# Fire resistance in a sunshading element

*as a substitute for fire retardant glazing*

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J.E. Goldbach
#4084268
First tutor: F.A. Veer
Second tutor: R.M.J. Bokel

# Colophon

Name: Juliette Goldbach

Student number: 4084268

Address: Waldorpstraat 45-71, 2521CA The Hague

Telephone number: 06-31966767

E-mail address: j.e.goldbach@student.tudelft.nl

Studio: Building Technology

Façade & Climate design

First (design) tutor: Fred Veer

E-mail address: F.A.Veer@tudelft.nl

Second (research) tutor: Regina Bokel

E-mail address: R.M.J.Bokel@tudelft.nl

Faculty of Architecture and the Built Environment

Department of Building Technology

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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 flux. 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 born 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 barely learned anything about fire safety, although it has been become more important in the building industry. To fill this gap of knowledge before graduating the decision had been made to do my final thesis about the subject of 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 sunshading had arisen. Architects are designing more with glass (façades) and because of all the glass sunshading 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 also wants more fire safety glass in public buildings like schools, daycares, hospitals and 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 existing frames.

## Aim & research question

The aim of the research is to get insight in fire retardant glazing and other fire retardant products, sunshading 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:

***In which way is it possible to use sun shading 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 sunshading 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?
  - How to ensure natural ventilation via the window and what will be the influence during fire?
- *Which materials will be used?*
  - What kind of materials are best to use for the sunshading?
  - What kind of materials are best to use for the fire resistance?
  - What will be the influence of UV over time?
  - What is the sustainability of the materials?

- *What will be the durability of the element?*
    - How is the price in relation to current fire retardant glazing and sunshading?
    - How to prevent malfunction, possible damage and wearing?
    - What will be the performance of the sunshading element in relation to thermal comfort?
- *What will be the influence of a fire retardant sun shading element on a fire and what will be the consequence for the fire fighters?*

## Project location
The location of the problem is 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
The posed problem is the lack of integration of fire safety and design in architecture and the high costs of fire retardant glazing. Also the problems which occur when fire retardant glazing needs to be placed into the older frames of monumental buildings is a problem.

## Design assignment
The design assignment will be a sunshading 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 insight 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 sunshading 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 flux. 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 an infrared thermometer. Also the time in which the mechanism of the element will be closing itself can be tested with the use of this furnace. Then, after the P3, possible adjustments are made to the prototype and then the official tests are done and evaluated.

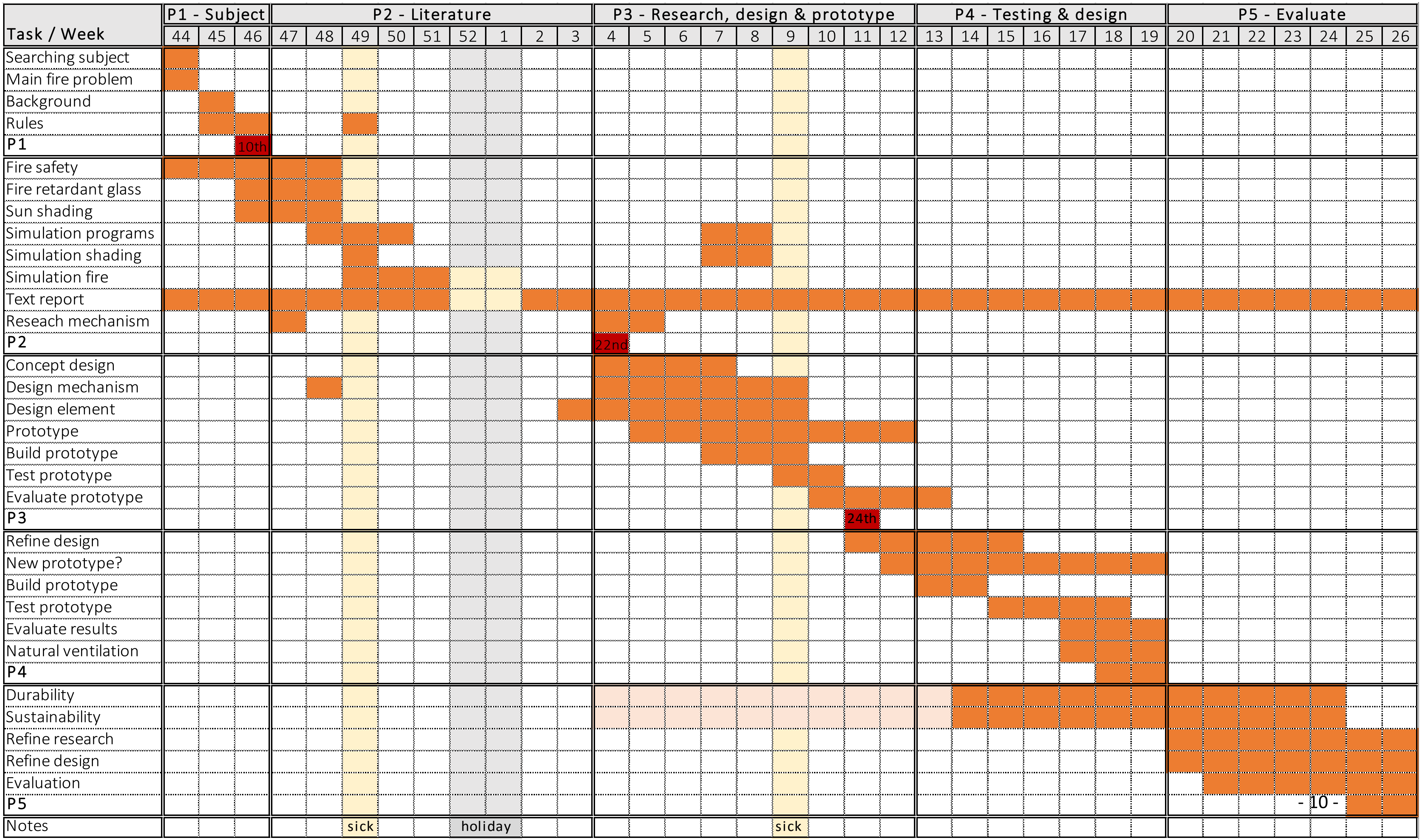
### Literature and general practical preference

- 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
    - Sunshading 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.
- Mechanism study in order to determine the best way to let the element close automatically (but not electrically) in case of fire.

▪ Measurements:
  - Making a prototype out of wood
  - Making a prototype out of steel
  - Testing & adjusting the prototype
  - Evaluating the results

## Time planning



# Sunshading

*Almost in every building with glass sunshading 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 sunshading 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 sunshading 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 sunshading 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. 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 sunshading in the façade, but globally they can be specified into five categories:

*Figure 1: awnings (Interdrape, 2016)*

- Awnings: this is the most common used sunshading. 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 sunshading the arms are put up and the fabric is coiled into the box, which is placed 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 sides. 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 an awning is that, because of the fixed arms, there is no free passage along the window 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 (figure 5): 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]

*Figure 6: folding arm awning (Sneyder, 2011)s*

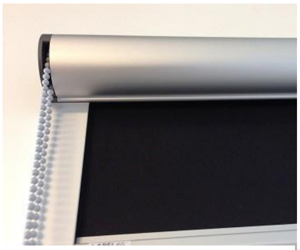


*Figure 7: roller shutter (Raambekleding Nederland.nl,2016)*

- Screens: this type of sunshading is moving parallel to the window, with using the same principle as a roller shutter (figure 6) which is often used as a sunshading element on the inside. 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 in front of 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 (figure 7). This shading system has the same principles as 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 sunshading: the main difference of this type of sunshading is that this one is placed on the inside of the window. Examples of this type of sunshading are blinds, lamellae and shades. The biggest disadvantage of this kind of sunshading is that the glass of the windows is 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]
- Sunshading in between glass panes (figure 8): because the sunshading 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 sunshading systems (except the screens) this will not take as much space as the others do. [Pilkington, 2015] This product is also available with fire retardant glazing instead of normal glazing.
- Overhang (figure 9): this is not a direct type of sunshading, because it is more a building element, but an overhang is an element perpendicularly 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 the room. [Zonwering-weetjes, 2015]

*Figure 8: markisolette (Markant, 2011)*

*Figure 9: shading between glass (Inblindz, 2016)*

*Figure 10: overhang (Holladay, 2014)*

# 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 as 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.

$$a + \rho + \tau = 1$$

With $a$ = absorption of the incident radiation
$\rho$ = reflection of the incident radiation
$\tau$ = transmission of the incident radiation

The heat transfer through radiation can be calculated with the use of the Stefan-Boltzmann law:

$$q_s = \varepsilon * \sigma * T^4$$

With $q_s$ = heat flow density of the emitted radiation
$\varepsilon$ = emission coefficient of the material's surface
$\sigma$ = $56.7*10^{-9}$ (Stefan Bolzmann constant)
T = absolute temperature in Kelvin

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:

$$q = h * A * (T_s - T_f)$$

With q = heat transfer per time unit
h = heat transfer coefficient
$T_s$ = temperature of the surface
$T_f$ = temperature of the fluid

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

$$q_{total} = q_{radiation} + q_{cconvection} = \varepsilon * \sigma * T^4 + h * A * (T_s - T_f) \; in \; W/m^2$$

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

$$Power * time = \rho * c * volume * \Delta T$$

With power in Watt
time in seconds
$\rho$ in kg/m$^3$
C in J/kg*K
volume in m$^3$
$\Delta T$ in Kelvin

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.*

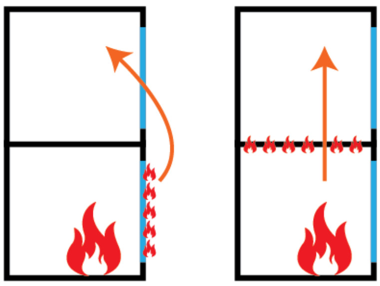


*Figure 2 flash-over & fire penetration*

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 m$^2$. 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 flux becomes important. When the heat flux on the threated space becomes more than 15 kW/m$^2$ radiant flux, preventive fire safety measures must be taken in order to prevent flash over. [Van der Veek et al., 2005] This heat flux consists of two factors, namely the radiation through the openings in the fire compartment and the radiation of the raging flames. The radiation through the openings in the fire compartment is the radiation of the heat because of the fire in the compartment. The radiation of the raging flames is the radiation caused by the raging flames out of the window. This combination is the heat flux which reaches the window of the threated space. The 15 kW/m$^2$ 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 plot and for a fire compartment where the maximum fire load is 500 MJ/$m^2$ [Bris Bouwbesluit online, 2015]. Also fire safety measurements are needed when there is a risk of spread of fire from one building on one lot to another building on the adjacent plot. In this case symmetry of an identical building on the adjacent plot is in order (see the scheme on the right), which façade is the same distance from the property boundary as the face of the respective building. In case there is on the adjacent plot 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]

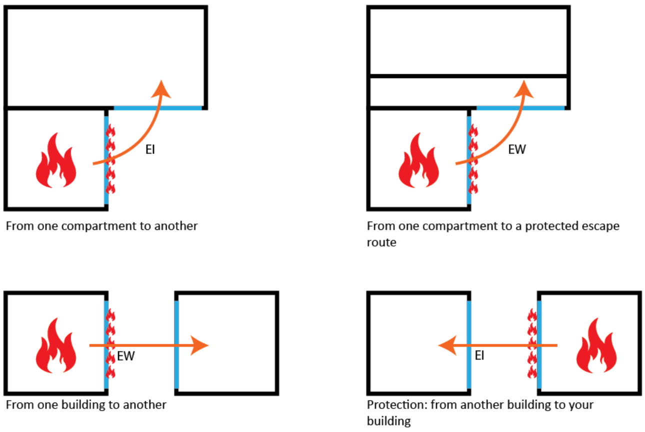



*Figure 3: Flash over and criteria*

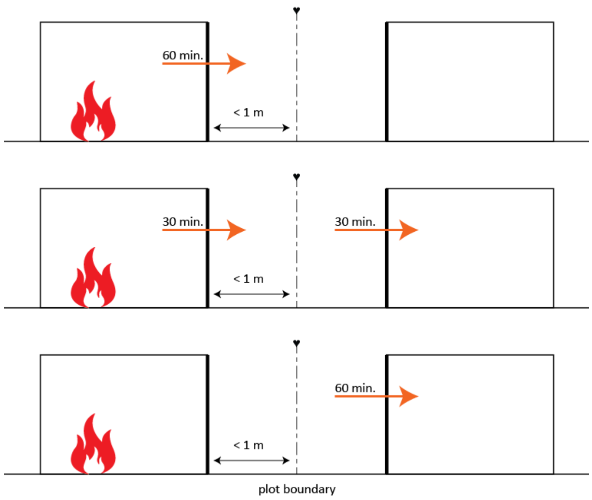


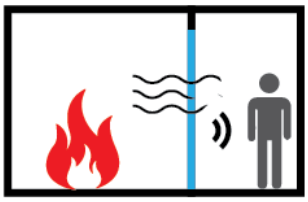

*Figure 4: wbdbo 60 min, symmetry of the plot boundary (based on Brandveilig met staal, 2016)*

## 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 heat flux 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 flux 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]
- 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 a., 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.

