GRADUATION PLAN

Iris van der Weijde

januari 2017
graduation plan

personal information:
Name: Iris van der Weijde
Student number: 4134206
Telephone number: (+31)612522951
E-mail address: irisvanderweijde@gmail.com

graduation studio
Name/theme: Building Technology
Teachers: Peter Teeuw, Christian Louter, Marcel Bilow
Argumentation of choice: Personal fascination for transparent architecture on a technical basis.

graduation project
Title of graduation project: Thin glass meeting the requirements of a facade panel while reducing its weight.

goal
Location: Countries with a temperate climate.
Posed problem: Insulation of facade panels is required but the amount of material and thereby the weight to achieve this increases. Which is a shame because glass embodies a large amount of energy.
Main research question: Can thin glass be applied in a sandwich panel in order to meet the requirements of a facade panel?
Sub questions:
- Can the required thermal insulation value be achieved with thin glass?
- Can thin glass be applied safely in the built environment?
- What are the possible applications of this panel?
- How much is the weight reduction of the panels and its support structure in comparison to traditional methods?
Design assessment: Design a safe, insulating sandwich panel with thin glass, in order to reduce the amount of glass as well as its support construction.

process
Method description: First literature study will be done on to discover the background information of the material and its possibilities. Than an exploration of precedents will show methods on how to stiffen, insulate glass. Also precedents of existing sandwich panels is required. This will be followed by the selection of a case study that will define the criteria of the design. Once the criteria is clear, mechanical and thermal calculations should be done either by software, or by hard. When the panel is according to these criteria, the detailing of the final design may start.

Literature &
gen general practical preference
Glass

Thin glass
So far, thin glass is applied only on electronic devices. It is quite a new material, which has a big potential for usage in the built environment. There have been several graduate students at the TU Delft studying on the possibilities of applying thin glass in buildings, however these studies have only been on uninsulating double skin facades.

The main reason why thin glass could have huge sustainable advantages in comparison to regular float glass, is its thinness. Reduced thickness means less material thus less emitted pollution while produced and transported thereby a lower environmental burden. Due to the size thus weight reduction that can be achieved in the facade, when thin glass sheets are used, there will be transport benefits. It basically means that more glass sheets could fit in a truck resulting in fewer trucks required thus less pollution emitted. Also, because of the weight reduction, the building speed could increase enourmously and heavy equipment might not be for assembly.
CHAPTER 1
research framework
research framework

problem statements

Historically, glass was used it provide a view and enable sunlight to enter in buildings. Due to increasing regulations for insulation values, single glass panels are not sufficient anymore. Now double glass and even triple glass panels are used in facades, causing the weight of the facade to increase enormously.
While insulation is very important in terms of a building’s energy performance it should also be taken into account that glass is a material with a very large amount of embodied energy due of its production process. The thinner the glass sheets, the less material, the smaller the ecological footprint.

problem
Glass is becoming increasingly heavy in the built environment by insulation regulations, which has a high environmental burden by its embodied energy.

sub-problem
By the increasing thickness of facade the light transmittance decreases.

hypotheses
The usage of thin glass in the built environment could save a substantial amount of material.

research objectives

general objective
Design a facade panel which reduces the weight and embodied energy by the implementation of thin glass.

sub objectives
- Explore existing methods of designing an insulating panel.
- Explore methods increasing the stiffness of glass panels.
- Provide enough stiffness in the panel for it to be safe for usage.
- Achieve thermal insulation, at least, according to building regulations.
- Provide a large amount of transparency thus light transmittance.

final products
A 1:1 model of a thin glass facade panel that is stiff enough for safe usage in the built environment.

hypotheses direction of solutions
In order to design a stiff and insulating panel, it is expected that the design of a sandwich panel could be an appropriate solution.

boundary conditions
The first boundary condition is formed by the location of the project. Especially in temperate climates, such as in the Netherlands, the need for insulating glass is high. For this reason, the Netherlands will be the location for this research. Therefore, the Dutch building code will provide regulations for the panel.

research questions

main question
Can thin glass be applied in a sandwich panel in order to meet the requirements of a facade?

sub questions
- Can the required thermal insulation value be achieved with thin glass?
- Can thin glass be applied safely in the built environment?
Approach & methodology

To be able to answer the research questions and come to a panel design, first, there has to be discovered what the material properties of glass are. What the difference is with thin glass in comparison to regular soda lime glass, what its production possibilities are and how it can be bonded in order to design an insulating panel.

Secondly, precedent studies need to be done, in order to explore the possible properties of the panel. It needs to be figured out how thermal losses can be reduced in glass, how sheets are stiffened and what type of sandwich panels already exist.

Then design criteria for insulation, light transmittance, and safety needs to be defined by current or future requirements. For this, a case study needs to be chosen that fits within the scope of this research. Once a case study is chosen, the design process of the panel may start, in which suitable geometries will be explored and calculated. Several geometries should be calculated for its mechanical properties by finite element analysis. Conclusions on the strength, stiffness and thereby safety of the panel are to be analyzed, simultaneously with the insulation and light transmittance. When the geometry meets the criteria, the detailing of the panel, the support construction, and interconnections can start in order to come to an architectural panel design. This process is summarized abstractly in image 1.

- What are the possible applications of this panel?
- How much is the weight reduction of the panels and its support structure in comparison to traditional methods?
- What sandwich panels are currently on the market (also in other materials like plastics)?

background questions
- What insulation value should be achieved?
- When is glass safe, if applied in the built environment?
- What building typologies are current applications of glass sheet?
- What is the weight of glass panels in traditional applications?

