Fire resistance in a sun shading element
as a substitute for fire retardant glazing

Preliminary research – P2
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List of abbreviations

WBD  Resistance against fire penetration  
WBO  Resistance against flash-over  
WBDBO  Resistance against fire penetration and flash-over

Glossary

Fire penetration  Fire expansion from one space to another space, through the construction. This will occur when the construction is burning, when the construction loses its cohesion or in an intact structure the temperature on the non-fire side will increase so that ignition occurs.

Fire propagation  This will occur in the same room, mostly by the interior. This may also occur because of internal flash-over.

Fire resistance  The time that these constructions can be resistive to fire, without the occurrence of flash-over.

Flash-over  The expansion of fire from one building to another building or via the outside from one room to another room in the building, because of flames, embers or heat radiation. Flash-over can also occur inside the room, for example between furniture, but when this the case it will be explicitly mentioned.
Introduction

The subject fire safety for this master thesis is grown while doing the bachelor and as well the master at the Faculty of Architecture & the built environment at the Delft University. After all the theory and projects I still learned hardly anything about fire safety, although it is becoming more important in the building industry. To fill this gap of knowledge before graduating the decision is made to do my final thesis about the subject fire safety.

Relevance

To get to know the current problems on fire safety in buildings the research has to begin at the people who know most of fire safety and fire prevention, namely the fire department, the people who give training for firefighters and also the fire consultancies. Therefore the Dutch Institute of Physical Safety (de Witte, L) and the fire department of The Hague (Schotanus, W.) were contacted to get to know the current problems of fire safety in buildings. The result was an unequivocal answer; the difference between what is said on paper and thus in the theory of fire safety, and what is happening in reality. Also the smoke expansion through the construction and, in particular for architects, the lack of integration of fire safety and design are current big problems in fire safety in buildings. That is where the question about fire safety in sun shading has arisen. Architects are designing more and more with glass (façades). Because of all the glass sun shading is, besides the specifications of the glass, becoming more important to keep the indoor environment comfortable. With glass surfaces also the risk of flashover of fire via the outside will be higher. That is where the fire retardant glazing is playing an important role. The government as well wants more fire safety glass in public buildings like schools, daycare, hospitals and also in governmental buildings. Architects are looking for a substitute for fire resistant glass, because this glass is relatively expensive in comparison to normal double or HR++ glass and not always wanted, especially in monuments where it will not always fit into the current frames.

Aim & research question

The aim of the research is to get insight in fire retardant glazing and other fire retardant products, sun shading products, how they work and from which materials they are made and from this conclude which materials and methods are best to use for the fire retardant shading element. It is also important to master the current rules regarding fire safety in public buildings. Therefore the following research question is made:

How can sun shading be used as a fire retardant element, such that it will be a substitute for fire retardant glazing in public buildings in Holland?

- What are the criteria and specifications of the fire retardant element?
  - What are the current rules in Holland regarding fire resistance of windows?
  - What are the current criteria for fire retardant glazing and how does it work?
  - What criteria should the fire retardant sun shading element meet?
  - What is the influence of the distance between the element and the window?
  - What is the critical time in which the system has to close in order to prevent the window from breaking?
  - How to ensure that the system will close automatically in case of fire?
- Which materials will be used?
  - What kind of materials are best to use for the sun shading?
  - What kind of materials are best to use for the fire resistance?
  - What will be the influence of UV over time?
- What will be the durability of the element?
  - How is the price in relation to current fire retardant glazing and sun shading?
  - How to prevent malfunction, possible damage and wearing?
- What will be the performance of the sun shading element in relation to thermal comfort?

Project location
The location of the problem will be public buildings in Holland in general. This because the rules and criteria regarding fire safety which are used are rules which are set in the Dutch Building Decree.

The posed problem
Lack of integration of fire safety and design in architecture and the high costs of fire retardant glazing. But also the problems which occur when fire retardant glazing needs to be placed into the older frames of monumental buildings.

Design assignment
The design assignment will be a sun shading element which also functions as a substitute for fire safety glass.
Method

To get to know the current relevant fire safety problems the Dutch Institute of Physical Safety and the fire department of The Hague are contacted to get insights in the current fire safety problems. Then a literature study will be done in order to get the basic knowledge about fire, fire development, fire safety and the current rules and regulations regarding fire safety in public buildings in Holland. Then a research will be done concerning current fire retardant glazing and other fire retardant products. For sun shading products also this study will be done. In these studies the materials, properties, the mechanism and the advantages and disadvantages are being discussed and used as reference. Also the lectures of the Civil Engineering course Fire Safety Design (CIE5131) will be studied and with this course a visit will be made to the Efectis Fire Laboratory in Bleiswijk and an official fire test will be attended.

After the research fire simulations in a small room (3.6 x 3.6 x 3.6 meters) and a large room (7.2 x 7.2 x 3.6 meters) are made in order to determine the optimal distance between the fire retardant shading element and the window. This optimal distance is important for the functionality of the element and to reduce the loss of space in the room. For this simulation the program Thermal Radiation Analysis (TRA) is used for simulating the heat radiation. The conduction and convection of the heat is simulated in the program TRISCO. Also a variation on the 4-16-4 millimeter glass is simulated in order to determine the effect of the thicker glass panes (6-16-6 millimeter) on the window and to determine the criteria of the glass for the program of requirements. If it is necessary also an internal heat simulation in the program Design Builder is made in order to determine the effect of the shading device on the room. The results of these simulations will be used in order to supplement the program of requirements.

When this is done, so after the P2, the design of the fire retardant shading element is further developed, in combination with a material study for the element and the mechanism. Also this mechanism for the shading element is developed and made into a prototype to see if it is working properly. Possible tests are done with (parts of a) prototype in a furnace in order to determine the temperature rise in the element and in the window over time, with the use of thermocouples. Also the mechanism of the element can be tested with the use of this furnace. Then a complete prototype of the whole element is made, and possibly tested and evaluated.

Literature and general practical preference

- Contact the Dutch Institute of Physical Safety to get to know the relevant and current fire safety problems.
- Contact the Fire Department of The Hague to get to know the relevant and current fire safety problems.
- Review the lectures of the Civil Engineering Course CIE5131
- Visit the Efectis fire laboratory and attend an official fire test with the CIE5131 course and U-base.
- General practice about:
  - Rules and regulations in Holland concerning fire safety design
  - Fire development
  - Fire safety
  - In general get to know more about fire safety in public buildings
- Literature study:
  - Fire retardant glazing, their materials, design, price and working
  - Other fire retardant products, their materials, design, price and working
  - Material study
  - Sun shading products, their materials, design and working
- Design research:
  - Simulation of the heat transfer of the fire by radiation on the fire retardant shading element and the window in order to determine the optimal distance between the element and the window with the use of the computer program TRA.
- Simulation of the heat transfer of the fire by conduction and convection on the fire retardant shading element and the window in order to determine the optimal distance between the element and the window with the use of the computer program TRISCO.
- Simulation with variations on the glass in order to determine the effect of thicker glass panes.
- An internal heat simulation in the program Design Builder in order to determine the effect of the shading device on the room.
- Mechanism study in order to determine the best way to let the element close automatically (but not electrically) in case of fire.
### Time planning

<table>
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<th>Task / Week</th>
<th>P1 - Subject</th>
<th>P2 - Literature</th>
<th>P3 - Research &amp; design</th>
<th>P4 - Design &amp; prototype</th>
<th>P5 - Prototype &amp; evaluate</th>
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Table 1: time planning P1 – P5
Theoretical framework

In the theoretical framework the theory of fire, rules and regulations and specifications for the fire retardant shading element are explained as well for the fire retardant glazing and other fire retardant products.