*Figure 5: E (integrity), EW (integrity + heat flux) & EI (integrity + insulation)*

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 flux 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.

| Fire resistance | $m^2$ wires | Per segment of |
|---|---|---|
| 20 minutes | 3,0 | 2,5 x 2,5 meters |
| 30 minutes | 1,7 | 2,5 x 2,5 meters |
| 60 minutes | 0,9 | 2,5 x 2,5 meters |

*Table 2: $m^2$ wire in safety wired glass*

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 flux 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 flux, 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.

- 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 flux 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 flux 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. 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. When the glass is heated in the middle, there will be a temperature difference between the middle and the edges of the glass, because glass is a poor conductor. This temperature difference will cause thermal expansion and this thermal expansion will be eventually 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 fire 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/$m^2$ [LeadFactor, 2015]. But for fire retardant glazing exclusive assembly the prices vary between 250 till 550 euro/$m^2$. 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 ribs and finished with a coating of polyurethane. The stainless steel yarns or ribs will provide reinforcement at overpressure because of the fire. The cloth is fire resistant against temperature above 1000 degrees Celsius and the heat flux 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 the foam will prevent the heat flow of hot gases along the steel and also the radiation will incident on the foam instead of on the steel. 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 will close automatically 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 pending construction element and not made for daily use, in comparison to the roller shutters which are described below. This non-flammable textile has 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. These roller shutters are also available with a fire resistance of 30 or 60 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 regulations 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 function as a combination of glass, fire protection and sunshading, 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 sunshading 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*

There are also fire retardant coatings available for cloth. When this coating, like the Finivlam Combi, is applied on cloth and when the fire reaches a temperature of 120 degrees Celsius the coating becomes 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 cover for example for pools or BBQ areas. There are also fire retardant roller shades made of fiber glass with a vinyl coating and provided with a spring mechanism. 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 the Netherlands 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 is often combined with the letter 's' for smoke and 'd' for droplets. The number behind the letter represents the grade of the classification. In the table below these classifications are shown, based on [RockPro, 2015].

| Euro classi-fication | Behavior of the material | | Smoke production | | Droplet forming | |
|---|---|---|---|---|---|---|
| A1 | No contribution | Non-flammable | S0 | none | D0 | none |
| A2 | Barely contribution | Practically incombustible | S1 | barely | D1 | <10 seconds |
| B | Limited contribution | Very hard combustible | S2 | average | D2 | >10 seconds |
| C | Big contribution | Combustible | S3 | big | | |
| D | High contribution | Good combustible | | | | |
| E | Very high contribution | Very good combustible | | | | |
| F | Dangerous contribution | Excellent combustible | | | | |

*Table 3: Euro classification for materials [RockPro, 2015].*

# Design research

*In this chapter the design research is elaborated. This starts with the criteria for the sunshading 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 sunshading 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.
- Heat flux: Besides integrity the system also has to stop heat flux from the fire side to the non-fire side to meet the criteria of EW fire retardant glazing. This only applies when the heat flux 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]
- Temperature: 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 cost of the new system has to be lower than the average costs of 250 till 550 euro per square meter for fire retardant glazing.
- Sunshading: The system has to function as sunshading, 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 chance of failure during a fire is 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 of the element.
- Glass: 4 mm and 6 mm glass panes are used as well in the simulations as well in the tests of the prototype.
- Distance: The optimal distance between the window and the fire retardant shading element has to be determined by heat transfer simulations of the fire. For the prototype the distances of 75 and 100 mm are used in order to lose as less space as possible. The optimal distance from the simulations were not reliable because a strange temperature drop occurred.

These requirements will result into a sunshading 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 sunshading point of view it is better to keep the shading on the outside, because sunshading on the outside of a building is more effective to reflect heat than shading on the inside. When the shading is placed on the inside of a building, heat flux and the convection from the window is already inside the building. On the other hand if the sunshading on the outside is better for heat reflection, it is also associated with higher requirements for the construction, for the weather resistance and it is more expensive, as well in purchase as well in maintenance. [Stichting Bouwresearch, 1980]

When the fire retardant system is placed on the inside of a building and inside the room a fire occurs, the windows are protected from the heat and radiation and will not break, as long as the fire retardant product is working. With regard 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 sunshading and as fire retardant element a short design study is done with the most common shading types and fire retardant products. An overview is given of the result of this study which you will find after the schematic overview. This schematic overview over the different places of the shading, the advantages and disadvantages and their principle can be found on the next pages.*

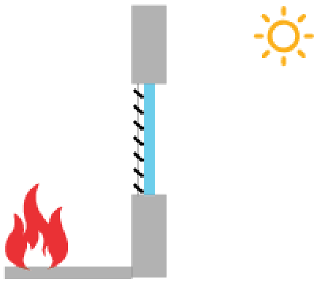
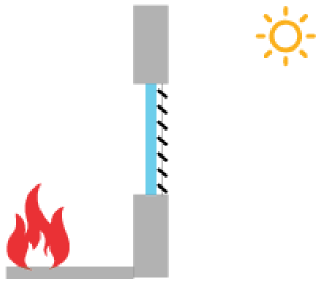
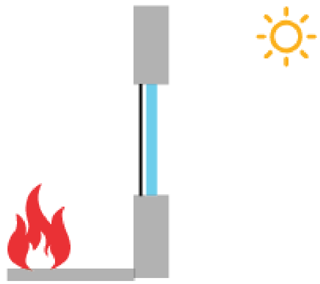
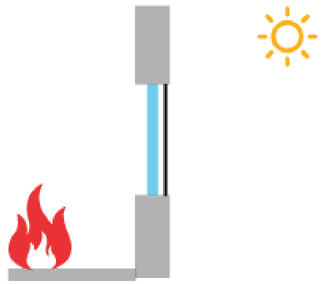
| Horizontal blinds on the inside | Horizontal blinds on the outside | Vertical blinds on the inside | Vertical blinds on the outside |
|---|---|---|---|
|  |  |  |  |
| + 1 side of the lamel UV coating<br>1 side of the lamel fire retardant coating<br>+ Window is not breaking<br>+ Different positions of the shading<br>+ Maintainance is easier | + 1 side of the lamel UV coating<br>1 side of the lamel fire retardant coating<br>+ Different positions of the shading<br>+ Sun shading on the outside | + 1 side of the lamel UV coating<br>1 side of the lamel fire retardant coating<br>+ Less sight disturbance<br>+ Window is not breaking<br>+ Differnt positions of the shading<br>+ Less dust / cleaning<br>+ Maintainance is easier | + 1 side of the lamel UV coating<br>1 side of the lamel fire retardant coating<br>+ Window is not breaking in case of fire<br>+ Different positions of the shading |
| - Sun shading on the inside<br>- Dust and cleaning<br>- Fully opened? | - Wind<br>- Cleaning?<br>- Window is breaking<br>- Possible damage by breaking the glass, preventing with safety layer | - Sun shading on the inside | - Wind?<br>- Cleaning?<br>- Window is breaking<br>- Possible damage by breaking the glass, preventing with safety layer |
| Principle<br><br>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. | Principle<br><br>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. | Principle<br><br>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. | Principle<br><br>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. |

*Figure 11: schematic overview sun shading study part 1/2*

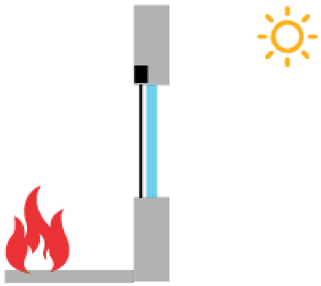
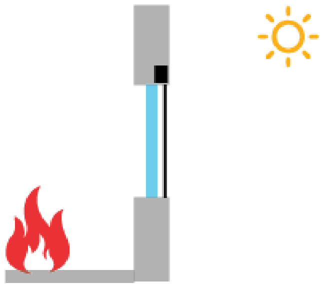
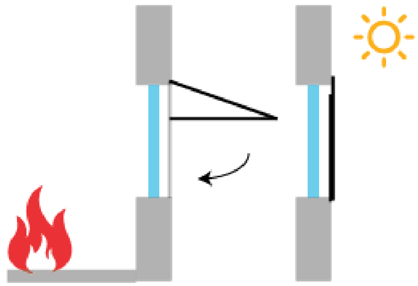
| Roller cloth on the inside | Roller cloth on the outside | Awnings on the outside |
| --- | --- | --- |
|  |  |  |
| + Window is not breaking<br>+ Maintainance is easier | + Different positions of the shading<br>+ Sun shading on the outside | + 1 side UV coating<br>1 side fire retardant coating<br>+ Less sight disturbance<br>+ Differnt positions of the shading<br>+ Cleaning |
| - UV & fire retardant in 1 cloth<br>- Sun shading on the inside<br>- Cleaning?<br>- No positions possible<br>- Wear of the coating?<br>- View or fully closed? | - UV & fire retardant in 1 cloth<br>- Cleaning?<br>- Window is breaking<br>- Possible damage by breaking the glass, preventing with safety layer<br>- No positions possible<br>- Wear of the coating? | - Wind<br>- Window is breaking<br>- No free walking space along the window |
| Principle<br><br>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. | Principle<br><br>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.<br>The cloth is windproof through the zipper. | Principle<br><br>When the window breaks the horizontal bar of the shading will fall and the shading will close the gap of the window |

*Figure 11: schematic overview sun shading study part 2/2*

*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 bottom 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 bottoms 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 sunshading, 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 sunshading 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.

## 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. Therefore the wire of the lamellae in front of the room is made out of plastic. This way in case of higher temperatures the wire will melt easily. This is also shown at the page of the steel prototype.

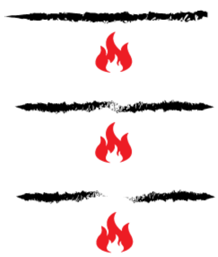


*Figure 12: mechanism of the burning wire*

One of the first ideas was to let the system stay closed with the use of magnets, however, at high temperatures magnets will lose their working. When magnets are used based on alnico alloys it may work at higher temperatures of 450 degrees Celsius. This is further explained in the material study. When one part of the lamellae are made heavier the system will also stay closed, because of gravity.