Image 1: research approach. Own image.
A more step-by-step overview of the research methodology is shown in image 2. It displays all methods and their corresponding subjects from literature study to final design.

**Research**
- Material
  - Glass
  - Thin glass
- Bonding
  - Interlayers
  - Glues

**Exploration**
- Precedents:
  - sandwich panels: plastics
  - insulation of glass panels
  - stiffening of glass
- Building regulations
  - insulation value
  - light transmittance
  - safety (strength & stiffness)

**Case study**
- Exploration
- Analyse case study
- Define criteria

**Study models**
- Mechanical properties
  - Physical models
  - Numerical models
- Climatological properties
  - thermal performance
  - light transmittance

**Detailing**
- Materialization support construction
- Connections
- Supports
The main reason why thin glass could have huge sustainable advantages in comparison to regular float glass is its thinness. The reduced thickness is a huge potential in terms of material saving. Reduced thickness means less material, less emitted pollution thus an environmental burden. This could be a simple calculation if thin glass would be produced with the same process and the same base materials as soda lime glass, unfortunately, this is not the case. Due to other production processes and a different chemical composition (aluminosilicate) the environmental burden is different. To be able to make a comparison of the environmental burden, some numbers are compared in table 1.

<table>
<thead>
<tr>
<th></th>
<th>Soda lime glass</th>
<th>Aluminosilicate glass</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>primary production</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>embodied energy [MJ/kg]</td>
<td>10.1 - 11.1</td>
<td>13.3 - 14.8</td>
<td>Energy required to make 1 kg of the material from its ores or feedstocks</td>
</tr>
<tr>
<td>CO2 footprint [kg/kg]</td>
<td>0.72 - 0.79</td>
<td>0.89 - 0.99</td>
<td>The CO2-equivalent mass of greenhouse gases (kg CO2e), in kg, produced and released into the atmosphere as a consequence of the production of 1 kg of the material</td>
</tr>
<tr>
<td>water usage [l/kg]</td>
<td>14.7 - 16.2</td>
<td>20.1 - 22.2</td>
<td>Fresh water required to make 1 kg of the material</td>
</tr>
<tr>
<td>molding energy [MJ/kg]</td>
<td>8.38 - 5.28</td>
<td>10.5 - 11.7</td>
<td>The energy required to process the material using the specified primary process (MJ/kg)</td>
</tr>
<tr>
<td>molding CO2 [kg/kg]</td>
<td>0.07 - 0.74</td>
<td>0.840 - 0.930</td>
<td>Material processing CO2: The CO2 footprint associated with processing the material using the specified primary process (kg CO2/kg)</td>
</tr>
<tr>
<td>melting water [l/kg]</td>
<td>2.40 - 2.74</td>
<td>3.15 - 4.73</td>
<td>The water required to process the material using the specified primary process (l/kg)</td>
</tr>
<tr>
<td>grinding energy [MJ/kg]</td>
<td>24.3 - 26.8</td>
<td>32.1 - 35.5</td>
<td>The energy required to process the material using the specified machinery process, based on the amount of material removed (MJ/kg)</td>
</tr>
<tr>
<td>grinding CO2 [kg/kg]</td>
<td>1.83 - 2.01</td>
<td>3.41 - 3.66</td>
<td>The CO2 footprint associated with processing the material using the specified machinery process, based on the amount of material removed (kg CO2/kg)</td>
</tr>
<tr>
<td>recycling</td>
<td>yes</td>
<td>yes</td>
<td>Indicates whether a material can be recycled into a grade of similar quality</td>
</tr>
<tr>
<td>embodied energy [MJ/kg]</td>
<td>8.54 - 9.11</td>
<td>10.9 - 12</td>
<td>The energy required to recycle 1 kg of the material</td>
</tr>
<tr>
<td>CO2 footprint [kg/kg]</td>
<td>0.563 - 0.596</td>
<td>0.025 - 0.069</td>
<td>The CO2-equivalent mass of greenhouse gases (kg CO2e), in kg, produced and released into the atmosphere as a consequence of recycling 1 kg of the material</td>
</tr>
<tr>
<td>recycle fraction in current supply [%]</td>
<td>22.7 - 25.1</td>
<td>0.1</td>
<td>The percentage of recycled and downcycled material in total worldwide supply of the material</td>
</tr>
<tr>
<td>downcycling</td>
<td>yes</td>
<td>yes</td>
<td>Indicates whether a material can be reprocessed into materials of lower quality or performance</td>
</tr>
<tr>
<td>combustion for energy recovery</td>
<td>no</td>
<td>no</td>
<td>Indicates whether the carbon content of a material can be recovered by controlled combustion (‘controlled’ to minimize toxic emissions)</td>
</tr>
<tr>
<td>landfill</td>
<td>yes</td>
<td>yes</td>
<td>Indicates whether a material can be safely disposed in landfill sites</td>
</tr>
<tr>
<td>biodegradable</td>
<td>no</td>
<td>no</td>
<td>Indicates whether a material is biodegradable</td>
</tr>
</tbody>
</table>

What could be concluded from the table 1 is that soda lime glass has a smaller environmental burden (amount of embodied energy, CO2 footprint,
Due to the reduced thickness thus weight that can be achieved in a facade when thin glass is used, there will be transport benefits. The glass is thinner meaning that it requires less space when transported and secondly, it has a larger impact resistance leading to a reduced risk of breakage while transported.

Another interesting possibility of thin glass is the fact that it could be cut after strengthening, so minor mistakes could possibly be fixed on site. Cutting for example, could be done without enormous reduction in strength. This should further be explored.

