The use of thin glass in heritage window glazing; testing different design concepts

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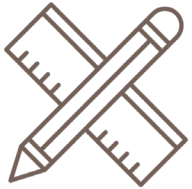
Current situation

Research questions



Design proposals

Computer analysis

Making prototypes

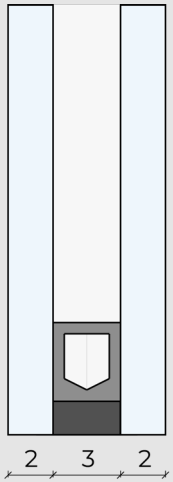
Testing

Conclusions

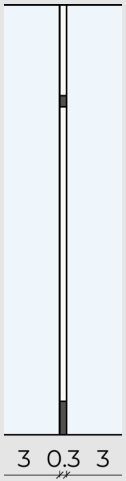
Current situation

Heritage windows

Single glazing with coating
U-value = 3.8 W/m²K
€80/m²



Thin insulating glass
U-value = 3.6 W/m²K
€220-250/m²



Vacuum glass
U-value = 0.5 W/m²K
€300/m²

Research questions

Research question

"What **alternative solutions** arise when **thin glass** is used to design an **insulating glass panel** that replaces single glazing in heritage buildings?"

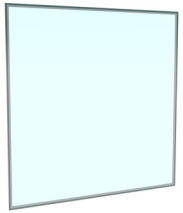
Design criteria

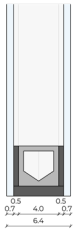
- Thickness is **less than 12 mm**, preferably between 4-8 mm
- U-value **lower than 3.8 W/m²K**
- Suit NEN on glass for windows; **w = 1 kPa**

- Outside layer of thin glass
- Cavity like in between layer
- Translucent, preferably transparency
- Does not age in color or transparency
- No cracks due to thermal expansion

Design proposals

1





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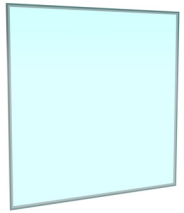

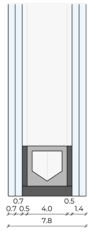

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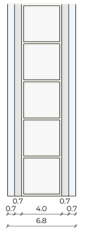

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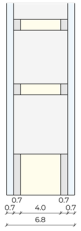

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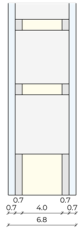

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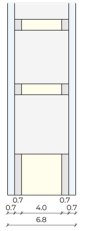

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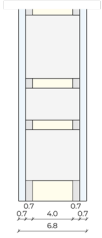

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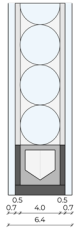

Computer analysis

SOLIDO

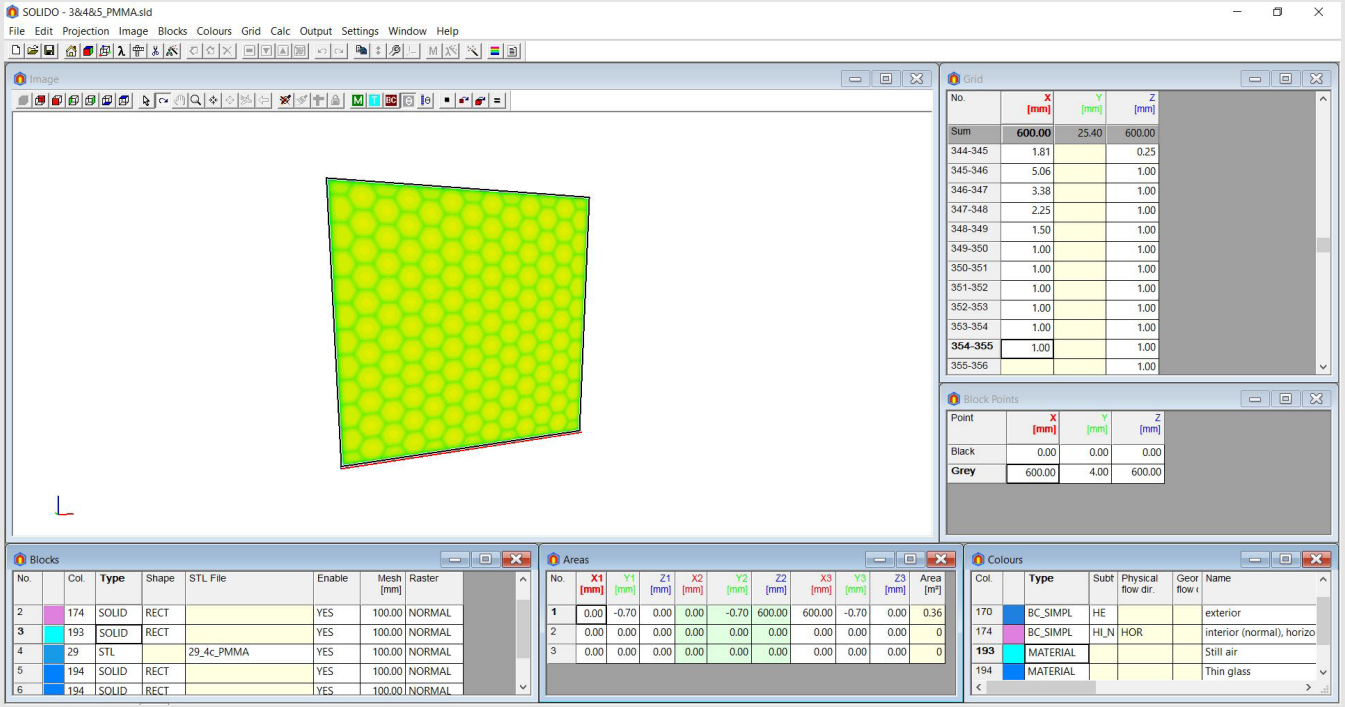
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Image
Grid
No. X [mm] Y [mm] Z [mm]
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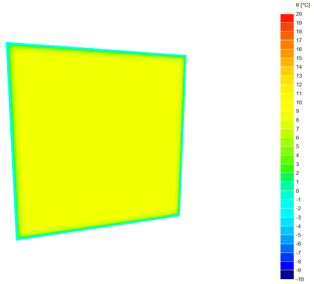
345-346 5.06 1.00
346-347 3.38 1.00
347-348 2.25 1.00
348-349 1.50 1.00
349-350 1.00 1.00
350-351 1.00 1.00
351-352 1.00 1.00
352-353 1.00 1.00
353-354 1.00 1.00
354-355 1.00 1.00
355-356 1.00
Block Points
Point X [mm] Y [mm] Z [mm]
Black 0.00 0.00 0.00
Grey 600.00 4.00 600.00
Blocks
No. Col. Type Shape STL File Enable Mesh [mm] Raster
2 174 SOLID RECT YES 100.00 NORMAL
3 193 SOLID RECT YES 100.00 NORMAL
4 29 STL 29_4c_PMMA YES 100.00 NORMAL
5 194 SOLID RECT YES 100.00 NORMAL
6 194 SOLID RECT YES 100.00 NORMAL
Areas
No. X1 [mm] Y1 [mm] Z1 [mm] X2 [mm] Y2 [mm] Z2 [mm] X3 [mm] Y3 [mm] Z3 [mm] Area [m²]
1 0.00 -0.70 0.00 0.00 -0.70 600.00 600.00 -0.70 0.00 0.36
2 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0
3 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0
Colours
Col. Type Subt Physical flow dir. Name
170 BC_SIMPL HE exterior
174 BC_SIMPL HI_N HOR interior (normal), horizo
193 MATERIAL Still air
194 MATERIAL Thin glass

1



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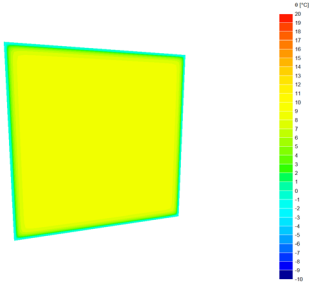

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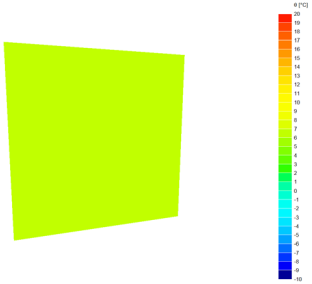

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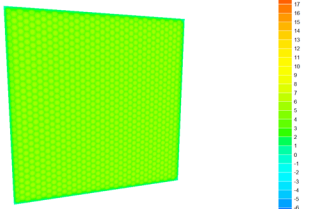

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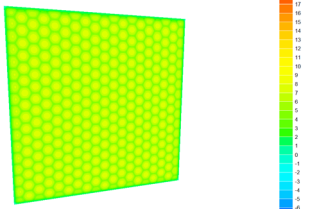

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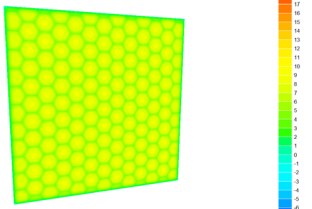

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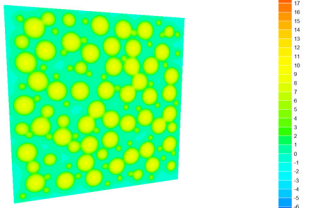

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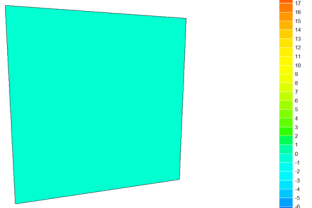
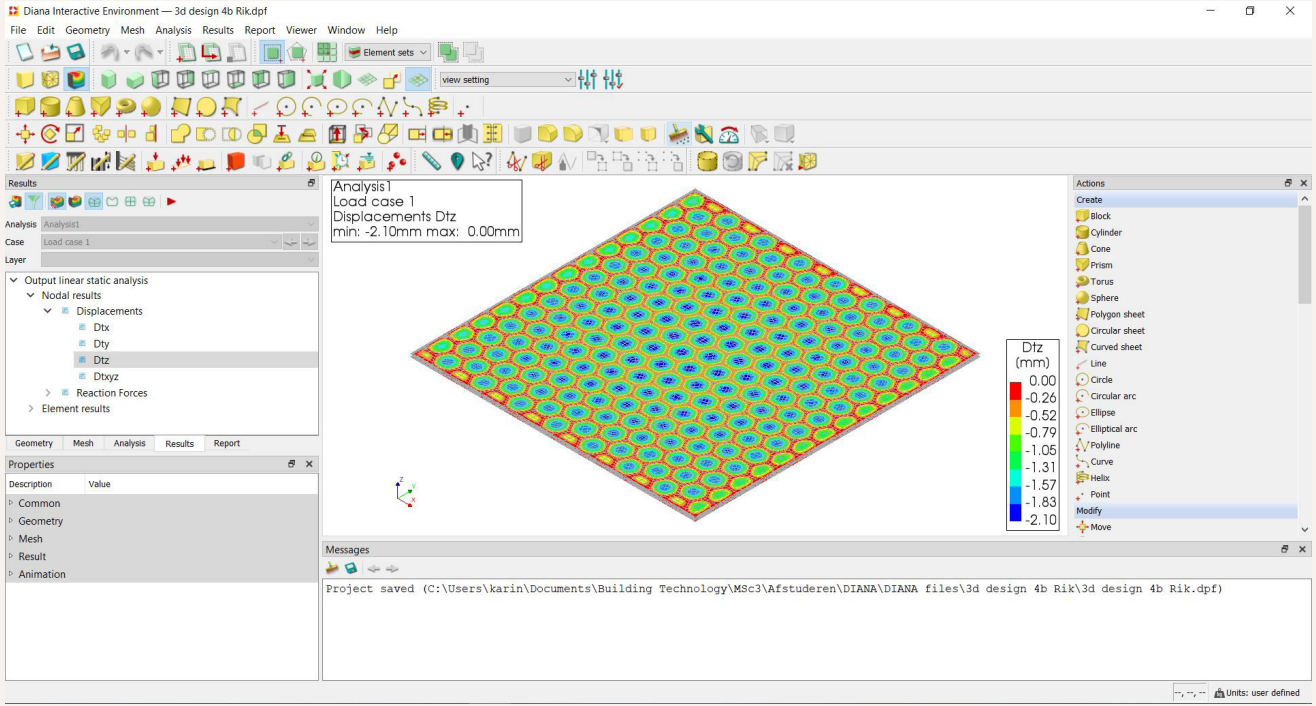
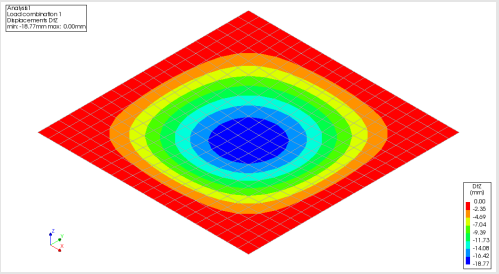
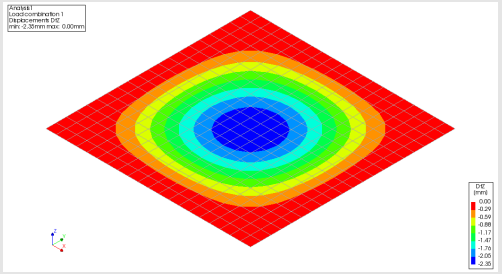


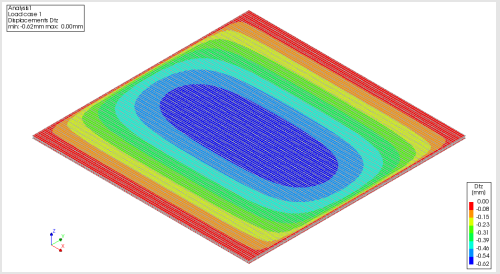
#	% still air	Q	A	U-value	>3,8
1	97%	23,87	0.25	3,18	:)
2	97%	24,02	0.25	3,20	:)
3	93%	26,00	0.25	3,47	:)
4a	76%	29,72	0.25	3,96	:(
4b	86%	26,97	0.25	3,60	:)
4c	89%	26,03	0.25	3,47	:)
5	44%	32,95	0.25	4,39	:(
6	48%	1,57	0.01	5,22	:(

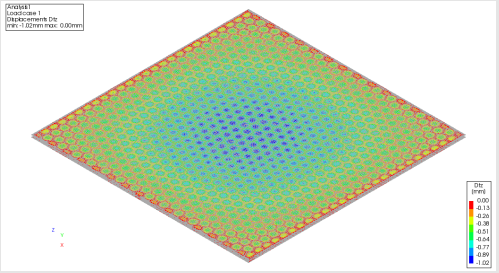
DIANA software

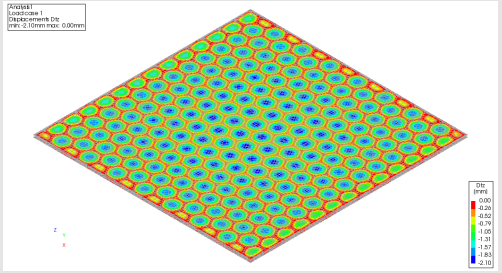


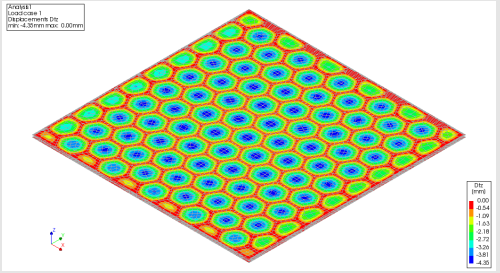

Analysis1
Load combination 1
Displacements Dtz
min -18.77mm max 0.00mm
Dtz [mm]
0.00
-2.35
-4.69
-7.04
-9.39
-11.73
-14.08
-16.42
-18.77

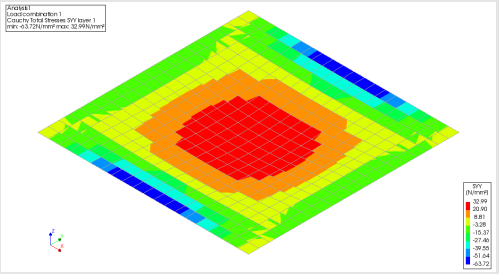

Analysis1
Load combination 1
Displacements Dtz
min -2.35mm max 0.00mm
Dtz [mm]
0.00
-0.29
-0.59
-0.88
-1.17
-1.47
-1.76
-2.05
-2.35

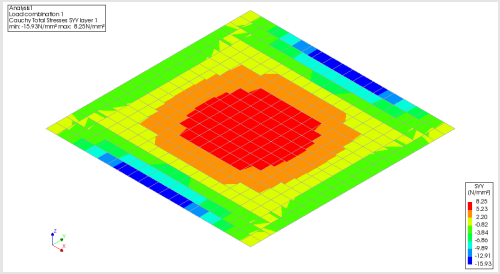

Analysis1
Load case 1
Displacements Dtz
min -0.62mm max 0.00mm
Dtz [mm]
0.00
-0.08
-0.15
-0.23
-0.31
-0.39
-0.46
-0.54
-0.62

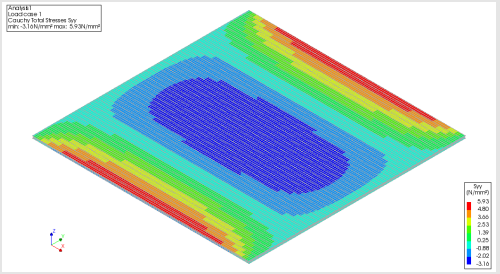

Analysis1
Load case 1
Displacements Dtz
min -1.02mm max 0.00mm
Dtz [mm]
0.00
-0.13
-0.26
-0.38
-0.51
-0.64
-0.77
-0.89
-1.02

