be able to mix and match doors in a building.
- Depending on door size, the side panels will differ.
- Look at the window types already offered by ASSA ABLOY.
- Look at adding thickness in glazing in windows, e.g., create a new item in the product catalogue (add 4 *cm* evenly distributed).
- Look at ways to use the existing glazing windows.
- 3-layer window should be the most interesting for OH1082FI since it is supposed to be a highly insulated frame.

Appendix E Data for windows

This appendix presents the data for the existing and suggested window types for the new frame sections.

E.1 U-values for windows

The information regarding the U_g-values from the different windows was provided by ASSA ABLOY Entrance Systems in document D001067072, see Table E.1.

Table E.1 Different window types U_g-value

Window type	*U_g-value [W/(K·m^2)]*
DAD	2.5290
DSD	2.5290
TAD	1.9180
TSD	1.9180
DE4D	1.1340
DE6D	1.1870
LIGHTWEIGHT ENERGY GLASS[a]	1.24

[a] This window is a window suggested by AGC and does not exist in ASSA ABLOY Entrance Systems portfolio. The U_g-value for this window was provided from a presentation made by AGC to ASSA ABLOY Entrance Systems.

E.2 Mass/m^2 for windows

The mass per square meter information for windows was provided by ASSA ABLOY Entrance System. The summary of these values can be seen in Table E.2.

Table E.2 Mass/m^2 *for different window types*

Window type	*Mass/m^2 [kg/m^2]*
DAD	7.21
DSD	7.21
TAD	10.24
TSD	10.24
DE4D	21
DE6D	31
LIGHTWEIGHT ENERGY GLASS[a]	12

[a] This window is a window suggested by AGC and does not exist in ASSA ABLOY Entrance Systems portfolio. The mass/m^2 for this window was provided from a presentation made by AGC to ASSA ABLOY Entrance Systems.

Appendix F Calculations

This appendix includes simpler calculations for the horizontal profiles of the frame sections.

F.1 Calculations for horizontal parts of the frame section

Data

	Concept 1	Concept 3	Concept 4	Concept 7	
P-wind Class 2	450	450	450	450	[*Pa*]
P-wind_Class 3	700	700	700	700	[*Pa*]
H-upper	0,0355	0,0355	0,0355	0,0355	[*m*]
H-lower	0,0353	0,0353	0,0353	0,0353	[*m*]
L	7,25	7,25	7,25	7,25	[*m*]
A-upper	0,257375	0,257375	0,257375	0,257375	[m^2]
A-lower	0,255925	0,255925	0,255925	0,255925	[m^2]
Safety factor EN12604	1,1	1,1	1,1	1,1	
Safety factor EN12424	1,25	1,25	1,25	1,25	
Safety factor (total)	1,375	1,375	1,375	1,375	
Upper Centre of Gravity	(15.22, 20.68, -3625)	(-0.94, 22.72, -3625)	(-17.98, 17.27, -3625)	(1.19, 24.14, -3625)	(x, y, z)
Lower Centre of Gravity	(15.25, 11.81, 3625)	(-3.18, 11.43, 3625)	(-20.93, 11.08, 3625)	(-2.73, 12.1, 3625)	(x, y, z)
Ix-upper	2,92006E-07	3,31199E-07	2,03E-07	3,59E-07	[m^4]
Ix-lower	9,68539E-08	9,9426E-08	1,02076E-07	9,7379E-08	[m^4]
ymax-upper	0,03818	0,04022	0,03823	0,04164	[*m*]

ymax-lower	0,03119	0,03157	0,03192	0,03092	[*m*]
E	69000003580	69000003580	69000003580	69000003580	[N/m^2]
Calculations - Upper horizontal part					
	Concept 1	Concept 3	Concept 4	Concept 7	
Q-wind_Class 2	159,2507813	159,2507813	159,2507813	159,2507813	[*N*]
Q-wind_Class 3	247,7234375	247,7234375	247,7234375	247,7234375	[*N*]
Wb	7,64815E-06	8,23468E-06	5,31382E-06	8,61897E-06	[m^3]
Mb_Class 2	144,3210205	144,3210205	144,3210205	144,3210205	[*Nm*]
Mb_Class 3	224,4993652	224,4993652	224,4993652	224,4993652	[*Nm*]
Sigma-max_Class 2	18870048,28	17526000,15	27159569,22	16744583,76	[N/m^2]
Sigma-max_Class 3	29353408,43	27262666,9	42248218,79	26047130,29	[N/m^2]
def_Class 2	0,03921866	0,034577725	0,056373402	0,031909449	[*m*]
def_Class 3	0,061006805	0,053787572	0,087691959	0,04963692	[*m*]
Calculations - Lower horizontal part					
	Concept 1	Concept 3	Concept 4	Concept 7	
Q-wind_Class2	158,3535938	158,3535938	158,3535938	158,3535938	[*N*]
Q-wind_Class3	246,3278125	246,3278125	246,3278125	246,3278125	[*N*]
Wb	3,10529E-06	3,14938E-06	3,19786E-06	3,14938E-06	[m^3]
Mb_Class 2	143,5079443	143,5079443	143,5079443	143,5079443	[*Nm*]
Mb_Class 3	223,2345801	223,2345801	223,2345801	223,2345801	[*Nm*]
Sigma-max_Class 2	46214063,88	45566998,93	44876261,71	45566985,3	[N/m^2]
Sigma-max_Class 3	71888543,81	70881998,34	69807518,21	70881977,13	[N/m^2]
def_Class 2	0,117574855	0,114533231	0,111560244	0,116940912	[*m*]
def_Class 3	0,182894219	0,178162803	0,173538158	0,181908086	[*m*]

F.2 Calculations for the U_f-value

The U_f-value calculations for concepts 3 and 7 was made in Flixo and pictures from the test reports are presented in the following sections. The assigned materials, boundary conditions, isoterms and U_f-values are presented for each concept.

F.2.1 Concept 3

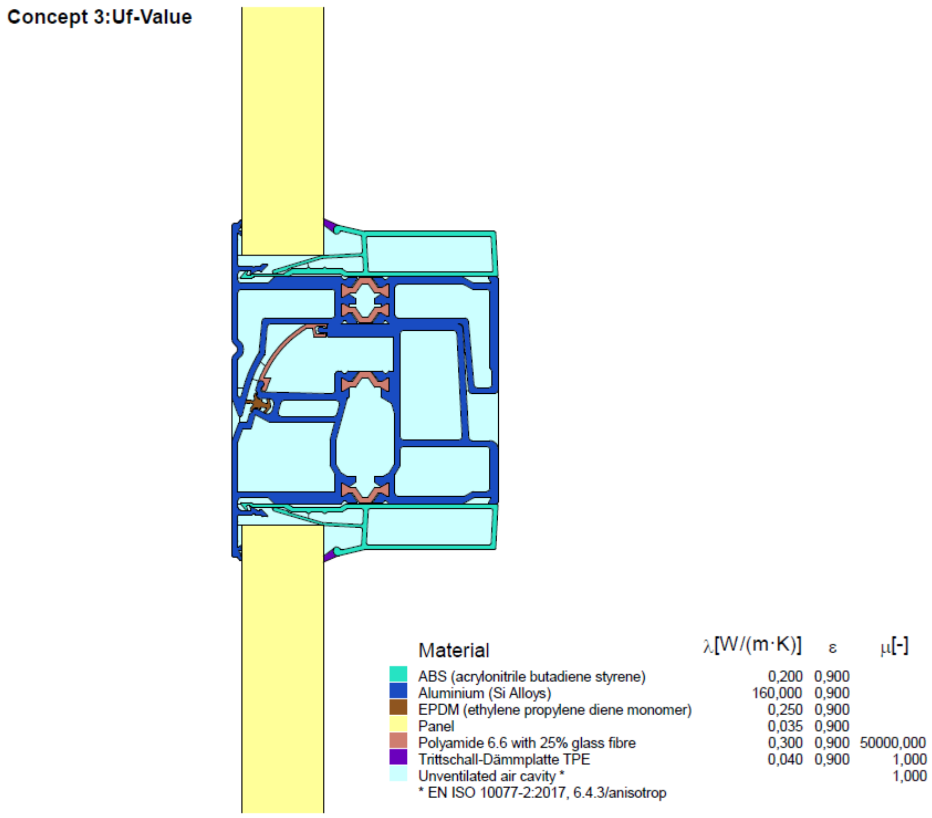


Figure F.1 Flixo model for concept 3.

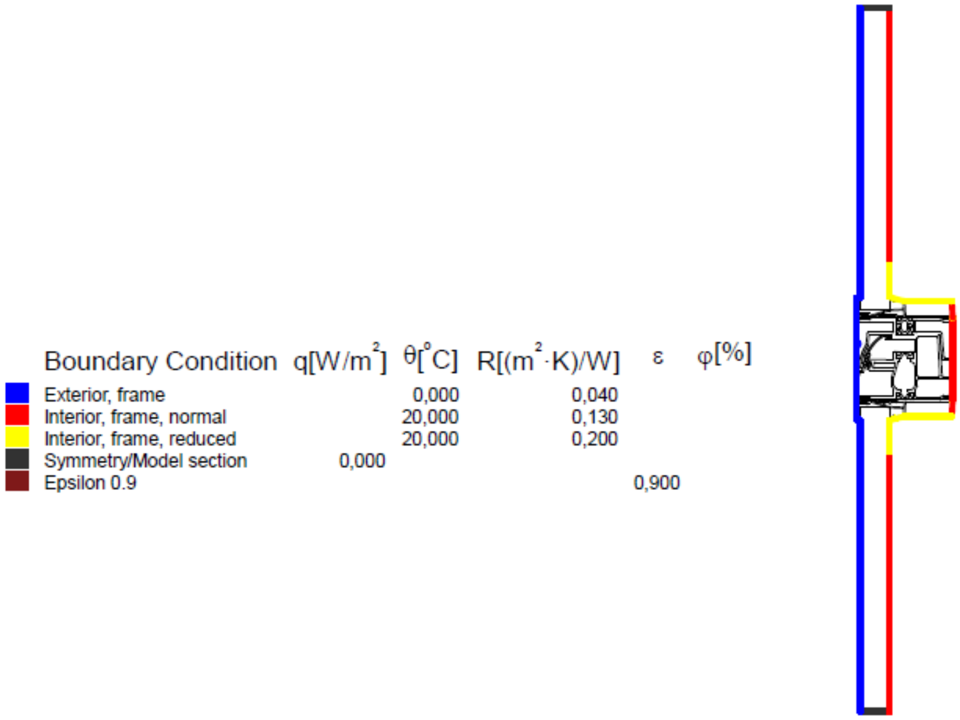


Figure F.2 The boundary conditions assigned to concept 3.