Fire

Development of fire
A fire in a compartment consists of three phases, namely the ignition, the fully developed fire and the decay of the fire. The phase of ignition and the increase of temperature and smoke will occur from 0 degrees to around 300 degrees Celsius. In the second phase the fire is fully developed and the temperature will raise from 500 degrees to 1000-1200 degrees Celsius. Then the fire will reach the third phase, namely the decay of the fire. At this moment most of the materials burnt and the temperature will also decrease. [Van der Veek & Janse, 2005]

Heat transfer in fires
To measure or simulate a fire there are two important kinds of heat transfer that have to be kept in mind, namely radiation and convection. These two factors represent the total heat transfer during a fire.

When radiation is occurring there is a heat transfer from one place to another place, in the form of electromagnetic waves, without a transfer medium. When this incident radiation reaches an object, a part of the heat is absorbed, another part is reflected and the rest is transmitted through the object. This incident radiation can be calculated with the use of the Stefan-Boltzmann law:

\[ q_r = q_{abs} - q_{emi} = \epsilon q_{inc} - \sigma T_s^4 \]

According to Kirchhoff’s identity the emission and the absorption are equal. This results in

\[ q_r = \epsilon (q_{inc} - \sigma T_s^4) \text{ in } W/m^2 \]

Convection is the other way of heat transfer during a fire. In this case the heat is transferred through a transfer medium. This can be for example air or another fluid. The gradient of heat transfer is then dependent on the velocity of the transfer medium and the temperature difference between the transfer medium and the object. This can be shown in the next formula:

\[ q_c = h(T_{fluid} - T_s) \text{ in } W/m^2 \]

So the total heat transfer is a combination of the heat transfer by radiation and the heat transfer by convection:

\[ q_{total} = q_r + q_c = \epsilon (q_{inc} - \sigma T_s^4) + h(T_{fluid} - T_s) \text{ in } W/m^2 \]

The relation between the incident heat radiation, the temperature rise in the glass and the time can be found in the next formula:

\[ \text{Power (W)} \times \text{Time (s)} = \rho \left( \frac{kg}{m^2} \right) + c \left( \frac{J}{kg \times K} \right) \times \text{Volume (m}^3) \times \Delta T \ (K) \]

Fire development and rules and regulations concerning public buildings in Holland
In the Dutch building decree rules are set concerning building, using and demolishing of a building. Here an overview is given of the rules concerning fire penetration and flash-over.
In order to reduce the spread of fire in a building is often divided into fire compartments. In general a fire compartment cannot exceed the area of 1000 m². To this compartment rules are set regarding the fire safety. These rules mostly concern the resistance against fire penetration (WBD) and flash-over (WBO), the WBDBO. This is the Dutch abbreviation of ‘weerstand tegen branddoorslag (WBD) en brandoverslag (WBO)’. Fire penetration is the spread of fire via the inside of the building. The WBD is the degree to which this expansion of fire via the inside of the building is prevented. Flash-over is the spread of fire via the outside of the building to another part of the building. The WBO is the degree to which this expansion of fire via the outside of the building is prevented. For flash-over the heat radiation becomes important. When the heat radiation on the threatened space becomes more than 15 kW/m² radiant flux, preventive fire safety measures must be taken in order to prevent flash over. [Van der Veek, Janse, & Bouwresearch, 2005] This heat radiation consists of two factors, namely the radiation through the openings in the fire compartment and the radiation of the raging flames. The 15 kW/m² is a fixed average based on possible combustibles and scenarios, where a fire will rise. [Van der Veek et al., 2005]

In case of a flash over glazing in the façade will be the weakest link, because windows will break in the first minutes of a fire and the openings will become a source for the expansion of fire, smoke and heat and a source for oxygen, which is one of the elements needed for a fire. [Tupker, 1961]

In the Dutch building decree cases are described to prevent the spread of fire. Fire safety measures in the façade are needed when there is a risk of spread of fire between one fire compartment to another fire compartment, or from one compartment to a protected escape route, to an elevator shaft of a fire fighters elevator and to a not-closed protected escape route. The resistance against fire penetration and flash over has to be at least 60 minutes, according to NEN6068 [BRIS Bouwbesluit online, 2015].

The requirement of 30 minutes only applies for fire compartments in a utility building where the highest floor is at a height of 5 meters or less (7 meters for residential functions) and it also applies for low buildings on the same parcel and for a fire compartment where the maximum fire load is 500 MJ/m². [Bris Bouwbesluit online, 2015] Also fire safety measurements are needed when there is a risk of spread of fire from one building on one parcel to another building on the adjacent parcel. In this case symmetry of an identical building on the adjacent parcel is in order, which façade is the same distance from the property boundary as the face of the respective building. In case if there is on the adjacent parcel no construction zoning and it is not intended as a playground, campground or storage of flammable substances, symmetry can take place as if the field is situated adjacent to public green. If a deviation of these rules is necessary, equivalence to these rules must be demonstrated. [BRIS Bouwbesluit online, 2015]

Fire safety glass

Here the classification of fire safety glass and the different types of fire safety glass are explained, in combination with how they work and the specifications of the glazing.

A single pane of float glass will crack during the first two minutes of a fire. A double pane of float glass will crack between 2 and 5 minutes of fire. This is not enough to be considered fire safe, therefore fire safety glass is used.

There are three different kind of classifications for fire safety glazing, namely E, EW and EI [NEN-EN 1999-1-2:2007 & NEN-EN 12101-9:2004]. The criteria are explained below:

- E (integrity): Fire-protective rated glass: this glass stops the spread of fire and smoke from the fire side to the non-fire side; integrity without radiation control.
- EW (integrity plus radiation control): this glass stops the spread of fire and smoke from the fire side to the non-fire side and has a very high heat insulation. The heat radiation at the non-fire side at 1 meter distance will not exceed 15 KW/m² during a certain period of time. [Van der Veek et al., 2005]
- EI (integrity and insulation): Fire-resistive rated glass: this glass stops the spread of fire and smoke from the fire side to the non-fire side and has a partial heat reduction up to <15KW at 1 meter distance. The average temperature on the not-heated side will not rise above 140 degrees Celsius and the local maximum temperature on the not-heated side will not rise above 180 degrees Celsius. [Van der Veek et al., 2005]

There is also a DH classification, but this classification is not applied on glass, because this classification is only for products which function as a smoke barrier, to prevent smoke expansion.

In general there are more than sixteen different fire retardant techniques for fire safety glass. These techniques can be globally classified into five classifications, namely safety wired glass, full tempered glass, full tempered glass with coating, full tempered glass with an epoxy resin interlayer and fire-resistant glass with intumescent interlayers. These classifications are explained below.

**Safety wired glass (E)**

There are different kinds of wired glass, but in general wired glass is glass with within the glass metal wires of 0,5 mm, mostly in a square grid pattern, used as a reinforcement of the glass. When a fire reaches the temperature of around 400 degrees Celsius, the glass will break but the metal wires will hold the glass together. In case of fire there is not a big vent, because the glass area is held together by the wires, so the fire and smoke are mostly stopped. [Vree, 2015] Cracks may partially melt close, when the temperature reaches the melting temperature of glass between 520 and 600 degrees Celsius, but the smoke still can go through [Devent & Dumont, 2013]. Also the heat radiation of the fire is not stopped by normal wired glass. Materials on the non-fire side of the glass can ignite because of the heat. Normal wired glass can be used only to reach the E classification. Safety wired glass can be provided with an extra film on the surface of the glass, which is fire-rated, to reach an EW classification. Normal safety wired glass may be applied as fire separation, but the fire resistance is dependent on the duration of the fire resistance and the surface area of the wires. [Boot-Dijkhuis, 2012] This is shown in table 2.