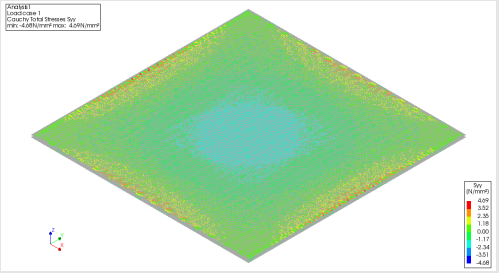

Analysis1
Load case 1
Displacements Dtz
min -2.10mm max 0.00mm
Dtz [mm]
0.00
-0.26
-0.52
-0.79
-1.05
-1.31
-1.57
-1.83
-2.10

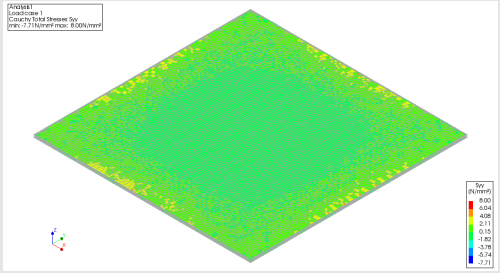

Analysis1
Load case 1
Displacements Dtz
min -4.36mm max 0.00mm
Dtz [mm]
0.00
-0.54
-1.09
-1.63
-2.18
-2.72
-3.26
-3.81
-4.36

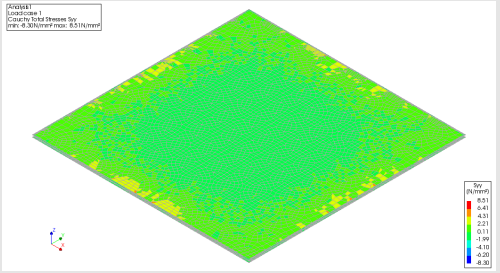

Analysis1
Load combination 1
Cauchy Total Stresses SYY layer 1
min: -53.72N/mm² max: 32.99N/mm²
SYY
(N/mm²)
32.99
20.60
8.81
-3.28
-15.37
-27.46
-39.55
-51.64
-63.72


Analysis1
Load combination 1
Cauchy Total Stresses SYY layer 1
min: -15.93N/mm² max: 8.25N/mm²
SYY
(N/mm²)
8.25
5.23
2.20
-0.82
-3.84
-6.86
-9.89
-12.91
-15.93


Analysis1
Load case 1
Cauchy Total Stresses Syy
min: -3.1kN/mm² max: 5.93N/mm²
Syy
(N/mm²)
5.93
4.80
3.66
2.53
1.39
0.25
-0.88
-2.02
-3.15


Analysis1
Load case 1
Cauchy Total Stresses Syy
min: -4.68N/mm² max: 4.69N/mm²
Syy
(N/mm²)
4.69
3.52
2.35
1.18
0.00
-1.17
-2.34
-3.51
-4.68


Analysis1
Load case 1
Cauchy Total Stresses Syy
min: -7.71N/mm² max: 8.00N/mm²
Syy
(N/mm²)
8.00
6.04
4.08
2.11
0.15
-1.82
-3.78
-5.74
-7.71

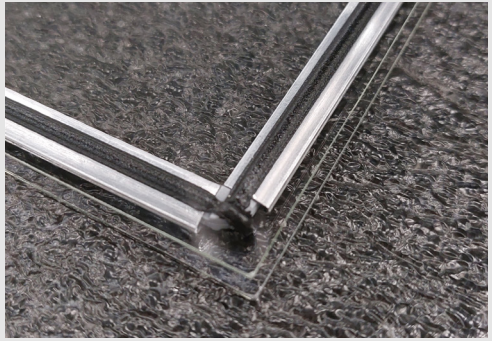
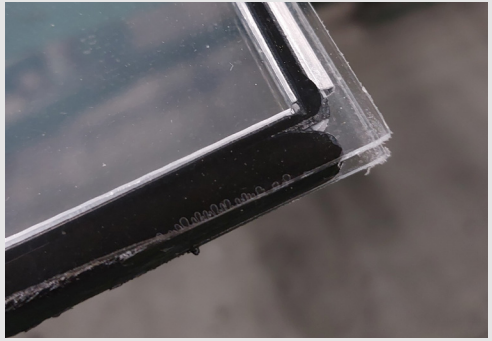
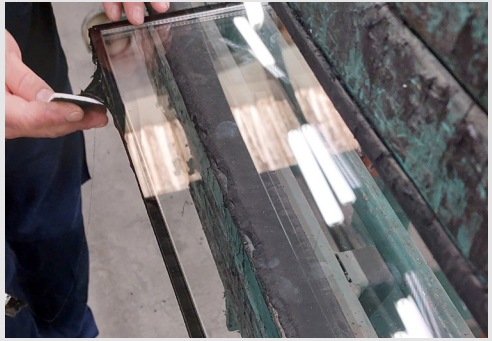

Analysis1
Load case 1
Cauchy Total Stresses Syy
min: -8.30N/mm² max: 8.51N/mm²
Syy
(N/mm²)
8.51
6.41
4.31
2.21
0.11
-1.99
-4.10
-6.20
-8.30

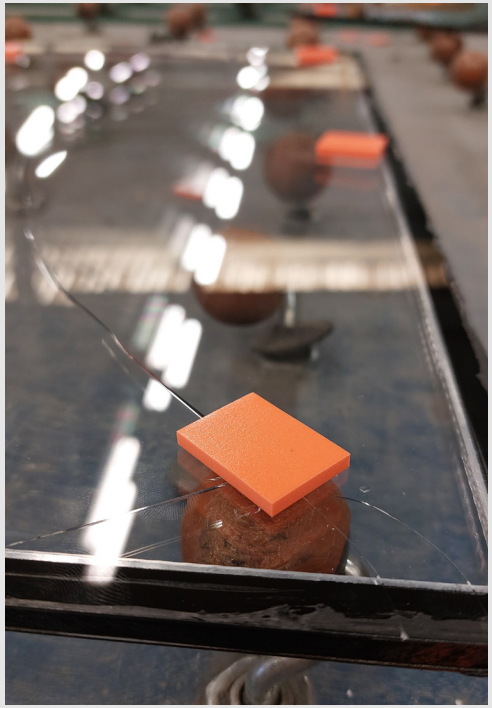
#	Deflection	Max. deflection	Check deflection	Stress	Max. stress	Check stress
1	18,77	10,88	:(	63,72	15	:(
2	2,35	10,88	:)	15,93	15	:(
3	0,62	10,88	:)	5,93	15	:)
4a	1,02	10,88	:)	4,69	15	:)
4b	2,10	10,88	:)	8,00	15	:)
4c	4,35	10,88	:)	8,51	15	:)