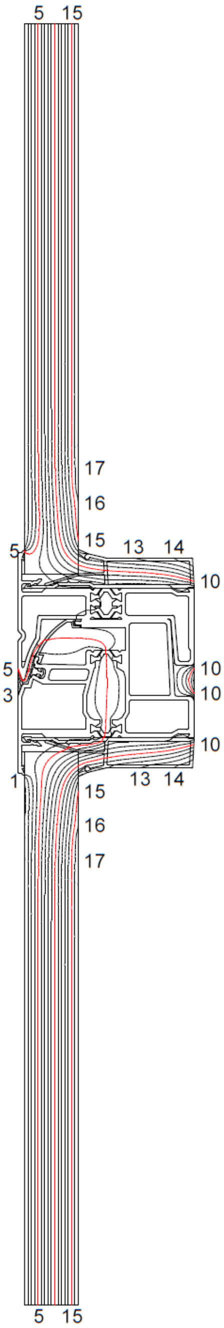
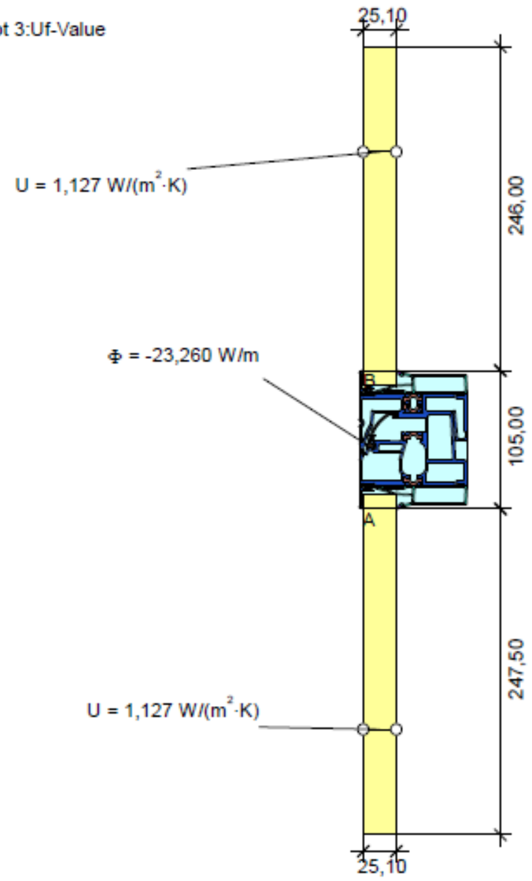


Figure F.3 The isotherms for concept 3.

Concept 3:Uf-Value



$$U_{f\,A,B} = \frac{\frac{\Phi}{\Delta T} - U_{p1} \cdot b_{p1} - U_{p2} \cdot b_{p2}}{b_f} = \frac{\frac{23{,}260}{20{,}000} - 1{,}127 \cdot 0{,}248 - 1{,}127 \cdot 0{,}246}{0{,}105} = 5{,}78 \text{ W/(m}^2\cdot\text{K)}$$

Figure F.4 The U_f-value calculation for concept 3.

F.2.2 Concept 7

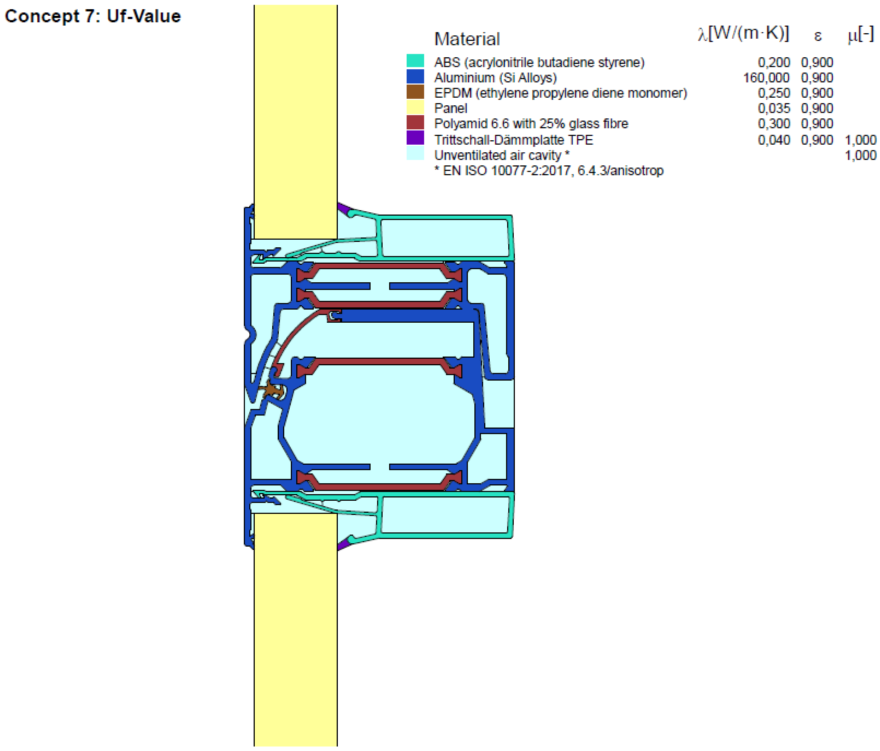


Figure F.5 Flixo model for concept 7.

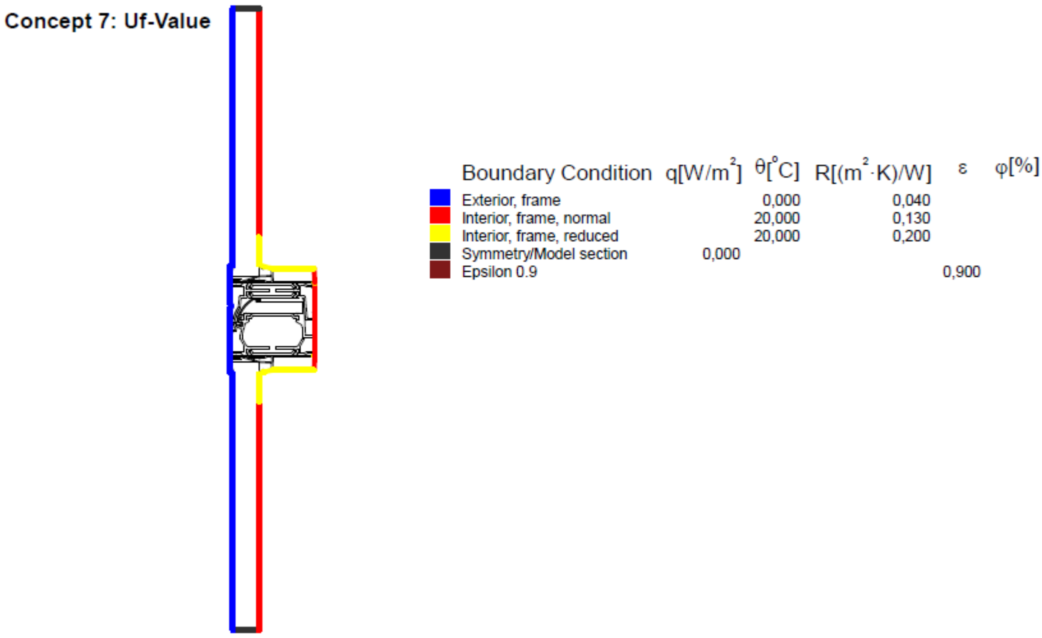


Figure F.6 The boundary conditions assigned to concept 7.

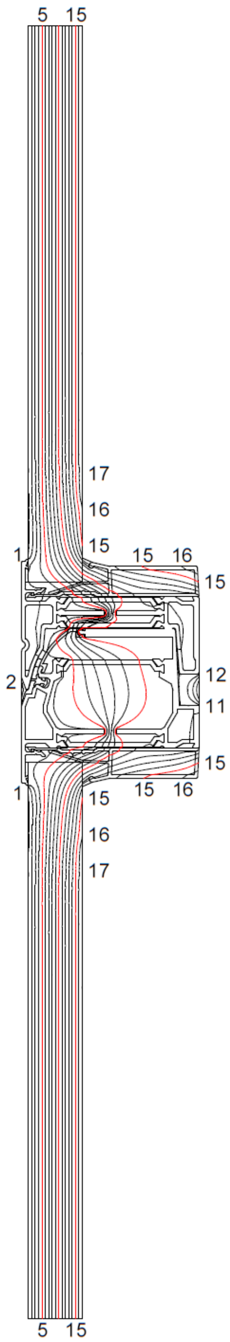
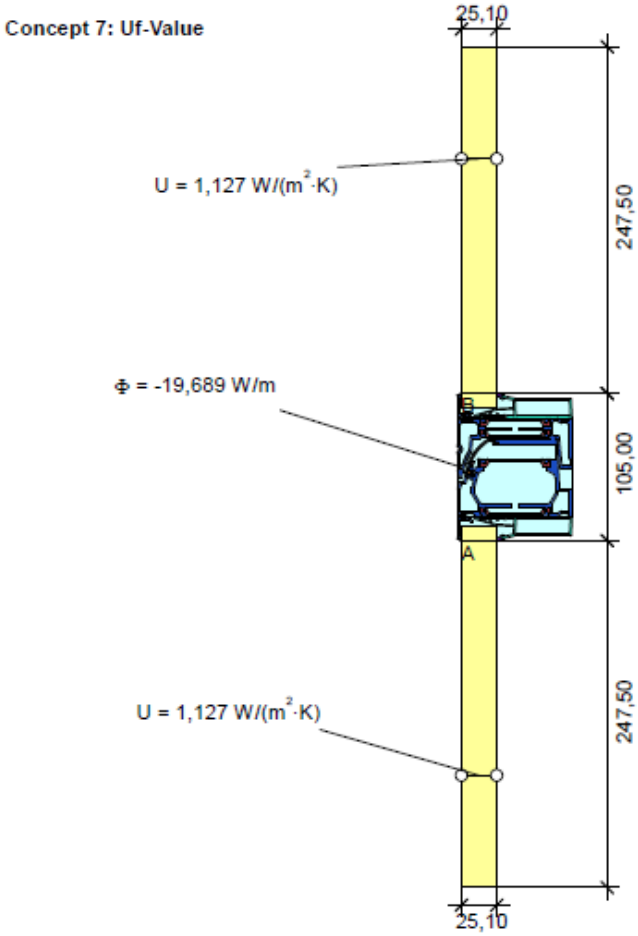


Figure F.7 The isotherms for concept 7.



$$U_{f,A,B} = \frac{\frac{\Phi}{\Delta T} - U_{p1} \cdot b_{p1} - U_{p2} \cdot b_{p2}}{b_f} = \frac{\frac{19,689}{20,000} - 1,127 \cdot 0,248 - 1,127 \cdot 0,248}{0,105} = 4,06\ W/(m^2 \cdot K)$$

Figure F.8 The U_f-value for concept 7.

Appendix G Subsystems and components

This appendix displays the frame section's subsystems and components.

In Table G.1 the subsystems and components are displayed both for the first version of concept 7 and for the further developed concept 7. The components that have the added number '-7' in the table are parts that has been modified by the team. Parts without a Dxxxxxxxxx-001 number are new additional parts.

