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Shallow Hollow Core Vacuum Panels Based on Tied Arch Skins

Design development of a novel building cladding panel using vacuum technology

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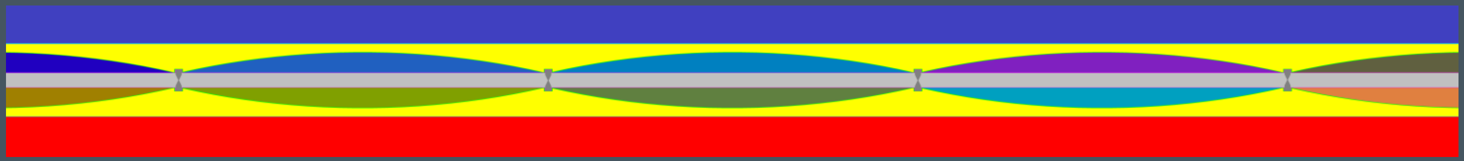

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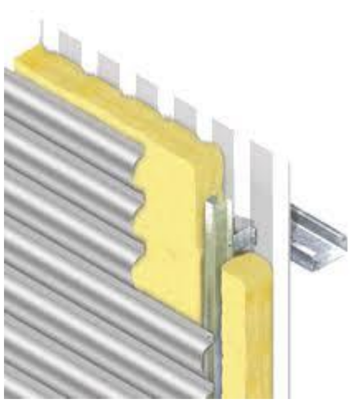
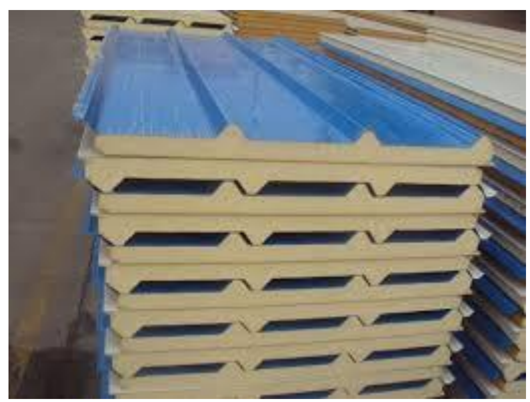
Introduction: Content

- Background (1): why use a vacuum cladding in buildings?
- Background (2): limits of conventional VIP cladding
- Design development: the concept, and challenges to be overcome.
- Design approaches: modelling, analysis and results.
- Next steps: prototyping and production.

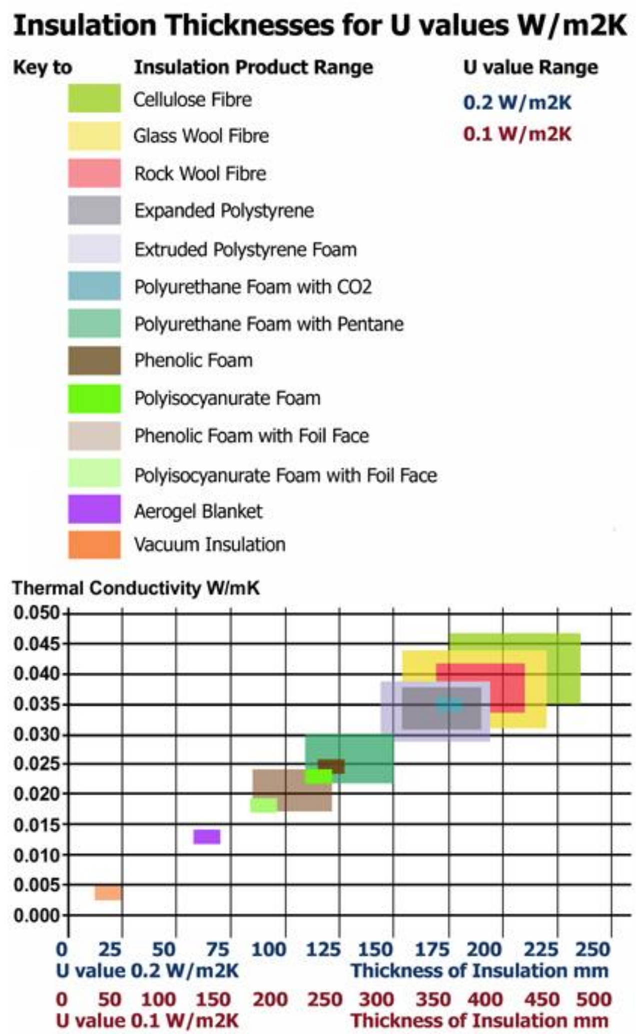
Background: why use vacuum cladding?