Making prototypes

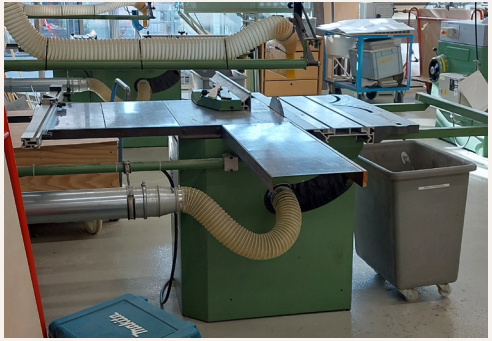
Design 1 & 2

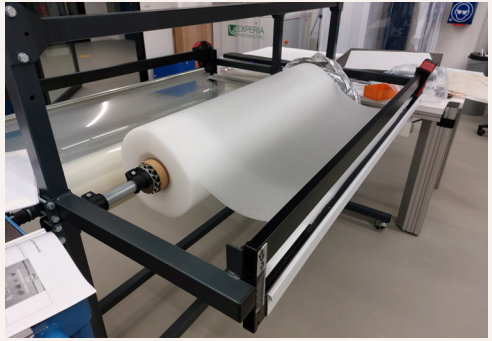


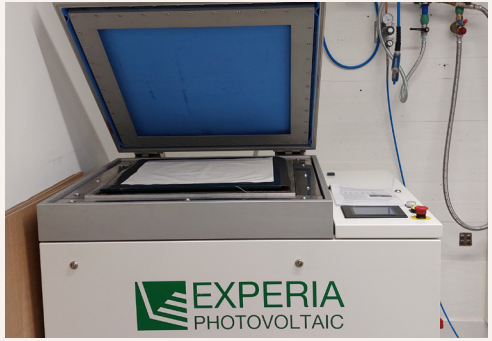





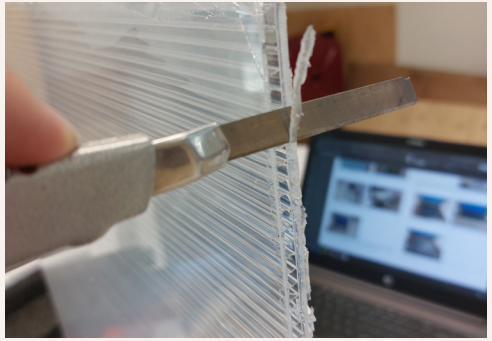


Design 3

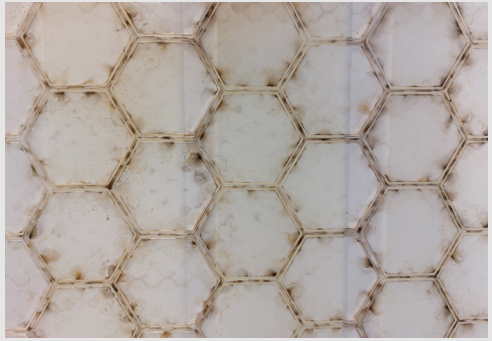


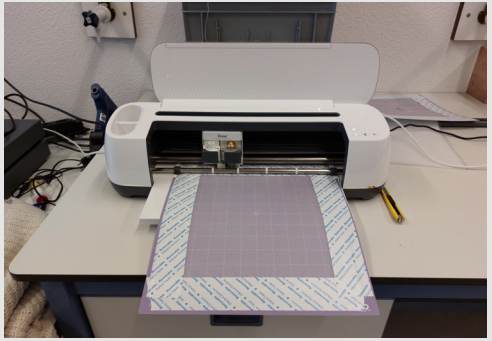


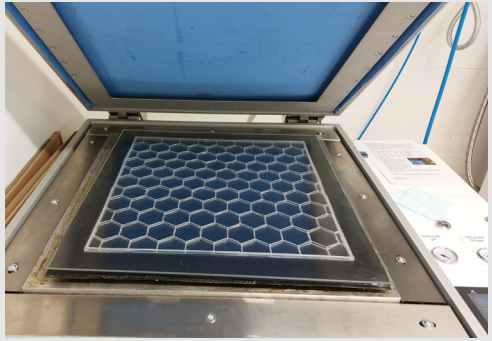


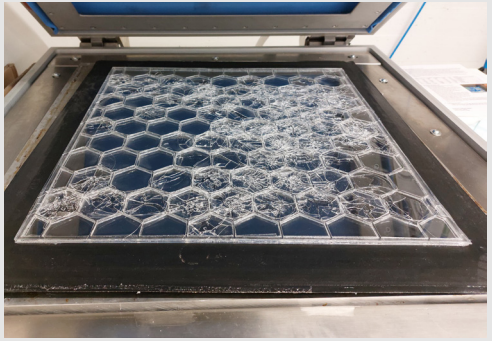


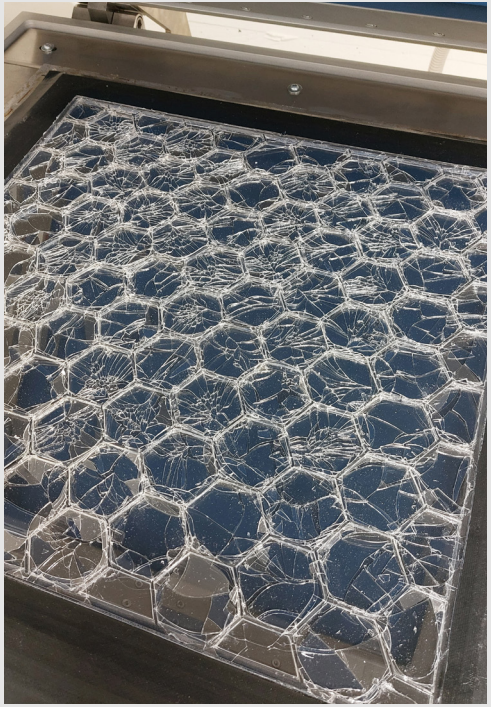
Design 4

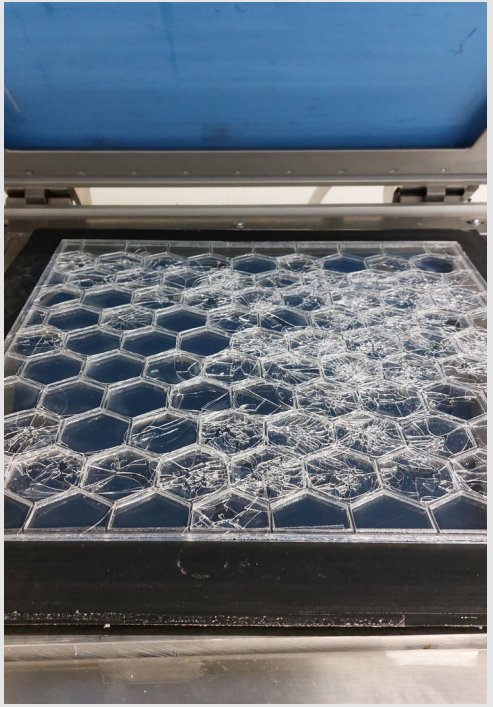




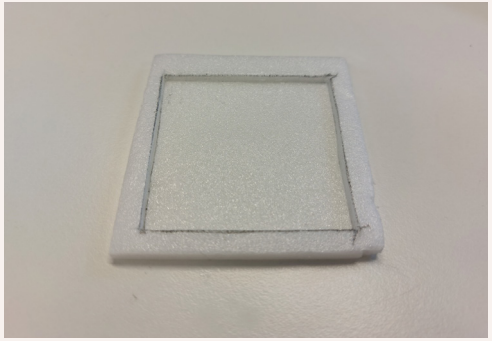


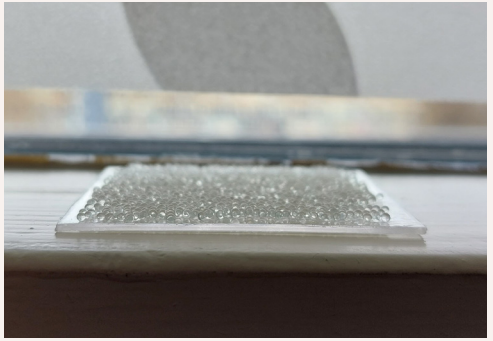


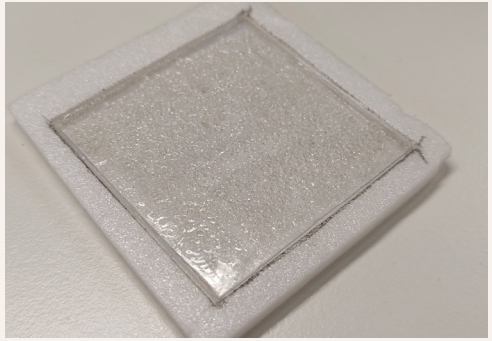


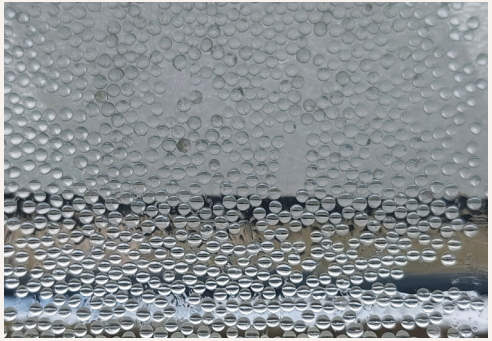


Design 6

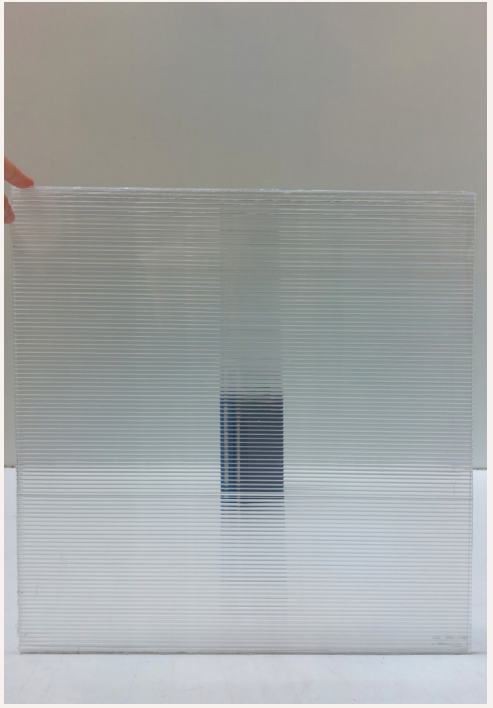






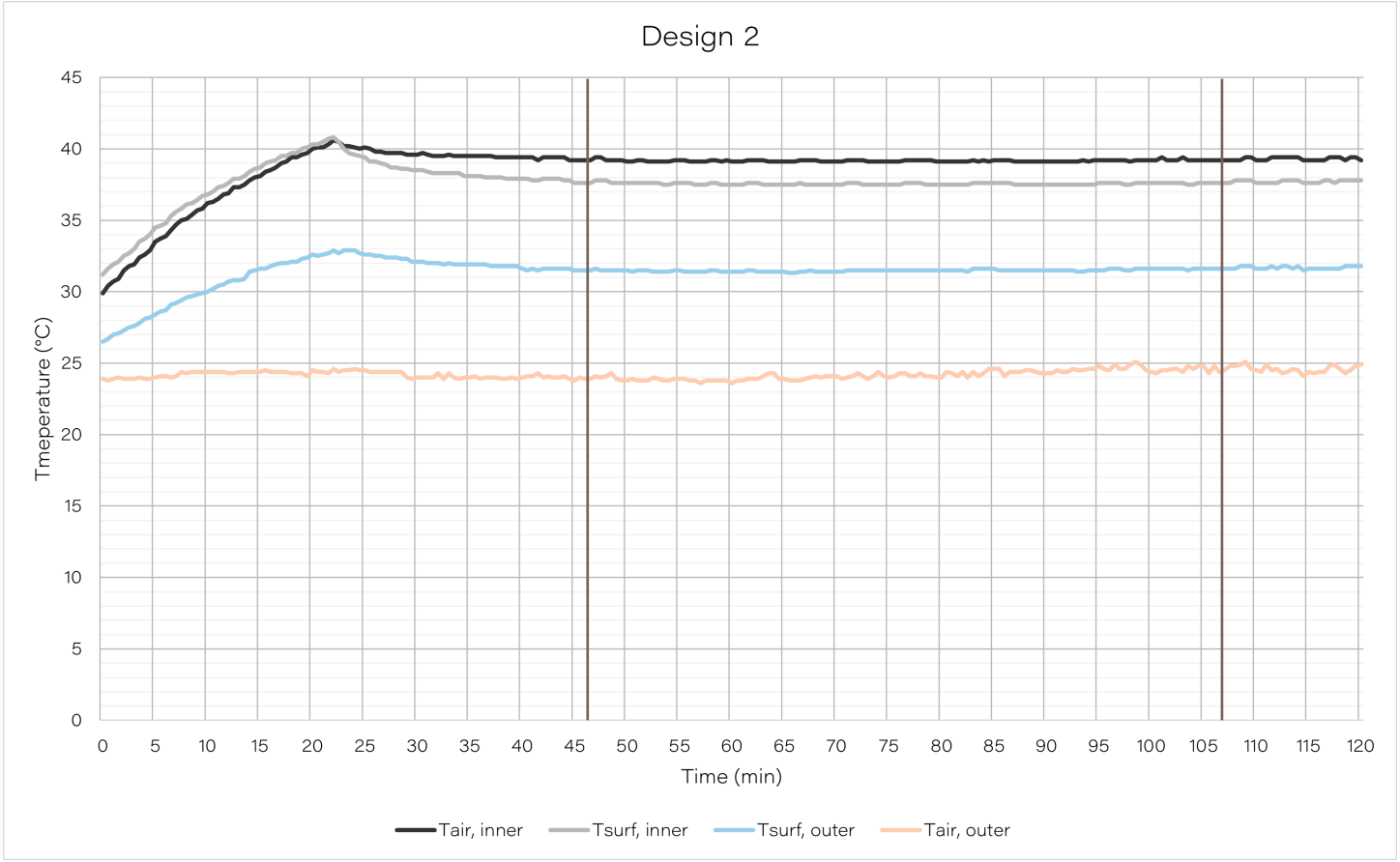


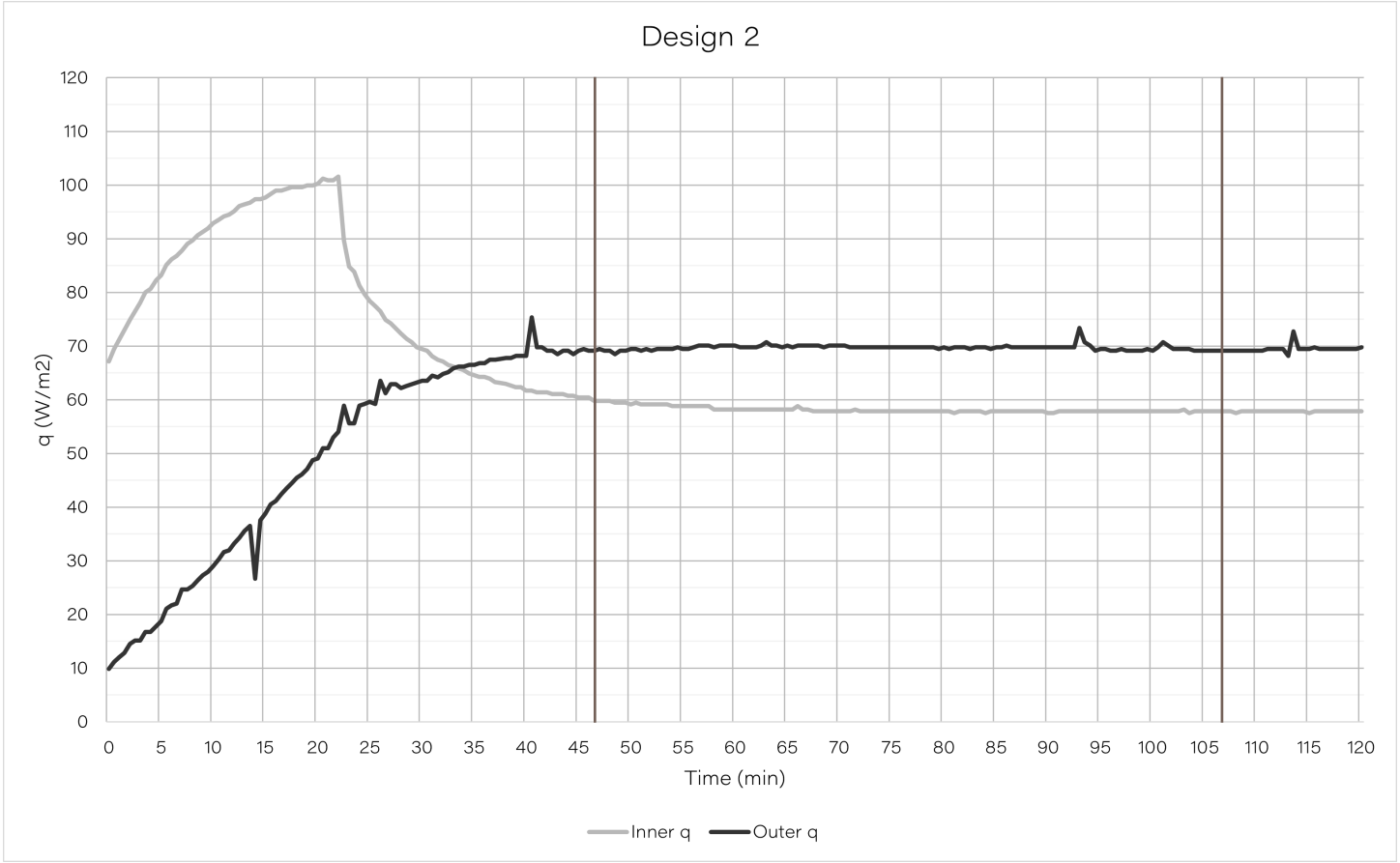
Final prototypes



Test setup

Unguarded hot box


Design 2
Tmeperature (°C)
45
40
35
30
25
20
15
10
5
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
Time (min)
Tair, inner
Tsurf, inner
Tsurf, outer
Tair, outer


Design 2
120
110
100
90
80
70
60
50
40
30
20
10
0
q (W/m2)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
Time (min)
Inner q
Outer q

$$R_c = \frac{(T_{inner\ surf} - T_{outer\ surf})}{q}$$

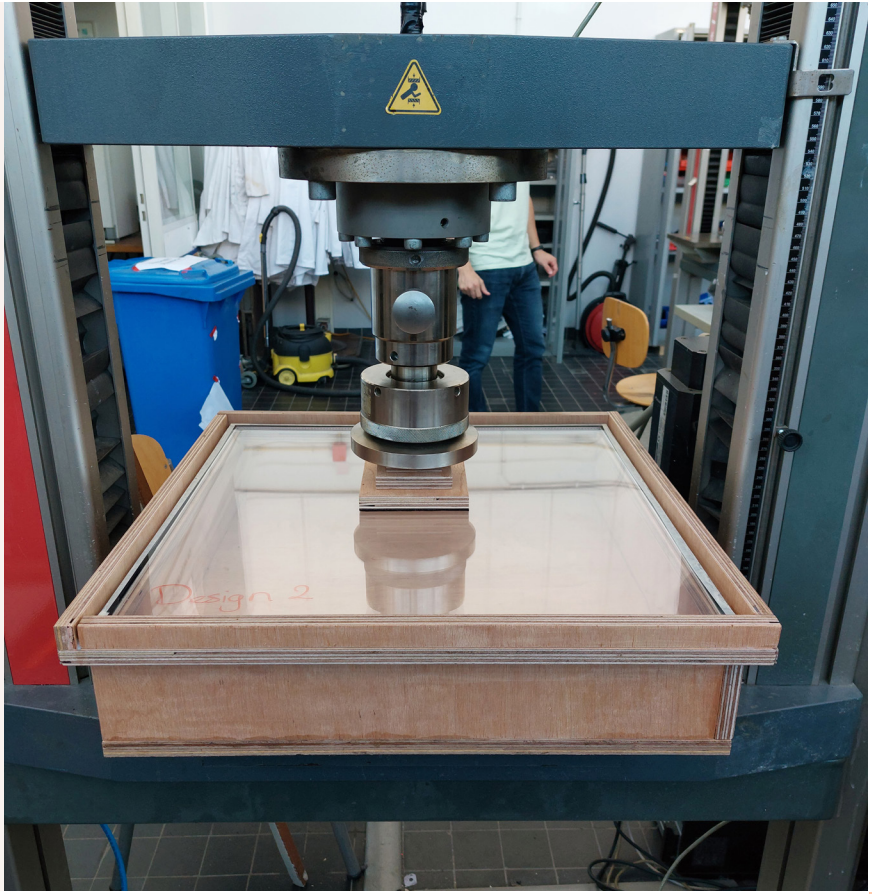
$$R_{total} = R_{si} + R_c + R_{se}$$

$$U_{total} = \frac{1}{R_{total}}$$

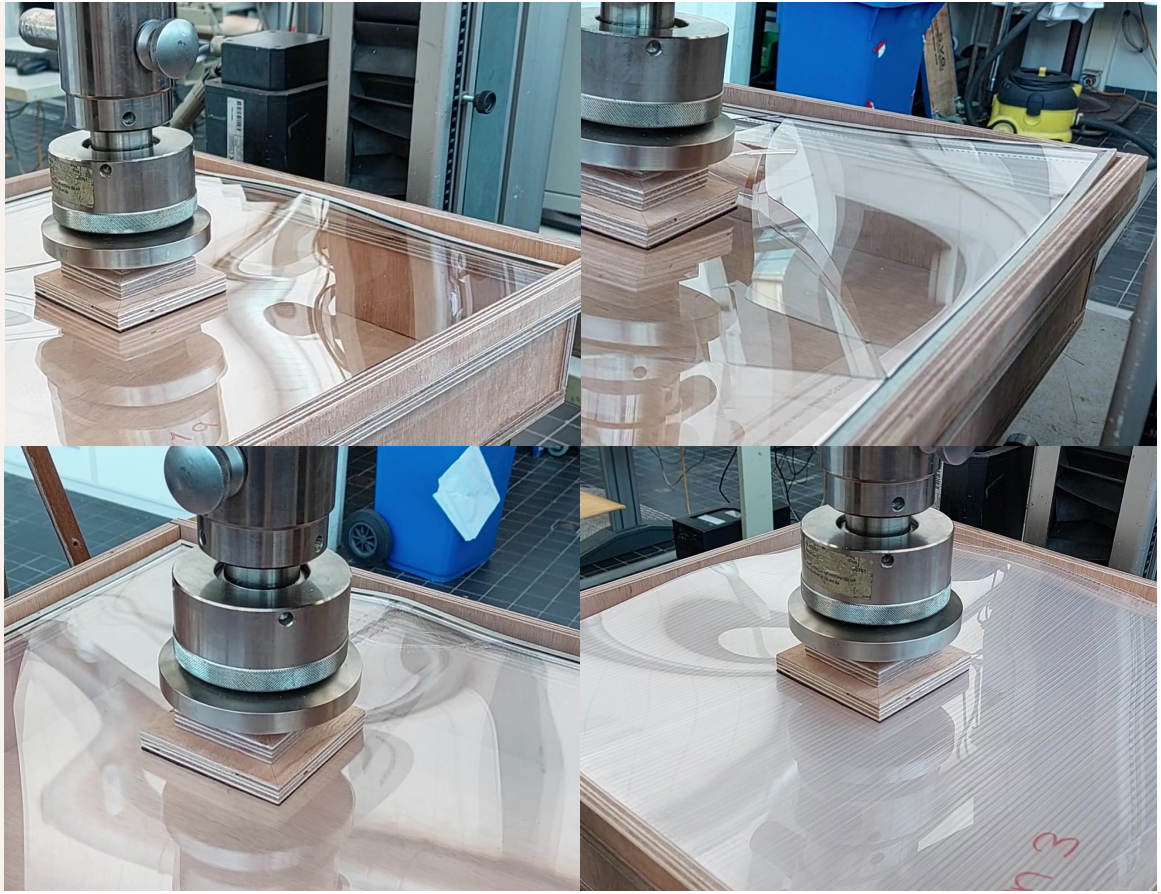
Time laps:	47 minutes to 107 minutes
Average temperature difference:	37.6 °C - 31.5 °C = 6.1 °C
Inside heat flux:	58.12 W/m²
Outside heat flux:	69.71 W/m²

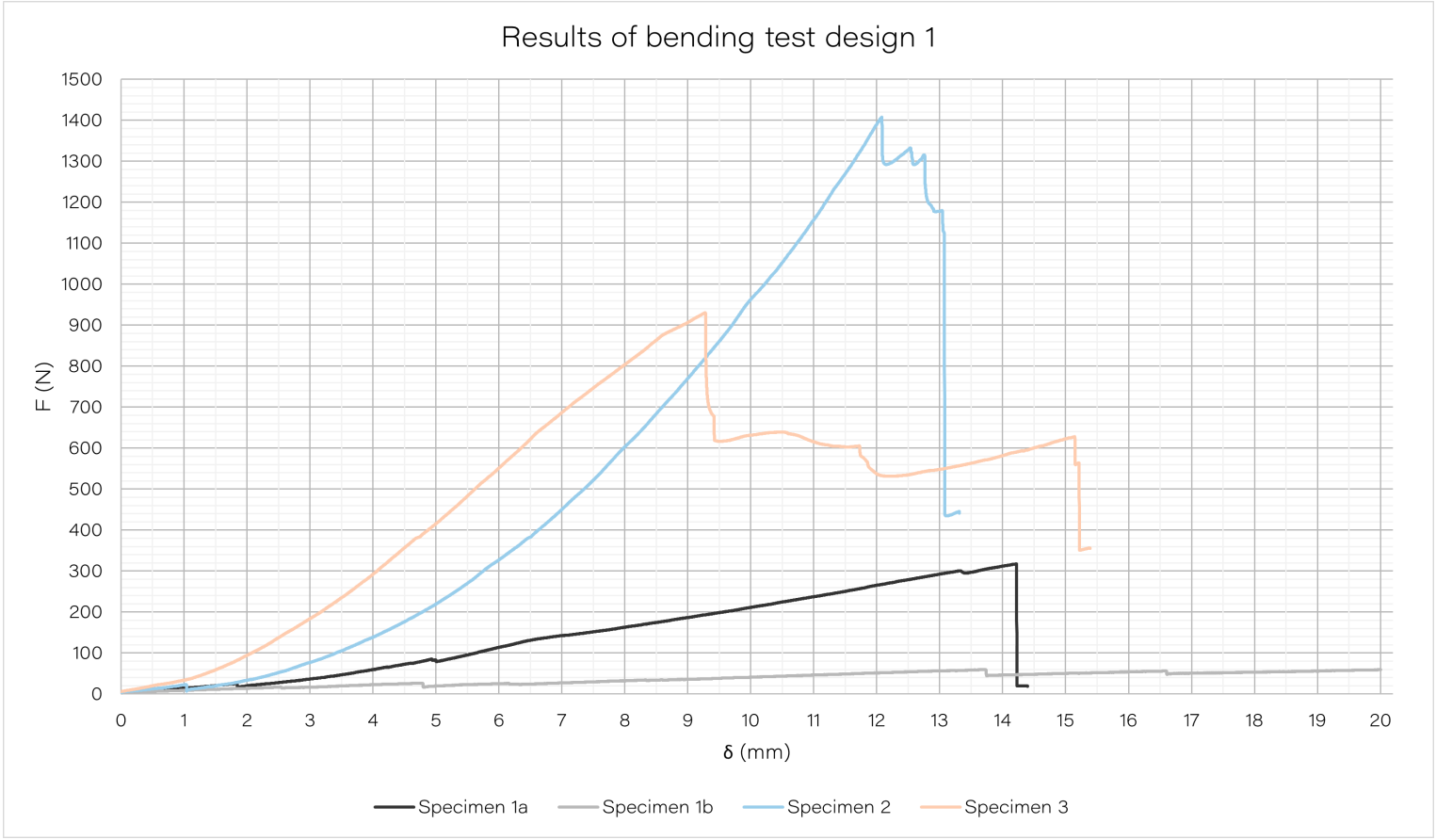
#	Delta T	Inner q-value	Inner U-value	Outer q-value	Outer U-value	Delta U-value	SOLIDO
1	4,9	78,57	4,30	91,63	4,47	4,39	3,18
2	6,1	58,14	3,64	69,71	3,88	3,76	3,20
3	6,4	57,50	3,55	66,20	3,75	3,65	3,47
4a	9,4	84,96	3,56	85,88	3,58	3,57	3,96

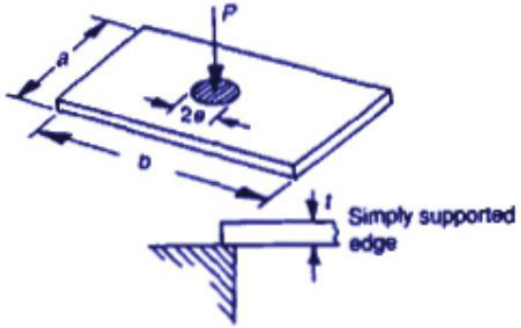
Load on plate



Second order effect

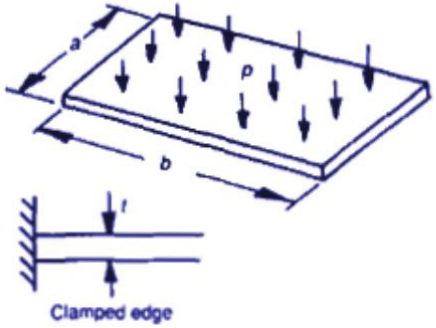



Results of bending test design 1
F (N)
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
δ (mm)
Specimen 1a
Specimen 1b
Specimen 2
Specimen 3