Table G.1 The frame sections subsystems and components

Main system	***Subsystem***	***Version***	***Component***
Top section assembly - D001084429-001-7 Middle section assembly - D001083312-001-7 Bottom section assembly - D001084503-001-7	Horizontal upper stile		D001079978-001-7[a]
			3311
			2655[a]
			D001079863-001[b]
			D001019914-001
		Without truss	D001079979-001-7[a]
		Short truss	D001080773-001-7[a]
		Long truss	D001080785-001-7[a]
	Horizontal lower stile		D001079981-001-7[a]
			D001079982-001-7[a]
			3311
			2655[a]
	Vertical side stile		D001080633-001-7[a]
			D001080640-001-7[a]
			3311
	Vertical middle stile		D001080721-001-7[a]
			D001080723-001-7[a]
			3311

	Top stile	D001081319-001-7[a] D001081320-001-7[a] 3311
	Bottom stile	D001081432-001-7[a] D001081459-001-7[a] 3311
Torx pan head tapping screw 6.3x38		D001018629-001
Infill assembly		Window Butyl
	Infill profile	D001081515-001-7 D001081525-001

Note: The window types do not exist with a CAD-Id in Solidworks and therefore the component is only referred to as window. The different window types can be seen in Appendix E. The Butyl is a material used to attach the window and infill profile and do not have a CAD-model.

[a] These parts that has been added or changed in the original concept 7.

[b] These parts that has been removed from the original concept 7.

Appendix H Wind load simulations

This appendix presents simulations conducted in Solidworks to test the frame section stiles regarding resistance to wind load. The boundary conditions, the applied load and a few results are presented in the following sections.

H.1 Boundary conditions and loads

The boundary conditions for the FEA-simulations for the OH1042FI and the new OH1082FI frame stiles can be seen in Figure H.1 to Figure H.4. These were applied to both sides of the stiles. A pressure was applied at the flat surfaces to represent the wind load, which was in relation to standard EN 12424. Both the pressure for wind class two and three were applied with the safety factors used in the earlier calculations in Appendix F. The areas that the pressure is applied to are illustrated in Figure H.5 to Figure H.8.

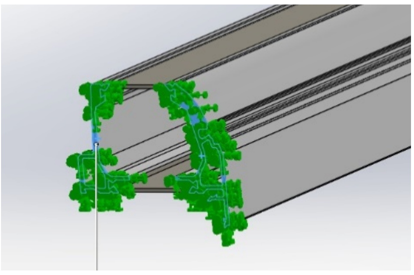


Figure H.1 Boundary conditions for the upper stile - fixed geometry.

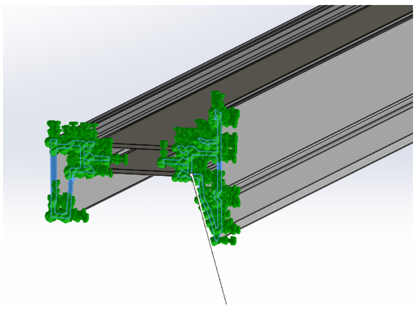


Figure H.2 Boundary conditions for the lower stile - fixed geometry.

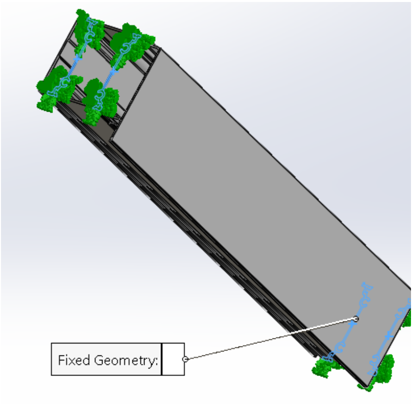


Figure H.3 Boundary conditions for the side stile - fixed geometry.

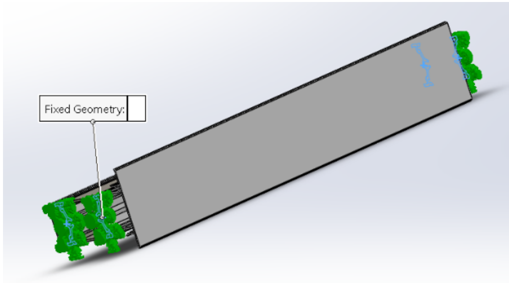


Figure H.4 Boundary conditions for the middle stile - fixed geometry.

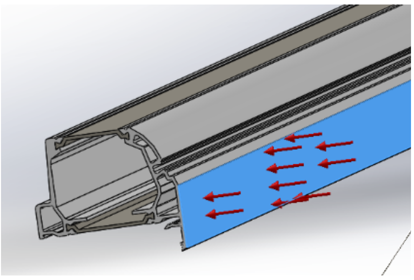


Figure H.5 Pressure applied to the upper stile.

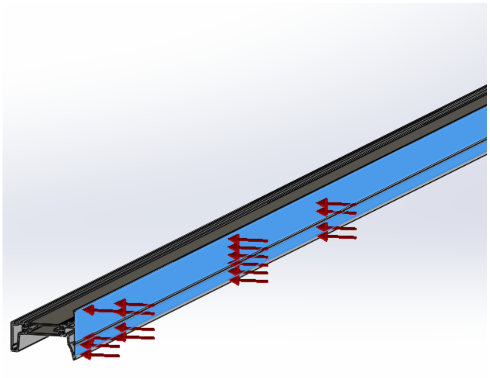


Figure H.6 Pressure applied to the lower stile.

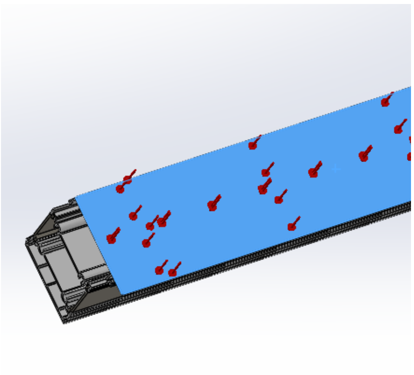


Figure H.7 Pressure applied to the side stile.

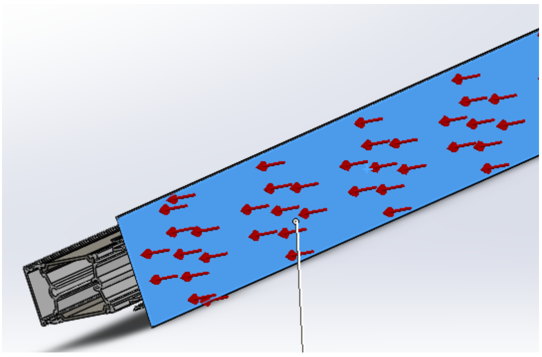


Figure H.8 Pressure applied to the middle stile.

H.2 Results

The results displaying the stress and deformation for the upper stile of the OH1041FI and OH1082FI can be seen in Figure H.9 and H.10. The load case is wind class three according to standard EN12424. These pictures present the output from the Solidworks simulation. The resulting values are displayed in Table 11.6 and Table 11.8 in section 11.1.5.1 *U-value simulations.*

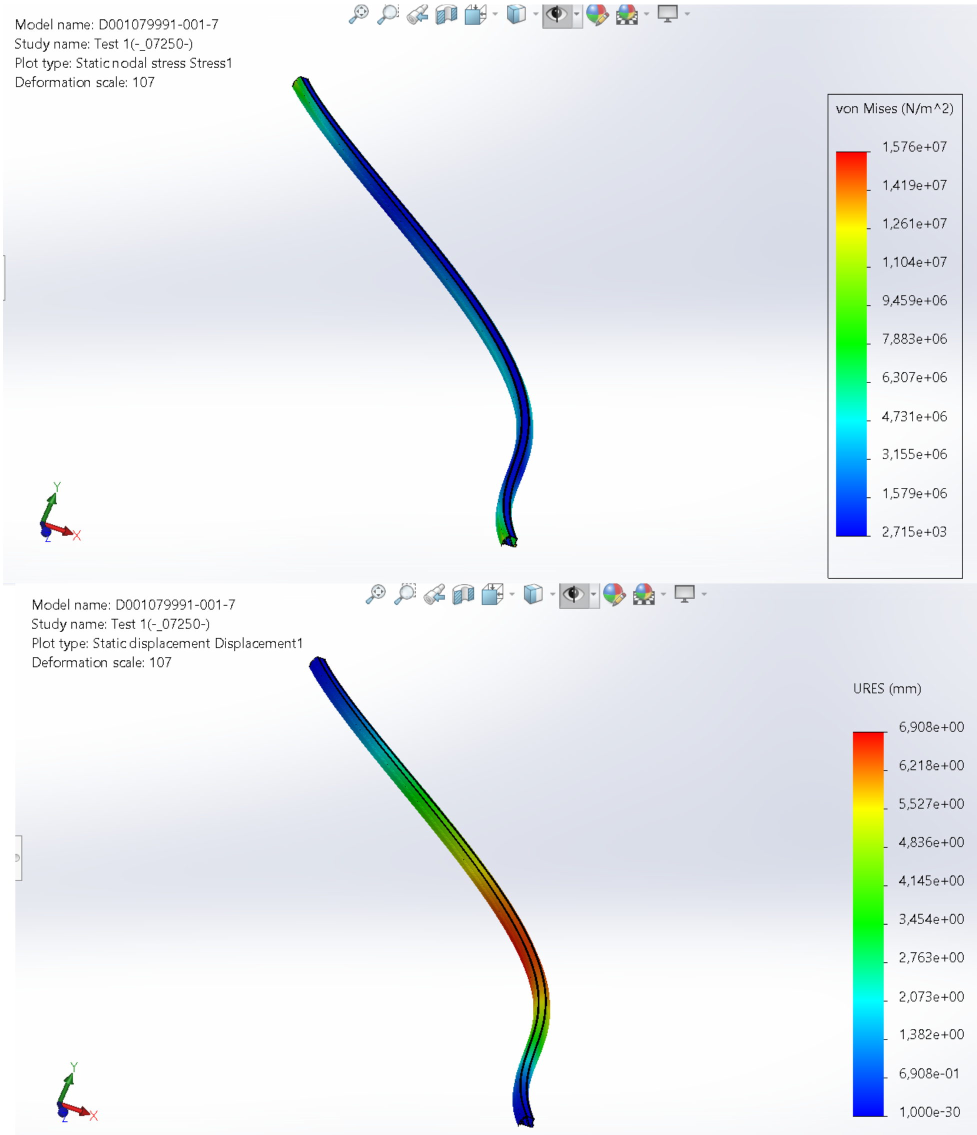


Figure H.9 The stress and deformation for the upper stile for OH1042FI.