Because thin glass is available from 0.025 - 1.0 mm it can save enormous amounts of weight when applied in facades (table 2). This reduces the amount of equipment that is required to lift a panel. Without taking support construction into account, a triple glazing panel is currently more than 20 kg per square meter, when 6 mm glazing is applied. Meaning that a crane and forklift are required for placement. When a thin glass facade panel is placed, the weight reduction might result in the unnecessary of heavy equipment. Thin glass has the potential of going below the 50 kg that is currently the maximum amount someone is allowed to carry.

And last but not least, in case a glass sheet breaks, this lightweight has advantages in terms of replaceability, again because less, or no, heavy equipment is required on site.

<table>
<thead>
<tr>
<th>thickness [mm]</th>
<th>volume: 1x1 m [m³]</th>
<th>weight single sheet: 1x1 m [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>0.008</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>0.006</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>0.006</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>0.002</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0.001</td>
<td>2.48</td>
</tr>
<tr>
<td>0.5</td>
<td>0.0006</td>
<td>1.24</td>
</tr>
<tr>
<td>0.25</td>
<td>0.00025</td>
<td>0.62</td>
</tr>
<tr>
<td>0.1</td>
<td>0.0001</td>
<td>0.248</td>
</tr>
<tr>
<td>0.05</td>
<td>0.00005</td>
<td>0.124</td>
</tr>
<tr>
<td>0.025</td>
<td>0.000025</td>
<td>0.062</td>
</tr>
</tbody>
</table>

Table 3: Potential in weight reduction of facade panel (1x1 m).
The Glass & Transparency Research Group at the TU Delft in the Netherlands focuses on the development of innovative glass solutions for structures, buildings and facades. The research group is based at the Chair of Structures at the Faculty of Architecture and the Built Environment and has strong links to the Faculty of Civil Engineering and Geosciences.

The topics that are addressed within the research group range from material investigations, via investigations into new connection technologies to the development and assembly of full scale glass structures. Several topics are currently under investigation, such as:

- Strength of structural glass components
- Innovative facade constructions by means of cast glass bricks
- Innovative bridge design making use of dry assembled glass bricks
- Production and residual stress investigations for glass bricks
- Safety performance of structural glass components
- Reinforcement technologies for optimized safety performance
- New glass material compositions
- Other applications.

planning

<table>
<thead>
<tr>
<th>weeknumber</th>
<th>course week</th>
<th>literature study</th>
<th>analyze precedents</th>
<th>define case study</th>
<th>case study analysis</th>
<th>determine design criteria</th>
<th>study physical models</th>
<th>numerical study models</th>
<th>detailing</th>
<th>final design</th>
<th>reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>2.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>3.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>3.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>3.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>3.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>3.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>4.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>4.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>4.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>4.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>4.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>4.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>4.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>4.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>4.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>4.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
research team
Main mentor  C. Louter
Second mentor  M. Bilow
Advisory board  F. Oikonomopoulou and possibly a consultant from the department of Climate Design

financial framework
According to my main mentor, C. Louter, there are sheets of thin glass available, from one of its main producers AGC.
Also, if bending tests are to be done in order to test the strength of the panel, this needs to be financed and facilitated.
At the moment, the main application of thin glass is electronic devices like smartphones and television screens. For the built environment, thin glass is still in its first steps.

The increasing regulations for low thermal transmittance and development of passive housing systems increased the demand of high insulating windows. When the insulation value increases by using several layers of glass with a cavity in between, also the weight increases. The demand for insulation caused the European commission to fund a project in which the feasibility of quadruple glass windows, with two thin glass layers, is studied. The panel reaches a U-value of 0.3 W/m2K.

Another application is found by one of the main producers: Corning. The impact and scratch resistance of thin glass together with its optical qualities make it possible for usage as a protective layer in interior architecture. By using thin glass as an external layer laminated onto panels the behind it, high optical quality can be achieved, without being subjected to damages.

Last but not least, an experimental study has been done by Jürgen Neugenbauer, realized by SFL Technologies. The result was shown at the GlassTec fair 2014 in Dusseldorf. It is a design of a movable glass canopy that is able to expand and contract in two directions showing the adaptability of the material.

references

At the moment, the main application of thin glass is electronic devices like smartphones and television screens. For the built environment, thin glass is still in its first steps.

The increasing regulations for low thermal transmittance and development of passive housing systems increased the demand of high insulating windows. When the insulation value increases by using several layers of glass with a cavity in between, also the weight increases. The demand for insulation caused the European commission to fund a project in which the feasibility of quadruple glass windows, with two thin glass layers, is studied. The panel reaches a U-value of 0.3 W/m2K.

Another application is found by one of the main producers: Corning. The impact and scratch resistance of thin glass together with its optical qualities make it possible for usage as a protective layer in interior architecture. By using thin glass as an external layer laminated onto panels the behind it, high optical quality can be achieved, without being subjected to damages.

Last but not least, an experimental study has been done by Jürgen Neugenbauer, realized by SFL Technologies. The result was shown at the GlassTec fair 2014 in Dusseldorf. It is a design of a movable glass canopy that is able to expand and contract in two directions showing the adaptability of the material.
At the TU Delft there have two students, so far, who have graduated on thin glass.

First Carlyn Simoen, her aim was to discover if thin glass could be implemented in a feasible configuration within a building envelope by using the process of cold bending. Feasibility was defined in terms of safety, ecological profitability and the consistence of architectural value. In the end, she achieved to design a curved glass panel that functions as a second skin facade.