Stress equation at center

$$\sigma_m = \frac{1.5P}{\pi t^2}\left[(1+\nu)\ln\frac{2b}{\pi e} + 1 - k_2\right]$$

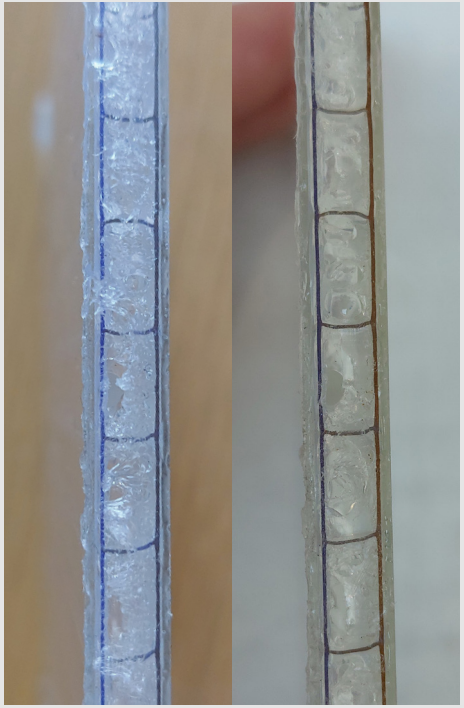


Stress equation

$$\sigma_m = \frac{pa^2}{2t^2[0.623(a/b)^6 + 1]} \text{ (at middle of edge } b\text{)}$$

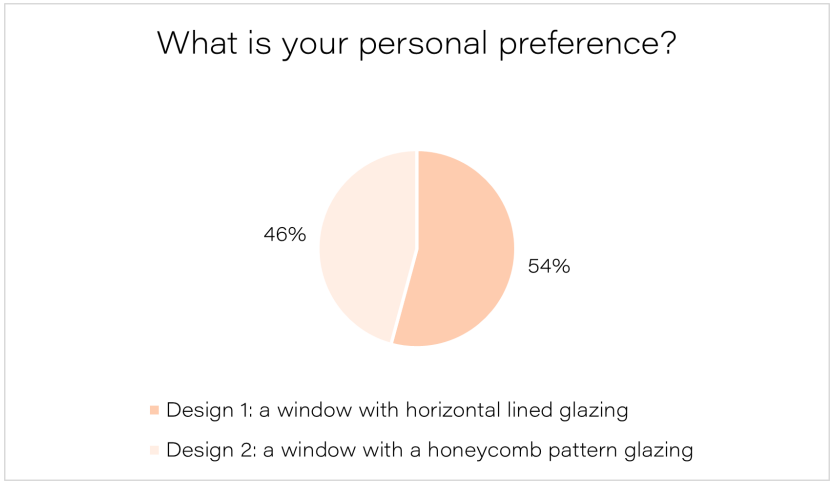
	F_{max} (N)	w_{max} (N/m^2)	<1
Specimen 1a	318	4800	4,8
Specimen 1b	60	908	0,9
Specimen 2	1407	21276	21,3
Specimen 3	931	14071	14,1

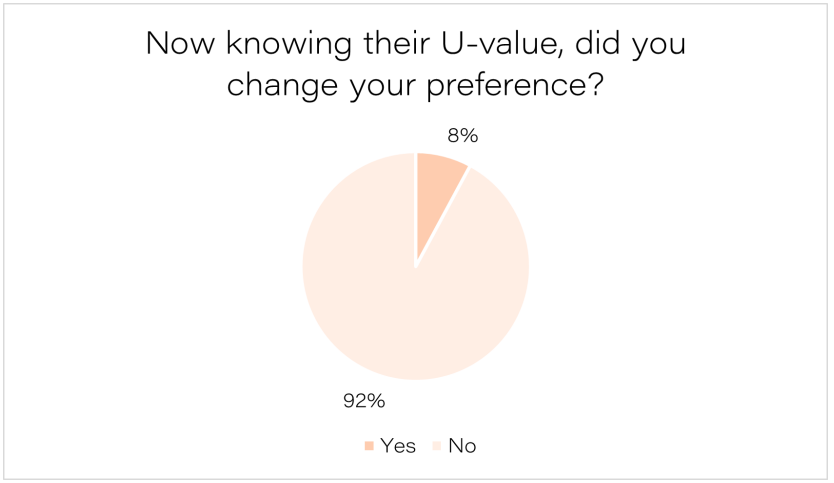
Ageing test



Survey





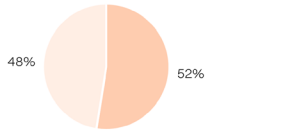


U-value

Single glazing:	5.8 W/m^2*K
Horizontal lines:	3.4 W/m^2*K
Honeycomp pattern:	3.6 W/m^2*K

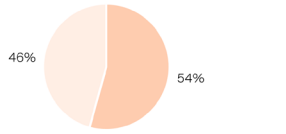
General functions

A housing building; the **living** room window



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

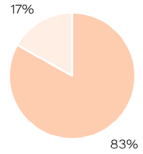
An **office** window



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

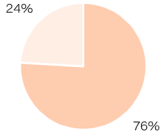
More private functions

A housing building; the **bathroom** window



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

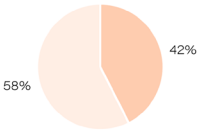
An office building; the **toilet** window



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

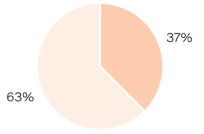
More public functions

A **library** window



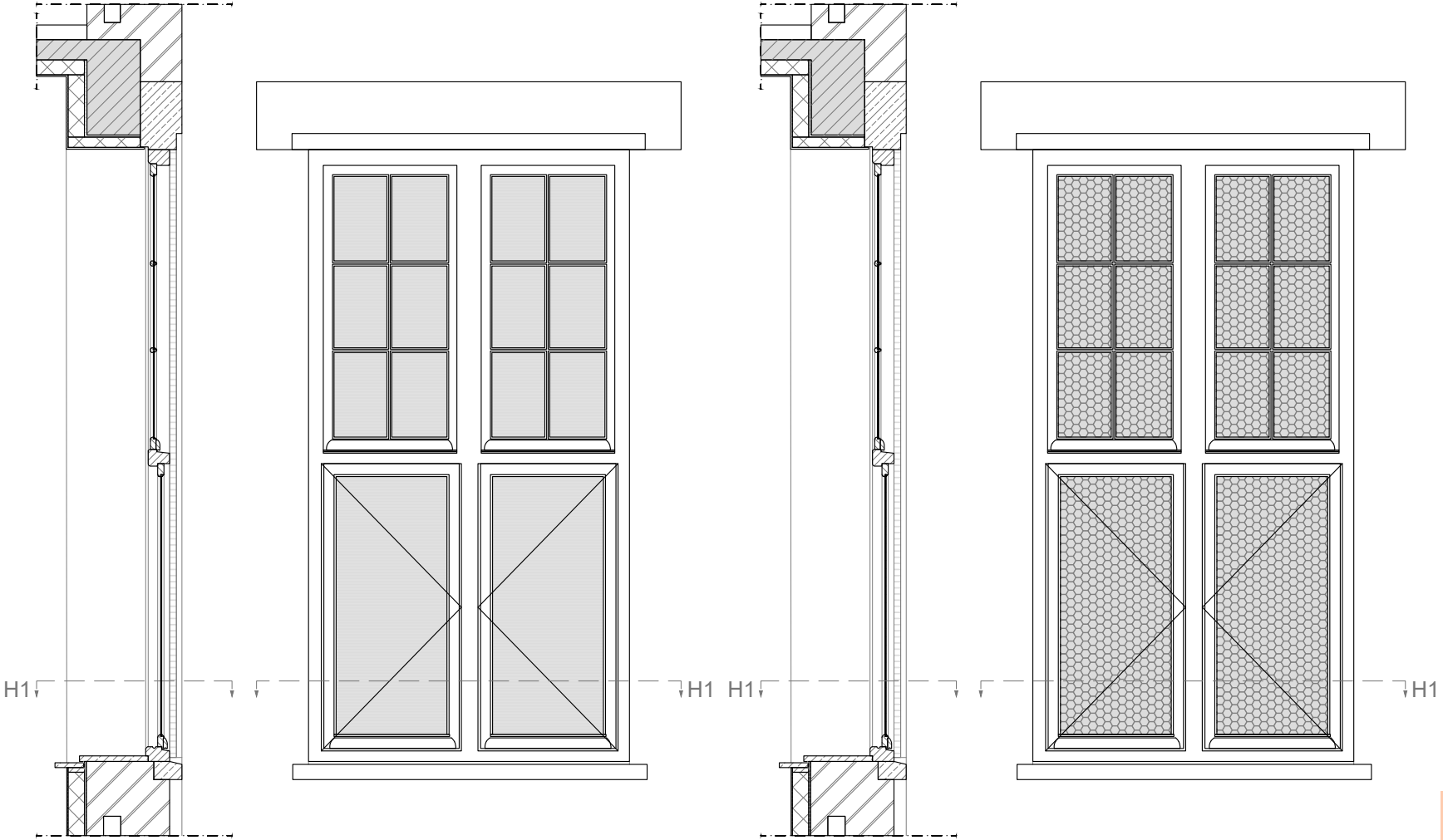
- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

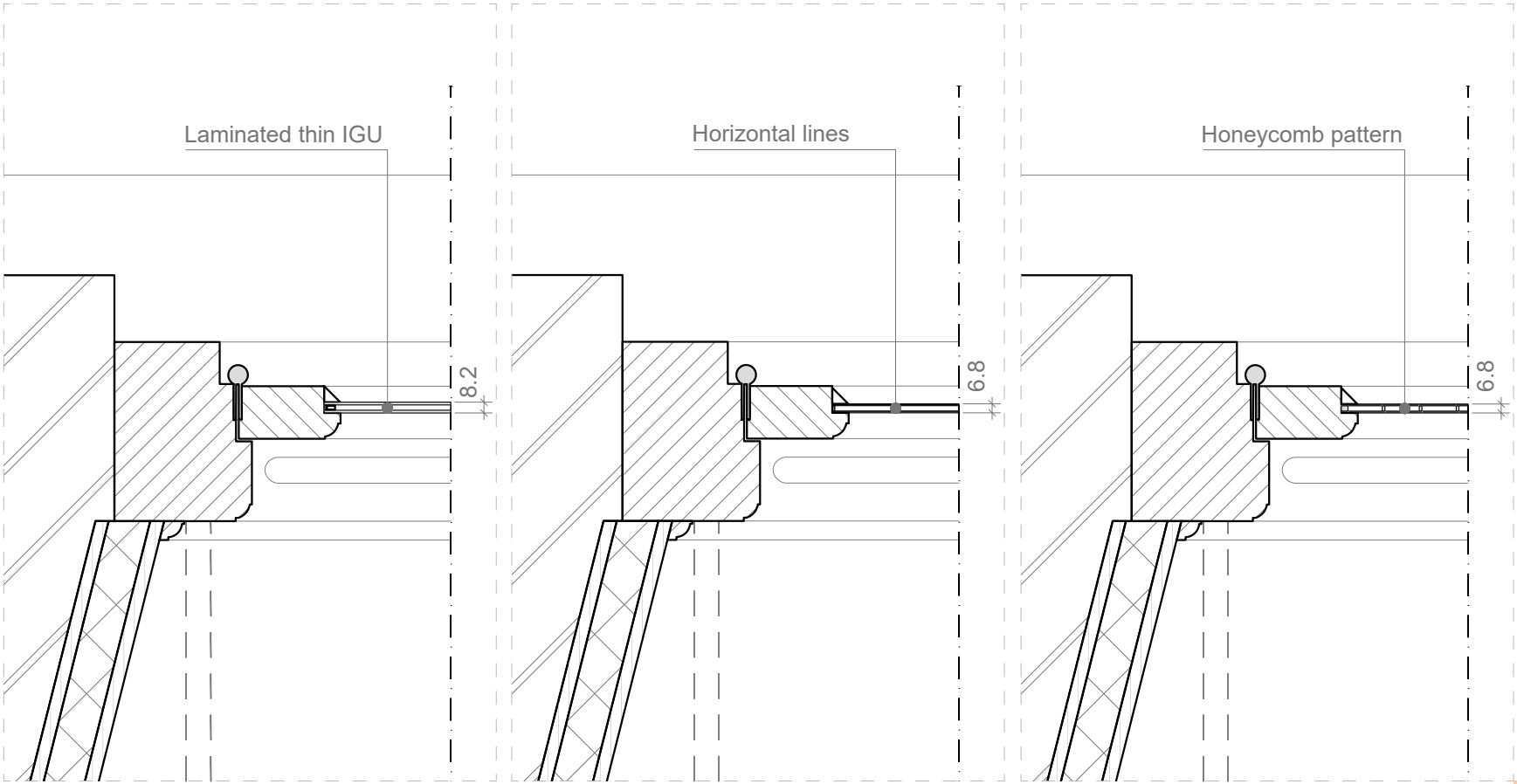
A **shop** window



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

Conclusions


H1
H1
H1
H1


Laminated thin IGU
8.2
Horizontal lines
6.8
Honeycomb pattern
6.8

Conclusion

	Thermal performance	Structural performance	Aesthetics	Makeability	Ageing	Total
Design 1	★★★	★★	★★★★★	★★★★	★★★★★	3,8 ★
Design 2	★★★★	★★★★★	★★★★	★★★★	★★★★	4,2 ★
Design 3	★★★★★	★★★★	★★★	★★★★★	★★	3,8 ★
Design 4	★★★★	★★★★	★★★	★★	★★★★	3,4 ★
Design 5	★★	★★★★	★★★	★★	★★★★	3,0 ★
Design 6	★	★★★	★	★★	★★★	2,0 ★

Recommendations

- Research the use of **chemically strengthened glass** for better structural performance.
- Experiment with **different lamination layers** for the highest transparency and strength (SG).
- The most optimal design for proposal 4 can be research.
- Try prototyping design 4 with structural tape or UV glue.
- Test the design also on **transport** forces or point loads.

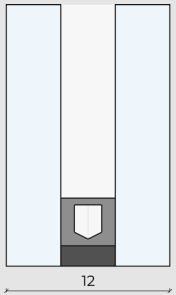
Thank you!

Design objective

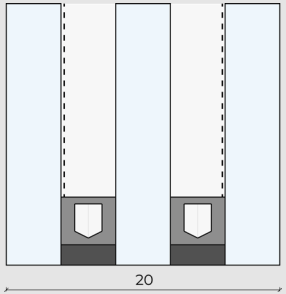
"Design a **thin glass panel** that could replace single glazing in heritage buildings, **aiming for similar U-values** as solutions for non-heritage buildings."

Regular windows

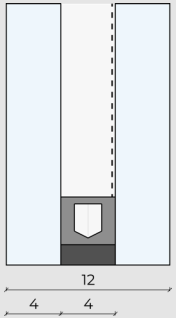
Single glazing
U-value = 5.8 W/m²K
€50/m²



Double glazing
U-value = 2.8 W/m²K
€80/m²



Triple glazing
U-value = 0.8 W/m²K
€120-150/m²

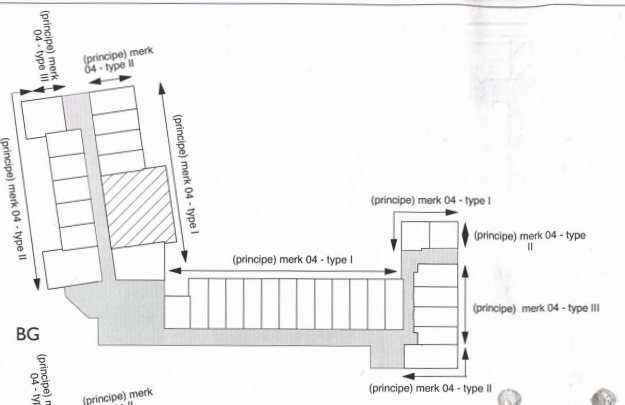


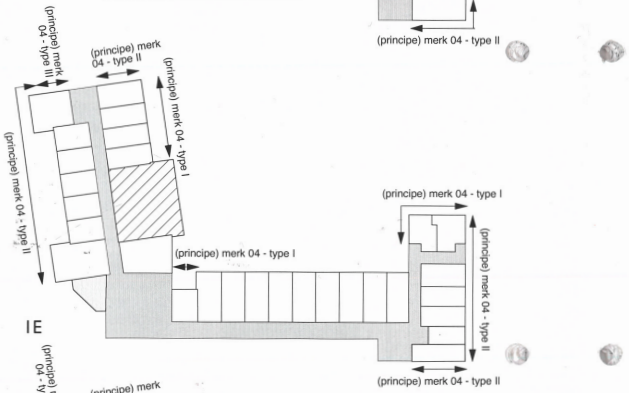
Low E coating
U-value = 1.6 W/m²K
€90/m²

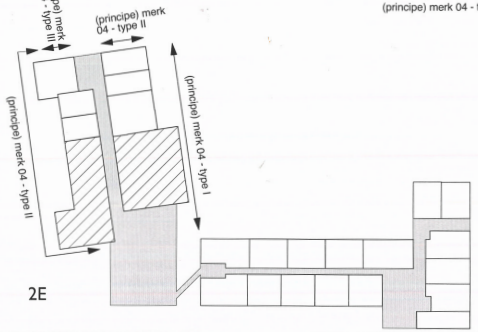
Case study

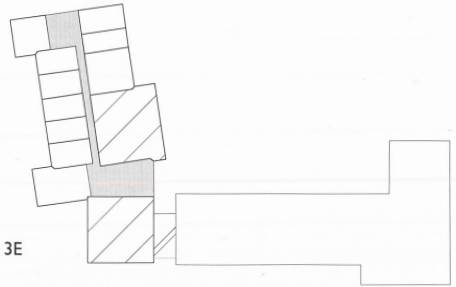
- Mijnbouwplein 11
- Built in 1930
- G. van Drecht
- Former faculty of Applied Physics
- DUWO