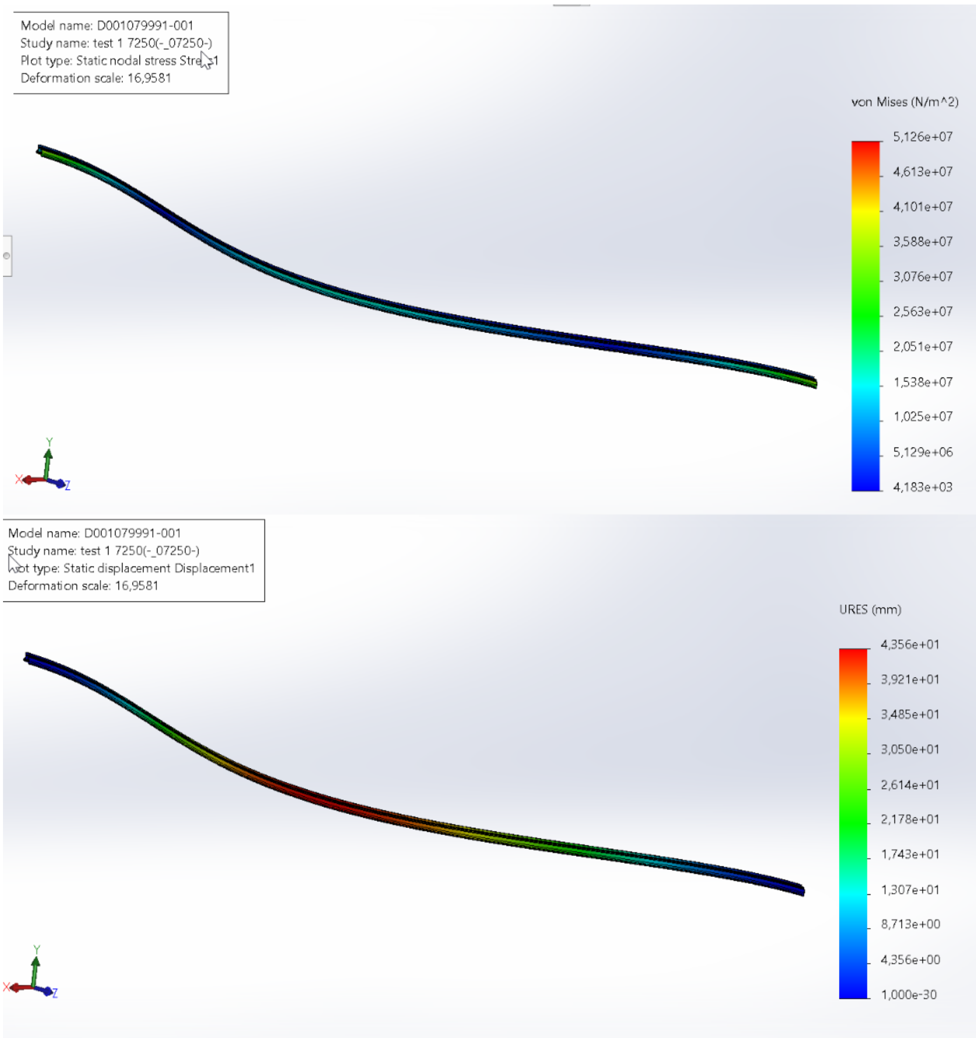


Figure H.10 The stress and deformation for the upper stile for new design.

Appendix I Screw simulations

This appendix presents the results of FEA-simulations that has been carried out in Solidworks to test the screws effect on different materials in the frame.

I.1 Screws in aluminium parts

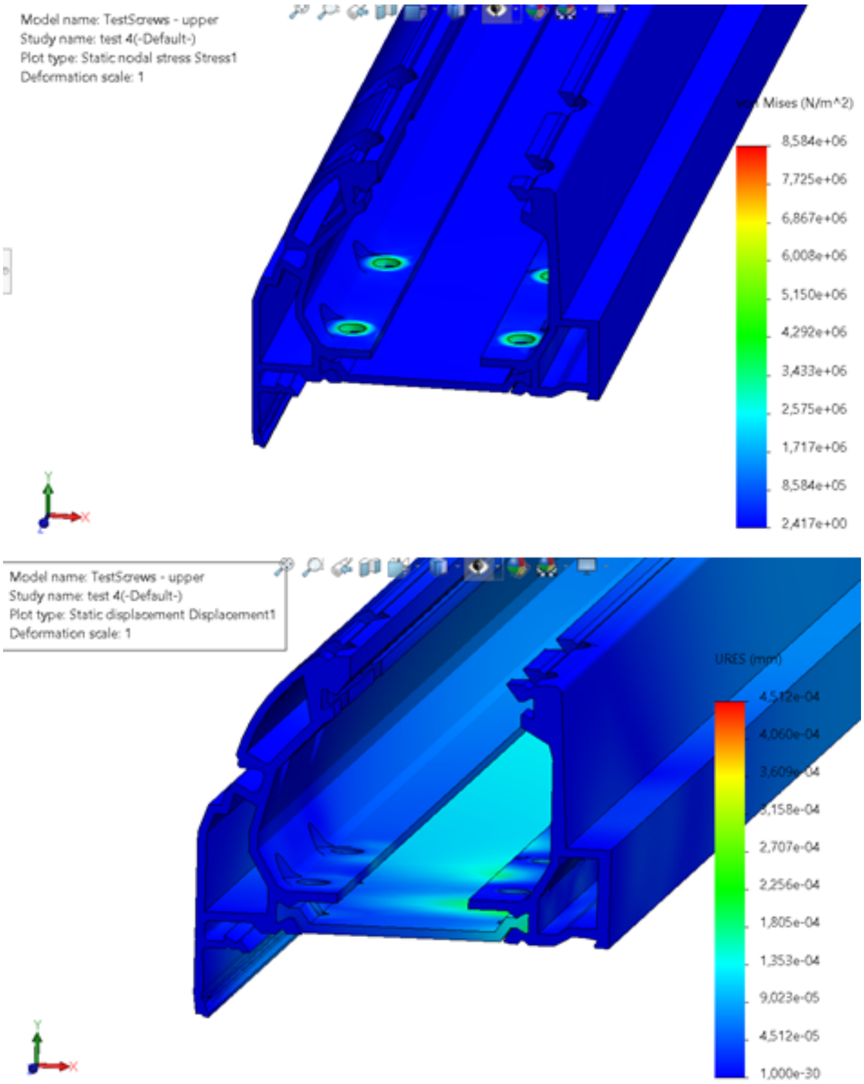


Figure I.1 The stress and deformation for the upper stile.

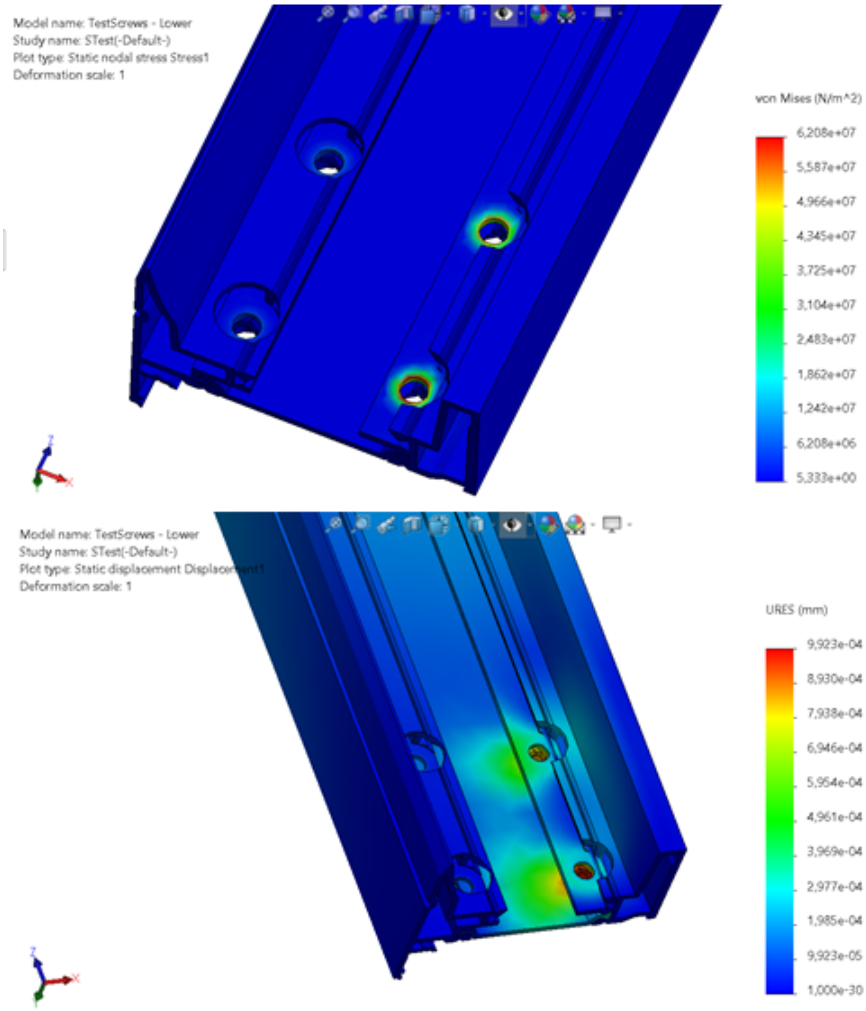


Figure I.2 The stress and deformation for the lower stile.

I.2 Screws in composite parts

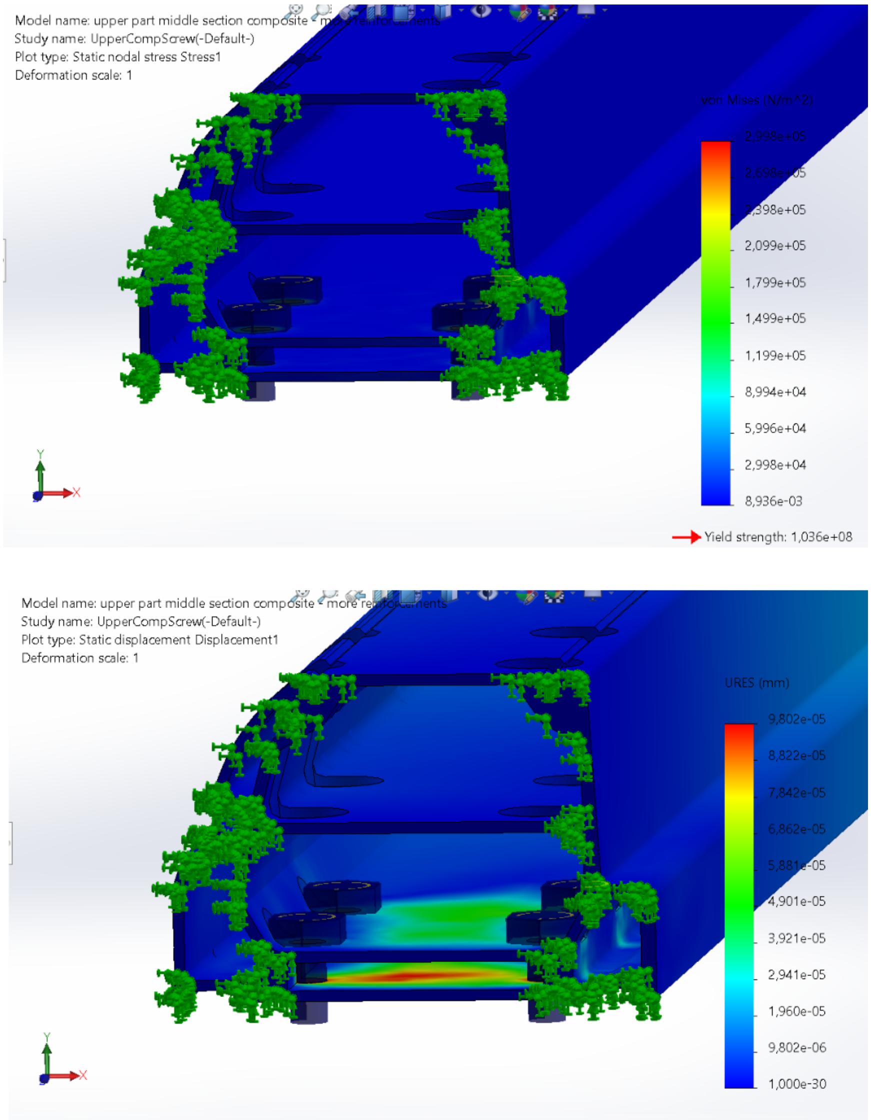


Figure I.3 The stress and deformation for the upper part.