Rafael Ribeiro Silveira, also designed a second skin facade, his approach was however very different. This main focus has been to embrace the flexibility of the material and using the material in adaptive facade panels. The behavior of thin glass is dependant on its thickness and size, while the bending limits are defined by the desired geometry and movement. Which will affect the stiffness and the visual outcome of the facade.
CHAPTER 2

literature survey
literature survey

Glass
The literature research starts with the material, glass. A lot of information is available on this topic concerning their material properties, manufacturing methods, available shapes and sizes, post-breakage behavior and possible processing methods.


Thin glass
This data needs to be compared with thin glass, its different appearance is due to different material properties, manufacturing methods and processing. For this, the manufacturer’s factsheets are to be consulted as well as an precedent study.


Exploration
Also, in order to get a grip on glass’s possibilities, a precedent study is required to gain information on the available products. By the following sources, this factual data will be collected.


Foreign precedents
Other materials might also be a source of inspiration in order to design a safe and insulating facade panel.


Criteria
In order to gain knowledge on the criteria of a facade panel, concerning safety and insulation values the dutch building regulations will be consulted.

CHAPTER 3
research results
background

glass usage

The last century a lot of glass development has taken place. Of all traditional major building materials (wood, stone, masonry, metals and concrete) glass is the one material where significant technological advantages are still being made. For a long time, glass has been used as a transparent infill panel, providing daylight and view, for quite some time. More recently is the development of glass as a structural element, this is one that shaped the appearance of contemporary architecture unlike any other. Glass is no longer just providing shelter from the elements.

Roots of this contemporary glass construction reach back to early 19th century greenhouses in England where Joseph Paxton pioneered this new development. The desire to cultivate exotic plants under controlled conditions proved ideal for the experiment of building with glass and iron. In this construction, glass panels were first used as a load-bearing structural element. After completion of this structure, similar ones followed quickly.

In the 20th century, a new generation of architects stood up and recognized the visual potential of glass as a new construction method, the openness of large glass surfaces became increasingly appealing. Nowadays, Sadeghi et al (2015), states:

*The invisible material has become a material that is a symbol of openness, democracy and modernity. What used to be a very defined line or wall, is now blurred. Rooms now blend into the outdoors without worrying about a solid distinction.*


The ratio of glazed versus non-glazed surfaces has increased, several realized buildings even show a fully glazed skin, for example, the Apple store in New York City. This building shows glass fins, beams and facade panels which are connected with small metal pieces.

The last decade the usage of curved glass panels has also been developed, bent glass sheets are shown in several buildings worldwide like the Casa da Musica Porto by OMA and MAS (Museum Aan de Stroom) by Neutelings Riedijk.
The approximation is, according to glassglobal.com, that the demand of glass usage will continue to increase in the future. Nevertheless, it must be mentioned that there are two disadvantages of using glass in architecture: energy considerations and costs, both should be considered when designing. In terms of energy, there are a few things to acknowledge. The melting point of glass is quite high (approximately 1800 °C) meaning that the material embodies a lot of energy after its production process. Secondly, the insulation value of single glazing is regularly not sufficient according to building regulation codes for new construction, meaning that a lot of heat will be lost through the glass surface in winter. And a lot of heat in summer could accumulate behind the glass’ surface. This is of course due to the transparency, which allows for sunlight to enter. In terms of costs, large glass surfaces can be quite expensive directly and indirectly. The extra energy costs due to the mentioned insulation value and heat losses are an indirectly increasing the costs of the building when in use. To prevent a lot of heat loss or gain, glass panes can be coated and insulated. These methods will increase the costs of the panel.

what is thin glass?

If a glass sheet is thinner than 2 mm it is called thin glass, when its thickness goes below 0.1 mm it may be called ultra thin glass. (Ultra) thin glass has been present in the daily life of people for quite some time. It is a material that is often applied to protect mobile electronics screens from scratches and impact. These functions might not seem appropriate for a brittle material like glass, but much different behavior is presented in (ultra) thin glass than regular soda lime glass sheets. Due to a different chemical composition, production process and strengthening method, thin glass has become more scratch- and impact resistant, stronger and surprisingly, flexible.

Currently, there are four glass manufacturing companies that are capable of producing thin glass: ACG (Leoflex, Dragontrail), Corning (Gorilla glass) and Schott (Xensation). Although they are not completely transparent on their products chemical composition and production methods, their thermal, mechanical and optical performance is available. These performances are very comparable to each other and slightly different than soda lime glass.

why use thin glass?

(Ultra) thin glass offers a lot of opportunities and advantages that could be interesting for architects, structural engineers, clients, and contractors. It has the potential of offering economic- and ecological benefits when used instead of the conventional glazing. In terms of architectural advantages, the flexibility offers plenty of possible shapes and even kinetic elements. The thinness allows for lighter facades, less color in the facade and a lighter support structure. Broadly these properties offer the possibility for a lighter, more sustainable alternative to the current glass industry.
conclusions

material properties

Thin glass differs from soda lime glass in its chemical composition and production process. These differences should be taken into account while estimating the material’s potential or while designing with this type of glass. When comparing the mechanical, thermal, optical and electrical properties of thin glass to soda lime glass quite some differences can be found. In table 3 the properties of thin glass sheets are derived from its three producers Schott, Corning, and AGC.

Interesting is that all manufacturers show slight differences in their product’s properties. The most compelling altered properties, in comparison to soda lime, are the Vickers hardness, melting-, and annealing point.

The Vickers hardness is much higher for thin glass than it is for soda lime, before and after chemical strengthening (CT). Meaning that thin glass offers higher scratch- and impact resistance.