**Full tempered glass (E)**

The temperature differences in full tempered glass can be accommodated in the glass until 250-300 degrees Celsius. With normal glass this can only be accommodated till a temperature difference between the glass and the edges of the glass is more than between 30 and 40 degrees Celsius. When this glass breaks, it will break into small non-cutting glass beads. Therefore the risk of personal injury at breakage is considerably reduced. In the first 10 minutes of a ‘regular’ fire the temperature difference in the glass may rise till 250 – 300 degrees Celsius, dependent on the depth of the rebates. When the depth is higher the temperature difference in the glass will be higher. After these first 10 minutes the temperature difference will decrease and the glass will not break because of thermal stresses. However at a temperature of around 520 degrees Celsius the glass will become plastic and it will soften. [Brandveilig met staal, 2015]

**Full tempered glass with coating (EW)**

This is the full tempered glass with a coating, whereby it will reach the EW classification. The coating will delay the ignition and limit the heat radiation from the fire side to the non-fire side. [Devent & Dumont, 2013] There are different kinds of coating which are explained below [Kandare et al., 2013]:

- **Reflective coating**: this type of coating, which is mostly applied on single pane glazing, reflects the heat radiation, whereby the temperature of the glass will increases less rapidly.
- **Char forming coating**: This coating becomes active in the condensed phase and is based on phosphorus. [Kandola et al., 2012] The coating is preventing oxygen supply, which is needed for the fire. Hereby the temperature rise of the glass will delay.

<table>
<thead>
<tr>
<th>Fire resistance</th>
<th>m² wires</th>
<th>Per segment of</th>
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<tbody>
<tr>
<td>20 minutes</td>
<td>3.0</td>
<td>2.5 x 2.5 meters</td>
</tr>
<tr>
<td>30 minutes</td>
<td>1.7</td>
<td>2.5 x 2.5 meters</td>
</tr>
<tr>
<td>60 minutes</td>
<td>0.9</td>
<td>2.5 x 2.5 meters</td>
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</table>

Table 2: m² wire in safety wired glass
- Flame-inhibiting coating: This coating becomes active in the gaseous phase and is based on a halogenated paraffin. [Kandola et al., 2012]

- Intumescent coating: At a certain temperature the coating will melt, bubbles occur and a multi-cellular carbonaceous char layer is formed. This layer is physically preventing the glass from a rapid temperature increase. [Kandola et al., 2012] This delay in temperature rise will also slow down the build-up of thermal strain in the glass, so the glass will crack less soon. [Veer et al., 2001] The barrier will not only slow down the heat transfer, but also between the gaseous phase and the condensed phase it slows down the mass transfer. Damage or scratches in the coating can influence the working of the coating and thus the fire resistance. [Duquesne et al., 2000]

*Full tempered glass with an epoxy resin interlayer (EW)*

This type of glass is the full tempered glass where there is an interlayer in between two or more tempered glass layers. This glass is provided with a high quality, moisture resistant spacer. In case of a fire the glass will break and the interlayer will carbonize and form a heat insulating shield. Hereby the heat radiation and the heat transfer are decreased. When this glazing is used in facades the outside glass layer has a low-emissivity coating in the direction of the radiation, so the interlayer will be protected against UV. [Brandveilig met staal, 2015] The biggest disadvantage of this type of glass during a fire is the development of smoke, as well on the fire side as on the non-fire side. [Hendrix, 2011]

*Fire resistant glass with intumescent interlayers (EW/EI)*

This (multi) laminated glass is provided with an intumescent interlayer. In case of fire the glass will break when a temperature of 550 degrees Celsius is reached. Then the silicate interlayer will expand within a couple of minutes and the opaque foam will isolate at high temperatures. This way the radiation and the temperature are reduced, because the heat transfer by convection is limited and the heat radiation is absorbed. The interlayers will also hold the broken glass in its position. With more interlayers the fire resistance is higher. Also here the outside glass layer will be provided with a low-emissivity coating. When the interlayer is made of silicate the total glass construction is UV stable. But this type of glass cannot be placed on locations where the temperature of the glass is beneath -40 and may rise above 60 degrees Celsius for double glazing and beneath -10 and above 45 degrees Celsius for single pane glazing, because then the interlayer will react on the temperature. This glass may also contain deviations like small inclusions, bubbles, small optical imperfection of slight haze. These deviations will not affect the fire resistance, if they fall within the quality standards. [Devent & Dumont, 2013]

*Influence of the breaking of the glass of a window during a fire*

Fire safety glass is just a part of the whole fire retardant element. Also the framing, profiles, details and seals must also qualify to get certain classifications, because the element is as strong as its weakest link. During a fire the center of the glass is heated mostly by radiation. Because glass is a poor conductor the edges are not heated, especially the ones into the frames. This temperature difference will cause thermal expansion and this thermal expansion eventually will be the reason why the glass will break. This will already happen during the first 2 till 5 minutes of a fire for non-fire retardant glazing. When the glass breaks the window is then just a big vent in the wall. [Emmons, 1986] This vent will provide fresh air for the fire to burn and the gasses are released, so the fire is spreading. [Keksi-Rahkonen, 1988]

*Price of glazing*

Where for regular double glazing the prize varies around 65 euro per square meter, exclusive assembly, for HR+++ it is already around 120 euro/m² [LeadFactor, 2015]. But for fire retardant glazing exclusive assembly the prices vary between 250 till 550 euro/m². Here also the transport, framework, assembly and finishing is more expensive than with regular glazing. Because damaging the coating will affect the working of the product.
Other fire retardant products

Fire resistive roller blinds (max. 120 minutes)

The cloth of fire resistive roller blinds is made of non-flammable cloth based on glass fiber, reinforced with stainless steel yarns or whalebones and finished with a coating of polyurethane. The stainless steel yarns or whalebones will provide reinforcement at overpressure because of the fire. The cloth is fire resistant against temperature above 1000 degrees Celsius and the heat radiation will be relatively low. The guides of the system are made of galvanized steel with baffles to keep the fire out. [Firetexx, 2015]

Because of the good heat resistance of polyurethane it is often used as coating to make products more fire safe and to protect the fire retardant coating underneath from UV and weathering. To make the coating more fire retardant, two other materials are added. Polyhedral oligomeric silsesquioxanes and montmorillonite clay are added for the processing of polyurethane nanocomposites. These nanoadditives have a reducing effect on the damaging effects of a fire. The PU nanocomposites can be melted and yarns can be made of it. These yarns can be knitted or woven and used as textile where fire resistance is desirable. Also textiles can be coated with this PU nanocomposites to make it more fire retardant. [Deveaux, Rochery & Bourbigot, 2002]

There are also roller blinds made of textile which is provided with a fire intumescent coating. In case of fire the coating will bulge and an air cavity arises, whereby the heat radiation will decrease. The roller blinds can be opened with a key switch, smoke or temperature detectors or units connected to the fire alarm system. The system is provided with special drives (230 V), which automatically closes in case of a (possible) fire. It is also possible to connect the system to an emergency battery in case of power failure. [Boot-Dijkhuis, 2012] The roller blinds are a ‘waiting’ construction element and not made for daily uses, in comparison to the roller shutters. This non-flammable textile is provided with a coating, which will wear of when it is used on daily basis. [Verloo, 2015]

Fire resistive roller shutters

The principle of the roller shutters is the same as the principle of the roller blinds. In case of fire the shutters will come down to prevent the spread of fire, smoke and heat for a maximum duration of 96 minutes. The roller shutters are made of galvanized steel with a mineral wool filling. In case of fire the profiles are provided with a fire intumescent layer. [Boot-Dijkhuis, 2012] For both the roller shutters as well the roller blinds it is important that both constructions can be closed and are not hindered by the inventory. These constructions are tested by the rules which apply to doors and windows and thus not as a wall. [Veek, Janse & Stichting Bouwresearch, 2005]