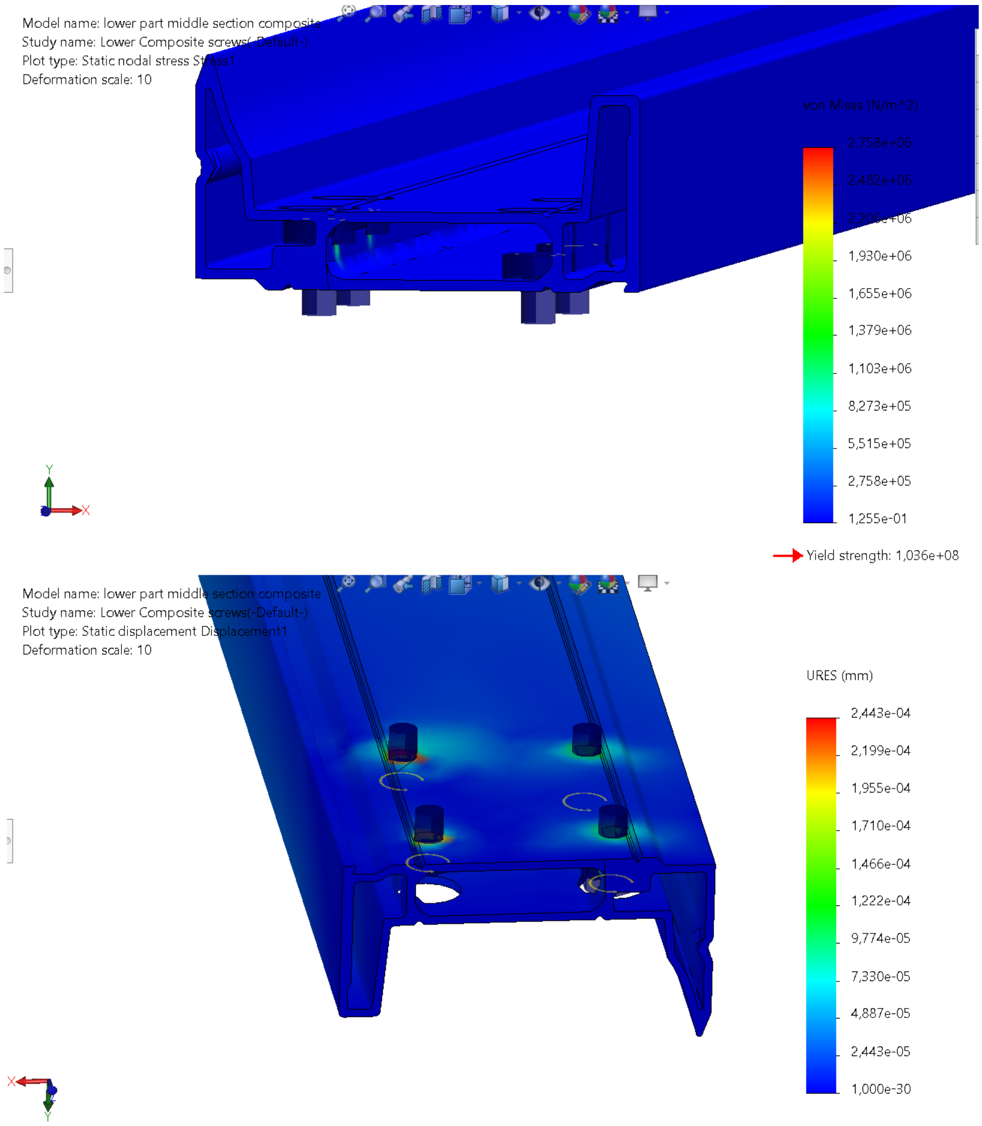


Figure I.4 The stress and deformation for the lower part.

Appendix J Wind load simulation

This appendix presents the result of FEA-simulations carried out in Solidworks for the complete frame sections regarding resistance to wind load for class 3.

J.1 Aluminium frames

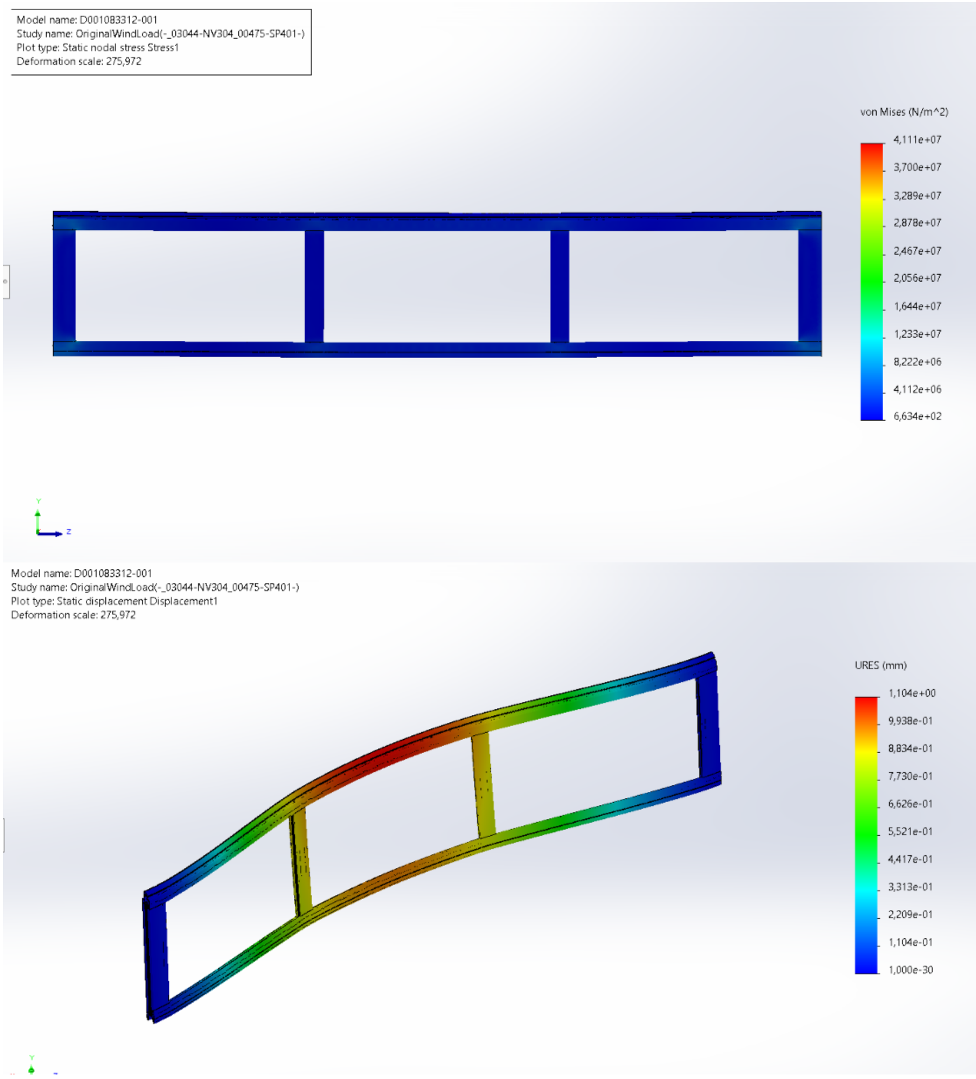


Figure J.1 The original frame section's stress and deformation.

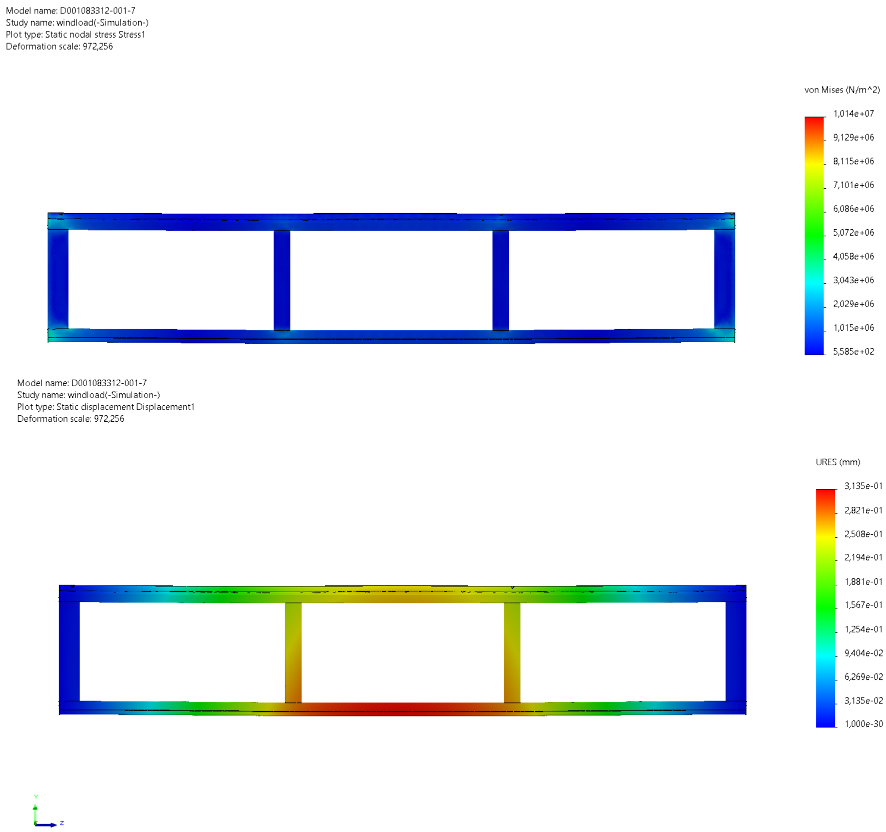


Figure J.2 The OH1082FI aluminium frame section's stress and deformation.