Over the years soda lime is optimized in such a way that it is economically more profitable than any other type of glass, explaining the lower melting-, and annealing point.

A property of thin glass that isn’t directly shown in table x is the flexibility. Curved sheets of glass can be made out of, cold or warm bent glass panels. Cold bending is the process of bending a panel under a normal atmospheric temperature. The glass is pressured to stay in its position because of the spring back effect, the joints should be able to counter this effect. When designing with cold bend glass it is very important to know what pressure the joints can tolerate and what maximum amount of internal stresses is allowed in the glass. The maximum radius cold bent glass is influenced by its thickness, size, supports and exposed forces. Other influencing aspects are whether the glass is laminated or insulated.

The thinnest soda lime glass pane, single glass of 4 mm, has a bending radius of 2.4 m. As a sequence of its thinness, sheets of 0.5 mm (thin) glass have a minimum bending radius of 150 mm. This property offers many

Table 3: material properties thin glass

<table>
<thead>
<tr>
<th>Properties</th>
<th>Schott</th>
<th>Corning</th>
<th>AGC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>2.5</td>
<td>2.477</td>
<td>2.39</td>
</tr>
<tr>
<td>Young’s modulus (GPa)</td>
<td>73</td>
<td>74</td>
<td>71.7</td>
</tr>
<tr>
<td>Shear Modulus (GPa)</td>
<td>30</td>
<td>30</td>
<td>20.7</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.21</td>
<td>0.215</td>
<td>0.21</td>
</tr>
<tr>
<td>Vickers Hardness, before CT</td>
<td>533</td>
<td>617</td>
<td>525</td>
</tr>
<tr>
<td>Vickers Hardness, after CT</td>
<td>580</td>
<td>681</td>
<td>674</td>
</tr>
<tr>
<td>CTE (°C)</td>
<td>0.85</td>
<td>?</td>
<td>0.86</td>
</tr>
<tr>
<td>Tg (°C)</td>
<td>560</td>
<td>615</td>
<td>?</td>
</tr>
<tr>
<td>Softening Point (°C)</td>
<td>793</td>
<td>880</td>
<td>852</td>
</tr>
<tr>
<td>Annealing Point (°C)</td>
<td>554</td>
<td>635</td>
<td>613</td>
</tr>
<tr>
<td>Strain Point (°C)</td>
<td>511</td>
<td>?</td>
<td>563</td>
</tr>
<tr>
<td>Optical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refraction Index (n)</td>
<td>1.51</td>
<td>1.51</td>
<td>1.51</td>
</tr>
<tr>
<td>Photoelastic Constant (Mpa)</td>
<td>26.6</td>
<td>29.2</td>
<td>?</td>
</tr>
<tr>
<td>Electrical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume Resistivity (logΩ/cm²)</td>
<td>8.5</td>
<td>8.9</td>
<td>8.4</td>
</tr>
<tr>
<td>Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>thickness (mm)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>maximum pane size (mm)</td>
<td>2100 x 2000</td>
<td>1500 x 900</td>
<td>1220 x 737</td>
</tr>
</tbody>
</table>

Image 11: Difference in bending radii 0.5 mm and 4 mm glass sheet. Source: own image
Kasper & Sediacek, 2003
opportunities for architectural applications. Another property that is different by the thinness is the transparency of glass. Less material results in less resistance to light and other to penetrate. Higher transparency can thus be achieved. Warm bent panels are bent in a factory under high temperatures and stay in their position after bending without the internal pressure that cold bend glass has to withstand. However, warm bending asks for exclusively made form works. This makes the production of warm bent glass panels time, energy and therefore money consuming. Also, the expansion coefficient of Aluminosilicate glass is higher, and so more tolerances should be allowed in detail.

bonding

Adhesive connections have several advantages when compared to bolted connections: no drilling is needed and stresses are more evenly distributed. The disadvantage of drilling holes is the decreased strength of the glass sheets after drilling and stress concentrating around the edges of the hole. There are several structural adhesives that can be applied locally on glass: silicone, acrylate, polyurethane and epoxy.

First, there are several types of silicones: one- and two-component variants and hot curing film (TSSA), they are used as a structural sealant. Generally, they have a high durability for UV as well as humidity but a low strength, except TSSA. When applied, its thickness should be more than 6 mm in order to achieve the correct amount of strength. Acrylate can be cured by UV or chemically (two components). In general, the optimal thickness is less than 0.5 mm. It has a high shear strength however it is brittle. UV-acrylates are transparent and have some durability problems. Often acrylate is applied in a structural double-sided tape which can be used for indoor applications. There are several types of polyurethane, one- and two-component variants and physical-, chemical curing types. It is generally stronger than silicones, less brittle than epoxies and acrylates but if has a lower UV resistance. It has applications in the automotive industry and bonding of non-transparent facade panels. Epoxy is, in general, a two-component adhesive their curing process can vary, it is done by UV, cold or heat. Like acrylate, its optimal thickness is generally less than 0.5 mm, it has a high strength and is brittle. It finds its application in air crafts boats and metal structures.

A transparent, full surface, laminated bond can also be applied on glass sheets for this, PVB (Polyvinyl Butyral), SG (SentryGlas), TPU and EVA can be used. Among these, SG has the highest stiffness and strength. Due to the large bonded surface, low material strength is needed. A property of these plastics is the visco-elasticity meaning that its strength is time- and temperature-dependent. The structural applications that can be obtained by these interlayers are laminated glass sheets, splice lamination, hybrid components and experimental point fixings. The interlayer always has a standard thickness: 0.38 mm or multiples. It should be considered that the interlayer has a different thermal expansion coefficient than the glass.