Similar products

There are already some products on the market which functions as a combination of glass, fire protection and sun shading, but this is mostly fire safety glass with in between the panes solar shading, like the Inblindz. With this kinds of products the problem of the thick and expensive fire safety glass is still there, only the sun shading is integrated into this product. From tests is concluded that with this product a fire resistance of EW30 is reached and a flame density of E30. [Bruin, 2015]

Coatings on cloth

When the fire reaches a temperature of 120 degrees Celsius the coating is becoming active. The coating will cool the surface and will prevent the spread of fire. Also the oxygen is exhausted from the direct area, so the fire will extinguish. [Finivlam, 2015]

Fire retardant shade cloth

In America and Australia there is also a fire retardant shade cloth on the market for domestic use. This is cloth is mostly used as overhead for example for pools or BBQ areas. There are also fire retardant spring roller shades made of fiber glass with a vinyl coating. These shades are made to darken the room and are fire retardant. In such products UV stabilizers are used to prevent degradation of the flame resistance by UV radiation.
**Defined fire classifications for materials**

For materials in Holland there are fire classes defined. These classes reach from 1 (the best) to 5 (the worse) and show the resistance against fire. There is also a Euroclass, this represents a classification method used in whole Europe. These classes reach from A1 to F, here also forming of smoke and droplets are taken into account. This classification often combined with the letter ‘s’ for smoke and ‘d’ for droplets. The number behind the letter represents grade of the classification. In the table below these classifications are shown, based on [RockPro, 2015].

<table>
<thead>
<tr>
<th>Euro classification</th>
<th>Behavior of the material</th>
<th>Smoke production</th>
<th>Droplet forming</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>No contribution</td>
<td>S0</td>
<td>D0</td>
</tr>
<tr>
<td>A2</td>
<td>Barely contribution</td>
<td>S1</td>
<td>D1</td>
</tr>
<tr>
<td>B</td>
<td>Limited contribution</td>
<td>S2</td>
<td>D2</td>
</tr>
<tr>
<td>C</td>
<td>Big contribution</td>
<td>S3</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>High contribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Very high contribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Dangerous contribution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Euro classification</th>
<th>Behavior of the material</th>
<th>Smoke production</th>
<th>Droplet forming</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>No contribution</td>
<td>S0</td>
<td>D0</td>
</tr>
<tr>
<td>A2</td>
<td>Barely contribution</td>
<td>S1</td>
<td>D1 &lt;10 seconds</td>
</tr>
<tr>
<td>B</td>
<td>Limited contribution</td>
<td>S2</td>
<td>D2 &gt;10 seconds</td>
</tr>
<tr>
<td>C</td>
<td>Big contribution</td>
<td>S3</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>High contribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Very high contribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Dangerous contribution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Euro classification for materials

**Sun shading**

Almost in every building with glass sun shading is used to prevent the sun from heating up the building and to prevent glare on the inside of the building. To get to know which type of sun shading may work best for the fire protection different kinds of shading are researched and later compared in relation to fire protection. For a fire retardant sun shading element especially the resistance against flash-over will become important, because then the fire will flash-over via the outside of the façade to another building (part) or to the next floor.

The effectiveness of sun shading is not only dependent on the physical properties of the fabric, but also the type of shading, the distance from the distance from the window, the edges of the shading and the surface are. With more fabric layers the insulation will be higher and the heat flow will be reduced by 15 – 20 %. [Dubois, 1997]

**Type of shading**

There are many different kinds of sun shading in the façade, but globally they can be specified into five categories:

- **Awnings**: this is the most common used sun shading. Awnings are sun screens which have two fixed arms. With a manual or electric action the arms come down and the screen is expanded. To fold the sun shading the arms are put up and the fabric is coiled into the box, which is places above the window against the façade. The sun screen will have an angle of between 10 and 90 degrees in relation to the façade. A markies is an old traditional awning with more arms. With this shading not only the front, but also the sides are provided with fabric. The fabric for the awnings is mostly made of acrylic canvas or polyester. The disadvantage of awning is that, because of the fixed arms, there is no free passage when the shading is expanded. Also the sides are not covered with cloth, so it is possible that sun will shine into the space through the sides. The maximum width is around 4 meters. [Zonwering-weetjes, 2015]
- Folding arm awnings: the awning is mounted to the wall above the window and with using 2 arms, which are nodding forward, the sunscreen can be expanded. In comparison to the normal awning there is a free passage underneath the screen when it is expanded. The maximum width is 10 meters. [Zonwering-weetjes, 2015]

- Screens: this type of sun shading is moving parallel to the window, with using the same principle as a roller shutter. The fabric is sliding in between two guides vertically downwards. The fabric is made out of glass fiber or polyester with a PVC coating, so there still will be view from the inside to the outside. From the outside however, it will not be possible to look to the inside of the building, so this screen also provides a bit of privacy. Because the screen is close to the window it has a better insulating properties. [Dubois, 1997] The big advantage of this type of shading is that it is does not take extra space and there is a free passage by the windows. This sunscreen is also available as a zip screen. Then the screen is zipped into the guides. These zippers run by a special plastic insert into the guides. This way the fabric is held in place and is more resistant against wind. Also insects cannot go along the side to the back side of the screen.

- There is also a combination of screen and awning, namely the markisolette. This shading system has the same principles of the screen, so the screen rolls down parallel to the window. At a chosen moment the screen is tilted forward, like a normal awning. [Zonwering-weetjes, 2015]

- Inside sun shading: the main difference of this type of sun shading is that this one is placed on the inside of the window. Examples of this type of sun shading are blinds, lamellae and shades. The biggest disadvantage of this kind of sun shading is that the glass of the windows are heated as well as the space between the window and the shading. This will prevent the sun from shining into the space, but there is still a bit of heat coming into the space, because the shading is inside instead of outside. The biggest advantage is that the screen will not suffer from wind, vandalism and also less from UV radiation because of the window. [Zonwering-weetjes, 2015]

- Sun shading in between glass panes: because the sun shading is in between two glass panes the shading is protected from wind, dirt and risk on damage. The light, heat and privacy can be adjusted with this system. In contrast to the other sun shading systems (except the screens) this will not take as much space as the others do. [Pilkington, 2015] This product is also available provided with fire retardant glazing instead of normal glazing.

- Overhang: this is not a direct type of sun shading, because it is more a building element, but an overhang is an element perpendicular fixed to the façade. In summer this will keep the direct sunlight from shining into the space and in the winter, because of the lower position of the sun the sun will be shining into the space and can heat. [Zonwering-weetjes, 2015]
Design research

In this chapter the design research is elaborated. This starts with the criteria for the sun shading and fire retardant element, followed by simulations to get to know certain design criteria for the element.