J.2 Composite frames

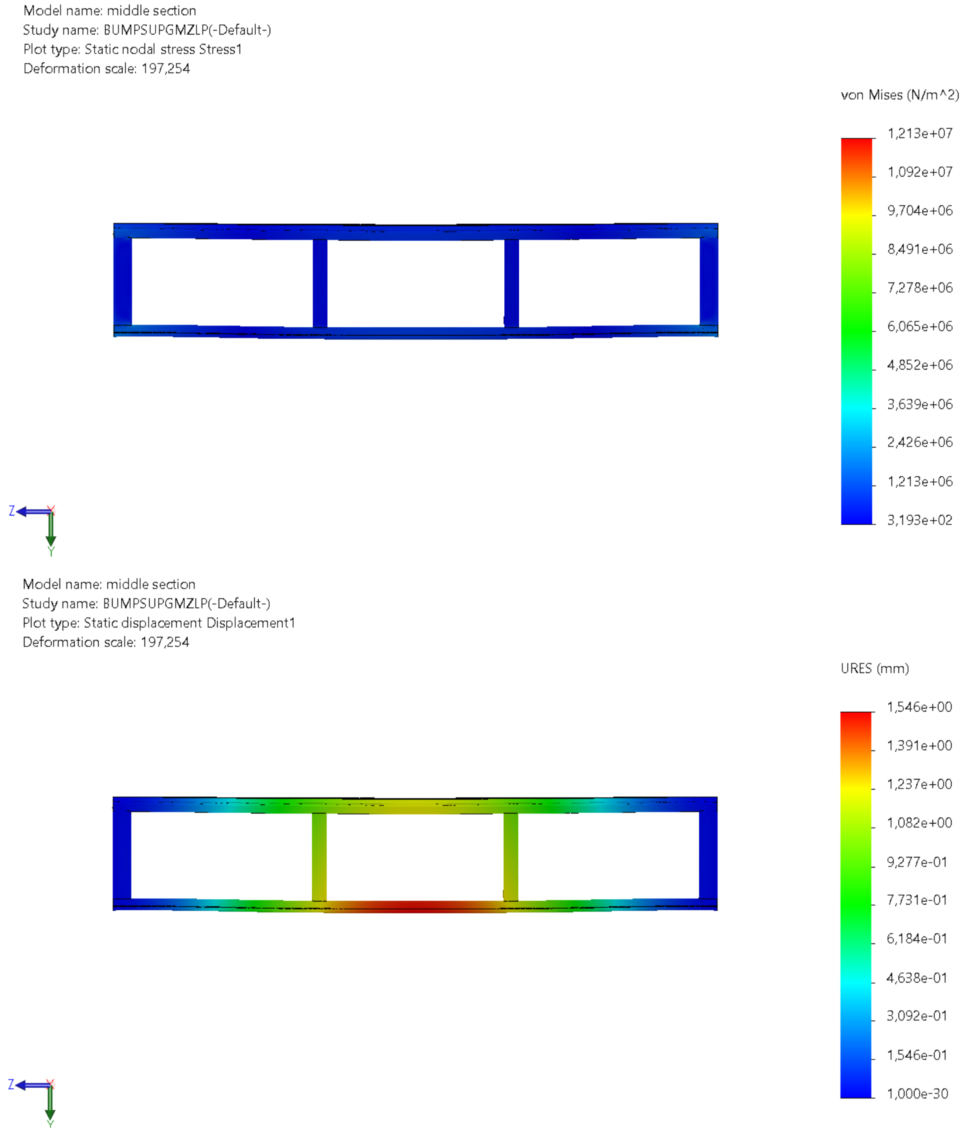


Figure J.3 The Durostone® UPGMZ-LP frame section's stress and deformation.

Appendix K Increased mass

This appendix contains the increase of the mass comparing the OH1042FI profiles with the OH1082FI profiles.

The mass of the profiles has been compared by checking the weight for each profile with a length of 1 *m* for the OH1042FI and the new designs. The increasement is presented in Table K.1.

Table K.1 Increased mass of new parts

Part	***Increased mass [%]***
Upper stile	32.26
Upper stile with short truss	24.93
Upper stile with long truss	22.78
Lower stile	22.50
Side stile	15.22
Vertical middle stile	19.86

Appendix L Assembly drawings

This appendix contains assembly drawings of the OH1082FI frame section as well as assembly drawings of the profiles and glazing list.

L.1 Middle section

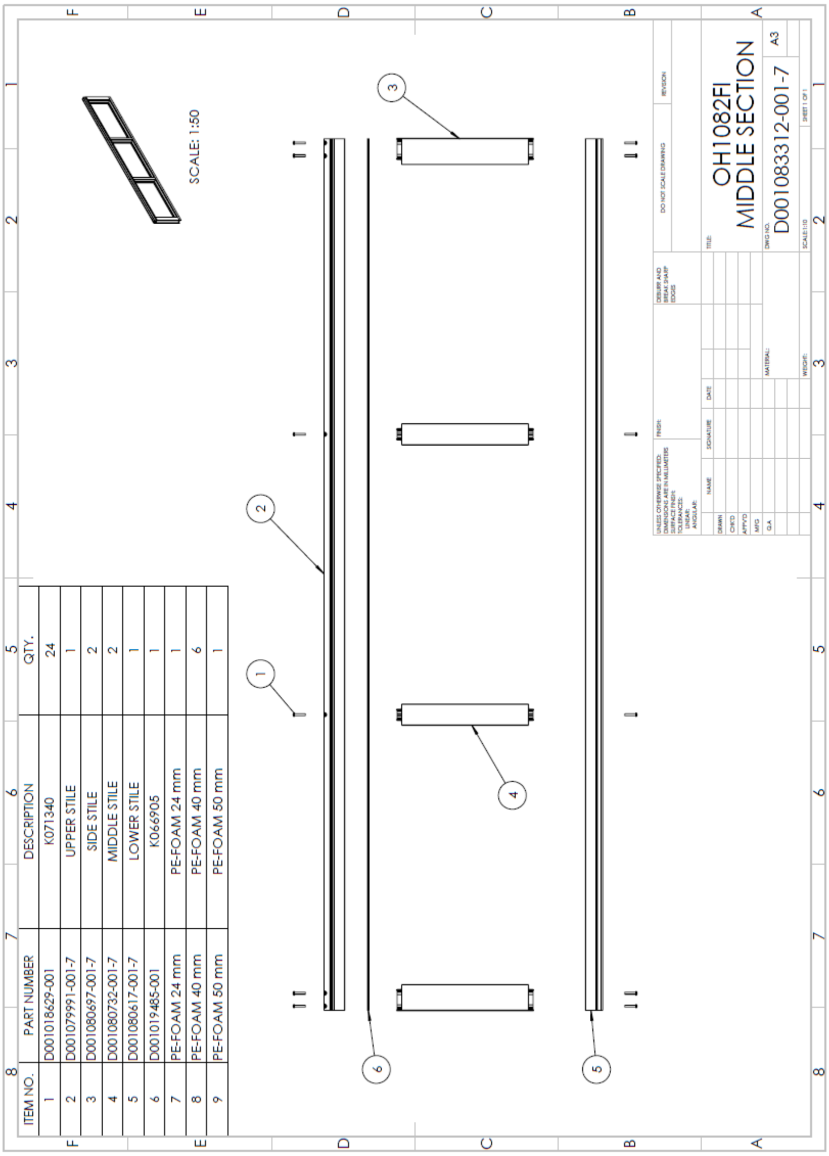


Figure L.1 Assembly drawing OH1082FI.

L.2 Profiles

Important to note is that the PE-foams are excluded in these drawings. The upper stile has a 50 *mm* PE-foam tube, the lower a 24 *mm* tube, the middle stile a 40 *mm* tube, and the side stile has two 40 *mm* tubes.

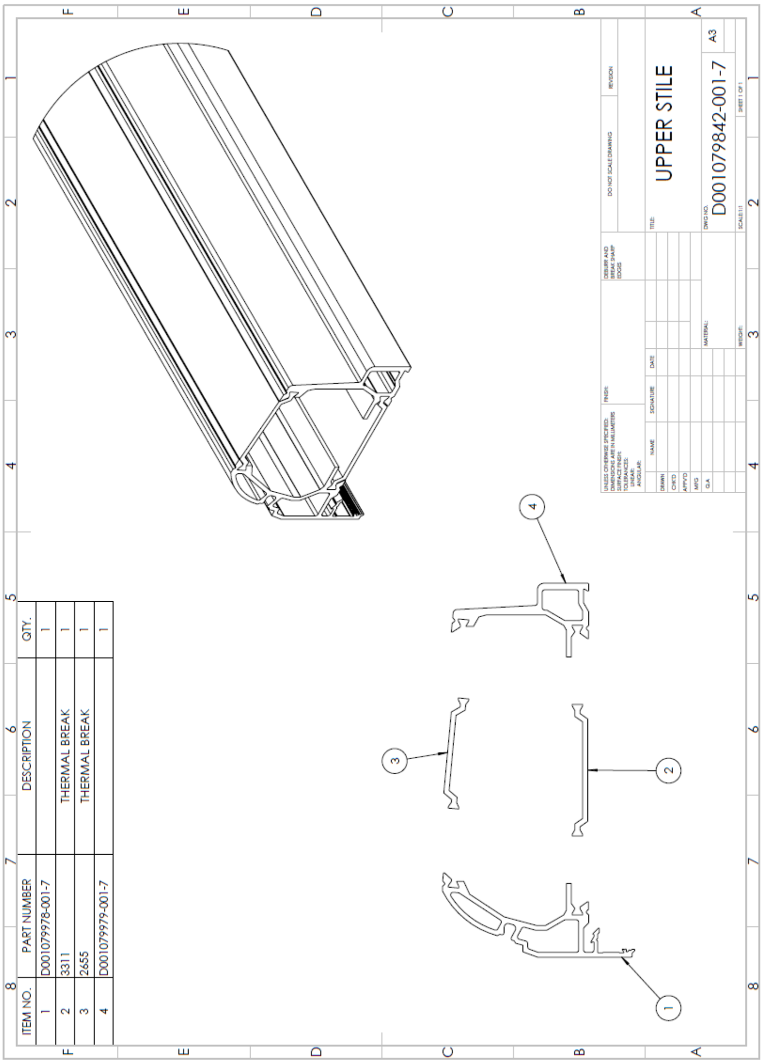


Figure L.2 Assembly drawing upper stile.

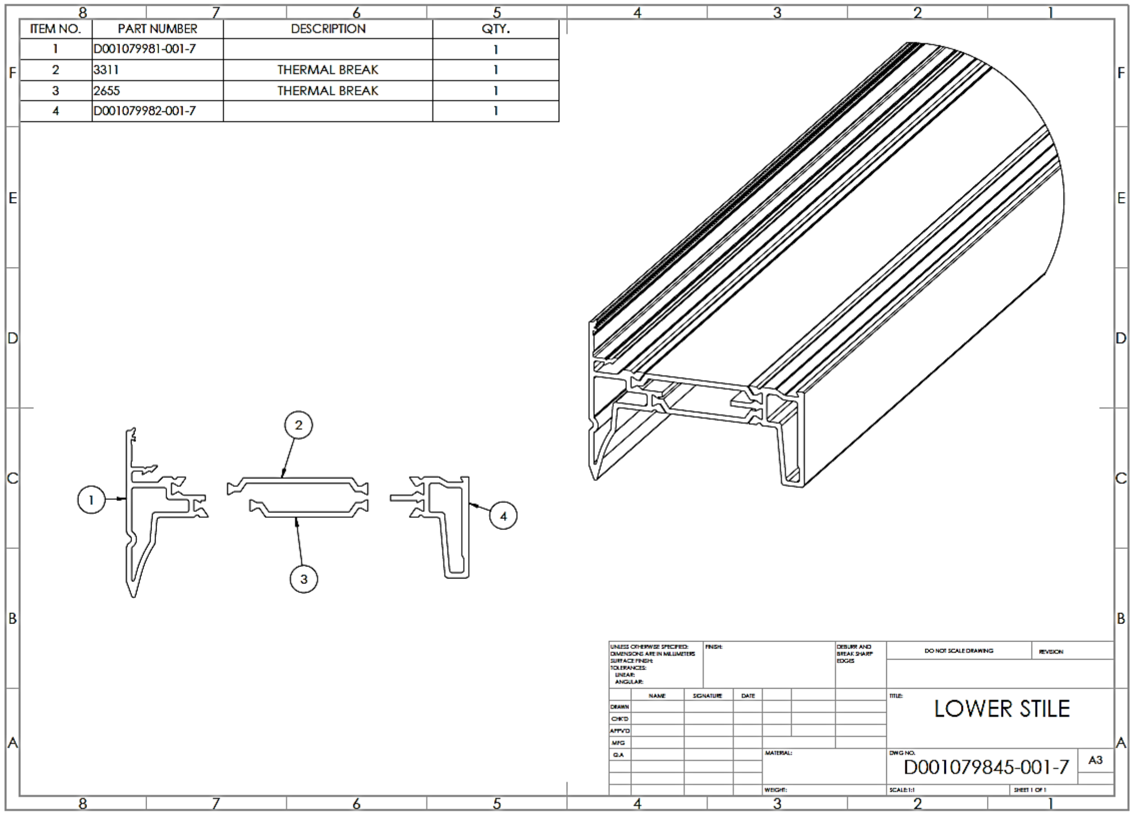


Figure L.3 Assembly drawing lower stile.