There are several loading directions, tensile, shear, cleavage, peel and compressive. Shear is strongest and peel forces should always be avoided when detailing with adhesive connections.
In order to get a grip on methods of creating an insulating sandwich panel that is sufficiently stiff and save, an inventory has been done in the products that are currently applied in buildings. Methods of creating a sandwich panel is done by a precedent study of products in the cardboard- and plastic industry. Ways to insulate are found by taking stock of producers and the current built environment. An equal exploration reveals methods of stiffening glass.

**Sandwich panels**

In polycarbonate as well as acrylate are plastics that are often applied in the built environment. They are thermoplastics that are well resistant to impact however they are not resistant to scratches. Both are extruded to obtain several types of profiles like honeycomb, and corrugated- sheets and many other cellular structures. Some of the cellular structures are shown in image x. For the cellular structures, it can be said that the more cells, the higher the insulation value. Their appearance is often not completely transparent, due to their cellular structure, this is shown in image 10.

Another well familiar sandwich panels are found in the cardboard industry. There are honeycomb-, triangular- and corrugated sheets both often used in the packaging industry. All types have a certain thickness, that increases the moment of inertia and thus the stiffness.

The honeycomb sheet has a paper honeycomb structure that is perpendicular to the top and bottom sheet, the triangular sheet can be compared to this, image 12. The corrugated sheet has a paper structure in-between parallel to the cover sheets. Both are made by glued connections. The cells that are created by these structures can offer acoustic and well as thermal insulation. Due to its low resistance to water, it is an uncommon building material. But since Shigeru Ban, a Japanese architect, has proven the world that it is possible building with cardboard, it has become a source of inspiration for many others. Nowadays several cardboard designs are completed, like in image 12.

**Insulation methods**

In order to create an insulating facade panel, there are plenty of methods. An inventory of the currently available methods to insulate with glass shows the options to apply cavities, capillary slab(s), aerogel, PCM plates, and vacuum panels. Most of these methods are not applied regularly because
they are either too expensive or not transparent. Translucent panels are very convenient for buildings that should be protected from solar radiation, like museums. However, architects should be willing to accept their aesthetics. Table 4 shows properties of the best performing insulation panels found in the inventory.

### Table 4: Inventory insulating facade panels.

<table>
<thead>
<tr>
<th>Method</th>
<th>Cavity</th>
<th>Capillary airs</th>
<th>Aerogel</th>
<th>PCM</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Kapithems</td>
<td>Kapilux</td>
<td>Okagel</td>
<td>Glass-x</td>
<td>VIG</td>
</tr>
<tr>
<td>Appearance</td>
<td>Transparent</td>
<td>Translucent</td>
<td>Translucent</td>
<td>Transparent</td>
<td>Transparent with tiny spacers</td>
</tr>
<tr>
<td>Built-up</td>
<td>- glass 6 mm</td>
<td>- glass 6 mm (coated)</td>
<td>- glass 4 mm</td>
<td>- glass 4 mm</td>
<td>- glass 4 mm</td>
</tr>
<tr>
<td></td>
<td>- cavity 14 mm</td>
<td>- cavity 6 mm glass</td>
<td>- capillary 4 mm</td>
<td>- aerogel</td>
<td>- prismatic glass &amp; glass</td>
</tr>
<tr>
<td></td>
<td>- glass 4 mm</td>
<td>- glass 4 mm</td>
<td>- capillary plate 10 mm</td>
<td>- glass 4 mm</td>
<td>- glass 4 mm (coated)</td>
</tr>
<tr>
<td></td>
<td>- glass 4 mm</td>
<td>- glass 4 mm</td>
<td>- cavity gas</td>
<td>- glass 4 mm (coated)</td>
<td>- cavity with PCM</td>
</tr>
<tr>
<td></td>
<td>- glass 4 mm</td>
<td>- glass 4 mm</td>
<td>- cavity with PCM</td>
<td>- glass 4 mm</td>
<td>- glass 4 mm (coated)</td>
</tr>
<tr>
<td></td>
<td>- glass 4 mm</td>
<td>- spacers 60 mm</td>
<td>- glass 4 mm</td>
<td>- glass 4 mm (coated)</td>
<td>- glass 4 mm</td>
</tr>
</tbody>
</table>

**Stiffening methods**

Because glass is often applied as a thin sheet in the built environment it does not have a large moment of inertia hence strength by its shape. So when applied, it cannot be carrying lots of weight. However, glass has a very high compressive strength that is comparable to concrete. Unfortunately, its resistance to tensile forces is low because it causes small cracks in the surface that will quickly scatter a whole sheet. To increase the strength of the shape the moment of inertia should be improved. An inventory shows this is achieved by creating a 3D shape, laminated glass sheets or other reinforcement. Some of these have been applied in buildings, others are experimental.

The lamination of glass sheets is often seen in the built environment, besides stiffening, it also increases the safety of glass sheets. Jan Wurm (2012), did several studies on other materials that can be laminated in between glass.

From left to right, image x shows a method with composite profiles, aluminum cubes, and a perforated corrugated steel sheet. All reinforce the glass, provide solar shading and thermal insulation. Besides the previously described properties, a added corrugated steel sheet improves the acoustic
performance. The composite (GFRP) beams are connected with a layer of adhesive. Solid-, C- and I-profiles can be used but the solid one can withstand most force, moment, stress and deformation. They are laminated by a silicon, the aluminum cubes are laminated by high performance, transparent, double-sided tape.