## Material study

*In this material study an overview is given of the used materials and their properties.*

Glass fiber: 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]

Magnets: at higher temperatures magnets will lose their magnetism. This will happen at the Curie temperature (named after Pierre Curie). At this temperature induces magnetism takes the place of the permanent magnetic field. Dependent on the materials of the magnet this will occur at a different temperature. For alnico magnets the Curie temperature will lie around 800 degrees Celsius. For neodymium magnets this temperature is a lot lower between 300 and 400 degrees Celsius.

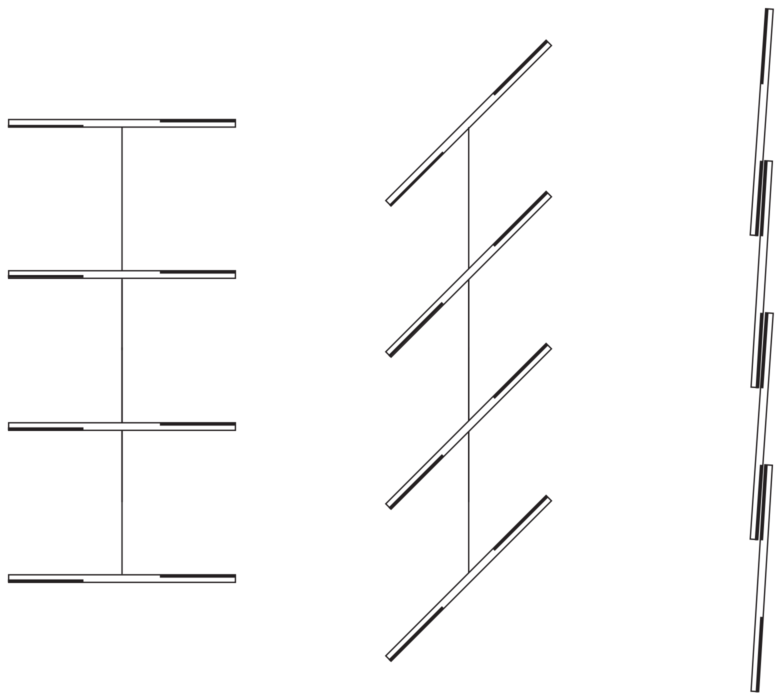
Plastic wire: the wire has to burn or melt in order to close the automatically in case of fire. If this happens at a relatively low temperature the glass pane is shorter exposed to high temperatures and the fire retardant sun shading will do its job.

Glass thicknesses: when the glass is heated slowly there is less tension within the glass because the heat can diffuse slowly in the glass. When the glass is heated quickly there is a bigger chance on thermal breakage caused by the tension which occurs because of the temperature differences in the glass pane. When thicker glass is used the chance on thermal breakage will be higher, because there is more volume in which the heat has to spread and thus the thermal stresses will occur sooner.
So thicker glass will result in earlier thermal breakage of the glass. In comparison with thinner glass the thicker glass is stronger and has more capacity to accumulate heat, so it will break less easy.

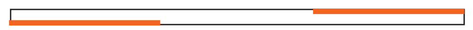
For sun shading the best type of material is dependent on the type of the sun shading. In the case of fire retardant sun shading on the inside of the building where lamellae are used a lightweight material which has an excellent performance while under UV is best for this use. The material should also be stiff enough to be used over larger widths without bending much. Materials such as steel and aluminum have an excellent UV resistance and can withstand high temperatures (aluminum around 600 degrees Celsius and steel around 1500 degrees Celsius). Also both materials are non-flammable. The UV resistance of wood is a bit worse than of steel and aluminum and it can withstand lower temperatures (till 350 degrees) and also wood is highly flammable and therefore wood is not a good option for this fire retardant sun shading.

For the fire resistance it is best to use a material which can withstand high temperatures and is non-flammable, like steel. Therefor the prototype will be made out of steel.

# Concept design



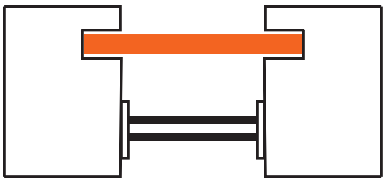
Three different positions of the system. Fully opened, half opened (45 degrees) and fully closed. Scale 1:1



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

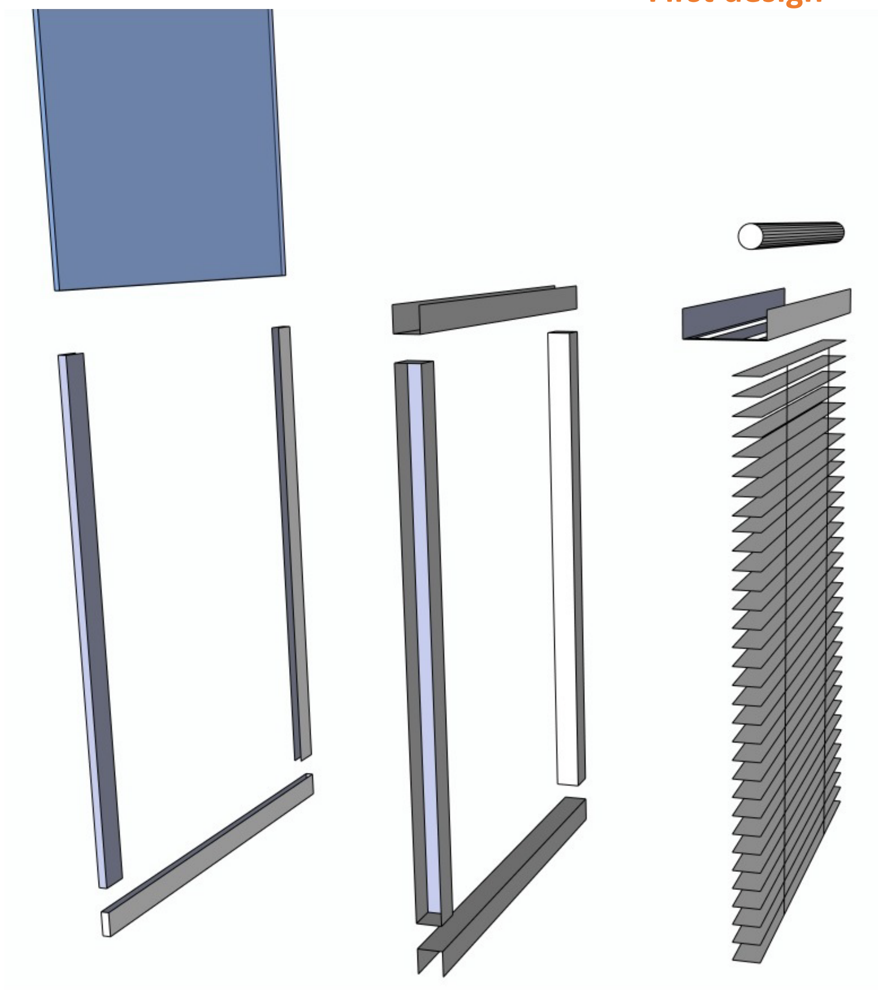
*Note: magnets will lose there magnetism in high temperatures*

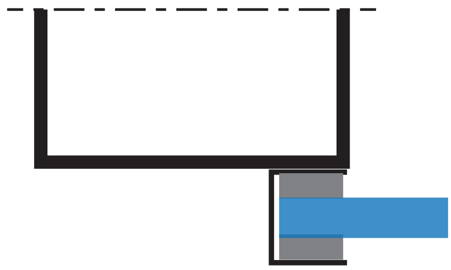
In orange: UV coating on the side which is closest to the window
In red: fire retardant coating
Scale 1:0,5



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

## First design

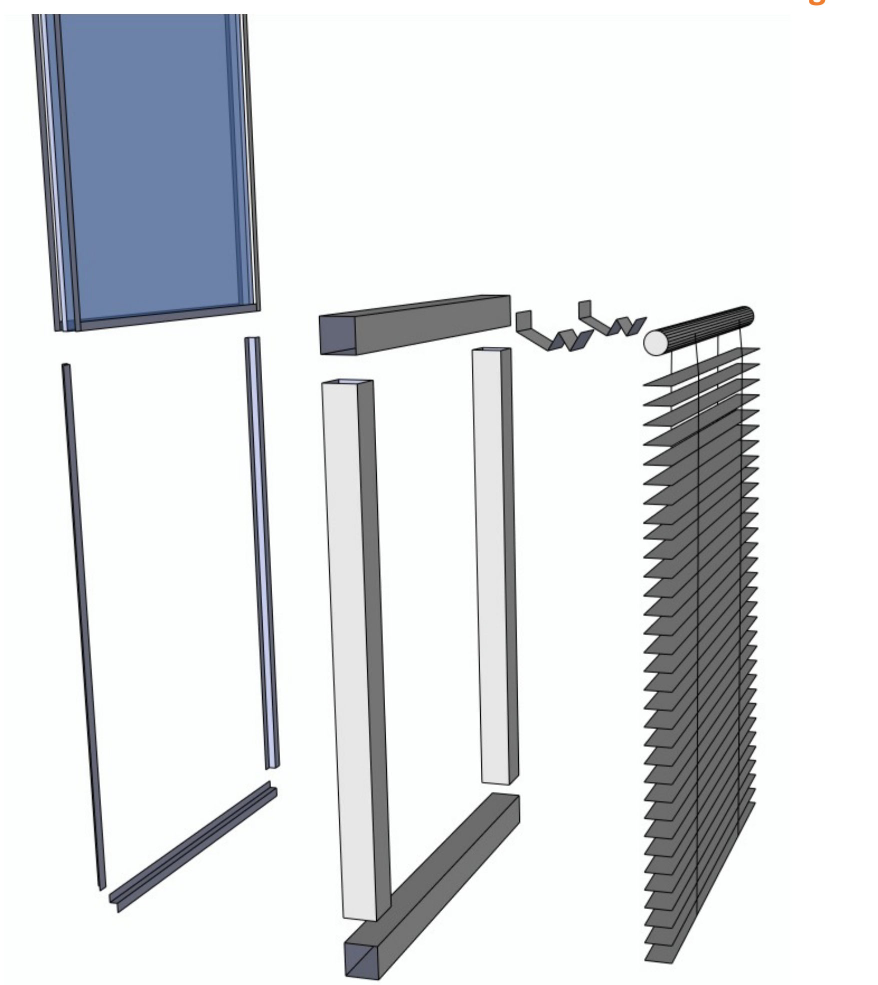


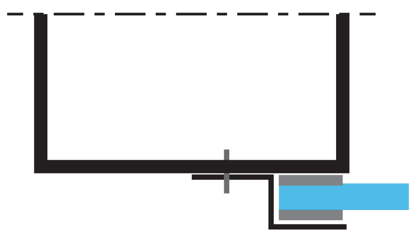


Horizontal section of the connection of the glass and the frame, with the use of a U-shaped profile. Between the glass and the U-profile there is a rubber.
Scale 1:1

Vertical section of the mounting element with the pipe which hangs the lamellae at two different distances from the window (7,5 mm and 10 mm)
Scale 1:1

## Second design

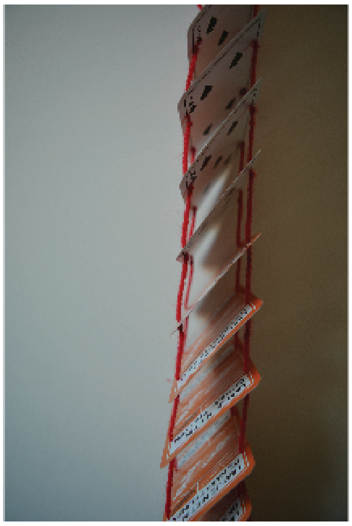




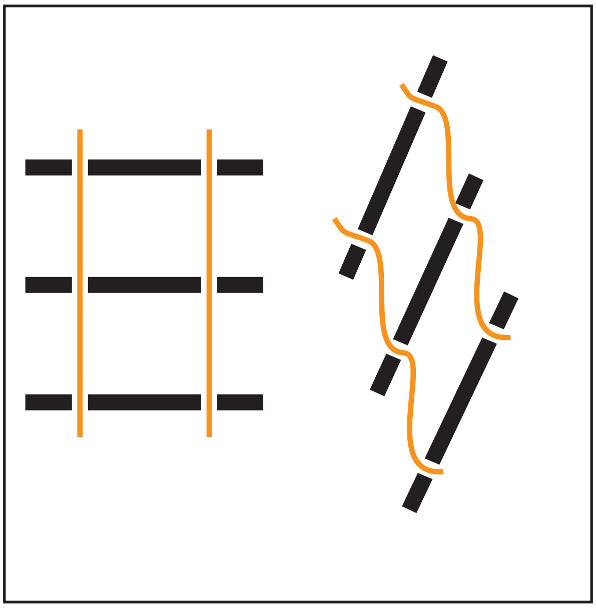
To make the profile easier to connect to the frame one leg of the U-shape is bend the other way.
Scale 1:1