Source: https://www.tudelft.nl/scd/collectie-tentoonstelling/tu-noord/monumenten-tu-noord/technische-fysica-1930









DETAILVERWIJZINGEN

Woningen BG 1e 2e 3e

Bedrijfsruimtes

Algemene verkeersruimte (gang, trap, hal)

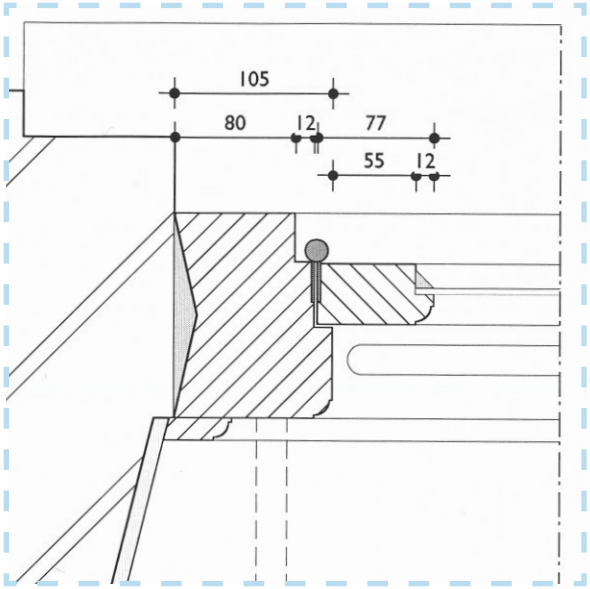
Algemene gebruiksruimte (wasruimte)

Restruimtes

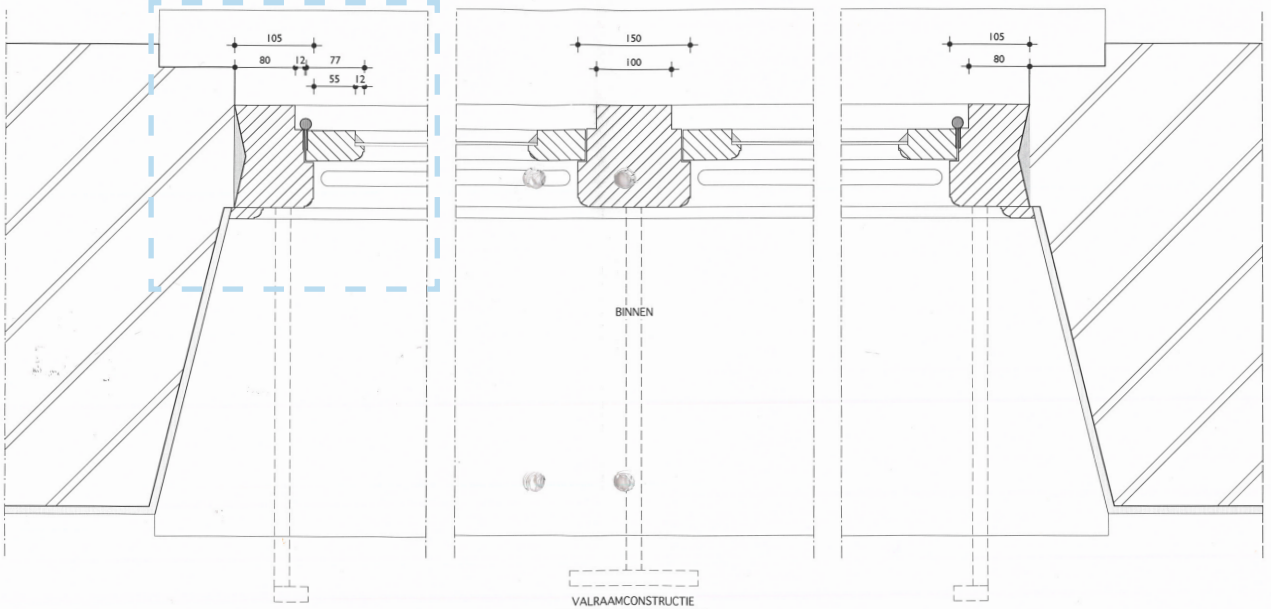
Alle kozijnen in betreffend gevelvlak worden gelijkwaardig opgelost i.o.m. architect

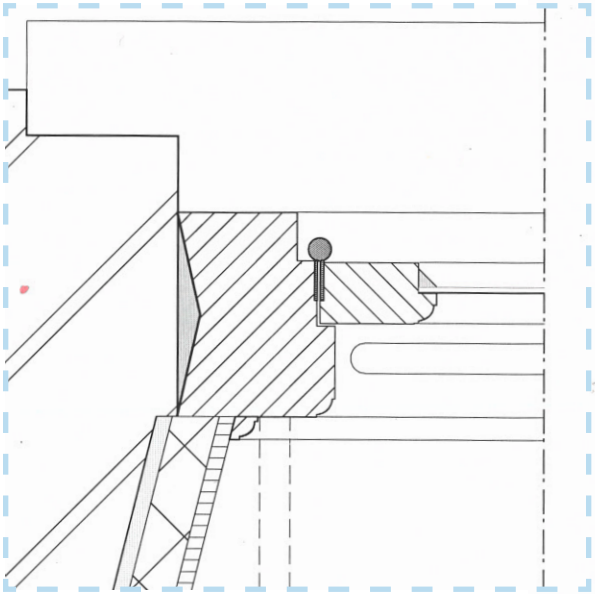
PLAATSAANDUIDING KOZIJNTYPES

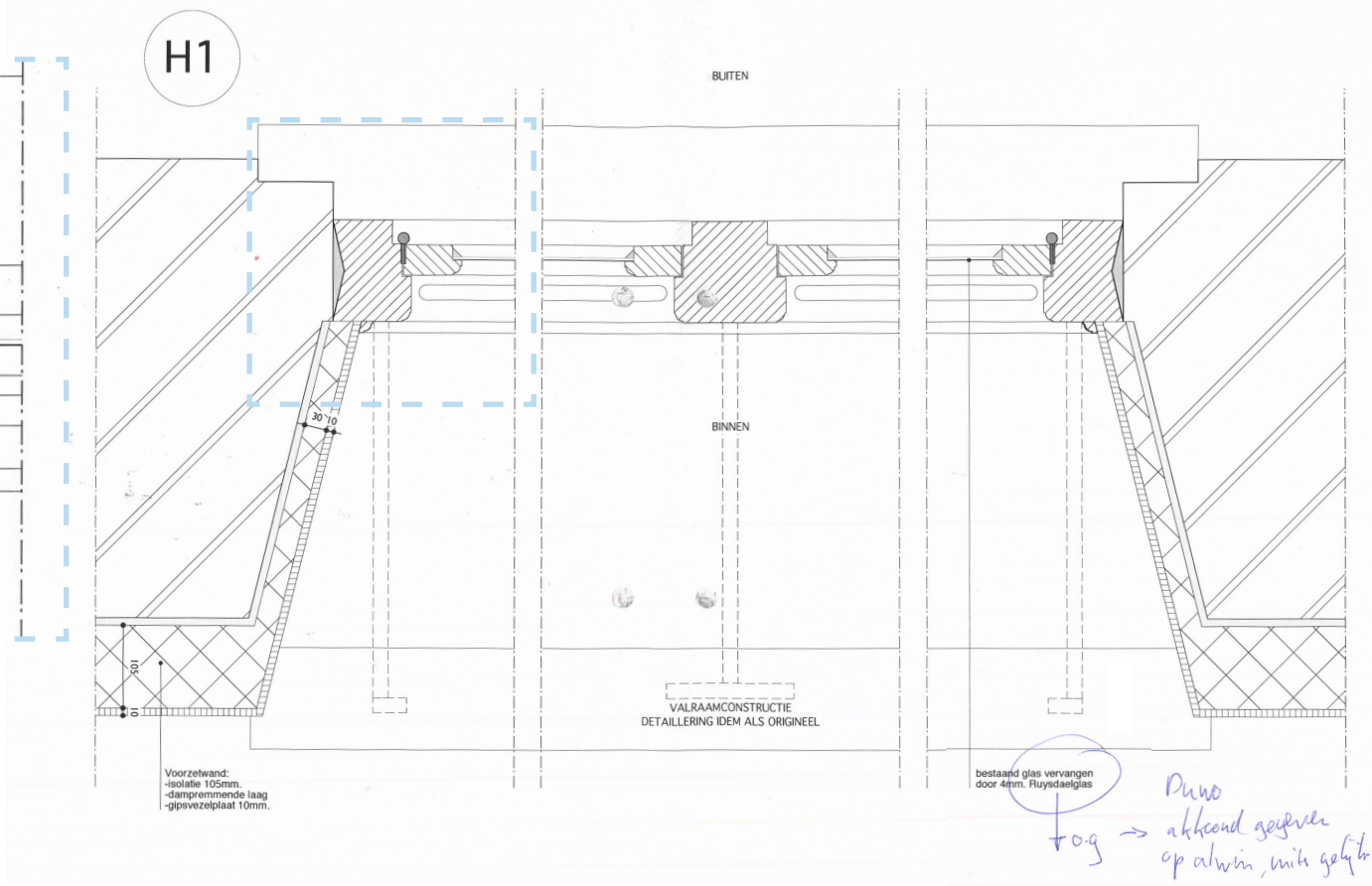
Blad:2

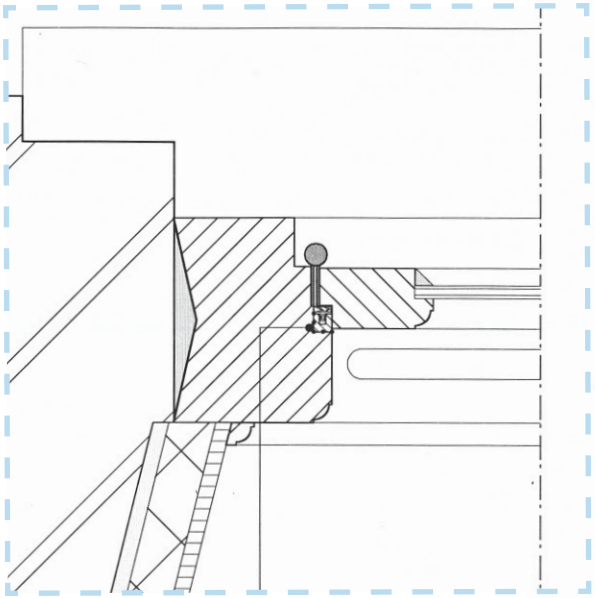

105
80
12
77
55
12

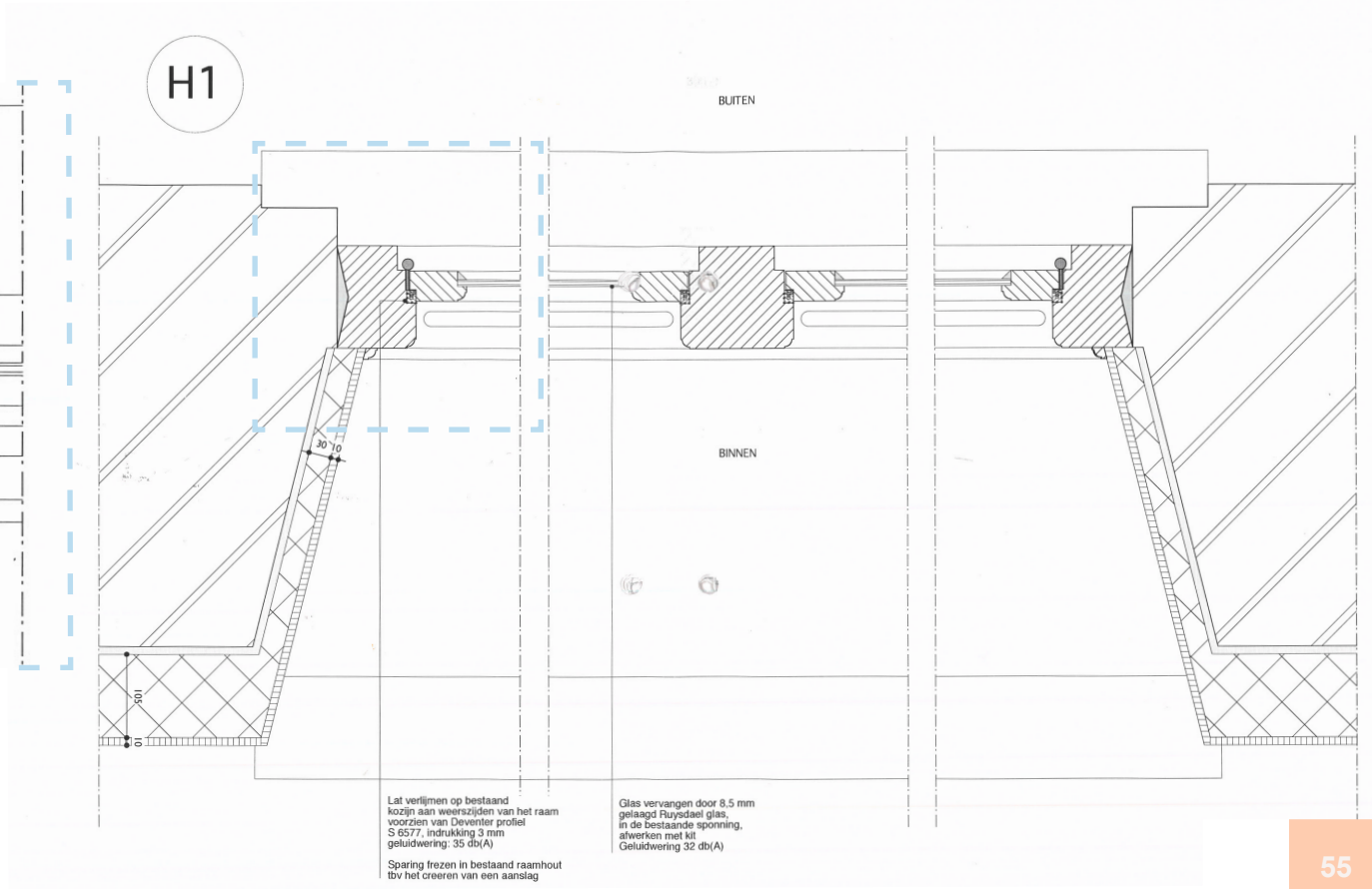
H1


BUITEN
105
80
12
77
55
12
150
100
105
80
BINNEN
VALRAAMCONSTRUCTIE
SPORADISCH NOG AANWEZIG



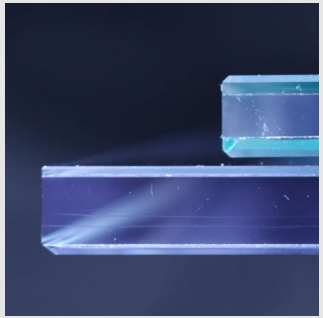

H1
BUITEN
BINNEN
30
10
105
10
VALRAAMCONSTRUCTIE
DETAILLERING IDEM ALS ORIGINEEL
Voorzetwand:
-isolatie 105mm.
-dampremmende laag
-gipsvezelplaat 10mm.
bestaand glas vervangen
door 4mm. Ruysdaelglas
t.o.v.
Duno
akkoord gegeven
op advies, mits geplakt




H1
BUITEN
BINNEN
30
10
105
10
Lat verlijmen op bestaand
kozijn aan weerszijden van het raam
voorzien van Deventer profiel
S 6577, indrukking 3 mm
geluidwering: 35 db(A)
Sparing frezen in bestaand raamhout
tbv het creeren van een aanslag
Glas vervangen door 8,5 mm
gelaagd Ruysdael glas,
in de bestaande sponning,
afwerken met kit
Geluidwering 32 db(A)

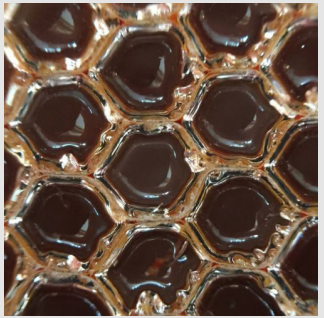
Literature study

Current studies



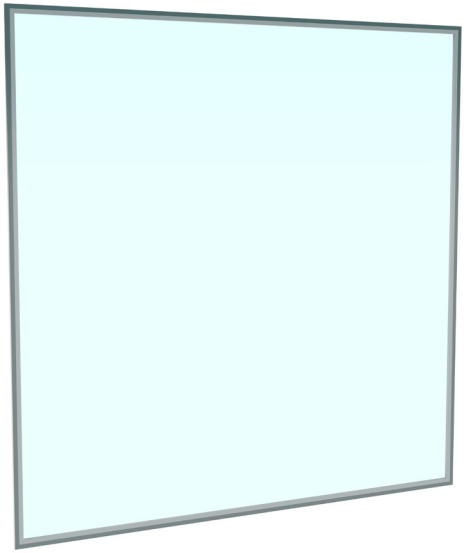
Hanig (2021)
- Cast PMMA
- Design posibility inside acrylic
- Bad thermal performance
- Focus on interior

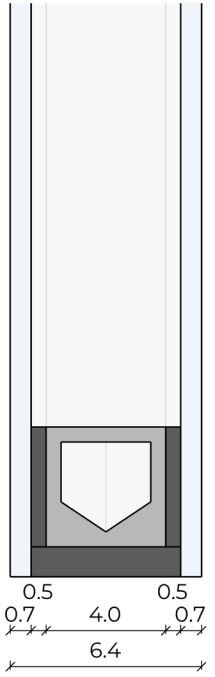
Saleh (2020)
- Composite with 3D printed PET
- Detailed testing methods
- Thermal performance not tested