These methods do achieve a higher stiffness, but they are not very transparent. To create a higher stiffness as well as high transparency, 3D shapes made out of glass perform much better.

When enhancing a high transparency there are several options: glass fins, slumping extra structural material and corrugated glass sheets (image x). Among these, glass fins are most common. They are connected to the glass sheets by mechanical, metal connections. For safety and structural reasons, there are laminated sheets of glass. The added structural material offers an increased loading capacity where needed. Like with the corrugated sheets, they provide large stiffness but distort view and reflection.

design criteria

**Insulation**
Dutch building regulations dictates the minimum amount of insulation for building components in new construction. This is described by R-values depending on its resistance to heat conduction, as well as the thickness and any heat losses due to convection and radiative heat transfer. The R-value for doors and windows should be at least 0.455 m²K/W. For doors and windows, the entire surface should be calculated, meaning that this value is a combination of the window frame as well as the glass surfaces. It should be noted that the higher R-value the better, so it is preferable to increase this number.

**Weight reduction**
As facades are becoming increasingly insulating by building regulations, they also become increasingly heavy because of added layers. This results in larger amounts of glass used and a heavier support construction, overall a larger amount of material is needed. Currently the required R-value of 0.455 m²K/W can be achieved by coated, double-, or triple glazing. This value should be achieved in the designed panel, by a lower amount of material (glass as well as support construction).

**Safety**
Regulations in the NEN-2608 state the boundary conditions for regular soda lime glass sheets, in which the serviceability limit state (SLS), and the ultimate limit state (ULS). The SLS describes the maximum allowed deformation in which a panel still functions properly, regarding deformation and deflection. The SLS is partly related to fear factors and partly to technical aspects. The ULS presents the maximum allowed stresses in the panel to prevent breakage. Because the type of glass and thereby its properties are different the allowable values can be questioned.

For the panel, it should be prevented that glass sheets break caused by its expected loading pressure in several scenarios. But if is occurs, the post-breakage behavior should be acceptable. This can be calculated by the product of the risk of damage, probability of damage, exposure to the risk of damage and the severity of the effects by breakage of the glass.
green houses

Greenhouses protect their vegetables, fruits, and flowers from external influences and make climate control possible. According to AVAG, the interbranch organization of the Dutch greenhouse construction and installation sector, there are two types of coverage for greenhouses currently in use. First, there is glass, which is 4 mm thick. It is UV resistant and has a light transmittance of 90%. Secondly, polyacrylate or polycarbonate sheets are applied in greenhouses. They have very good thermal insulating properties and are therefore often used when energy saving is a company’s main intention. Unfortunately, these sheets are not fire safe or UV-resistant and their light transmittance is only 70 to 78 percent.

For all Dutch greenhouses, the following building codes should be respected: NEN 3859, NEN-EN 1990, Bouwbesluit 2012. Only then, structural safety over a period of 15 years is guaranteed, AVAG says. These building codes and norms deal with the structural requirements of the structure and the coverage. However, there have been several problems within the greenhouse industry lately. On the 24th of June 2016, a huge disaster in the Dutch greenhouse industry took place. A hailstorm that was so fierce it caused over a 100 million euro worth of damage. Lots of glass coverage sheets were broken, leaving a hundred hectares of scattered glass fragments behind.

Besides that, there are no regulations about minimum thermal insulation which is a shame, because most greenhouses are often heated to maintain a certain temperature. Meaning that for greenhouses the demands of a glass sheet are stiffness, impact resistance, light transmittance and possibly thermal insulation.

passive buildings

In architecture, the principle of a greenhouse is often applied in passive buildings. A greenhouse basically heats a structure with walls and a roof made chiefly of transparent material, such as glass. When sunlight passes through the transparent or translucent façade/roof material, the short IR-waves of the sun enter the greenhouse. When they strike an opaque surface inside some of the light energy is changed into heat. These surfaces will then radiate heat, resulting in warmed air heating the greenhouse. The radiation

http://www.avag.nl/page/58/kassenbouw.html

Image x: Damage Dutch greenhouses June 2016. Source: NOS
waves from the surfaces have changed frequency when they were converted to heat, these waves cannot pass through the glass. This passive principle can save quite some energy.

There are several applications in passive housing inspired on a greenhouse: whether it is direct solar gain, a solar space a Trombe wall or a vented solar wall. All require glass sheets that enable lots of solar radiation to pass through.

A Trombe wall does not offer a view nor daylight in the area behind. It is a closed wall that provides a thermal buffer. A vented wall is basically a Trombe wall which can be specially discharged via rear vents. A solar space does offer a view and daylight transmission.

A solar space is a south facing glazed area located in- or outside of the main envelope of the building. This space functions as an intermediate space between the inside and outside of the building. By effectively adding another layer to the building envelope, this space becomes a thermal buffer comparable to air within a cavity wall. A further effect of the sunspace is to shelter the envelope from wind, chill, and rain this factor becomes increasingly important in northerly and exposed locations.

The addition of a sunspace can realize significant gains in energy efficiency. This can amount to around 30% when compared with a direct gain equivalent, though this varies according to climate and latitude where buildings benefit from southern locations. An example of a solar space is the Edge in Amsterdam, certified with several sustainable awards.

renovation project
The award-winning design for the solar decathlon 2014, Prêt-à-Loger is a renovated Dutch row house. Prêt-à-Loger presents a solution for approximately 1.4 million energy consuming Dutch row houses from around 1960. Buildings, like these, with a low Energy Performance Coefficient (EPC), have the possibility to save much energy when solar spaces are applied. This is comparable to the previous describes the method, that is applied in passive buildings.
Large cities are becoming our main habitat, according to Deelstra and Girardet (2000) the global urban population has expanded from 15 to 50%, in one century.