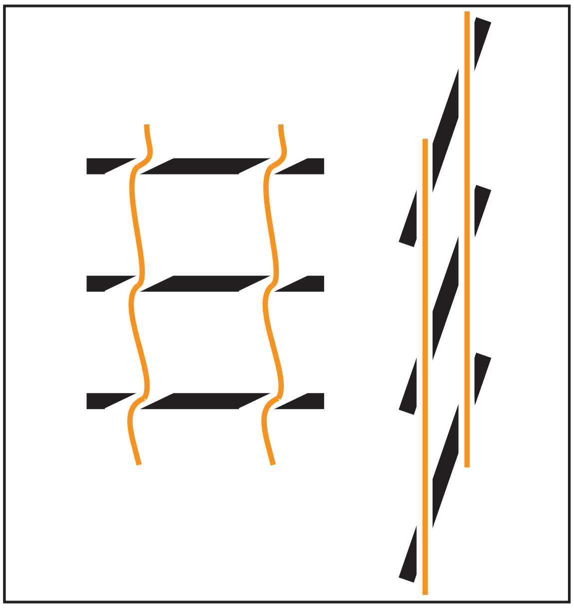
Two simple mounting points to lay the pipes in is enough to hang the lamellae at two different distances from the window (7,5 mm and 10 mm)
Scale 1:2

## Prototype playing cards

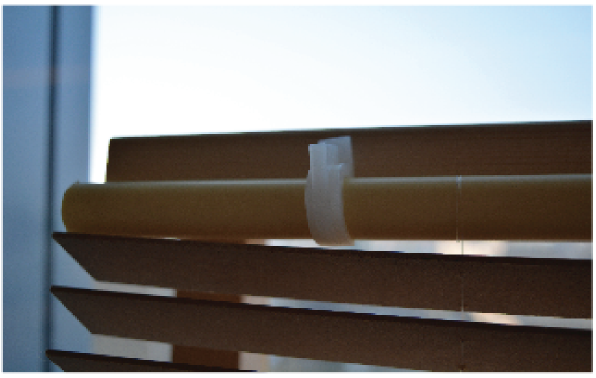


This is the first prototype I made of the lamellae. This prototype was very usefull in order to determine one of the problems. On the photo top left the 'lamellae' are open and in the picture in the middle the lamaellae are as closed as possible. Here the first problem occured. In the right picture the problem is shown. Because I made the holes throught the cards perpendicular to the cards, the wire is bended in a strange way. This problem is also schematically shown below. However, when the holes are made at an angle,  this problem is solved and the lamellae will close better because then the wire is in a straight line (scheme on the right). When the lamellae are open the wire will not be in a straight line, but this will help to keep the lamellae in place and to prevent the lamellae from sliding down the wire.

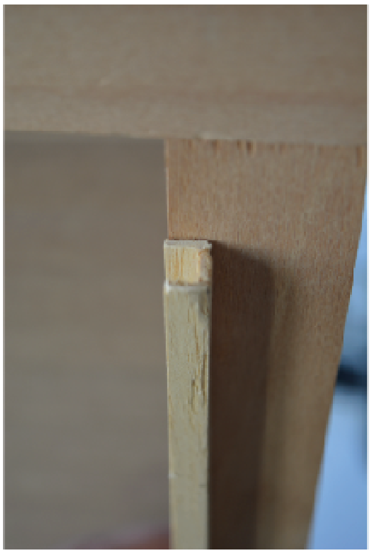


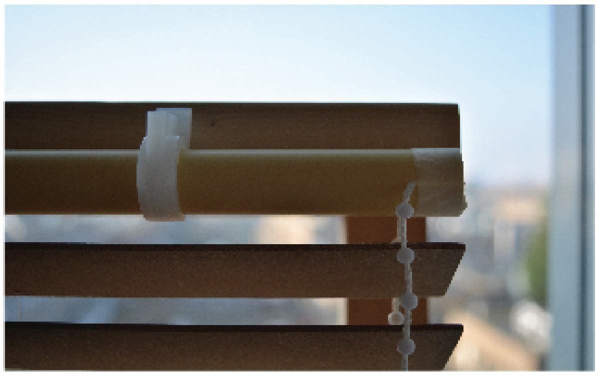


## Prototype wood



The pictures show the wooden prototype. This prototype was just the first, to get to know the right measurements to place it perfectly into the opening of the furnace and to get to know the most common problems while making this prototype. It functions as a learning model before making a prototype out of steel.





At left the mounting mechanism of this prototype is shown. This was just an easy connection with a clip in which the pipe can be clamed in. This prototype was just made for one distance between the element and the window. The steel prototype will have a mounting mechanism to hang the lamellae at two different distances from the window (75 mm and 100 mm)

With the use of a cord the lamellae can be opened and closed. In this prototype the lamellae are connected by a fishing wire which is knitted.

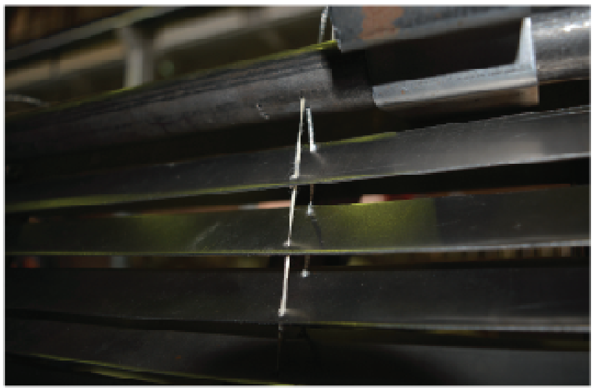
As shown in the picture at the top right the window will be held in place by the U-profile.

The lamellae will cover the whole frame in order to protect the framework.

## Prototype steel

The prototype made out of steel is based on the wooden prototype, only litte adjustments are made in order to make it easier to build.
The frame is made out of 4 steel beems welded together. With two mounting points where the steel pipe can be layed in, the lamellae can hang at two different distances.

The pictures shows the vertical view of the mounting principle of the steel prototype. It is a bended steel plate, which allows you to place the pipe with the lamellae at two different distances from the window, namely 75 mm and 100 mm. It also allows the pipe to turn in order to turn the lamellae from open to closed.



The lamellae are conncected with two kind of wires. In front a plastic wire which will met at higher temperatures in order to close the system automatically. The wires in the back are made out of steel and will keep the lamellae in place. There is also a small steel wire in between the plastic wire and the steel wire, in order to keep the lamellae in place.

The front of the steel prototype, with all the lamellae and the mounting principle.

At the back a profile is made in order to slide the glass pane in. It will also hold the pane in place.
The ends of the glass pane are provided with a rubber to protect the glass while it is in the frame. This rubber is also there in a normal window frame.

## Explanation of the design

The prototype is made as simply as possible. Not only because adjusting steel was new for me but also because the design has to be as simple as possible.

***Cleaning & maintenance***

The pipe with lamellae lies loose on the bended profiles. This way the distance between the window and the element can be easily adjusted. Also when after the fire the plastic wire has to be replaced the whole element can be easily taken of the system and be replaced if necessary. Because the system is that easy to take off also maintenance and cleaning of the lamellae becomes a lot easier.

***Prototype vs. reality***

The dimensions of the prototype are based on the dimensions of the furnace. In reality the dimensions of the element and the frame are dependent on the dimensions of the window. Because the tests are done in order to determine the concept of the fire retardant shading elements the scale will not have a big influence. However, when the perimeter of the glass is less, the chance of thermal stresses caused by temperature differences also will be less.

# Simulation of the fire

The simulation of the fire is divided into two simulations, namely one for the heat flux 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 flux (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 flux 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]

*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

[1] Another type of glass with the same specifications will reach comparable results.

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.

*Figure 13: simulation in TRA*

*Distances*
As shown in the schematic section the distance X is the distance between the window and the element. This is the distance which would be determined with the use of the simulations. However an important thing to keep in mind is when distance X becomes bigger, the element will be closer to the fire (distance Y will become less).

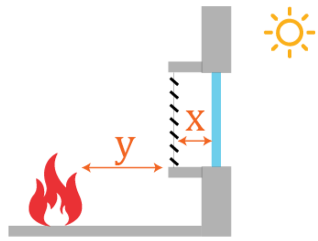



*Figure 14: vertical section of the distances*

*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:

| | Material | λ [W/mK] | Temperature [°C] | H [W/m2K] |
|---|---|---|---|---|
| Wall | Stony 2300 kg/m$^2$ | 0.700 | - | - |
| Window | Glass 2x 4 mm | 0.800 | - | - |
| Cavity window | Air 16 mm | 0.024 | - | - |
| Interior air | Air | - | 24.9 | 7.70 |
| Exterior air | Air | - | 4.9 | 25.00 |
| Element | Steel 1 mmm | 16 | * | - |
| Space between element and window | Air | - | 24.9 | 7.70 |

Table 4: materials used for the simulation in TRISCO

The temperature of the element is the temperature which follows from the maximum incident heat flux 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. Now a problem may occur in the corners of the blocks, so the next time a bit of overlap will be better.