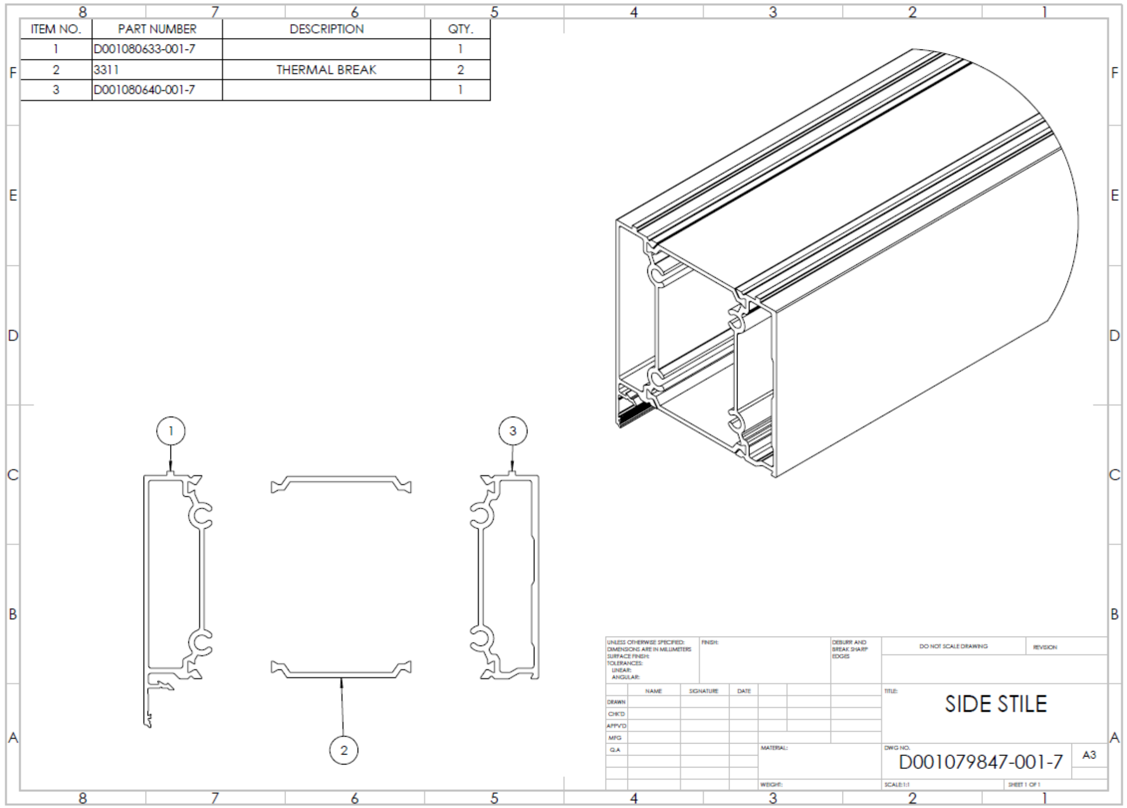


Figure L.4 Assembly drawing side stile.

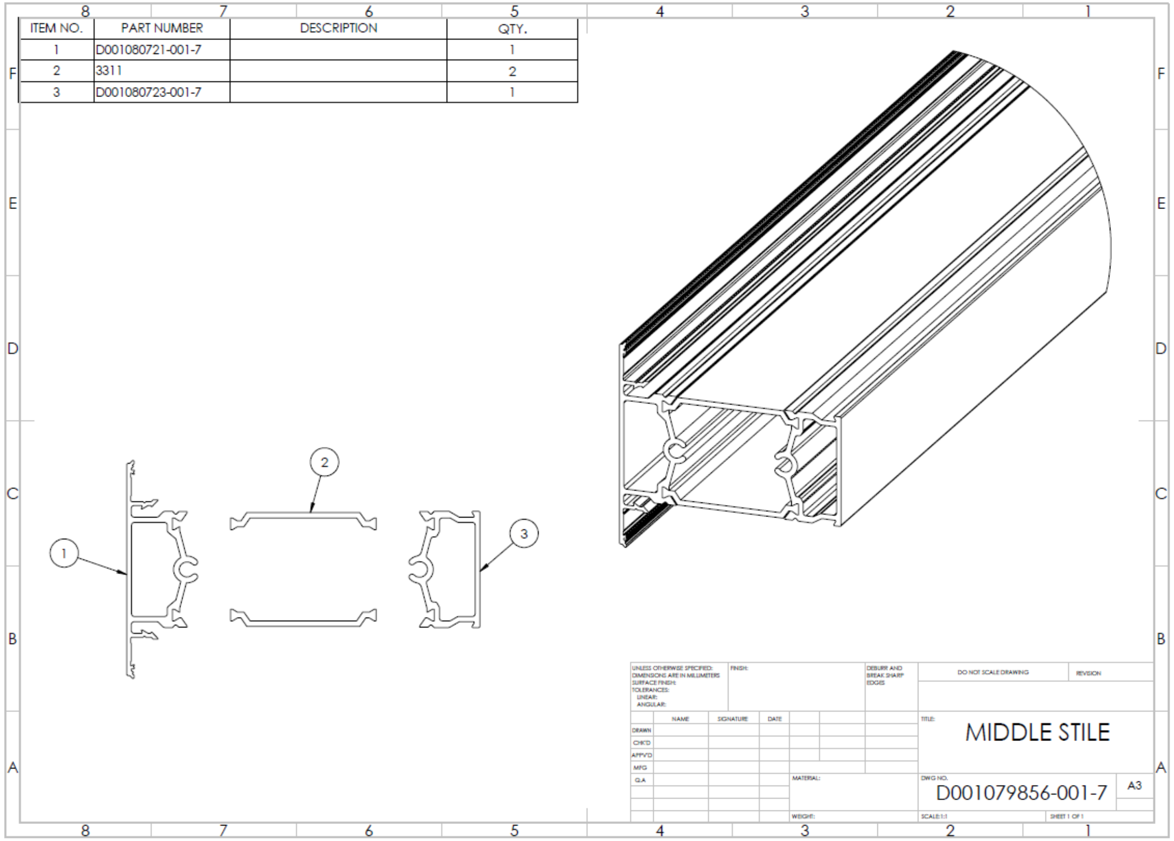


Figure L.5 Assembly drawing middle stile.

L.3 Reinforced stiles

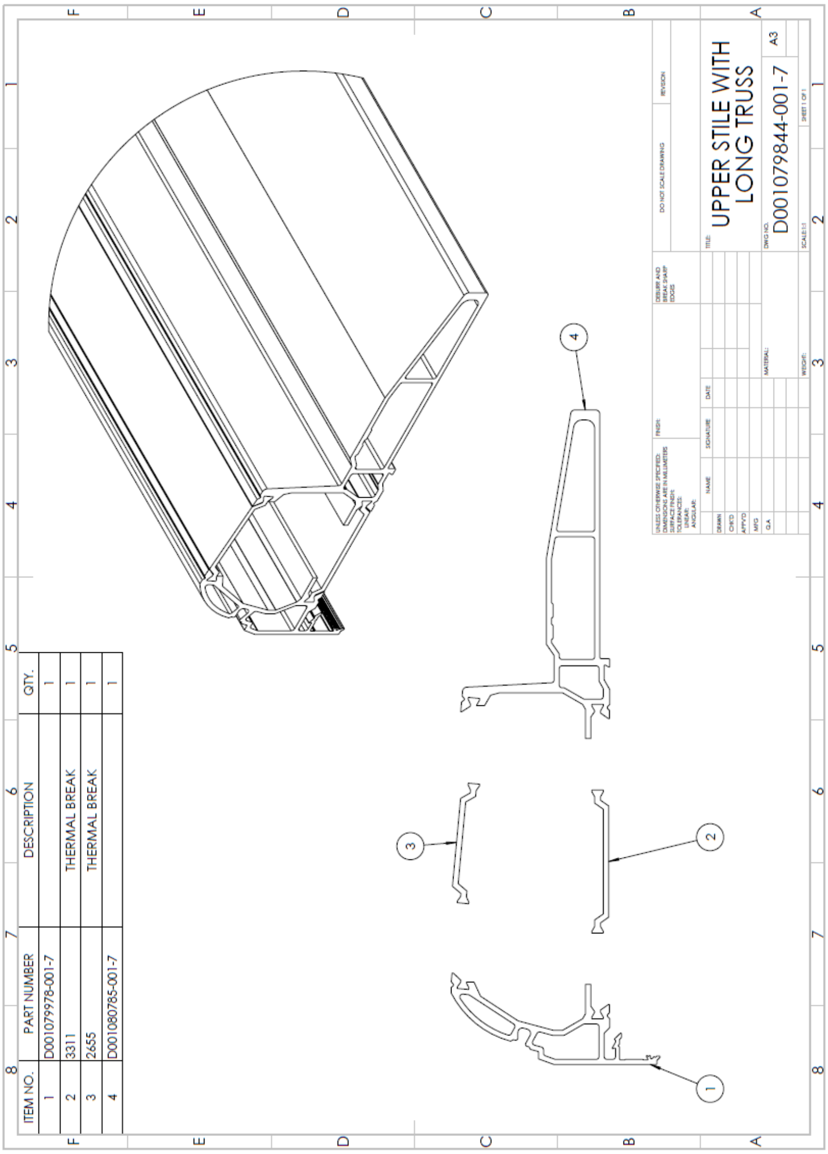


Figure L.6 Assembly drawing upper stile with long truss.