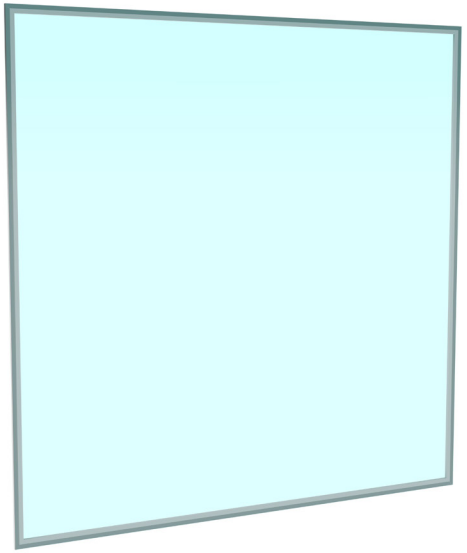
Van der Weijde (2017)
- Composite with amirid paper
- Translucent
- Different lamination techniques
- U-value of 1.4 W/m^2K

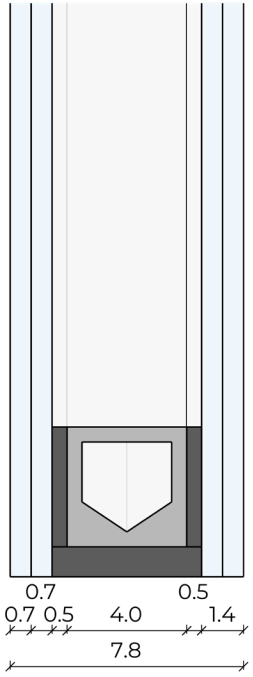
Design proposal 1



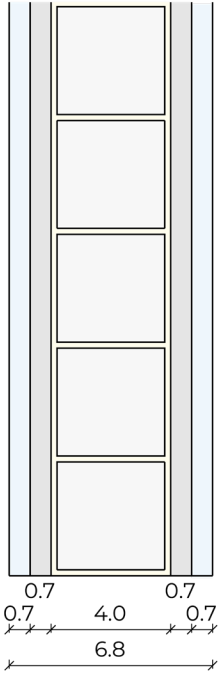


Design proposal 2

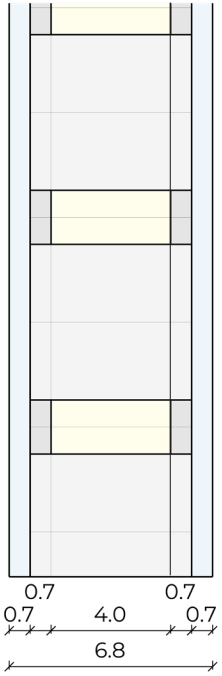


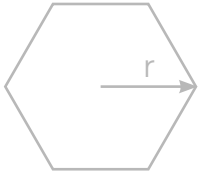


Design proposal 3



Design proposal 4



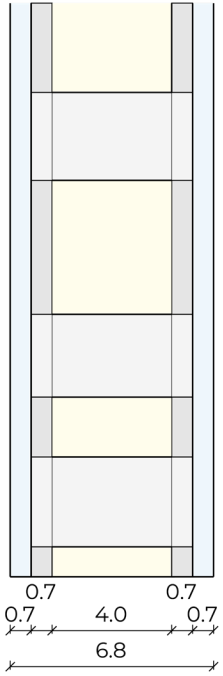


r = 10 mm

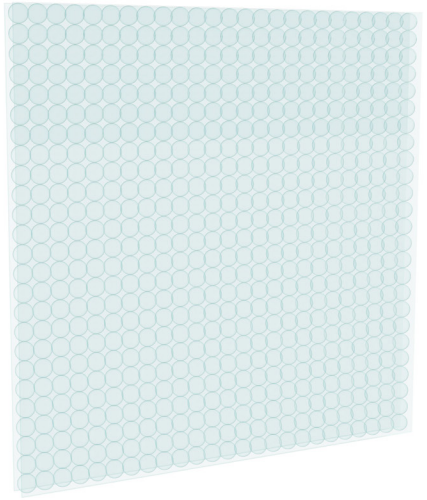
r = 20 mm

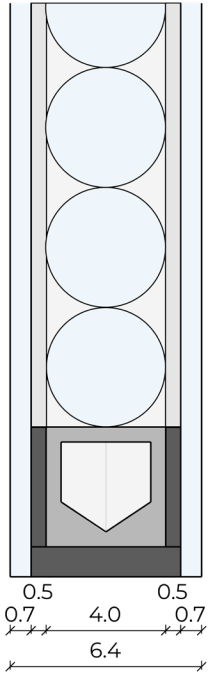
r = 30 mm

Design proposal 5

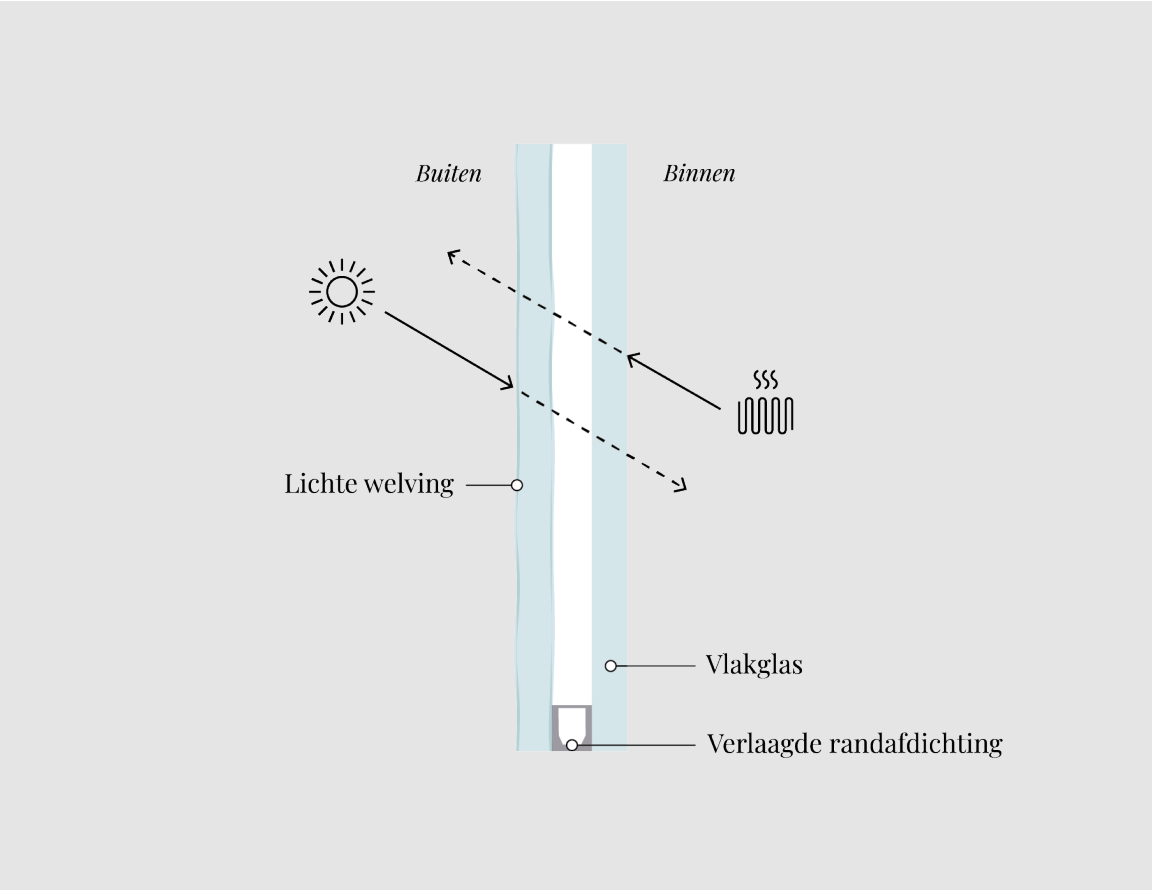


Design proposal 6





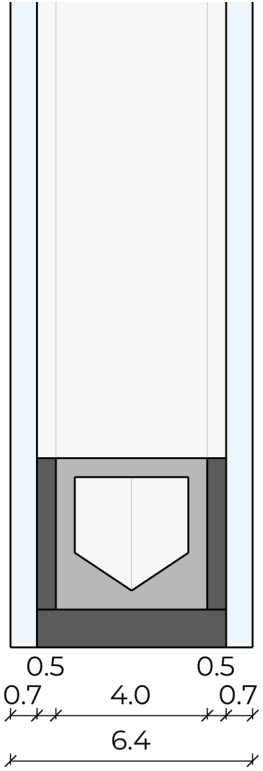
Inspiration



Source: https://monuglas.nl/oplossingen/stm-c0736a/

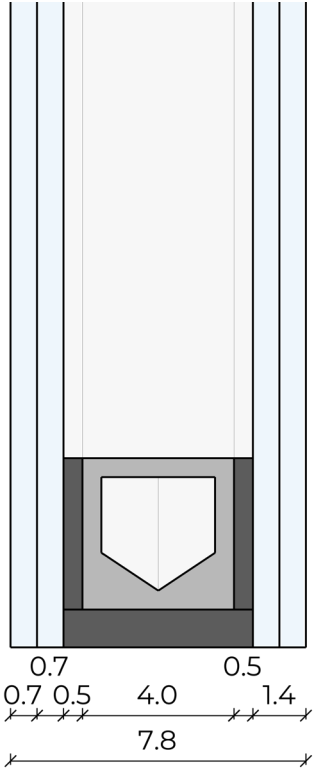
Design proposal 1

- Use current technique
- 3 mm spacer and silicone sealant
- Panel stiffness
- U-value = 3.37 W/m^{2}K
- Total thickness = 4.5 mm

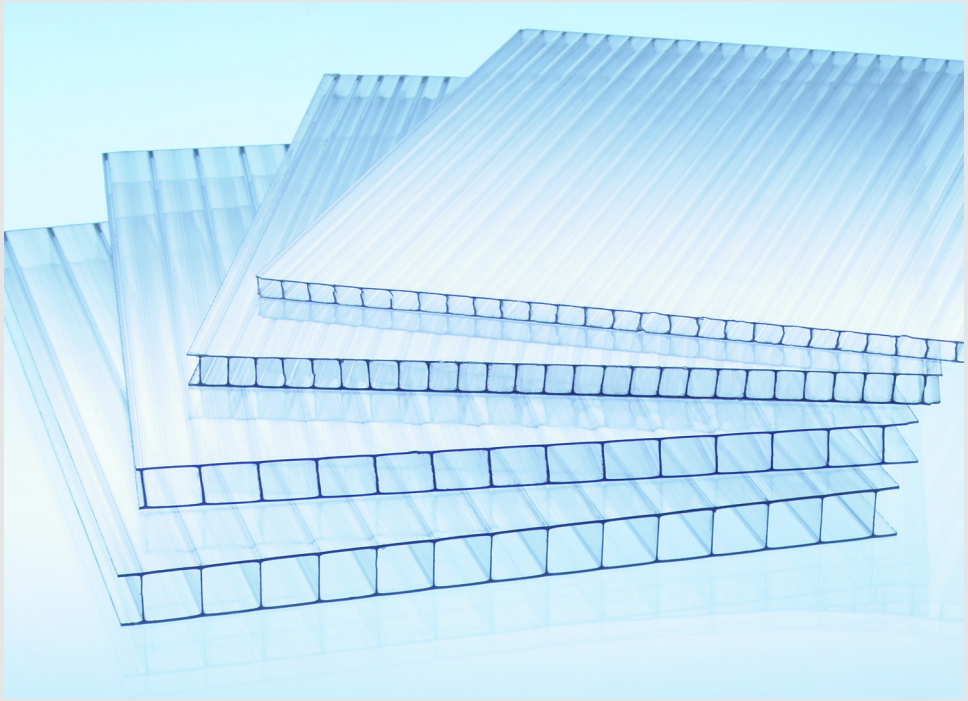


Design proposal 2

- Use current technique
- Laminated thin glass
- 3mm spacer and silicone sealant
- Panel stiffness
- U-value = 3.37 W/m^{2}K
- Total thickness = 6 mm



Inspiration



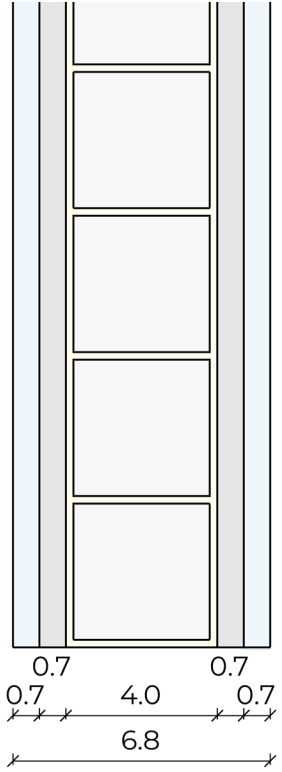
Source: https://www.terrassendach.at/Stegplatten-Polycarbonat/4-mm-Doppelstegplatten-Polycarbonat-glashell.html#articlemain-1

Design proposal 3

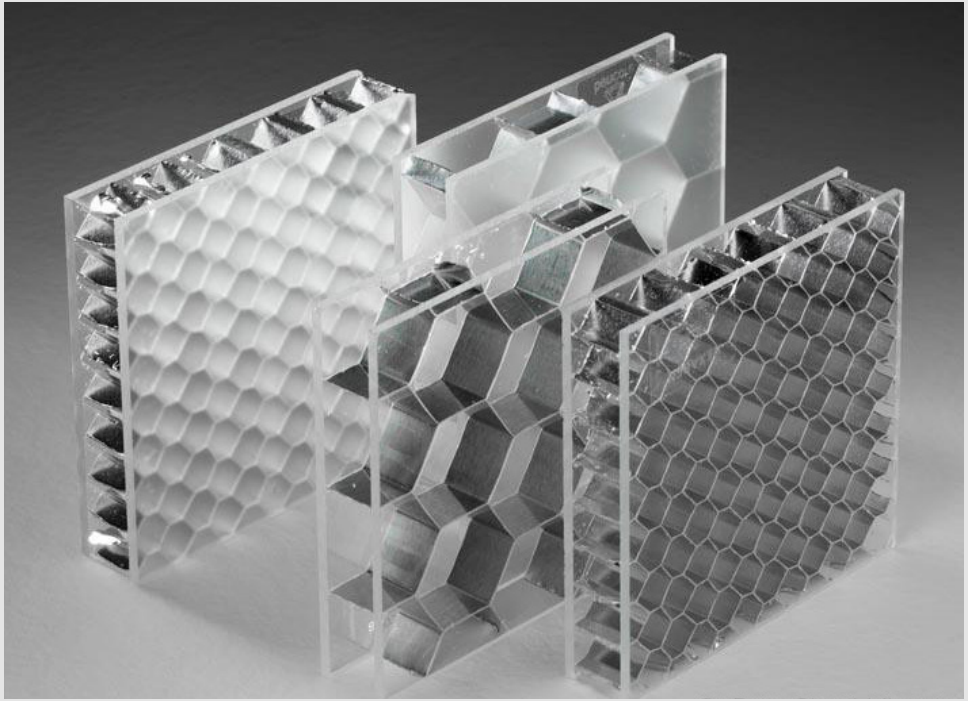
- Use excisting material
- Laminate with PVB or ionomer interlayer
- Melting temperatures

PVB	138°C
PC	147°C
PMMA	160°C

- Silicone seal needed?
- U-value = 2.37 W/m^2K
- Total thickness = 5.5 mm



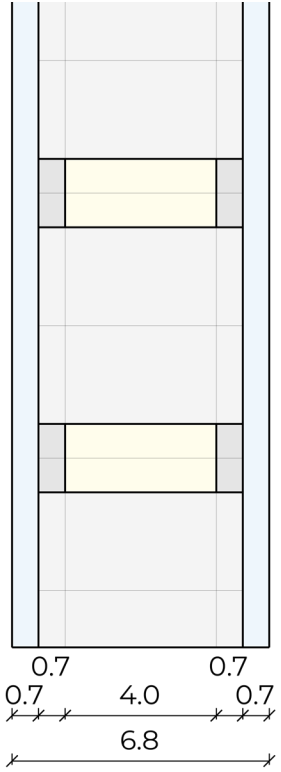
Inspiration



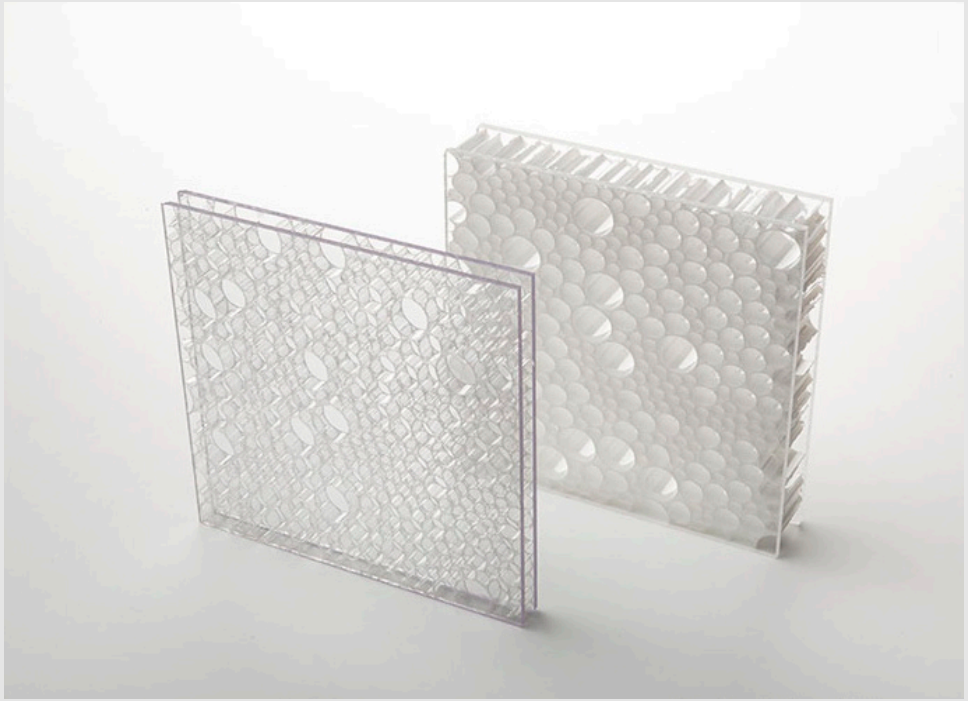
Source: https://www.pyrasied.nl/product/hexaben-design-composietplaat/