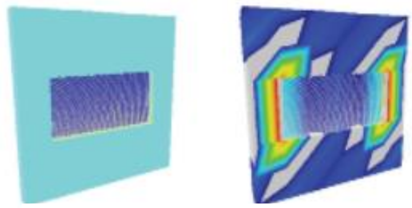


*Figure 15: simulation in TRISCO*

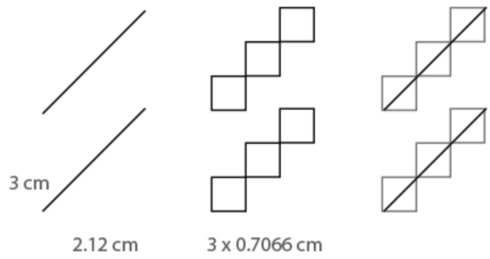



*Figure 16: simulation of the sloped elements*

## Results of the radiation simulation (in TRA)

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

| **Small space** | **Element opened (fully horizontal)** | | | | **Element half opened (45 degrees)** | | | | **Element closed** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance between window and element | Average incident radiation window* [kW/m2] | Temperature [°C] | Maximum incident radiation window *[kW/m2] | Temperature [°C] | Average incident radiation window *[kW/m2] | Temperature [°C] | Maximum incident radiation window *[kW/m2] | Temperature [°C] | Average incident radiation element [kW/m2] | Temperature [°C] | Maximum incident radiation element [kW/m2] | Temperature [°C] |
| 100 mm | 6.09 | 309.56 | 30.38 | 585.54 | 1.87 | 176.47 | 18.57 | 487.86 | 24.33 | 539.90 | 41.22 | 652.73 |
| 110 mm | 6.28 | 313.75 | 31.53 | 593.44 | 2.12 | 188.13 | 20.22 | 503.86 | 24.39 | 540.39 | 41.42 | 653.83 |
| 120 mm | 6.54 | 319.34 | 32.62 | 600.73 | 2.33 | 197.29 | 21.26 | 513.45 | 24.44 | 540.80 | 41.62 | 654.94 |
| 130 mm | 6.64 | 321.45 | 33.09 | 603.82 | 2.58 | 207.54 | 22.63 | 525.58 | 24.49 | 541.21 | 41.82 | 656.04 |
| 135 mm | 6.87 | 326.21 | 33.86 | 608.81 | 2.69 | 211.85 | 22.91 | 527.99 | 24.51 | 541.37 | 41.92 | 656.54 |
| 140 mm | 6.89 | 326.62 | 33.97 | 609.52 | 2.81 | 216.42 | 23.58 | 533.68 | 24.54 | 541.62 | 42.02 | 657.14 |
| 150 mm | 7.11 | 331.07 | 34.60 | 613.53 | 3.05 | 225,20 | 24.57 | 541,86 | 24.59 | 542.02 | 42.22 | 658.23 |
| 200 mm | 8.21 | 351.95 | 36.19 | 623.24 | 4.23 | 262.77 | 27.88 | 567.58 | 24.81 | 543.81 | 43.19 | 663.48 |
| 300 mm | 10.39 | 388.05 | 37.66 | 632.28 | 6.53 | 319.13 | 31.03 | 590.03 | 25.16 | 546.62 | 45.07 | 673.42 |
| 400 mm | 12.11 | 412.85 | 38.00 | 634.29 | 8.68 | 360.26 | 32.76 | 601.66 | 25.39 | 548.46 | 46.88 | 682.68 |
| 500 mm | 14.00 | 437.33 | 38.60 | 637.81 | 10.61 | 391.38 | 33.64 | 607.40 | 25.54 | 549.65 | 48.82 | 692.33 |

Table 5a: radiation simulation of a small 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

| Distance between window and element | Average incident radiation window [kW/m2] | Temperature [ºC] | Maximum incident radiation window [kW/m2] | Temperature [ºC] |
|---|---|---|---|---|
| 100 mm | 2.21 | 192.12 | 20.66 | 507.96 |
| 110 mm | 2.45 | 202.29 | 22.00 | 520.07 |
| 120 mm | 2.66 | 210.68 | 22.82 | 527.22 |
| 130 mm | 2.91 | 220.13 | 23.94 | 536.68 |
| 135 mm | 3.02 | 224.13 | 24.31 | 539.74 |
| 140 mm | 3.15 | 228.72 | 24.87 | 544.29 |
| 150 mm | 3.37 | 236.23 | 25.35 | 548.14 |
| 200 mm | 4.56 | 271.98 | 28.24 | 570.24 |
| 300 mm | 6.87 | 326.21 | 31.21 | 591.26 |
| 400 mm | 8.97 | 365.24 | 32.62 | 600.73 |
| 500 mm | 10.84 | 394.81 | 33.57 | 606.94 |

| Large space | Element opened (fully horizontal) | | | | Element half opened (45 degrees) | | | | Element closed | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance between window and element | Average incident radiation window *[kW/m2] | Temperature [ºC] | Maximum incident radiation window *[kW/m2] | Temperature [ºC] | Average incident radiation window *[kW/m2] | Temperature [ºC] | Maximum incident radiation window *[kW/m2] | Temperature [ºC] | Average incident radiation element [kW/m2] | Temperature [ºC] | Maximum incident radiation element [kW/m2] | Temperature [ºC] |
| 100 mm | 3.53 | 241.48 | 6.33 | 314.83 | 0.00 | 24.85 | 0.00 | 24.85 | 9.79 | 378.7 | 12.74 | 421.3 |
| 110 mm | 3.39 | 236.89 | 6.47 | 317.85 | 0.00 | 24.85 | 0.00 | 24.85 | 9.83 | 379.34 | 12.82 | 422.35 |
| 120 mm | 3.44 | 238.55 | 6.98 | 328.45 | 0.01 | 26.5 | 0.06 | 34.38 | 9.88 | 380.13 | 12.89 | 423.27 |
| 130 mm | 3.49 | 240.18 | 7.17 | 332.26 | 0.05 | 32.85 | 0.38 | 74.39 | 9.92 | 380.76 | 12.97 | 424.31 |
| 140 mm | 3.57 | 242.77 | 7.62 | 341.01 | 0.12 | 43.1 | 0.81 | 112.73 | 9.96 | 381.39 | 13.05 | 425.35 |
| 150 mm | 3.67 | 245.95 | 7.72 | 342.91 | 0.20 | 53.70 | 1.31 | 146.42 | 10.01 | 382.18 | 13.13 | 426.38 |
| 200 mm | 3.86 | 251.84 | 8.46 | 356.41 | 0.47 | 83.48 | 2.82 | 216.79 | 10.23 | 385.60 | 13.54 | 431.6 |
| 300 mm | 3.96 | 254.86 | 9.05 | 366.59 | 0.70 | 104.00 | 4.13 | 259.88 | 10.70 | 392.73 | 14.41 | 442.31 |
| 400 mm | 4.17 | 261.04 | 10.30 | 386.67 | 1.04 | 129.28 | 6.19 | 311.77 | 11.18 | 399.78 | 15.35 | 453.37 |
| 500 mm | 4.34 | 265.89 | 11.00 | 397.16 | 1.37 | 149.96 | 7.64 | 341.39 | 11.57 | 405.36 | 16.33 | 464.39 |

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

| Distance between window and element | Average incident radiation window [kW/m2] | Temperature [ºC] | Maximum incident radiation window [kW/m2] | Temperature [ºC] |
|---|---|---|---|---|
| 100 mm | 0.00 | 24.85 | 0.00 | 24.85 |
| 110 mm | 0.03 | 29.73 | 0.24 | 58.64 |
| 120 mm | 0.09 | 38.83 | 0.64 | 98.96 |
| 130 mm | 0.15 | 47.20 | 1.05 | 129.96 |
| 140 mm | 0.22 | 56.20 | 1.44 | 153.98 |
| 150 mm | 0.27 | 62.21 | 1.78 | 172.04 |
| 200 mm | 0.47 | 83.48 | 2.96 | 221.96 |
| 300 mm | 0.70 | 104.00 | 4.32 | 265.33 |
| 400 mm | 1.01 | 127.24 | 6.24 | 312.87 |
| 500 mm | 1.31 | 146.42 | 7.49 | 338.52 |

## Results of conduction and convection simulation

*Tables 6 & 7: 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 (7a) and with 6-16-6 mm glass (7b) with the element in three positions.*

| Small space<br>4-16-4 mm glass | | Element open (fully horizontal) Temperatures [°C] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 135 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 197.39 | 188.55 | 181.61 | 170.59 | 165.86 | 160.06 | 149.44 | 11.56 | 11.56 | 11.51 | 11.56 |
| Concrete | 300 mm | 585.54 | 593.44 | 600.73 | 603.82 | 608.81 | 609.52 | 613.53 | 21.32 | 21.32 | 21.35 | 21.32 |
| Glass outside pane | 4 mm | 204.42 | 195.26 | 188.06 | 176.63 | 171.72 | 165.71 | 154.68 | 11.83 | 11.83 | 11.78 | 11.83 |
| Air cavity glass | 16 mm | 234.13 | 223.60 | 215.32 | 202.16 | 196.50 | 189.58 | 176.86 | 24.54 | 24.54 | 24.60 | 24.54 |
| **Glass inside pane** | **4 mm** | **241.76** | **230.89** | **222.34** | **208.73** | **202.89** | **195.73** | **182.58** | **24.71** | **24.71** | **24.76** | **24.71** |
| Steel plate | 1 mm* | 585.54 | 593.44 | 600.73 | 603.82 | 608.81 | 609.52 | 613.53 | 623.24 | 632.28 | 634.29 | 637.81 |
| Inside air | 24.9 °C | 585.54 | 593.44 | 600.73 | 603.82 | 608.81 | 609.52 | 613.53 | 623.24 | 632.28 | 634.29 | 637.81 |

Table 6a.1: conduction and convection simulation of a small space with 4-16-4 mm glass with the element open
*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

| Small space<br>4-16-4 mm glass | | Element half open (45 degrees) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 199.27 | 192.95 | 184.73 | 177.87 | 170.15 | 11.69 | 9.66 | 9.66 | 9.66 | 9.66 |
| Concrete | 300 mm | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 21.32 | 15.19 | 15.19 | 15.19 | 15.19 |
| Glass outside pane | 4 mm | 207.16 | 200.57 | 192.00 | 184.85 | 176.80 | 11.95 | 9.90 | 9.90 | 9.90 | 9.90 |
| Air cavity glass | 16 mm | 240.34 | 232.64 | 222.62 | 214.26 | 204.85 | 24.29 | 24.51 | 24.51 | 24.51 | 24.51 |
| **Glass inside pane** | **4 mm** | **248.86** | **240.88** | **230.49** | **221.82** | **212.06** | **24.45** | **24.67** | **24.67** | **24.67** | **24.67** |
| Steel plate | 1 mm* | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 |
| Inside air | 24.9 °C | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 |

Table 6a.2: conduction and convection simulation of a small space with 4-16-4 mm glass with the element half open
*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

| Small space<br>4-16-4 mm glass | | Element closed Temperatures [°C] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 135 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 174.45 | 158.18 | 148.69 | 140.07 | 136.04 | 12.76 | 12.76 | 12.76 | 12.76 | 12.93 | 14.13 |
| Concrete | 300 mm | 652.73 | 653.83 | 654.94 | 656.04 | 656.54 | 23.04 | 23.04 | 23.04 | 23.04 | 29.34 | 32.68 |
| Glass outside pane | 4 mm | 182.97 | 166.28 | 156.23 | 147.12 | 142.85 | 13.15 | 13.15 | 13.15 | 13.15 | 13.07 | 14.23 |
| Air cavity glass | 16 mm | 229.90 | 210.79 | 197.72 | 185.86 | 180.31 | 31.32 | 31.32 | 31.32 | 31.32 | 32.27 | 28.03 |
| **Glass inside pane** | **4 mm** | **238.57** | **219.01** | **205.37** | **193.01** | **187.23** | **31.50** | **31.50** | **31.50** | **31.50** | **32.42** | **28.14** |
| Steel plate | 1 mm* | 652.73 | 653.83 | 654.94 | 656.04 | 656.54 | 657.14 | 658.23 | 663.48 | 673.42 | 682.68 | 692.33 |
| Inside air | 24.9 °C | 652.73 | 653.83 | 654.94 | 656.04 | 657.14 | 657.14 | 658.23 | 663.48 | 673.42 | 682.68 | 692.33 |

Table 6a.3: conduction and convection simulation of a small space with 4-16-4 mm glass with the element closed
*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

| Small space<br>6-16-6 mm glass | | Element open (fully horizontal) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 193.07 | 184.66 | 177.25 | 166.19 | 155.87 | 145.49 | 11.45 | 11.85 | 11.41 | 11.45 |
| Concrete | 300 mm | 585.54 | 593.44 | 600.73 | 603.82 | 609.52 | 613.53 | 21.34 | 21.34 | 21.37 | 21.34 |
| Glass outside pane | 4 mm | 203.42 | 194.54 | 186.71 | 175.03 | 164.13 | 153.16 | 11.85 | 11.85 | 11.80 | 11.85 |
| Air cavity glass | 16 mm | 232.70 | 222.50 | 213.51 | 200.09 | 187.53 | 174.90 | 24.37 | 24.37 | 24.44 | 24.37 |
| **Glass inside pane** | **4 mm** | **244.00** | **233.31** | **223.88** | **209.78** | **196.59** | **183.32** | **24.71** | **24.61** | **24.69** | **24.61** |
| Steel plate | 1 mm* | 585.54 | 593.44 | 600.73 | 603.82 | 609.52 | 613.53 | 623.24 | 632.28 | 634.29 | 637.81 |
| Inside air | 24.9 °C | 585.54 | 593.44 | 600.73 | 603.82 | 609.52 | 613.53 | 623.24 | 632.28 | 634.29 | 637.81 |