- Increasing demand for highly performing building cladding systems: Engineered building components; build off-site; prefabrication; structural cladding (floor-floor)
- Low U-values (< $0.1 W/m^2K$)/ high R values (>10) for approaching zero carbon buildings as a response to man-made climate change.
- Thinner panels: increased rentable floor space or more dwellings per unit area; reduced mechanical problems (lower self-weight, smaller fixings, lighter building structure)
- Lower embodied carbon in the building envelope as less material is used, and the panels are smaller, lighter and cheaper to transport.





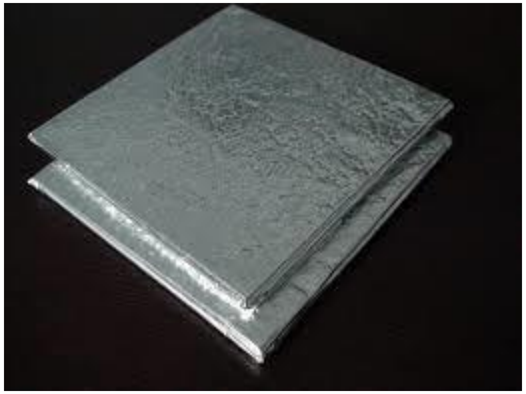
Background: why use vacuum cladding?



Source: Audacity.org

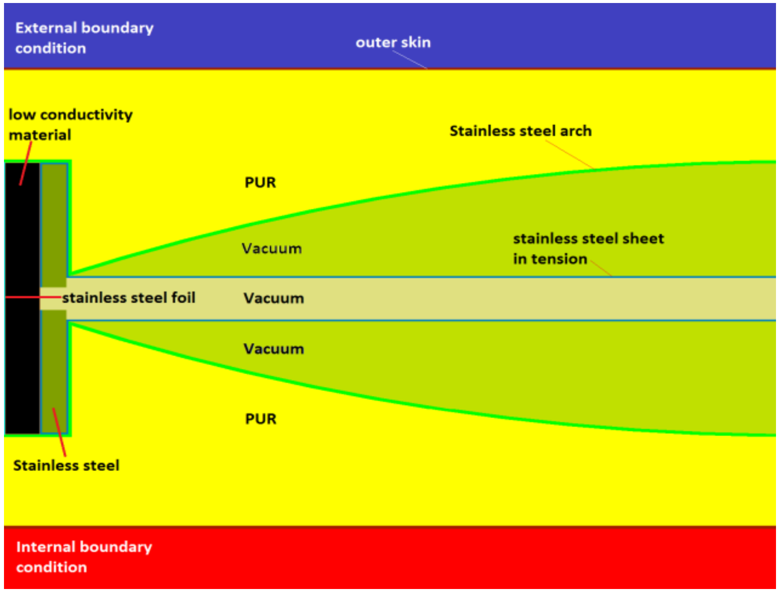
Background: limits of conventional VIP cladding

- Durability during storage, transport, and the building phase: susceptible to mechanical damage and consequent loss of thermal properties.
- Lifespan may not reach more than 30 years: building panels should last at least 60 years before replacement.
- Thermal bridging through the panel junctions and encapsulating barrier film can significantly affect the U-value achieved.
- Alternative approaches such as foam encapsulation of VIPS and evacuated spheres introduce more thermal conduction paths