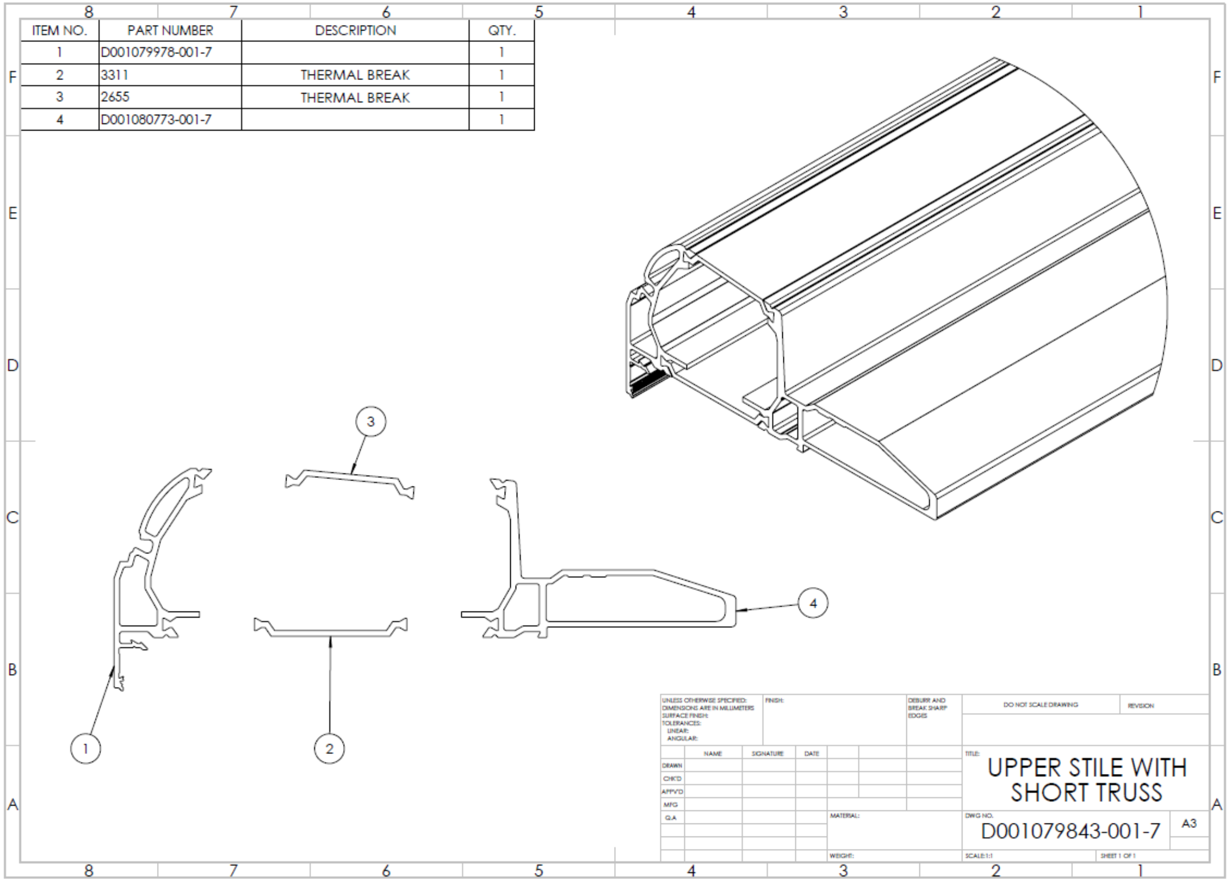


Figure L.7 Assembly drawing upper stile with short truss.

L.4 Glazing list

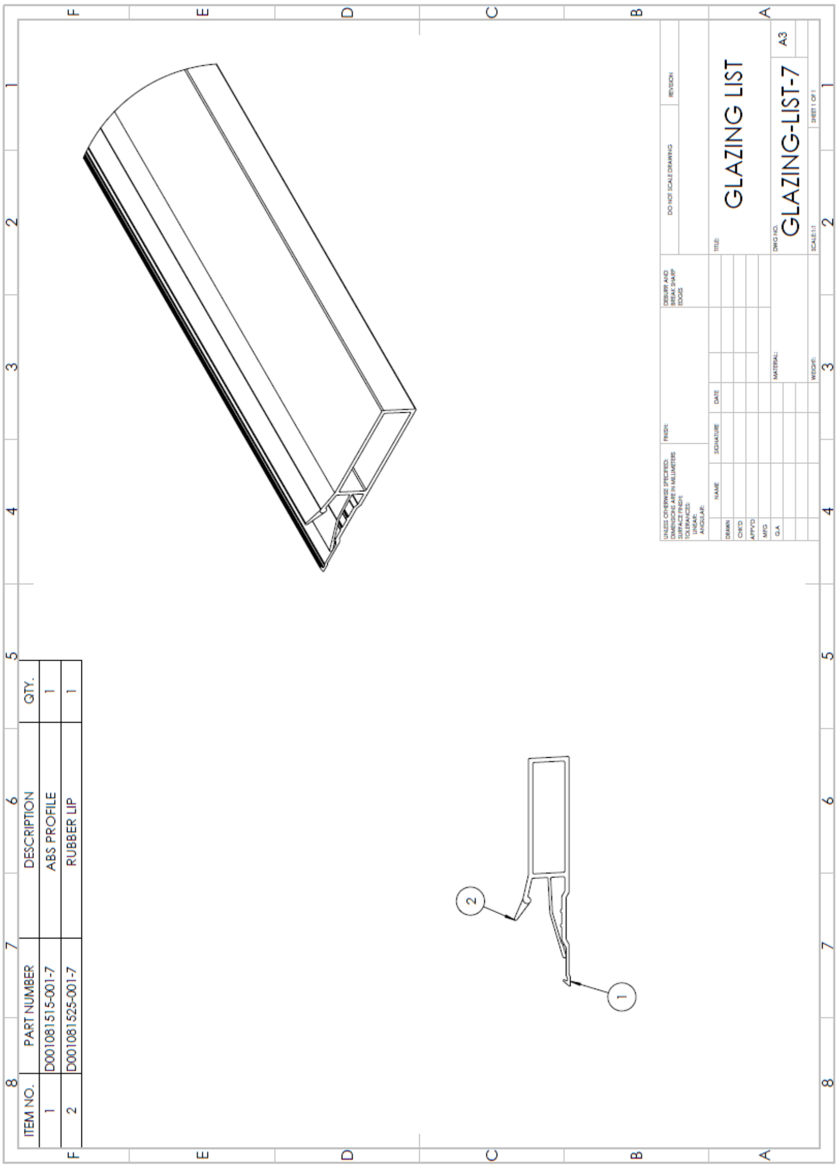
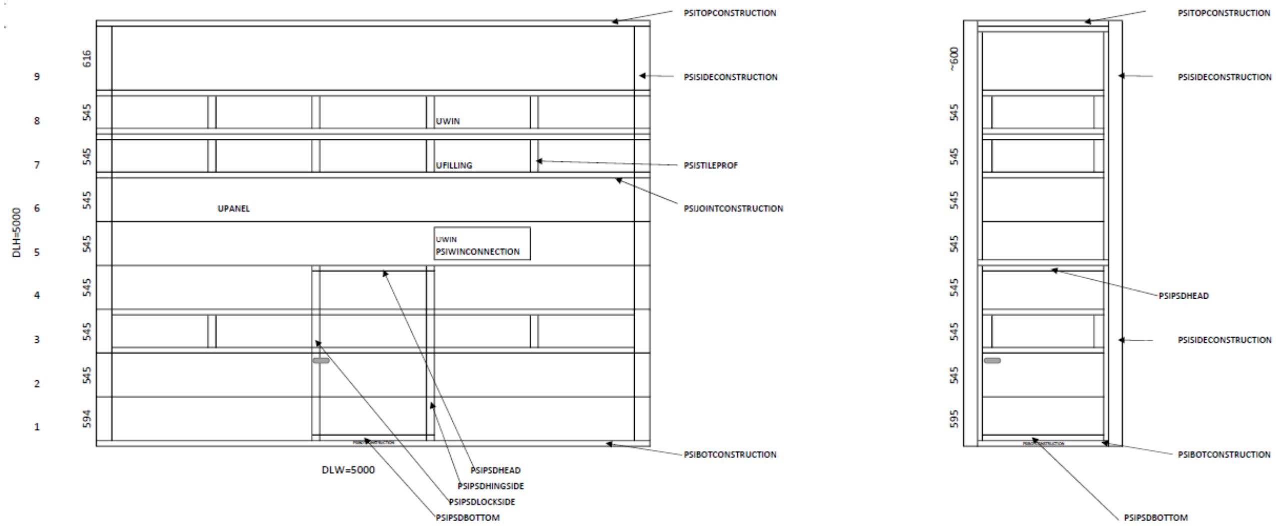


Figure L.8 Assembly drawing glazing list.

Appendix M U-value calculation sheet

This appendix contains the equations and visual representation of the values used in the excel document used to calculate the U-value for a complete overhead sectional door.



9	closed panel Top	=UPANEL*m² section + PSIJOINTCONSTRUCTION*DLW + PSITOPCONSTRUCTION*DLW + PSISIDECONSTRUCTION*HSECT
8	Framed window	=UWIN*m² section + PSISTILEPROF*HPANE*(NPANES-1) + PSIJOINTCONSTRUCTION*DLW + PSISIDECONSTRUCTION*HPANE
7	Framed filling	=UFILLING*m² section + PSISTILEPROF*HPANE*(NPANES-1) + PSIJOINTCONSTRUCTION*DLW + PSISIDECONSTRUCTION*HPANE
6	Closed panel	=UPANEL*m² section + PSIJOINTCONSTRUCTION*DLW + PSISIDECONSTRUCTION*HSECT
5	Panel window	=UPANEL*(m² section-m² of windows) + PSIJOINTCONSTRUCTION*DLW + UWIN*m² of windows + PSIWINCONNECTION*perimeter of windows + PSISIDECONSTRUCTION*HSECT
4	Panel with PSD TOP	=UPANEL*m² section + PSIJOINTCONSTRUCTION*(DLW-LJOINTSEALPSD) + PSIPSDHEAD*LJOINTSEALPSD + PSIPSDHINGSIDE*HSECT + PSIPSDLOCKSIDE*HSECT + PSISIDECONSTRUCTION*HSECT
3	Framed filling with PSD mid	=UFILLING*m² section + PSISTILEPROF*HPANE*(NPANES-3) + PSIJOINTCONSTRUCTION*DLW + PSIPSDHINGSIDE*HSECT + PSIPSDLOCKSIDE*HSECT
2	Panel with PSD mid	=UPANEL*m² section + PSIJOINTCONSTRUCTION*DLW + PSIPSDHINGSIDE*HSECT + PSIPSDLOCKSIDE*HSECT + PSISIDECONSTRUCTION*HSECT + PSISIDECONSTRUCTION*HPANE
1	Panel with PSD BOT	=UPANEL*(HSECT-HBOTMIDDIF)*DLW + PSIBOTCONSTRUCTION*DLW + PSIJOINTCONSTRUCTION*DLW + PSIPSDBOTTOM*WMIDPANE* + PSIPSDHINGSIDE*(HSECT-HBOTMIDDIF) + PSIPSDLOCKSIDE*(HSECT-HBOTMIDDIF) + PSISIDECONSTRUCTION*HSECT

LJOINTSEALPSD= Use WMIDPANE when door has no frame sections, use WABPSDPANE when door has a frame section

U-value=Total value/(DLW*DRH)

Figure M.1 U-value calculation sheet with equations with visual schematic.