Table 6b.1: conduction and convection simulation of a small space with 6-16-6 mm glass with the element open
*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

| Small space 6-16-6 mm glass | | Element half open (45 degrees) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 194.00 | 187.98 | 180.03 | 173.41 | 165.89 | 11.46 | 9.59 | 9.59 | 9.59 | 9.59 |
| Concrete | 300 mm | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 24.59 | 15.24 | 15.24 | 15.24 | 15.24 |
| Glass outside pane | 4 mm | 205.62 | 199.15 | 190.70 | 183.65 | 175.65 | 11.85 | 9.95 | 9.95 | 9.95 | 9.95 |
| Air cavity glass | 16 mm | 238.20 | 230.64 | 220.78 | 212.54 | 203.21 | 24.16 | 24.38 | 24.38 | 24.38 | 24.38 |
| **Glass inside pane** | **6 mm** | **250.78** | **242.82** | **232.41** | **223.72** | **213.87** | **24.40** | **24.62** | **24.62** | **24.62** | **24.62** |
| Steel plate | 1 mm* | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 |
| Inside air | 24.9 °C | 487.86 | 503.86 | 513.45 | 525.58 | 533.68 | 541.86 | 567.58 | 590.03 | 601.66 | 607.40 |

Table 6b.2: conduction and convection simulation of a small space with 6-16-6 mm glass with the element half open
*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

| Small space 6-16-6 mm glass | | Element closed Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 170.80 | 154.93 | 145.71 | 137.34 | 12.64 | 12.64 | 12.64 | 12.64 | 12.86 | 14.06 |
| Concrete | 300 mm | 652.73 | 653.83 | 654.94 | 656.04 | 23.07 | 23.07 | 23.07 | 23.07 | 29.40 | 32.73 |
| Glass outside pane | 4 mm | 183.33 | 166.83 | 156.81 | 147.70 | 13.22 | 13.22 | 13.22 | 13.22 | 13.07 | 14.20 |
| Air cavity glass | 16 mm | 229.36 | 210.50 | 197.53 | 185.74 | 31.08 | 31.08 | 31.08 | 31.08 | 31.91 | 27.66 |
| **Glass inside pane** | **4 mm** | **242.13** | **222.60** | **208.81** | **196.29** | **31.35** | **31.35** | **31.35** | **31.35** | **32.13** | **27.82** |
| Steel plate | 1 mm* | 652.73 | 653.83 | 654.94 | 656.04 | 657.14 | 658.23 | 663.48 | 673.42 | 682.68 | 692.33 |
| Inside air | 24.9 °C | 652.73 | 653.83 | 654.94 | 656.04 | 657.14 | 658.23 | 663.48 | 673.42 | 682.68 | 692.33 |

Table 6b.3: conduction and convection simulation of a small space with 6-16-6 mm glass with the element closed
*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

| Large space 4-16-4 mm glass | | Element open (fully horizontal) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 116.20 | 112.40 | 109.98 | 104.70 | 100.64 | 94.70 | 11.51 | 11.51 | 11.51 | 11.51 |
| Concrete | 300 mm | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 21.35 | 21.35 | 21.35 | 21.35 |
| Glass outside pane | 4 mm | 119.99 | 116.07 | 113.54 | 108.07 | 103.86 | 97.72 | 11.78 | 11.78 | 11.78 | 11.78 |
| Air cavity glass | 16 mm | 135.92 | 131.48 | 128.54 | 122.29 | 117.46 | 110.42 | 24.60 | 24.60 | 24.60 | 24.60 |
| **Glass inside pane** | **4 mm** | **140.00** | **135.42** | **132.38** | **125.93** | **120.94** | **113.68** | **24.76** | **24.76** | **24.76** | **24.76** |
| Steel plate | 1 mm* | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 |
| Inside air | 24.9 °C | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 |

Table 7a.1: conduction and convection simulation of a large space with 4-16-4 mm glass with the element open
*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

| Large space 4-16-4 mm glass | | Element half open (45 degrees) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 14.25 | 13.87 | 17.05 | 30.38 | 41.66 | 11.55 | 9.70 | 9.70 | 9.70 | 9.70 |
| Concrete | 300 mm | 25.54 | 25.25 | 34.38 | 74.39 | 112.73 | 24.61 | 14.70 | 14.70 | 14.70 | 14.70 |
| Glass outside pane | 4 mm | 14.62 | 14.23 | 17.52 | 31.36 | 43.07 | 11.81 | 9.94 | 9.94 | 9.94 | 9.94 |
| Air cavity glass | 16 mm | 24.05 | 24.09 | 23.77 | 35.48 | 48.97 | 24.34 | 24.60 | 24.60 | 24.60 | 24.60 |
| **Glass inside pane** | **4 mm** | **24.21** | **24.26** | **23.93** | **36.52** | **50.48** | **24.50** | **24.76** | **24.76** | **24.76** | **24.76** |
| Steel plate | 1 mm* | 24.85 | 24.85 | 34.38 | 74.39 | 112.73 | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 |
| Inside air | 24.9 °C | 24.85 | 24.85 | 34.38 | 74.39 | 112.73 | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 |

Table 7a.2: conduction and convection simulation of a large space with 4-16-4 mm glass with the element half open
*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

| Large space<br>4-16-4 mm glass | | Element closed Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 119.93 | 13.44 | 13.44 | 13.44 | 12.95 | 12.95 | 12.95 | 12.95 | 12.95 | 12.95 |
| Concrete | 300 mm | 421.30 | 20.74 | 20.74 | 20.74 | 23.26 | 23.26 | 23.26 | 23.26 | 23.26 | 23.26 |
| Glass outside pane | 4 mm | 125.51 | 13.86 | 13.86 | 13.86 | 13.34 | 13.34 | 13.34 | 13.34 | 13.34 | 13.34 |
| Air cavity glass | 16 mm | 156.12 | 31.51 | 31.51 | 31.51 | 31.63 | 31.63 | 31.63 | 31.63 | 31.63 | 31.63 |
| **Glass inside pane** | **4 mm** | **161.76** | **31.69** | **31.69** | **31.69** | **31.82** | **31.82** | **31.82** | **31.82** | **31.82** | **31.82** |
| Steel plate | 1 mm* | 421.30 | 422.35 | 423.27 | 424.31 | 425.36 | 426.38 | 431.6 | 442.31 | 453.37 | 464.39 |
| Inside air | 24.9 °C | 421.30 | 422.35 | 423.27 | 424.31 | 425.36 | 426.38 | 431.6 | 442.31 | 453.37 | 464.39 |

Table 7a.3: conduction and convection simulation of a large space with 4-16-4 mm glass with the element closed
*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

| Large space<br>6-16-6 mm glass | | Element open (fully horizontal) Temperatures [°C] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 113.92 | 109.66 | 107.61 | 102.31 | 98.29 | 93.20 | 11.41 | 11.41 | 11.41 | 11.41 |
| Concrete | 300 mm | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 21.37 | 21.37 | 21.37 | 21.37 |
| Glass outside pane | 4 mm | 119.50 | 115.01 | 112.85 | 107.26 | 103.02 | 97.66 | 11.80 | 11.80 | 11.80 | 11.80 |
| Air cavity glass | 16 mm | 135.22 | 130.09 | 127.60 | 121.23 | 116.36 | 110.24 | 24.44 | 24.44 | 24.44 | 24.44 |
| **Glass inside pane** | **6 mm** | **141.25** | **135.89** | **133.28** | **126.60** | **121.50** | **115.08** | **24.69** | **24.69** | **24.69** | **24.69** |
| Steel plate | 1 mm* | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 |
| Inside air | 24.9 °C | 314.83 | 317.85 | 328.45 | 332.26 | 341.01 | 342.91 | 356.41 | 366.59 | 386.67 | 397.16 |

Table 7b.1: conduction and convection simulation of a large space with 6-16-6 mm glass with the element open
*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

| **Large space 6-16-6 mm glass** | | **Element half open (45 degrees) Temperatures [°C]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 14.03 | 13.67 | 16.77 | 29.79 | 40.80 | 11.40 | 9.63 | 9.63 | 9.63 | 9.63 |
| Concrete | 300 mm | 25.50 | 25.36 | 34.38 | 74.39 | 112.73 | 24.59 | 14.75 | 14.75 | 14.75 | 14.75 |
| Glass outside pane | 4 mm | 14.58 | 14.19 | 17.47 | 31.23 | 42.87 | 11.80 | 9.99 | 9.99 | 9.99 | 9.99 |
| Air cavity glass | 16 mm | 23.94 | 23.99 | 23.66 | 35.28 | 48.68 | 24.23 | 24.48 | 24.48 | 24.48 | 24.48 |
| **Glass inside pane** | **6 mm** | **24.18** | **24.22** | **23.90** | **36.83** | **50.91** | **24.47** | **24.72** | **24.72** | **24.72** | **24.72** |
| Steel plate | 1 mm* | 24.85 | 24.85 | 34.38 | 74.39 | 112.73 | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 |
| Inside air | 24.9 °C | 24.85 | 24.85 | 34.38 | 74.39 | 112.73 | 146.42 | 216.79 | 259.88 | 311.77 | 341.39 |

Table 7b.2: conduction and convection simulation of a large space with 6-16-6 mm glass with the element half open
*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

| **Large space 6-16-6 mm glass** | | **Element closed Temperatures [°C]** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Specifications | | 100 mm | 110 mm | 120 mm | 130 mm | 140 mm | 150 mm | 200 mm | 300 mm | 400 mm | 500 mm |
| Outside air | 4.9 °C | 117.60 | 13.33 | 13.33 | 13.33 | 12.83 | 12.83 | 12.83 | 12.83 | 12.83 | 12.83 |
| Concrete | 300 mm | 421.30 | 20.74 | 20.74 | 20.74 | 23.31 | 23.31 | 23.31 | 23.31 | 23.31 | 23.31 |
| Glass outside pane | 4 mm | 125.81 | 13.95 | 13.95 | 13.95 | 13.41 | 13.41 | 13.41 | 13.41 | 13.41 | 13.41 |
| Air cavity glass | 16 mm | 155.85 | 31.30 | 31.30 | 31.30 | 31.43 | 31.43 | 31.43 | 31.43 | 31.43 | 31.43 |
| **Glass inside pane** | **6 mm** | **164.15** | **31.58** | **31.85** | **31.85** | **31.71** | **31.71** | **31.71** | **31.71** | **31.71** | **31.71** |
| Steel plate | 1 mm* | 421.30 | 422.35 | 423.27 | 424.31 | 425.36 | 426.38 | 431.6 | 442.31 | 453.37 | 464.39 |
| Inside air | 24.9 °C | 421.30 | 422.35 | 423.27 | 424.31 | 425.36 | 426.38 | 431.6 | 442.31 | 453.37 | 464.39 |

Table 7b.3: conduction and convection simulation of a large space with 6-16-6 mm glass with the element closed
*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

## Conclusions of the simulation

Conclusions for the simulation in the small space:

- The average and maximum radiation are the closest to each other in a closed position.
- The optimal distance between the window and the element in open position will be between 150 and 200 mm for both glass types.
- The optimal distance between the window and the element in half open position will be between 140 and 150 mm for both glass types.
- The optimal distance between the window and the element in open position will be between 130 and 140 mm for both glass types.
- When the element is in a more closed position the optimal distance between the element and the window will be smaller.
- The temperature of the glass is in all the three positions around the same value for each distance.
- When the distance between the element and the window is bigger the temperature on the window will be lower.
- 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.