The design of the system which will function as well as sun shading as well as a fire retardant product, which functions as a substitute for fire retardant glazing, has to meet different criteria. Here the most important criteria are showed in the following program of requirements:

- **Integrity:** To meet criteria E for fire retardant glazing, the system has to stop the spread of fire and smoke from the fire side to the non-fire side.
- **Radiation:** Besides integrity the system also has to stop heat radiation from the fire side to the non-fire side to meet the criteria of EW fire retardant glazing. This only applies when the heat radiation at the non-fire side at 1 meter distance will not exceed 15 KW/m$^2$ during a certain period of time. [Van der Veek et al., 2005]
- **Insulation:** The system also has to stop heat from the fire side to the non-fire side. When the average temperature on the not-heated side will not rise above 140 degrees Celsius and the local maximum temperature on the not-heated side will not rise above 180 degrees Celsius and the radiation at the non-fire side at 1 meter distance will not exceed 15 kW/m$^2$ it will meet the EI criteria of fire retardant glazing. [Van der Veek et al., 2005]
- **Costs:** The costs of the new system have to be lower than the average costs per square meter for fire retardant glazing.
- **Sun shading:** The system has to function as sun shading, which is manually adjustable from almost transparent to fully closed.
- **Esthetical:** From an architectural viewpoint the shading/fire retardant system has to make an esthetical contribution to the design.
- **Self-closing:** In case of fire the system has to close automatically, without the use of electricity or human effort. This way the chances of failure during a fire are lowered.
- **Material:** The material has to be UV resistant and at the same time fire retardant and non-flammable. Also it has to be UV proof. These properties can be divided over different places on the element.
- **Glass:** Influence of the thickness of the glass will follow from the simulation. Result of the simulation: there is not an important significant difference between 4 or 6 mm glass panes in case of fire.
- **Distance:** The optimal distance between the window and the fire retardant shading element has to be determined by heat transfer simulations of the fire. Result of the simulation: the optimal distance will be between 100 and 200 mm, to be further defined.

These requirements will result into a sun shading fire retardant element.

**Placing of the element on the inside or on the outside of the window?**

One of the biggest questions for this system is if it is better to place it on the inside of a building or on the outside. From the sun shading point of view it is better to keep the shading on the outside, because sun shading on the outside of a building is more effective to reject heat than shading on the inside. When the shading is placed on the inside of a building, heat radiation and the convection from the window is already inside the building. On the other hand sun shading on the outside better for heat rejection, but it is also associated with higher requirements for the construction, for the weather resistance and it is more expensive, as well in purchase as in maintenance. [Stichting Bouwresearch, 1980]
When the fire retardant system is placed on the inside of a building, the windows are protected from the heat and radiation and it will not break, as long as the fire retardant product is working. With regards to the shading properties the distance between the shading device and the window will have a negligible influence on the indoor room temperature, because only the air flow between the element and the window will have an influence, but this air flow is so small in comparison to the rest of the room that the difference in temperature in the room, caused by a different distance between the window and the element, will be negligible. So this distance will be determined by the fire retardant specification of the element.

So when the fire retardant system is placed on the outside, during a fire the glass will break already after 2 to 5 minutes, dependent on the type of glass. The breaking of the glass and the shards may damage the fire retardant system or coating, which will influence the time that the system is fire and flame resistant. For the fire retardant properties it is better to place the fire retardant shading element on the inside of the window.

**Design study**

To get insight in the different places and different types of the element which functions as sun shading and as fire retardant element a short design study is done with the most common shading types and fire retardant products. Here an overview is given of the result of this study. A schematic overview over the different places and types can be found in appendix 1.

**Horizontal blinds on the inside**

This principle is based on basic horizontal blinds on the inside of the building. The blinds have to cover not only the whole window but also the framework, because of the chance on breaking the glass caused by thermal expansion because of temperature differences in the glass. [Joshi & Pagni, 2004]

The horizontal lamellae are on the top side provided with a UV coating and on the down side the lamellae are provided with a fire retardant coating. This way the coating is not directly exposed to UV light. The horizontal blinds are connected to the guides on the side, to keep the lamellae in place. These guides are also provided with a fire retardant coating. The side of the lamellae which is the closest to the window is made heavier. In case of fire the lamellae will close automatically, because the stress is released from the system and the heavier part of the lamellae will fall down, because of the extra weight and gravity. The biggest disadvantage of this system is dust and cleaning. Because the lamellae are placed horizontally.

Questions that are raised with this system:
- Is there a different mechanism for opening and closing and the fire retardant system which will work in case of fire?
- When the lamellae are fully opened and thus all at the top and the view to the window is clear, how is the break on the system turned off during a fire?

**Horizontal blinds on the outside**

Horizontal lamellae are placed on the outside of a window. In this case the lamellae are well connected to guides on the side, to keep the lamellae in its place in case of wind. The system works the same as the system for lamellae on the inside of the window. Only now the part of the lamellae which is the furthest away from the window is made heavier. On the outside the chance on damaging and wearing are bigger, because of the weather (wind, rain, sun, temperature differences and possible vandalism).

**Vertical blinds on the inside**
The top of the lamellae is a rotating pin. The bottom of the lamellae are connected to a spring. When the lamellae are fully closed the spring is released from tension. In every other position of the lamellae the spring is under tension. A small wire connects every lamellae and causes the lamellae to stay in place or to rotate parallel. In case of fire this wire is burned. Because the wire is then not holding the lamellae in place, the lamellae will rotate because of the release of tension in the spring. This way the lamellae will close automatically in case of fire.

*Vertical blinds on the outside*
The vertical blinds on the outside will work following the same principle as the blinds on the inside. Only here the working and wearing of the spring has to be checked every now and then, because of the weather conditions.

*Roller blinds on the inside*
In this case the principle of normal roller blinds is used. Only then the inside of the cloth is provided with a fire retardant coating and the side of the cloth which is the closest to the window is provided with an UV coating. The biggest disadvantage is the possible wearing of the cloth by often opening and closing the system, because then the cloth is rolled up. To keep the cloth in place, use is made of zip screens. These screen are on the side provided with half zippers, so the screen is fixed into the profile. The cloth has to be a bit transparent, so when the system is fully down as sun shading, there is still a bit of view to the outside.

*Roller blinds on the outside*
This system has the same principle as the roller blinds on the inside. On the outside it has to be kept in mind that the chance on wearing and damaging is bigger than on the inside of a building, because of the weather and possible vandalism.

*Awnings on the outside*
This is one of the most traditional sun shading systems. When this principle is used also as a fire retardant system, the top of the cloth is provided with an UV coating, while the down side of the cloth is provided with a fire retardant coating.
The vertical arms of the awnings are connected to the wall. The horizontal awnings are locked, so they won’t exceed the angle of 90 degrees in relation to the vertical awnings. In case of fire there has to be a mechanism to ensure that the lock falls away and the arms of the awning fall down and the window is covered with fire retardant cloth.

**Concept design of the mechanism**
One of the most important specifications for the design of the mechanism is that is has to close in case of fire automatically, preferably without the use of electricity. So the closing mechanism has to react to the fire. One of the first concept ideas of this mechanism is sort of wire which will burn at low temperatures. Because the breakage of the wire the tension on the system is released and because of gravity the system will close automatically and it will stay close because of the magnets which are included in the horizontal shading elements, which is explained on the next page of concept design.

**Material study**
The maximum service temperature of glass fiber is a temperature of around 410-480 degrees. Also it has an excellent durability against water, acids and UV radiation and it is non-flammable. [CES Edupack]

*The material study will be further developed after P2.*
Three different positions of the system. Fully opened, half opened (45 degrees) and fully closed. Scale 1:1

In orange: aggravation at the both ends of the element, which will also function as a magnetic element, to ensure automatical closing of the system due to gravity and to ensure the system to stay closed because of the magnetical attraction. Scale 1:0.5
Dimensions: 3 cm widht, 1 mm height, length dependent on the window.

In orange: UV coating on the side which is closest to the window
In red: fire retardant coating
Scale 1:0.5

Sketch of the top view of hiding the element in the wall to ensure fully fire sealing. Scale 1:10
Simulation of the fire

The simulation of the fire is divided into two simulations, namely one for the heat radiation from the fire onto the element and a simulation of the conduction in the element and convection of the heat from the element to the window. The radiation simulation will be done in the simulation program TRA (Thermal radiation analysis). The simulation of the conduction and convection will be done in the computer program Trisco. From the radiation simulation the temperature and radiation flux on the element and on the window are determined for variable distances between the element and the window. These numeric results are used as specifications of the element in the conduction and convection simulation. With this simulation the temperature on the window with variable distances of the element are determined.