Design proposal 4

- Lasercut PMMA sheet with hexagons
- Laminate with PVB or ionomer interlayer
- Laminate without air bubbles
- U-value = ? W/m^2K
- Total thickness = 3.5 mm



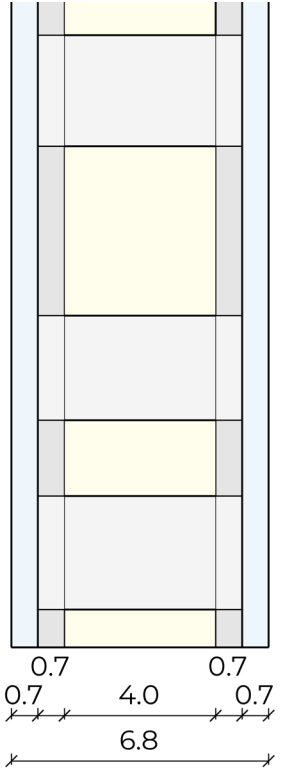
Inspiration



Source: https://www.pyrasied.nl/en/product/kaos-3d-clear-and-black/

Design proposal 5

- Lasercut PMMA sheet with ‘random’ shapes
- Laminate with PVB or ionomer interlayer
- Laminate without air bubbles
- U-value = ? W/m^{2}K
- Total thickness = 3.5 mm

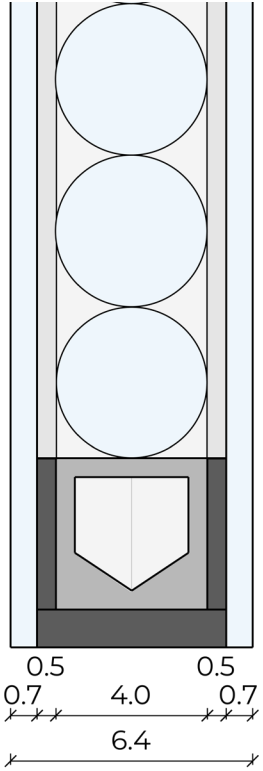


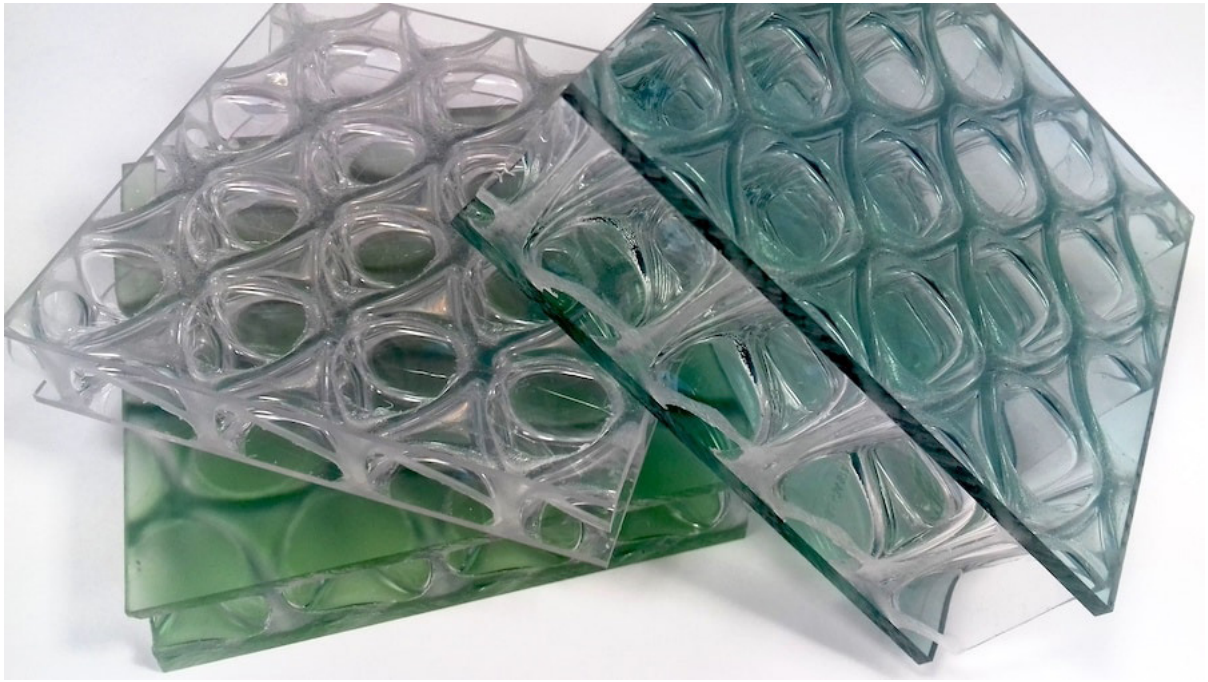
Inspiration

Source: https://www.made-in-china.com/showroom/handicraftt/product-detailAsvmfYjUgckl/

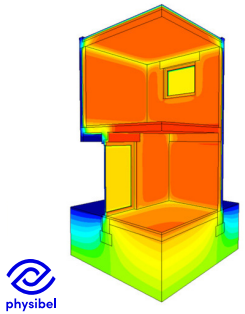
Design proposal 6

- Use existing material
- Glue balls to one sheet
- Add second glass sheet
- Seal air inside
- U-value = ? W/m^2K
- Total thickness = 4.5 mm

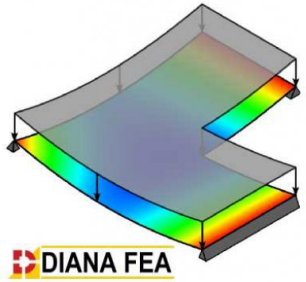




Simulations



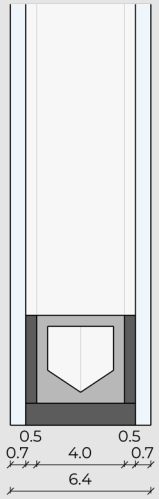
TRISCO
- Testing thermal performance
- Gives heat flow
- $R_{TRISO} = \frac{Q}{A * \Delta T}$
- $U_{TRISCO} = \frac{1}{R_{TRISCO}}$

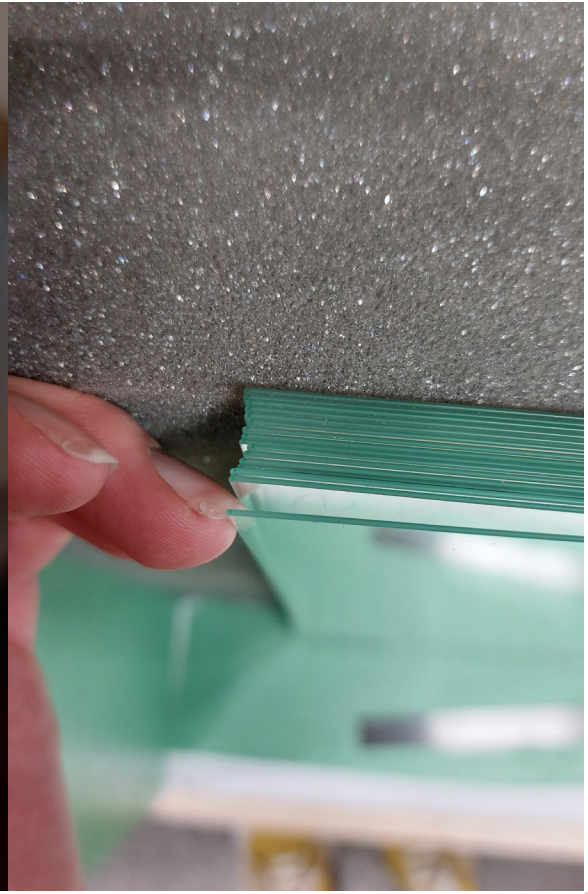


DIANA FEA
- Testing structural performance
- Input NEN
- Gives stresses and deflection

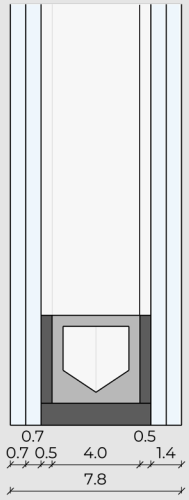
Source: https://www.physibel.be/en/products/trisco
Source: https://dianafea.com/tutorial-plate

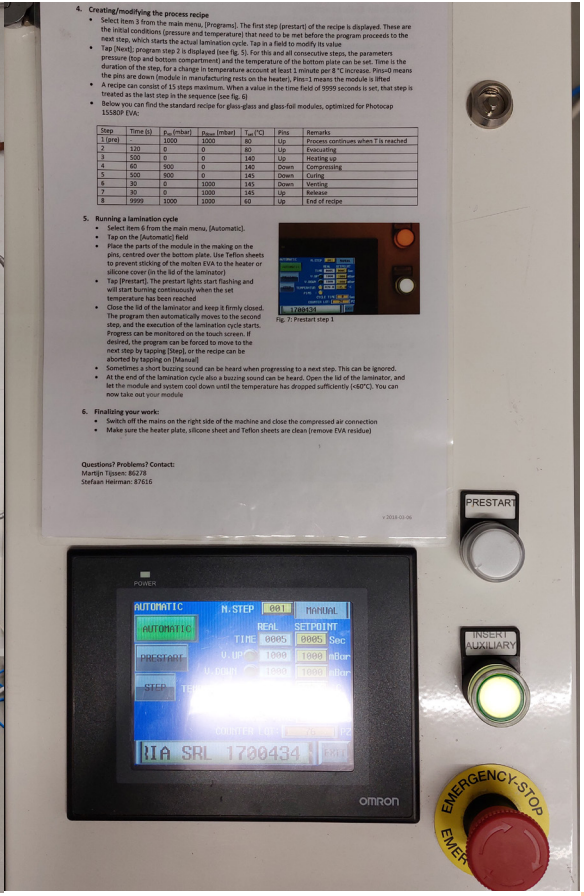
Design 1





Design 2





4. **Creating/modifying the process recipe**
   - Select item 3 from the main menu, [Programs]. The first step (prestart) of the recipe is displayed. These are the initial conditions (pressure and temperature) that need to be met before the program proceeds to the next step, which starts the actual lamination cycle. Tap in a field to modify its value
   - Tap [Next]; program step 2 is displayed (see fig. 5). For this and all consecutive steps, the parameters pressure (top and bottom compartment) and the temperature of the bottom plate can be set. Time is the duration of the step, for a change in temperature account at least 1 minute per 8 °C increase. Pins=0 means the pins are down (module in manufacturing rests on the heater), Pins=1 means the module is lifted
   - A recipe can consist of 15 steps maximum. When a value in the time field of 9999 seconds is set, that step is treated as the last step in the sequence (see fig. 6)
   - Below you can find the standard recipe for glass-glass and glass-foil modules, optimized for Photocap 155ROP EVA:

Step	Time (s)	P_{top} (mbar)	P_{bottom} (mbar)	T_{set} (°C)	Pins	Remarks
1 (pre)	...	1000	1000	80	Up	Process continues when T is reached
2	120	0	0	80	Up	Evacuating
3	500	0	0	140	Up	Heating up
4	60	900	0	140	Down	Compressing
5	500	900	0	145	Down	Curing
6	30	0	1000	145	Down	Venting
7	30	0	1000	145	Up	Release
8	9999	1000	1000	60	Up	End of recipe

5. **Running a lamination cycle**
   - Select item 6 from the main menu, [Automatic].
   - Tap on the [Automatic] field
   - Place the parts of the module in the making on the pins, centred over the bottom plate. Use Teflon sheets to prevent sticking of the molten EVA to the heater or silicone cover (in the lid of the laminator)
   - Tap [Prestart]. The prestart lights start flashing and will start burning continuously when the set temperature has been reached
   - Close the lid of the laminator and keep it firmly closed. The program then automatically moves to the second step, and the execution of the lamination cycle starts. Progress can be monitored on the touch screen. If desired, the program can be forced to move to the next step by tapping [Step], or the recipe can be aborted by tapping on [Manual]

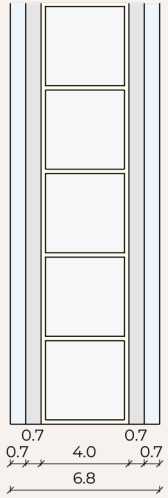
Fig. 7: Prestart step 1

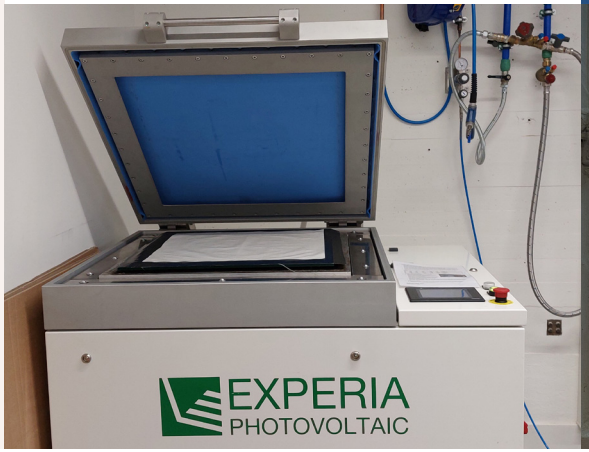
   - Sometimes a short buzzing sound can be heard when progressing to a next step. This can be ignored.
   - At the end of the lamination cycle also a buzzing sound can be heard. Open the lid of the laminator, and let the module and system cool down until the temperature has dropped sufficiently (<60°C). You can now take out your module

6. **Finalizing your work:**
   - Switch off the mains on the right side of the machine and close the compressed air connection
   - Make sure the heater plate, silicone sheet and Teflon sheets are clean (remove EVA residue)

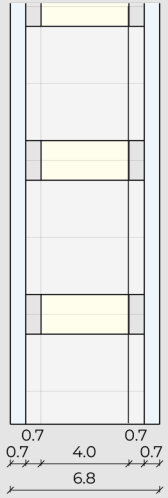
Questions? Problems? Contact:
Martijn Tijssen: 86278
Stefaan Heirman: 87616