Conclusions for the simulation in the large space:

- The optimal distance between the window and the element in open position will be between 130 and 140 mm when the 4 mm glass is used. For the 6 mm glass type the optimal distance in this position will be between 150 and 200 mm.
- When the element is half opened the temperatures of the window are very low, with a small deviation at 130 and 140 mm. This applies for both types of glass.
- The optimal distance between the window and the element in closed position will be between 100 and 110 mm for both types of glass.
- 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.

Conclusions for both the simulations in the small and the large space:

- When the element is placed closer to the fire, the incident radiation on ass well the element as well on the window will be higher, this also applies for the temperature.
- There is a strange temperature fluctuation in the temperature of the concrete.
- 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 had any effect.

Because there is an unexplainable temperature decrease in the simulations the distances of 75 and 100 millimeters are chosen for the prototype in order to safe as much space as possible.

# Time versus heat flux

Glass is a poor conductor and that is why normal float glass will break when a temperature differences 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 flux. The temperature rise in the glass and the time can be found:

$$Power * Time = \rho \left(\frac{kg}{m^3}\right) * c \left(\frac{J}{kg * K}\right) * Volume\ (m^3) * \Delta T\ (K)$$

With Power in Watt

Time in seconds

ρ 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.

| 4-16-4 mm glass | Small space | | | | Large space | | | |
|---|---|---|---|---|---|---|---|---|
| | Element open | | Element half open | | Element open | | Element half open | |
| Distance between window and element | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] |
| 100 mm | 30.38 | 10.1 | 18.57 | 16.5 | 6.33 | 48.3 | 0.00 | 305760.0 |
| 110 mm | 31.53 | 9.7 | 20.22 | 15.1 | 6.47 | 47.3 | 0.00 | 305760.0 |
| 120 mm | 32.62 | 9.4 | 21.26 | 14.4 | 6.98 | 43.8 | 0.06 | 5096.0 |
| 130 mm | 33.09 | 9.2 | 22.63 | 13.5 | 7.17 | 42.6 | 0.38 | 804.6 |
| 140 mm | 33.97 | 9.0 | 23.58 | 13.0 | 7.62 | 40.1 | 0.81 | 377.5 |
| 150 mm | 34.60 | 8.8 | 24.57 | 12.4 | 7.72 | 39.6 | 1.31 | 233.4 |
| 200 mm | 36.19 | 8.4 | 27.88 | 11.0 | 8.46 | 36.1 | 2.82 | 108.4 |
| 300 mm | 37.66 | 8.1 | 31.03 | 9.9 | 9.05 | 33.8 | 4.13 | 74.0 |
| 400 mm | 38.00 | 8.0 | 32.76 | 9.3 | 10.30 | 29.7 | 6.19 | 49.4 |
| 500 mm | 38.60 | 7.9 | 33.64 | 9.1 | 11.00 | 27.8 | 7.64 | 40.0 |

Table 8a: time versus maximal heat flux with 4 mm glass

| 6-16-6 mm glass | Small space | | | | Large space | | | |
|---|---|---|---|---|---|---|---|---|
| | Element open | | Element half open | | Element open | | Element half open | |
| Distance between window and element | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] | Maximum incident radiation window *[kW/m2] | Time [s] |
| 100 mm | 30.38 | 15.1 | 18.57 | 24.7 | 6.33 | 72.5 | 0.00 | 458640.0 |
| 110 mm | 31.53 | 14.5 | 20.22 | 22.7 | 6.47 | 70.9 | 0.00 | 458640.0 |
| 120 mm | 32.62 | 14.1 | 21.26 | 21.6 | 6.98 | 65.7 | 0.06 | 7644.0 |
| 130 mm | 33.09 | 13.9 | 22.63 | 20.3 | 7.17 | 64.0 | 0.38 | 1206.9 |
| 140 mm | 33.97 | 13.5 | 23.58 | 19.5 | 7.62 | 60.2 | 0.81 | 566.2 |
| 150 mm | 34.60 | 13.3 | 24.57 | 18.7 | 7.72 | 59.4 | 1.31 | 350.1 |
| 200 mm | 36.19 | 12.7 | 27.88 | 16.5 | 8.46 | 54.2 | 2.82 | 162.6 |
| 300 mm | 37.66 | 12.2 | 31.03 | 14.8 | 9.05 | 50.7 | 4.13 | 111.1 |
| 400 mm | 38.00 | 12.7 | 32.76 | 14.0 | 10.30 | 44.5 | 6.19 | 74.1 |
| 500 mm | 38.60 | 11.9 | 33.64 | 13.6 | 11.00 | 41.7 | 7.64 | 60.0 |

Table 8b: time versus maximal heat flux with 6 mm glass

## Measuring plan

*In this chapter the goal, the method and the types of measurements and materials are explained.*

The goal of the measurements is to get to know the heat accumulation in the glass, with and without the sun shading element. Also the time is measured in which the element will close automatically, with the corresponding temperature. The specific goals of these tests are as follows:

- To get to know the heat accumulation in the 4 mm glass over time, without an element
- To get to know the heat accumulation in the 6 mm glass over time, without an element
- To get to know the time in which the system will close automatically and the corresponding temperature
- To get to know the heat accumulation in the 4 mm glass:
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element
    - With a closed element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element
    - With a closed shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element
    - Possible option: with an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element and a fire retardant coating on the lamellae
    - Possible option: with an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element and a fire retardant coating on the lamellae
- To get to know the heat accumulation in the 6 mm glass:
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element
    - With an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element
    - Possible option: with an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 75 mm distance between the window and the element and a fire retardant coating on the lamellae
    - Possible option: with an open shading element which will close automatically and with a lamellae thickness of 0.8 mm and 100 mm distance between the window and the element and a fire retardant coating on the lamellae

These goals will result in the following types of measurements:

- 4 mm / without an element
- 6 mm / without an element
- 4 mm / open element with a thickness of 0.8 mm / 75 mm distance
- 4 mm / open element with a thickness of 0.8 mm / 100 mm distance
- 4 mm / closed element with a thickness of 0.8 mm / 75 mm distance
- 4 mm / closed element with a thickness of 0.8 mm / 100 mm distance
- 4 mm / open element with a thickness of 0.8 mm / 75 mm distance / fire retardant coating
- 4 mm / open element with a thickness of 0.8 mm / 100 mm distance / fire retardant coating

- 6 mm / open element with a thickness of 0.8 mm / 75 mm distance
- 6 mm / open element with a thickness of 0.8 mm / 100 mm distance
- 6 mm / closed element with a thickness of 0.8 mm / 75 mm distance
- 6 mm / closed element with a thickness of 0.8 mm / 100 mm distance
- 6 mm / open element with a thickness of 0.8 mm / 75 mm distance / fire retardant coating
- 6 mm / open element with a thickness of 0.8 mm / 100 mm distance / fire retardant coating

To get this prototype made and tested the following materials are needed:

- Steel plate: 12 steel plates of 960 x 458 x 0.8 mm
- Fire retardant coating for steel
- Steel wire
- Steel frame with mounting options for the element
- Steel pipe for mounting the element
- Plastic wire
- 4 mm glass 7 panes: 400 x 625 mm
- 6 mm glass 7 panes: 400 x 625 mm
- Fire retardant sealant
- Stopwatch
- Infra-red measurement tool
- Heat resistant suits

### Measuring method

To simulate a fire in a furnace as real as possible the furnace is first heated till 600 degrees with bricks on the inside which accumulate the heat. Then the furnace is turned off. With the use of heat-resistant clothing the frame is placed in the opening of the furnace as you see on the picture. This way the element is quickly exposed to high temperatures. Every 10 seconds the temperature of the glass is measured with an infrared thermometer. With the use of a stopwatch also the time till the element closes s measured and the corresponding temperature is also written down. In the meanwhile everything is recorded, so the time, temperatures and the whole process can later be reviewed.

*Figure 17: prototype without glass in the furnace*

### Test measurement

At Wednesday 16th of March a test measurement will be done in order to see how the prototype would react to the heat and to test if the mechanism is really closing.

## Test measurement

*Here you see the results of the test measurements. These results are shortly discussed here, because they are only test results and also in the reflection.*

| Time with 5 mm glass and 10 cm distance | Temperature in degrees Celsius |
|---|---|
| 0 sec. | 37,6 |
| 10 sec. | 38,8 |
| 20 sec. | (5)42,2 |
| 30 sec. | (4)47,1 |
| 40 sec. | 48,8 |
| 50 sec. | 53,5 |
| 1 min. | 66,4 |
| 1 min. + 10 sec. | (4)79,8 |
| 1 min. + 20 sec. | (4)88,5 |
| 1 min. + 30 sec. | 97,2 |

*Table 9: resuts of the test measurements*

The results show a temperature increase in the glass, until the glass broke because of thermal stresses. The test was done with 5 mm glass, a thickness which will not be used in the real measurements. But this was only to test the prototype and the mechanism.

The mechanism did close itself but there is not a time registered in which this mechanism did close itself, because we first placed the element in the furnace and after that we placed the glass in the frame, because otherwise it was not possible to place the prototype into the oven with the heat-resistant suit on. So this was not representative for a real fire. Also the wire did not melt all at once, but at different places at different times, so the mechanism closed part by part. This was the purpose of the test, to see how it will work and to see how everything will be done during the test. One of the conclusions is that the prototype has to be provided with handles in order to place the prototype easy in the furnace with the heat-resistant suits on.

Also the temperatures which are noted are discussable. We asked someone to help and to write the temperatures down that I told her and not the numbers on the screen of the furnace, every ten seconds. After the test she already told me she missed a number probably at 50 seconds, so she wrote down what she thought it was. Also she wrote sometimes a 4 or a 5 in front of the numbers, because perhaps sometimes she took the numbers on the screen from the oven or she made her own numbers, but in any case not always the numbers I told her. With the next measurements I will note the temperatures myself, in order to know the correct temperatures are written down.

In the photos on the right is visible how the wire in front is melted away and the lamellae are closed. In the other picture is the prototype out of the furnace and as you can see the glass is broken because of the thermal stresses.

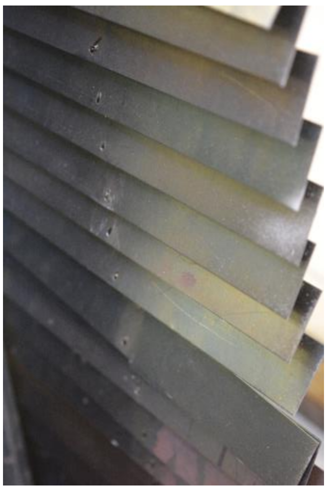


*Figure 18: closed element after the test*

*Figure 19: broken glass pane after the test*

# Results of the measurement

To be done

# Conclusions of the measurements

To be done

# Discussion

Simulation

Furnace

Materials

Fire

Measurements

Concept

Lamellae

Test measurement

# Evaluation

To be done

# Draft reflection

*The subject fire safety for this master thesis is born 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 barely learned anything about fire safety, although it has been become more important in the building industry. To fill this gap of knowledge before graduating the decision had been made to do my final thesis about the subject of fire safety. The subject fire safety does not directly fit into the building technology theme of the graduation lab, actually with none of the themes of the graduation lab, but because it is a broad subject and also related to building (parts) and safety in buildings there are a lot of subjects which correspond.*

I started with randomly searching for problems, recent fires in buildings and other subjects concerning fire safety in buildings as a graduation topic. This range of articles and problems was so big and often there was not just one building problem that searching for a subject and a research question this way was very confusing. So I started with a new approach in order to find a topic. Now the starting point of the graduation topic was contacting the fire safety department of The Hague and the Dutch Institute of Physical Safety to ask what the current biggest problems are concerning fire safety in buildings. This way I would get a clear answer from the people who know most about fire and fire safety. One of the biggest problems was the lack of integration between fire safety and design. Also the growing demand for fire retardant glazing in public buildings and monuments and their relatively high price per square meter is a current topic. Asking these people for problems and topics concerning fire safety in buildings has led to a relevant question for this graduation topic, namely "*In which way is it possible to use sun shading as a fire retardant element, such that it will be a substitute for fire retardant glazing in public buildings in Holland?".* This method with questioning the ones who know most about fire safety was a very well working approach. This way the subject was a relevant problem and because these people are experienced with fires in buildings the problem is well-grounded.