So both simulations take place in order to determine the optimal distance between the window and the fire retardant element on the inside of the building. To determine this optimal distance it is important to get to know the following variables on forehand:

- Start temperature of the glass in degrees Celsius = 298 K (24,9 degrees Celsius)
- Start temperature of the room in degrees Celsius = 298 K (24,9 degrees Celsius)
- Start temperature of the element in degrees Celsius = 298 K (24,9 degrees Celsius)
- Start temperature of the space between the element and the window = 298 K (24,9 degrees Celsius)
- Configuration of the fire retardant element: as explained under assumptions
- The type of glass: as explained under assumptions

The results of the simulations should determine the following variables:

- Incident radiation on the glass during the simulation
- Incident radiation on the element during the simulation
- Temperature of the glass during the simulation
- Temperature of the element during the simulation

Assumptions for the simulation in TRA

Because the distance between the window and the shading element will have a negligible effect on the indoor room temperature, this distance will be determined by the fire retardant specification of the element. Therefore a simulation will be done in order to determine the optimal distance between the window and the fire retardant shading element. In the program Thermal Heat Radiation (TRA) the heat transfer by radiation is simulated.

For the simulation the following assumptions are made:

**Glass and framework**

For the simulation HR++ glazing is used with a filling of air. This type of glass is currently (December 2015) one of the most common used glazing types in Dutch public buildings. HR++ glazing is glazing with on the inner glass pane a heat reflective coating on the side of the cavity. This will reflect the longwave heat radiation back into the room. For the simulation SGG Climaplus 4-16-4 millimeter glass is used\(^1\). Later on also a variant simulation with 6-16-6 millimeter glass is used. For the framework wood is chosen, because this will set higher limits to the fire resistance of the fire retardant shading element. [Saint-Gobain Glass, 2015]

\(^1\) Another type of glass with the same specifications will reach comparable results.
Configuration of the element
For the beginning of the simulation horizontal lamellae with the dimension of 3 cm depth and 1 mm thickness are chosen. To start with the lamellae are made of steel, later in the simulations other materials like glass fiber or other metals will be used. When they are fully closed, in case of fire, this will result in a wall with on average a thickness of 1.67 mm, this because of the overlap. The simulations are done with the element in three positions, namely opened (fully horizontal), half opened (45 degrees slope) and fully closed. In order to determine the optimal distance between the window and the element simulations are done with a varying distance of 100 millimeters. After that maybe a subdivision is simulated, depending on the results.

Fire retardant coating on the inside
The simulation will first start without a coating on the inside of the element, on the bottom of the horizontal lamellae. Further on in the simulations a simulation with a coating can be done if this is necessary.

Space
The dimensions of the space which is taken to do the simulations with are 7.2 x 7.2 x 3.6 meters. This is just a representative large space in public buildings. Also a simulation will be done with a space with the dimensions of 3.6 x 3.6 x 3.6 meters. This will be a representative small space in public buildings.

Fire
The fire, with a cone shape, will take place in the middle of the room (3.6 : 3.6 : 0 for the large space, 1.8 : 1.8: 0 for the small space), will have a diameter of 3 and a height of 1.8 meters. The temperature of the fire will be 1223.15 Kelvin (950 degrees Celsius).

Smoke
In the simulations the smoke of the fire is not taken into account. The temperature of the smoke must be so high before it will radiate heat, that in these simulations this is negligible.

Assumptions for the simulation in TRISCO
In the program TRISCO the heat transfer by conduction and convection is simulated. The assumptions which are made for the simulation in TRA are also applied to the simulation in TRISCO. In the next table the used materials and their specifications are showed.

Used materials in TRISCO:

<table>
<thead>
<tr>
<th>Material</th>
<th>λ [W/mK]</th>
<th>Temperature [°C]</th>
<th>H [W/m2K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall Stony 2300 kg/m³</td>
<td>0.700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Window Glass 2x 4 mm</td>
<td>0.800</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cavity window Air 16 mm</td>
<td>0.024</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Interior air</td>
<td>-</td>
<td>24.9</td>
<td>7.70</td>
</tr>
<tr>
<td>Exterior air</td>
<td>-</td>
<td>4.9</td>
<td>25.00</td>
</tr>
<tr>
<td>Element Steel 1 mm</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Space between element and window Air</td>
<td>-</td>
<td>24.9</td>
<td>7.70</td>
</tr>
</tbody>
</table>

Table 4: materials used for the simulation in TRISCO
The temperature of the element is the temperature which follows from the maximum incident heat radiation on the element from the TRA simulations. For the simulation with the shading element half open (rotated under 45 degrees), the shading elements are not oblique simulated, but every shading element of 3 cm with and 1 millimeter height is split into three blocks of 7 millimeter by 7 millimeter, which is shown in the picture on the right. This is done because the program cannot simulate sloped elements because they do not occur in the rules on which this program is based.

Figure 2: simulation of the sloped element
### Results of the radiation simulation

**Table 5a & 5b: results of the radiation simulation in a small space (4a) and a large space (4b)**

<table>
<thead>
<tr>
<th>Small space</th>
<th>Element opened (fully horizontal)</th>
<th>Element half opened (45 degrees)</th>
<th>Element closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between window and element</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 mm</td>
<td>6.09</td>
<td>309.56</td>
<td>30.38</td>
</tr>
<tr>
<td>150 mm</td>
<td>7.11</td>
<td>331.07</td>
<td>34.60</td>
</tr>
<tr>
<td>200 mm</td>
<td>8.21</td>
<td>351.95</td>
<td>36.19</td>
</tr>
<tr>
<td>300 mm</td>
<td>10.39</td>
<td>388.05</td>
<td>37.66</td>
</tr>
<tr>
<td>400 mm</td>
<td>12.11</td>
<td>412.85</td>
<td>38.00</td>
</tr>
<tr>
<td>500 mm</td>
<td>14.00</td>
<td>437.33</td>
<td>38.60</td>
</tr>
</tbody>
</table>

*The incident radiation on the element when this one is open or half open, will be (almost) equal to the incident radiation on the window.*
<table>
<thead>
<tr>
<th>Distance between window and element</th>
<th>Large space</th>
<th>Element opened (fully horizontal)</th>
<th>Element half opened (45 degrees)</th>
<th>Element closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mm</td>
<td>3.53</td>
<td>314.83</td>
<td>24.85</td>
<td>6.33</td>
</tr>
<tr>
<td>150 mm</td>
<td>3.67</td>
<td>342.91</td>
<td>53.70</td>
<td>7.72</td>
</tr>
<tr>
<td>200 mm</td>
<td>3.86</td>
<td>356.41</td>
<td>83.48</td>
<td>8.46</td>
</tr>
<tr>
<td>300 mm</td>
<td>3.96</td>
<td>366.59</td>
<td>104.00</td>
<td>9.05</td>
</tr>
<tr>
<td>400 mm</td>
<td>4.17</td>
<td>386.67</td>
<td>129.28</td>
<td>10.30</td>
</tr>
<tr>
<td>500 mm</td>
<td>4.34</td>
<td>397.16</td>
<td>149.96</td>
<td>11.00</td>
</tr>
</tbody>
</table>

Table 5b: radiation simulation of a large space

*The incident radiation on the element when this one is open or half open, will be (almost) equal to the incident radiation on the window.
Results of conduction and convection simulation