“Cities require vast areas of land for their sustenance and have come to depend on large amounts of food being brought in from outside the land area they actually occupy. London, for instance, has a surface area of some 160,000 ha. With only 12% of Britain's population, London requires the equivalent of 40% of Britain's entire productive land for its food.”

This number shows the large geographic area that is required to facilitate a city like London, this number could, however, be reduced by urban farming. With this, a city could become more self-sustaining. Despite the inherent density in cities, many cities also face the challenge of vacancy, in the Netherlands, this mostly concerns office buildings and dwelling (Rijksoverheid, 2016). Combined with the increasing food demand of growing cities, there lies an interesting opportunity of converting vacant buildings into urban farms. In order for food to grow in an urban context, most of these buildings would require a larger glass surface.

**demands**

Requirements like insulation, stiffness, light transmittance, architectural value and acoustic performance are diverse for the described building types. In order to be able to choose a case study corresponding to the possible properties of the thin glass sandwich panel, these typologies need to be investigated and compared (table x).

<table>
<thead>
<tr>
<th>Demands</th>
<th>Greenhouse</th>
<th>Solar space</th>
<th>Renovation project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Stiffness</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Light transmittance</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Architectural</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Acoustic</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

For all typologies, safety and thereby stiffness is obliged. Most crucial for the greenhouse is the light transmittance in order to grow plants. For the solar space, light transmittance is also required however, the percentage is not as strict as with greenhouses. For a renovated project the requirements depends on it's particular function.


https://www.rijksoverheid.nl/onderwerpen/leegstand-kantoren

Table x: comparing demands of building typologies.
program of requirements

**Insulation**
At least a R-value of 0.455, according to Bouwbesluit 2012.

**Lightweight**
Less material usage than the 4 mm thick float glass sheets currently used.

**Light transmittance**
At least 90 %, which is the transmittance as it is currently when 4 mm float glass is used.

**Stiffness**
Ut ligendi tibusdant. Sedis molut ius dolorei ureperu ptiuntibus es mint. Mincid et auda dis et eate nobitet aute dere lit vororit occulla borepudis pe dolorupiet omnis reic to dipsandunt.

**Safety**
No scattered glass sheets allowed, lamination should be applied to avoid this.

draft design

There are several types of insulating sandwich panels that can be designed with thin glass. The first one is laminated, when a strong interlayer (like SG) is applied and several thin glass layers are added. The panel could become strong enough while beine 100 percent transparent at the same time. The required insulation value can be achieved in a comparable way as double- or triple glazing.

The second type is increasing the height and thereby the second moment of inertia by an interlayer (that might also be glass) this intermediair grid perpendicular to the top- and bottom sheet. Several ones could be stacked on top of eachother in order to increase the insulation value.

Last type is comparable to the previous described. It also has an interlayer that increases the moment of inertia, only, this interlater not oriented perpendicular to top- and bottom sheet. This could, for example, be made out of corrugated sheets of thin glass.
Glass is made out from mineral material, the base material is silica (sand), combined with soda and lime. To gain glass, these minerals should be subjected to a relatively long heating process to become usable.

‘The transparency of glass is not seen in many other materials, before the advent of plastics only air, open space and possibly water knew the enigma of transparency. Therefore glass is one of rare materials which manages to trick flies and birds by its transparent appearance’.

When glass is at room temperature, it is in its solid state. To obtain glass in the preferred form and size silica sand should be melted. The rise in temperature makes the silica undergo an irreversible physical and chemical transformation. When the solid is heated to approximately 1400 °C to 1600 °C it reaches its melting point, meaning it will liquefy. Conversely if the temperature goes below its melting point, the liquid will become solid once again. When cooled however, glass can never go back to its original shape of sand.

If a material can be cooled to below its melting point while retaining its liquid state, in some extent, this is called supercooling. In case of glass, liquid silica can be cooled to below its melting point with an increase in viscosity whilst still remaining liquid. In most materials and throughout most of the solid state atoms are organized according to a very precise arrangement (in crystalline or semi-crystalline structure, for example). This arrangement stabilizes and compresses the material. In the case of molten glass, the liquid sets gradually whilst still keeping its irregular atomic structure (vitreous state). The material is therefore said to be non-crystalline or amorphous. A vitreous state is an intermediary state which is just as distinct as the other ‘liquid, solid and gaseous’ states. Thus glass is a solid with the structure of a liquid, a brittle and rigid material at ambient temperature and yet extremely plastic when heated.

**Chemical composition glass**

The composition and ratio of ingredients provide large variety in the characteristics of glass. Desired properties for specific usage can be designed. Unlike crystals, glass’ irregular atomic structure gives scope for the integration of foreign elements. However a glass former, flux, stabilizer and additives are crucial in all types.

- **Former:** The essential base constituent; generally silica (sand).
- **Flux:** Soda, alkaline oxides of sodium lower the temperature of the melting point. Silica itself melts at 1800 °C, when mixed with these flux materials the melting point can decrease towards approximately 1400 °C.
- **Stabilizer:** Lime makes the glass more stable, inert and greatly incapable of being dissolved in water.
- **Additives:** There a many opportunities of improving the physical (malleability, thermal stability) and optical (color, optical transmission, refractive index) qualities of glass. The glass beer bottles of Heineken, for example, are well known for its green color. This color is provided by added ferric oxide.