This research question should result in a concept of a sun shading product which also functions as a fire retardant product and thus as a substitute for fire retardant glazing. This was a very clear topic, also for me to know which result this whole research should give. This concept product should replace the expensive (250 - 550 euro per square meter) fire retardant glazing and also be a design solution for fire retardant glazing in monuments. In order to delimit the question the choice is made to specify this only for public buildings in Holland, this with regards to the regulations in the Dutch Building Decree which result in more specific specifications in the program of requirements in comparison to a product which may be used in all buildings in Holland. If, in the end, a concept for a product is developed, the product may be further developed into a product which also functions in for example residential buildings, but then it also has to meet other criteria. The method for this concept was to do research which will result in the program of requirements for the concept. Also the rules and regulations in Holland are applied to this and therefore I delimited the question in order to get a specific concept, which later may be applied to other building types.

Because I knew barely anything about fire safety after I had chosen the topic, I started with doing some research about fire safety, fire development, the current rules and regulations and fire retardant products. I also did some research about sun shading and the sun shading products. This resulted in a schematic overview with the advantages and disadvantages when it would be used as a fire retardant product. From this overview I could conclude that inside sunshading was the best option to use for the further development of the concept. Making this overview helped me also to get a sort of SWAT analysis of the sun shading.

The question raised about what will be the optimal distance between the sun shading / fire retardant element and the window, in order not to break the glass in case of fire. Therefore I made simulations of a small and a big room with different distances between the element and the window in the programs TRA for the radiation of the fire and TRISCO for the heat transfer from the element to the window. Because fire is very unpredictable the simulations where only important to get a global idea and feeling of the optimal distance and the corresponding material temperatures. These simulations also gave me a good feeling about the temperatures in a fire.

Figure 20: simulaton in TRA

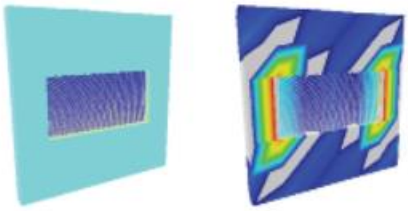
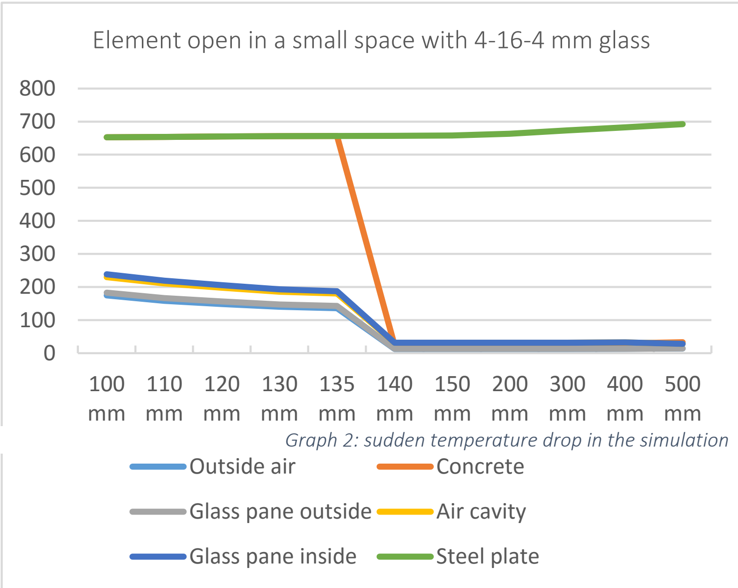


Figure 21: simulation in TRISCO

However, the results from TRISCO showed an unexplainable sudden decrease in temperature, which is shown in the diagram on the right. Possible because of the high temperatures this sudden temperature drop occurred in the program. So if the distance in between 130 and 140 millimetres between the element and the window is the most optimal is discussable. In order to lose as less space as possible for the concept of the product the distances of 75 mm and 100 mm were taken for the prototype. This problem of sudden decrease in temperature could possibly be prevented when an official fire simulation program, for example Brando, was used. However this was not available for free online or within the available software of the university. Because this whole research is about developing a concept and fire is very unpredictable this inaccurate simulation method is not very harmful. For developing a real product better simulations would improve the product.




Graph 2: sudden temperature drop in the simulation

Graph 1: sudden temperature drop in TRISCO

The method in this period (between P1 and P2) was to get to know a lot about fire, fire safety, rules, fire retardant products and sun shading products and to get a clear overview of all the information and to form a program of requirements before the design phase. The research and the simulations I did are not directly visible into the design, but the research did result in certain specifications for the program of requirements of the element. For example the type and place of the sun shading / fire retardant element was a result of the research. The choices regarding the materials where substantiated by a material study. Because the simulations took place in order to get to know the optimal distance also here the goal was very clear.

After the simulations the design phase had started. In this phase (between P2 and P3) the design of the element and mechanism are developed in combination with a material study. Because of the high temperatures during a fire steel was one of the most obvious materials.

For me this phase was hard, because I'm very result oriented and this phase was about thinking, sketching and trial and error, so although I did a lot of work personally it felt like I had not accomplished that much. I started to make a model out of wood in order to get the sketches and thoughts into a model. I first measured the dimensions of the furnace and made a model out of wood, which could be used as a starting point for the prototype made out of steel. This in order to test the mechanism and to check the dimensions, because when I make it in steel the dimensions have to be correct, because steel is hard to adjust. For me the model in wood made me think about the actual connections between the lamellae and the mechanism and between the element and the mechanism. Also it raised a lot of questions about the mechanism and the materials. It was a good reminder when one of my tutors said I have to develop a concept for a fire retardant sun shading product and I do not have to develop a complete product which can be sold directly. This way some of the questions I had become more important and other questions faded because sometimes I can be too much of a perfectionists. This wooden model was made in just one day, so this was very promising for the steel model. However this model took weeks, because steel is not that easy to adjust as wood. So also in these weeks it felt like I had not accomplished that much, but on the other hand I had made one of the most important things of this whole research.

For the lamellae I first made a model out of play cards. Although the scale was totally wrong an important problem came to light. When the holes for the wire were made perpendicular to the cards, the system would not fully close, because the wire had to make a strange angle. See the schematic view of the lamellae and the wires below. When the holes where made at an angle of around 45 degrees or less this problem was solved and the system was able to close better.

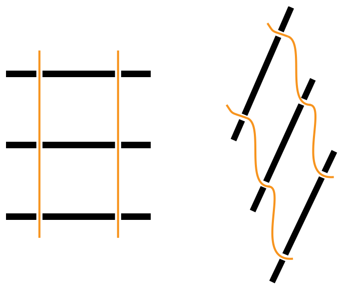


*Figure 22a: bending of the wire because of the straight holes*

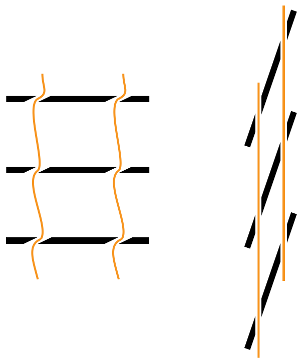


*Figure 22b: solution of the bending of the wire because of the sloped holes*

Making the lamellae out of wood was easy, because this could also be done with knotting a wire. Then with making the steel lamellae the problems occurred. This phase was literally trial and error, because the steel wire could not be knotted as easily as normal wire and when the whole element was assembled the rotating mechanism did not work, although it worked when only three lamellae were assembled. Because of the knots and the heavier weight of the steel in comparison to the weight of the wood and the playing cards it did not work when the whole element was assembled. Then I tried to fold the steel wire around the lamellae, but in the end also the rotating mechanism did not work. So then I replaced the steel wire in front with a plastic wire, which in case of higher temperatures would burn or melt. This way in each case the self-closing mechanism of the lamellae was taken care of, although the rotating mechanism did not work perfectly.

The method of making models in different materials worked very well in order to solve some problems and also it made me think about the properties of the different materials and their connections. The trial and error part of the steel lamellae however did not work for me. It was very frustrating to spend a day on assembling the lamellae and to see that it would not work in the end. But this also resulted in thinking about other ways to assembly the lamellae and try again till it would work. So with a little perseverance this phase was still very informative.

At Wednesday the 16th of March a test was done in the furnace in order to test the method, the prototype and the mechanism. When making the prototype I did not think of placing the element with the glass plate in the oven with a heat-resistant suit on, so we had to place the element in parts in the furnace. First the steel element with the sun shading lamellae and after that we placed the glass into the frame. This resulted in the conclusion that handles have to be made in front of the prototype in order to handle it and place it in the oven including the glass plate. Also because of the time it took for the lamellae to shut down could not be measured precisely, but it was already nice to see that the melted wired caused the closing of the system. Also the temperatures the girl who helped us wrote down are discussable. Although we explained very clear to her what to do, the wrong temperatures are written down. For me it was very clear I will write the temperatures down myself the next time and then with the use of the handles on the prototype it is possible to place it in the furnace by another person.

The last part of the graduation will consist of the design of the element and the design of the mechanism. It also contains the development of the prototype and making adjustments to it. First a test is done in order to see possible buckling or melting of the steel plates of the element and in order to evaluate the method and the prototype. After that possible adjustments are made to the steel prototype and possibly also to the method and then measurements with different distances between the element and the glass and with different glass thicknesses are done and eventually also tests with a fire retardant coating on the inside of the element are done. After all the tests I hopefully can answer the rest of the unanswered research (sub)questions and the questions about price and durability of the element. Also I will critically evaluate the whole process and design.

Where I first thought that the P1 phase was for choosing the subject, the P2 phase for doing the research, the P3 phase for the design by research of research by design, the P4 phase for the definitive design and evaluation and at last the P5 phase for building the prototype, I switched some phases because my prototype is also used for executing the tests in the furnace. So during the P2 research phase I did a study to get to know which type of sun shading is best to use as a fire retardant element and what type of self-closing mechanism could work in combination with this type of shading. During the P3 phase I started to develop this mechanism and this sun shading into a prototype, so this prototype can be used for testing. This way the research by design is done on the basis of the wooden and steel prototypes and the tests in the furnace in the P4 phase. This way I could use the last phase to evaluate the design, the prototype and the tests.

# Goal

The goal of this research and design is to get a substitute for fire retardant glazing in public buildings which also functions as sunshading. 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 sunshading and further developed. These specifications are combined and integrated into a design for a fire retardant sunshading 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 sunshading 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 the Netherlands 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 sunshading 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?
  - Answer in the design of the mechanism and in the prototype of steel

Which materials will be used?

- What kind of materials are best to use for the sunshading?
  - Answer in the material study
- What kind of materials are best to use for the fire resistance?
  - Answer in the material study
- 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 sunshading?
  - To be researched
- How to prevent malfunction, possible damage and wearing?
  - To be researched
- What will be the performance of the sunshading element in relation to thermal comfort?
  - For now the fire retardant shading element will be on the inside of the window. Sunshading 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

- What will be the influence of a fire retardant sun shading element on a fire and what will be the consequence for the fire fighters?

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

In the next phase the main focus be on proceeding with all the tests in the furnace and to collect and analyze the data from these tests. Also possible adjustments on the prototype will be made if necessary. In the last phase, between P4 and P5, the focus will be on evaluating the whole process and design and to discuss the durability and the sustainability and to find an answer on the last (unanswered) research questions.

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