Table 6a & 6b & 6c & 6d: results of the conduction and convection simulation in a small space with 4-16-4 mm glass (6a) and with 6-16-6 mm glass (6b), and in a large space with 4-16-4 mm glass (6c) and with 6-16-6 mm glass (6d) with the element in three positions.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Small space 4-16-4 mm glass</th>
<th>Element opened (fully horizontal)</th>
<th>Element half opened (45 degrees)</th>
<th>Element closed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 mm</td>
<td>150 mm</td>
<td>200 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>Concrete</td>
<td>300 mm</td>
<td>585.54</td>
<td>613.53</td>
<td>21.32</td>
</tr>
<tr>
<td>glass</td>
<td>16 mm</td>
<td>234.13</td>
<td>176.86</td>
<td>24.54</td>
</tr>
<tr>
<td>pane</td>
<td>1 mm</td>
<td>585.54</td>
<td>613.53</td>
<td>623.24</td>
</tr>
<tr>
<td>Steel plate</td>
<td>24.9 °C</td>
<td>585.54</td>
<td>613.53</td>
<td>623.24</td>
</tr>
</tbody>
</table>

*results are equal with a steel plate of 2 mm. In reality 2/3rd of the shading element is 2 mm and 1/3rd of the shading element is 1 mm.
| Specifications          | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|        |
| Outside air            | 4.9 °C | 193.07 | 145.49 | 11.45  | 11.85  | 11.41  | 11.45  | 194.00 | 11.46  | 9.59   | 9.59   | 9.59   | 9.59   | 170.80 | 12.64  | 12.64  | 12.64  | 12.64  | 14.06  |        |        |        |        |        |
| Concrete               | 300 mm | 585.54 | 613.53 | 21.34  | 21.34  | 21.37  | 21.34  | 487.86 | 24.59  | 15.24  | 15.24  | 15.24  | 15.24  | 652.73 | 23.07  | 23.07  | 23.07  | 29.40  | 32.73  |        |        |        |        |        |
| Air cavity glass       | 16 mm  | 232.70 | 174.90 | 24.37  | 24.37  | 24.44  | 24.37  | 238.20 | 24.16  | 24.38  | 24.38  | 24.38  | 24.38  | 229.36 | 31.08  | 31.08  | 31.08  | 31.91  | 27.66  |        |        |        |        |        |
| Steel plate            | 1 mm   | 585.54 | 613.53 | 623.28 | 632.28 | 634.29 | 637.81 | 487.86 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 | 652.73 | 658.23 | 663.48* | 673.42* | 682.68* | 692.33* |        |        |        |        |        |
| Inside air             | 24.9 °C| 585.54 | 613.53 | 623.28 | 632.28 | 634.29 | 637.81 | 487.86 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 | 652.73 | 658.23 | 663.48* | 673.42 | 682.68 | 692.33 |        |        |        |        |        |

Table 6b: Conduction and convection simulation of a small space with 6-16-6 mm glass

*results are equal with a steel plate of 2 mm. In reality 2/3 of the shading element is 2 mm and 1/3 of the shading element is 1 mm.
Table 6c: conduction and convection simulation of a large space with 4-16-4 mm glass

| Specifications                  | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
|--------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Outside air                    | 4.9 °C | 116.20 | 98.19  | 11.51  | 11.51  | 11.51  | 14.25  | 11.53  | 9.70   | 9.70   | 9.70   | 9.70   | 120.78 | 12.95  | 12.95  | 12.95  | 12.95  | 12.95  | 12.95  | 12.95  |
| Air cavity glass               | 16 mm  | 135.92 | 114.51 | 24.60  | 24.60  | 24.60  | 24.05  | 24.34  | 24.60  | 24.60  | 24.60  | 24.60  | 157.24 | 31.63  | 31.63  | 31.63  | 31.63  | 31.63  | 31.63  | 31.63  |
| Glass inside pane              | 4 mm   | 140.00 | 117.88 | 24.76  | 24.76  | 24.76  | 24.21  | 24.50  | 24.76  | 24.76  | 24.76  | 24.76  | 162.92 | 31.82  | 31.82  | 31.82  | 31.82  | 31.82  | 31.82  | 31.82  |
| Steel plate                    | 1 mm   | 314.83 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 | 24.85  | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 | 424.44* | 430.21 | 436.22* | 448.49* | 461.29* | 474.72* |
| Inside air                     | 24.9 °C| 314.83 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 | 24.85  | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 | 424.44  | 430.21 | 436.22  | 448.49  | 461.29  | 474.72  |

*results are equal with a steel plate of 2 mm. In reality 2/3rd of the shading element is 2 mm and 1/3rd of the shading element is 1 mm.
Table 6: Conduction and convection simulation of a large space with 6-16-6 mm glass

*results are equal with a steel plate of 2 mm. In reality 2/3\(^\text{rd}\) of the shading element is 2 mm and 1/3\(^\text{rd}\) of the shading element is 1 mm.

| Specifications | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm | 100 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
|----------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Air cavity glass | 16 mm | 135.22 | 110.24 | 24.44  | 24.44  | 24.44  | 23.94  | 24.23  | 24.48  | 24.48  | 24.48  | 24.48  | 156.96 | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  | 31.43  |
| Steel plate    | 1 mm   | 314.83 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 | 24.85  | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 | 424.44 | 430.21 | 436.22 | 448.49 | 461.29 | 474.72 | 424.44 | 430.21 | 436.22 | 448.49 | 461.29 | 474.72 |
| Inside air     | 24.9 °C | 314.83 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 | 24.85  | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 | 424.44 | 430.21 | 436.22 | 448.49 | 461.29 | 474.72 | 424.44 | 430.21 | 436.22 | 448.49 | 461.29 | 474.72 |
Conclusions of the simulation

Conclusions for the simulation in the small space:
- The average radiation with the element opened and half opened will not exceed 15 W/m², the maximum radiation and the radiation on the closed element will exceed this number.
- When the element is fully opened there is a big differences between the results of 100/150 mm and 200 mm. Between 100 and 200 an optimal distance has to be found. This optimal distance is also dependent on the results of when the element is half opened and fully closed. This applies for both types of glass.
- When the element is half opened and fully closed an optimal distance will be between 100 and 150 mm.

Conclusions for the simulation in the large space:
- As well the average radiation as the maximum radiation will not exceed 15 W/m², except for the maximum radiation at 400 & 500 mm when the element is fully closed.
- When the element is fully opened there is a big differences between the results of 100/150 mm and 200 mm. Between 100 and 200 an optimal distance has to be found. This optimal distance is also dependent on the results of when the element is half opened and fully closed. This applies for both types of glass.
- When the element is half opened the temperatures of the window are very low.
- When the element is fully closed an optimal distance will be between 100 and 150 mm.

Conclusions for both the simulations in the small and the large space:
- The closer the element is placed to the window, the lower the incident radiation will be on as well the element as well on the window.
- How closer the fire retardant shading element to the window, the higher the temperature on the window will be.
- As shown in the tables the biggest influence on the temperature increase of the inner glass pane is the heat transfer by radiation.
- The differences in thickness of the glass panes hardly have an effect.
**Time versus heat radiation**

Glass is a poor conductor and that is why normal float glass will break when a temperature difference between 30 and 40 degrees occurs between the glass and the edges of the glass in the frame. From the formula beneath the relation between the incident heat radiation, the temperature rise in the glass and the time can be found:

\[
\text{Power} \times \text{Time} = \rho \left( \frac{kg}{m^3} \right) + c \left( \frac{J}{kg \cdot K} \right) \times \text{Volume} \left( m^3 \right) \times \Delta T \left( K \right)
\]

With  
- **Power** in Watt  
- **Time** in seconds  
- \( \rho \) in kg/m\(^3\) – for glass this is 2600  
- \( c \) in J/kgK – for glass this is 840  
- **Volume** in m\(^3\) – with 4 mm glass for the small space it is 0.01152 and for the large space 0.02304  
- \( \Delta T \) is 35 degrees (between 30 and 40 degrees)

With this formula and the maximum incident radiation the maximum time is calculated in which this element may be half or fully opened and exposed to this maximum radiation in order not to break the window because of a temperature difference of 35 degrees.