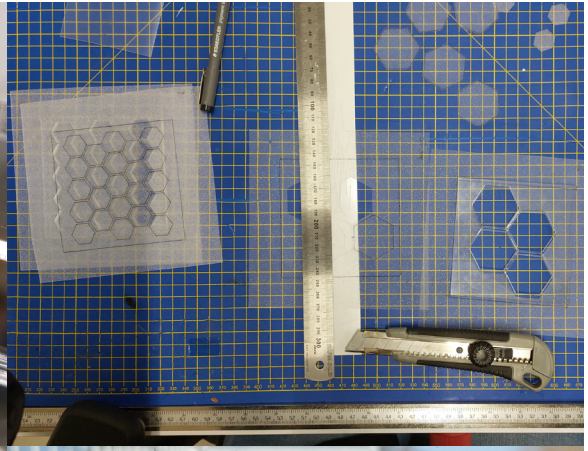
Design 3

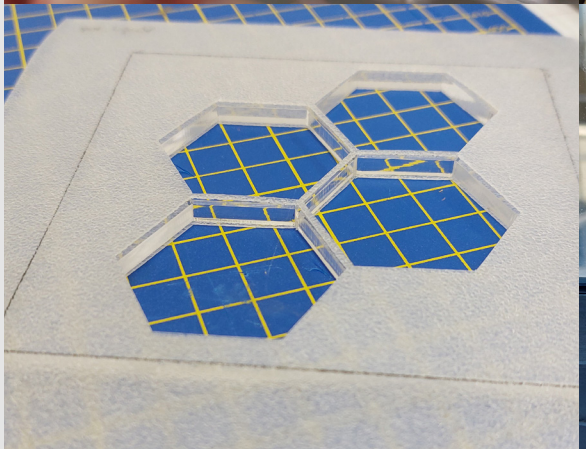


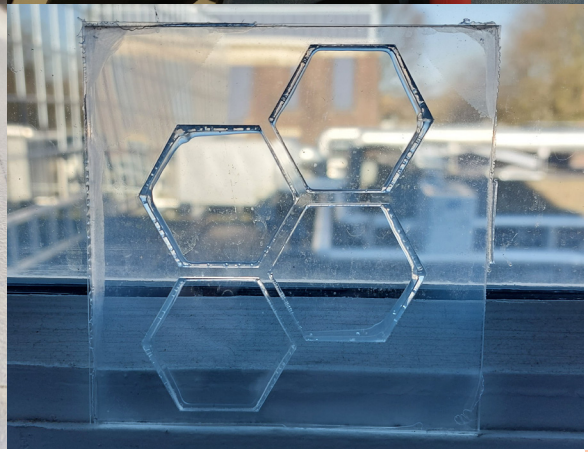


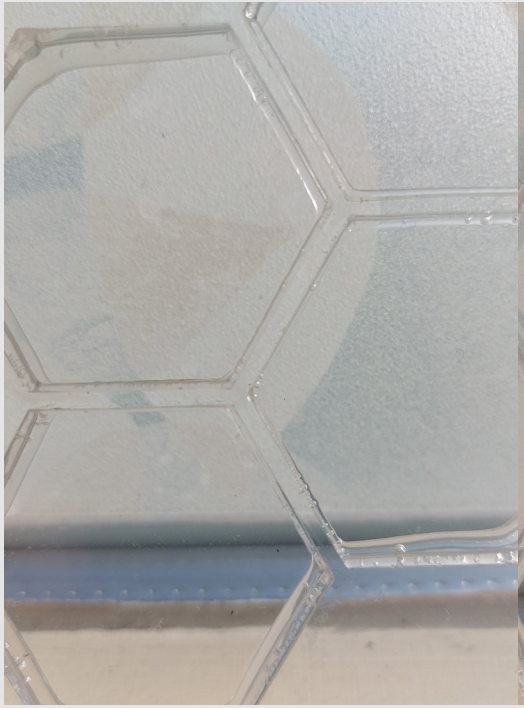
Design 4a & 4b

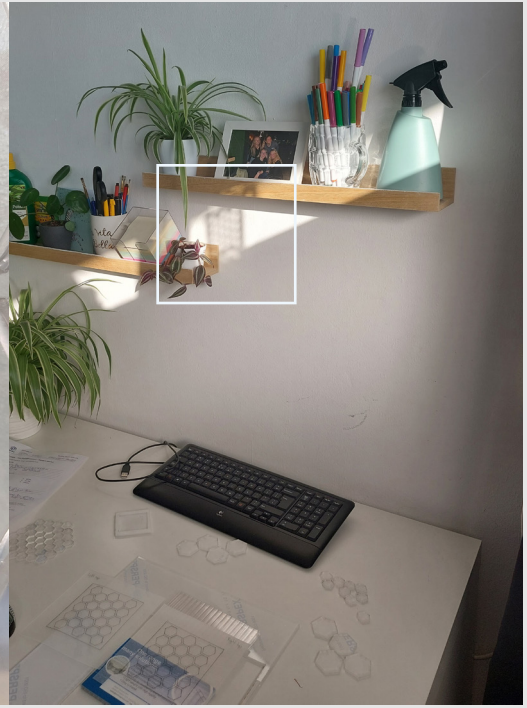




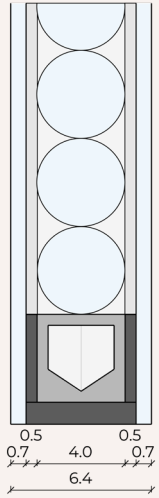


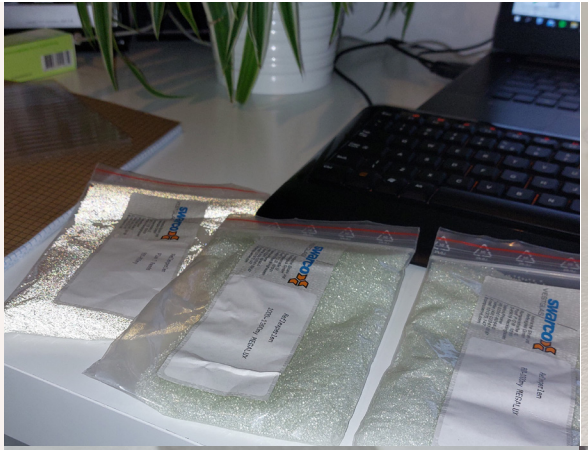


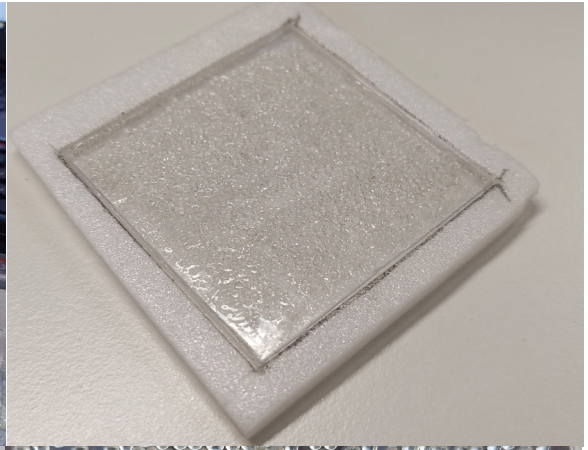


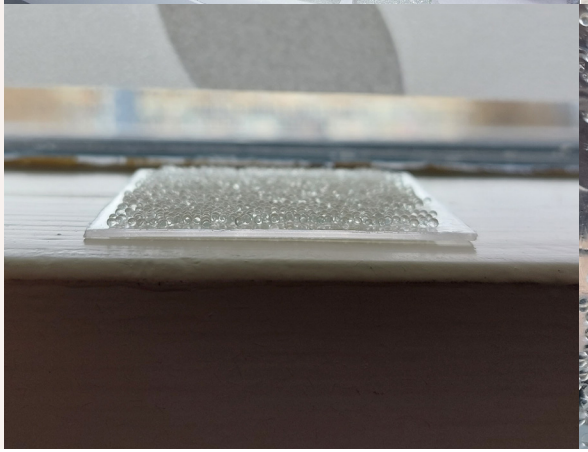


Design 6

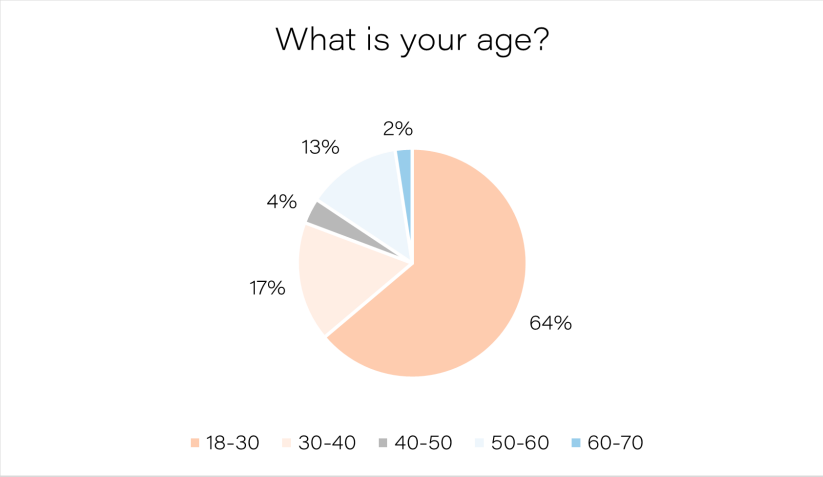


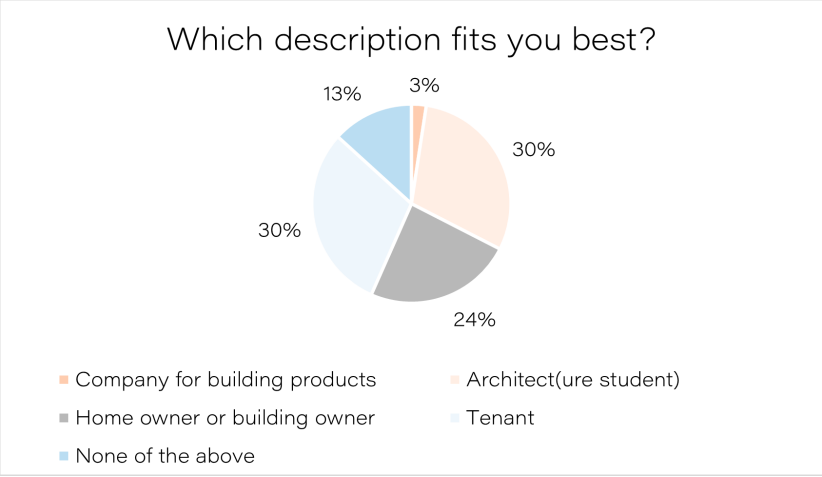




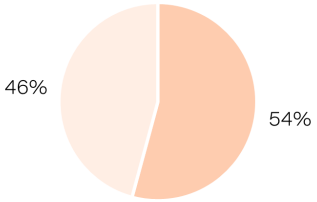


Survey


What is your age?
2%
13%
4%
17%
64%
18-30
30-40
40-50
50-60
60-70

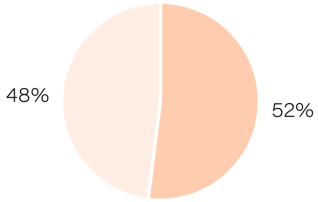

Which description fits you best?
13%
3%
30%
30%
24%
Company for building products
Architect(ure student)
Home owner or building owner
Tenant
None of the above

What is your personal preference?



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

Architects: What is your personal preference?



- Design 1: a window with horizontal lined glazing
- Design 2: a window with a honeycomb pattern glazing

Hand calculations

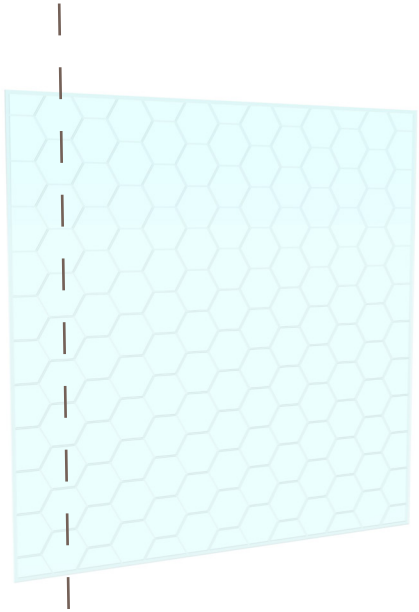
$$Width_{glass,new} = Width_{glass} * (E_{glass}/E_{PMMA})$$

$$I_{total} = \sum I + \sum (A * y^2)$$

$$\delta_{max} = \frac{1}{384} * \frac{ql^4}{EI}$$

$$M_{max} = \frac{1}{12} * ql^2$$

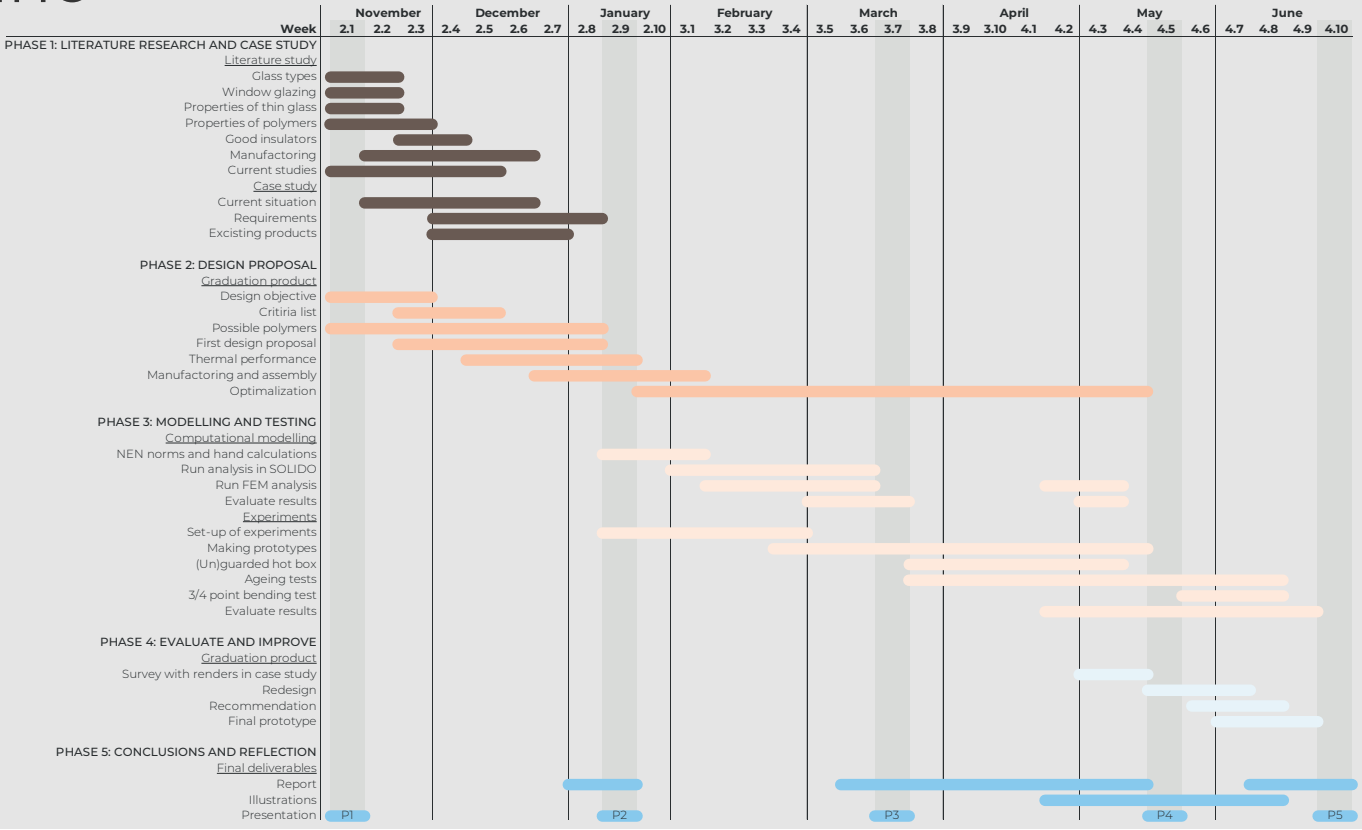
$$\sigma_{max} = \frac{M * y}{I}$$



#	Material	Deflection	Allowed deflection	Check deflection	Max stress	Allowed stress	Check stress
1	Glass	40,673	10,88	:(	127,55	15	:(
2	Glass	5,084	10,88	:)	31,89	15	:(
3	Glass	0,29748	10,88	:)	7,20	15	:)
	PC				0,17	70	:)
4a	Glass	0,29753	10,88	:)	7,21	15	:)
	PMMA				0,22	70	:)
4b	Glass	0,29793	10,88	:)	7,21	15	:)
	PMMA				0,22	70	:)
4c	Glass	0,29806	10,88	:)	7,20	15	:)
	PMMA				0,22	70	:)

Planning

Timeline


November
December
January
February
March
April
May
June
Week
2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 2.10 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 3.10 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 4.10
PHASE 1: LITERATURE RESEARCH AND CASE STUDY
Literature study
Glass types
Window glazing
Properties of thin glass
Properties of polymers
Good insulators
Manufactoring
Current studies
Case study
Current situation
Requirements
Excisting products
PHASE 2: DESIGN PROPOSAL
Graduation product
Design objective
Critiria list
Possible polymers
First design proposal
Thermal performance
Manufactoring and assembly
Optimalization
PHASE 3: MODELLING AND TESTING
Computational modelling
NEN norms and hand calculations
Run analysis in SOLIDO
Run FEM analysis
Evaluate results
Experiments
Set-up of experiments
Making prototypes
(Un)guarded hot box
Ageing tests
3/4 point bending test
Evaluate results
PHASE 4: EVALUATE AND IMPROVE
Graduation product
Survey with renders in case study
Redesign
Recommendation
Final prototype
PHASE 5: CONCLUSIONS AND REFLECTION
Final deliverables
Report
Illustrations
Presentation
P1
P2
P3
P4
P5

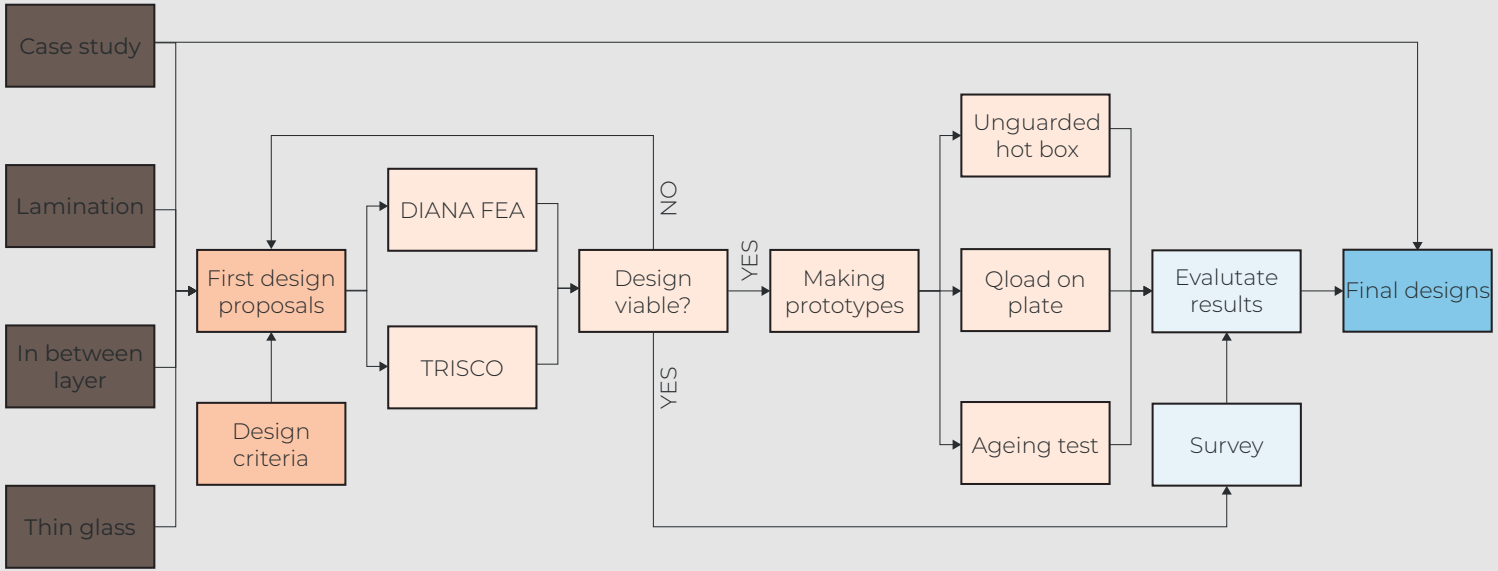
To do list

- Test on wind load
- Take UV samples out
- Make final results, conclusions and recommendations part
- Make 2D details of window (1:20 and 1:5)
- Decide where to place which window in case study

Problem statement

"To **reduce the heating energy** in heritage buildings, **modern solutions** that replace the single glazing **are not as good** as solutions for non-heritage buildings."

Flowchart



PHASE 1: Literature research and case study

PHASE 2: Design proposal

PHASE 3: Modelling and testing

PHASE 4: Evaluate and improve

PHASE 5: Conclusions and reflections