<table>
<thead>
<tr>
<th>4-16-4 mm glass</th>
<th>Small space</th>
<th>Large space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Element open</td>
<td>Element half opened</td>
</tr>
<tr>
<td>Distance between window and element</td>
<td>Maximum incident radiation window *[kW/m(^2)]</td>
<td>Time [s]</td>
</tr>
<tr>
<td>100 mm</td>
<td>30.38</td>
<td>10.1</td>
</tr>
<tr>
<td>200 mm</td>
<td>36.19</td>
<td>8.4</td>
</tr>
<tr>
<td>300 mm</td>
<td>37.66</td>
<td>8.1</td>
</tr>
<tr>
<td>400 mm</td>
<td>38.00</td>
<td>8.0</td>
</tr>
<tr>
<td>500 mm</td>
<td>38.60</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Table 7: time versus maximal heat radiation

*This calculation will be further developed after P2.*
Goal

The goal of this research and design is to get a substitute for fire retardant glazing in public buildings which also functions as sun shading. This because this glazing is very expensive in comparison to other types of glazing and this glazing is not always wanted, especially in monuments where it will not fit into the older frames. To get this substitute the specifications of the fire retardant glazing are combined with the specifications of sun shading and further developed. These specifications are combined and integrated into a design for a fire retardant sun shading element.

To reach this goal a literature study is done to get insight in fire retardant glazing and other fire retardant products. This research is also done for sun shading products, how they work and from which materials they are made. Also the Dutch Building Decree is studies to get to know the current rules regarding fire safety in public buildings.

To substantiate choices for the design answers have to be given to the following sub-research questions:

What are the criteria and specifications of the fire retardant element?
- What are the current rules in Holland regarding fire resistance of windows?
  - Answer in the theoretical framework fire
- What are the current criteria for fire retardant glazing and how does it work?
  - Answer in the theoretical framework fire
- What criteria should the fire retardant sun shading element meet?
  - Answer in the program of requirements in the design research
- What is the influence of the distance between the element and the window?
  - Answer in results and the conclusion of the simulation
- What is the critical time in which the system has to close in order to prevent the window from breaking?
  - To be calculated and to be tested in the furnace
- How to ensure that the system will close automatically in case of fire?
  - To be further researched

Which materials will be used?
- What kind of materials are best to use for the sun shading?
  - To be researched
- What kind of materials are best to use for the fire resistance?
  - To be researched
- What will be the influence of UV over time?
  - Because the fire retardant shading element will be on the inside of the window the element will suffer less from UV radiation than on the outside of the window, because a part of the UV radiation is stopped by the glass. The upper side of the shadings will be provided with an UV coating. The downside will be provided with a fire retardant coating, however this will not be exposed to direct UV light.

What will be the durability of the element?
- How is the price in relation to current fire retardant glazing and sun shading?
  - To be researched
- How to prevent malfunction, possible damage and wearing?
  - To be researched
- What will be the performance of the sun shading element in relation to thermal comfort?
  - For now the fire retardant shading element will be on the inside of the window. Sun shading elements on the inside of a building is not as effective as on the outside of the building, because the glass of the windows are heated as well as the space between the window and the shading. This will prevent the sun from shining into
the space. But there is still a bit of heat coming into the space, because the shading is inside instead of outside. The biggest advantage is that the screen will not suffer from wind, vandalism and also less from UV radiation because of the window. The effect on the thermal comfort between the shading element on the inside in comparison to the outside has to be researched or simulated.

Besides the main goal of this research and design there is also my personal goal and that is to fill the gap of fire safety knowledge before graduating with knowledge about fire safety in public buildings.

The next steps
After the P2 presentations the design of the fire retardant shading element is further developed in combination with a material study. Also the mechanism for the shading element is developed and made into a prototype to see if it is working properly. And possible tests are done in a furnace in order to determine the temperature rise in the element and in the window over time and to test the mechanism.
Reference list


Appendix 1: overview of the systems
**Horizontal blinds on the inside**

- 1 side of the lamel UV coating
- 1 side of the lamel fire retardant coating
- Window is not breaking
- Different positions of the shading
- Maintenance is easier

- Sun shading on the inside
- Dust and cleaning
- Fully opened?

**Horizontal blinds on the outside**

- 1 side of the lamel UV coating
- 1 side of the lamel fire retardant coating
- Different positions of the shading
- Sun shading on the outside

- Wind
- Cleaning?
- Window is breaking
- Possible damage by breaking the glass, preventing with safety layer

**Vertical blinds on the inside**

- 1 side of the lamel UV coating
- 1 side of the lamel fire retardant coating
- Different positions of the shading
- Sun shading on the outside

- Window is not breaking
- Different positions of the shading
- Maintenance is easier

**Vertical blinds on the outside**

- 1 side of the lamel UV coating
- 1 side of the lamel fire retardant coating
- Window is not breaking in case of fire
- Different positions of the shading

**Principle**

Heavier weight on the right side. During a fire a wire will burn and loosen the shading out of its position and it will fall, because of the weight, and closes. It has to cover also the framework.

Heavier weight on the right side. During a fire a wire on the inside will burn and loosen the shading out of its position and it will fall, because of the weight, and closes.

At the bottom the lamellae are connected to a spring. A wire causes the lamellae to move parallel. In case of fire this wire breaks and because of the spring the lamellae closes.

At the bottom the lamellae are connected to a spring. In case of fire the wire breaks and because of the spring the lamellae closes.
<table>
<thead>
<tr>
<th><strong>Roller cloth on the inside</strong></th>
<th><strong>Roller cloth on the outside</strong></th>
<th><strong>Awnings on the outside</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Window is not breaking</td>
<td>+ Different positions of the shading</td>
<td>+ 1 side UV coating</td>
</tr>
<tr>
<td>+ Maintenance is easier</td>
<td>+ Sun shading on the outside</td>
<td>1 side fire retardant coating</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Less sight disturbance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Different positions of the shading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Cleaning</td>
</tr>
<tr>
<td>- UV &amp; fire retardant in 1 cloth</td>
<td>- UV &amp; fire retardant in 1 cloth</td>
<td>- Wind</td>
</tr>
<tr>
<td>- Sun shading on the inside</td>
<td>- Cleaning?</td>
<td>- Window is breaking</td>
</tr>
<tr>
<td>- Cleaning?</td>
<td>- Window is breaking</td>
<td>- No free walking space along the window</td>
</tr>
<tr>
<td>- No positions possible</td>
<td>- Possible damage by breaking the glass, preventing with safety layer</td>
<td></td>
</tr>
<tr>
<td>- Wear of the coating?</td>
<td>- No positions possible</td>
<td></td>
</tr>
<tr>
<td>- View or fully closed?</td>
<td>- Wear of the coating?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Principle</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavier weight on the bottom. During a fire a wire will burn and loosen the shading and it will fall, because of the weight, and closes. It has to cover also the framework.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Principle</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavier weight on the bottom. During a fire a wire on the inside will burn and loosen the shading and it will fall, because of the weight, and closes. The cloth is windproof through the zipper.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Principle</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>When the window breaks the horizontal bar of the shading will fall and the shading will close the gap of the window.</td>
</tr>
</tbody>
</table>