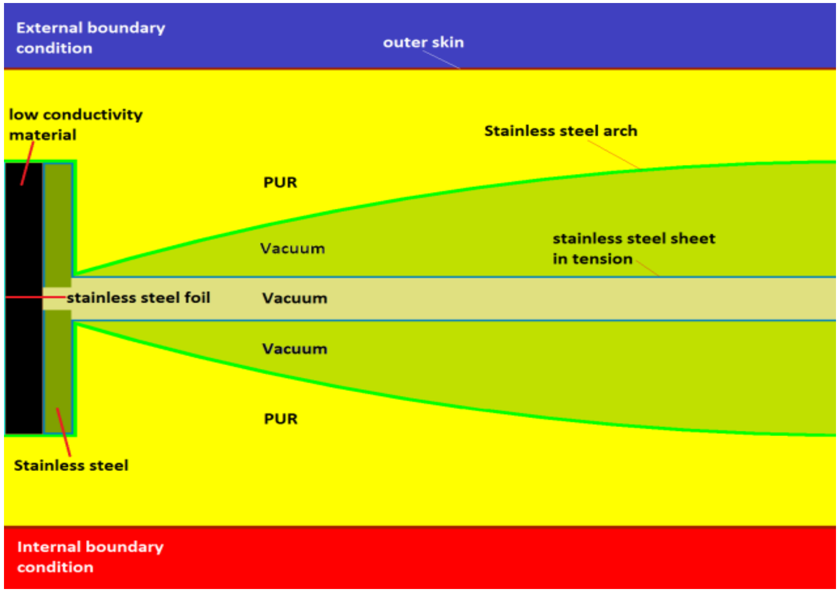
Design development: the concept

- Opposing tied shallow arches of thin stainless steel, held in shape by stainless steel foil under tension.
- Polymeric foam around the assembly protects the panel and provides additional insulation where required (junctions)
- Edge detailing is crucially important to maintain thermal performance



Design development: design criteria

- Largest possible panel size to maintain a favourable area to edge ratio
- Stainless steel to avoid contamination of the vacuum, thickness <0.7mm
- U-values of 0.11 – 0.09W/m^{2}K
- A nominal panel thickness of 115-140mm



Design development: Structural assessment

- Panels must resist atmospheric pressure of approximately 10 tonnes/m^2
- Arch configuration make use of thin gauge steel possible.

Key design issues:

- Geometry of the arch (span, height)
- Gauge and profile of steel used

The height-width ratio is critical – if the arch is too shallow, bending and shear dominate.

Second order elastic analyses were undertaken for a height of 50mm at various widths using an un-profiled skin

Design development: Structural assessment – flat steel

Width	Tie thickness (mm)	Skin thickness (mm)	Inertia (mm^4/m)*
600	0.43	3.73	4325
500	0.3	2.92	2075
400	0.19	2.2	887
300	0.11	1.54	304
200	0.05	0.95	71
150	0.03	0.71	30
100	0.02	0.50	10

Skin has to be very thick to withstand the stresses at 600mm when un-profiled (flat) steel is used

Design development: Structural assessment – ribbed steel

- Profiled steel (ribbed) was considered, of 200mm, 100mm, 50mm and 20mm spacing.
- 200mm and 100mm spacing were susceptible to local bucking and rejected.
- 50mm and 20mm spacing both worked.

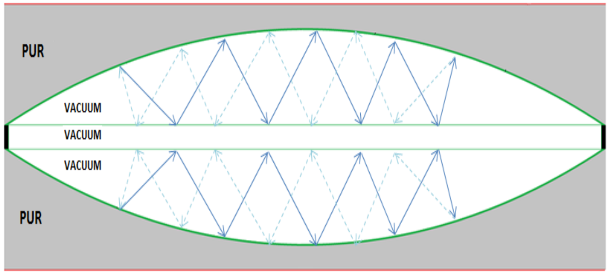
Table shows results for

20mm ribs.

Rib height (mm)	Suitable arch width (mm)			
	0.7mm skin	**0.6mm skin**	**0.5mm skin**	**0.4mm skin**
1	200	200	200	200
2	300	300	300	300
3	400	400	400	400
4	500	500	500	400
5	**600**	500	500	500
6	-	**600**	**600**	500
7	-	-	-	**600**

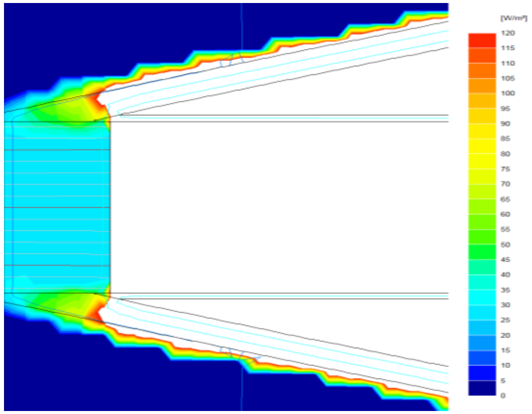
Design development: Thermal assessment

- Heat transfer through the panel is 15-20% radiative and 80-85% conductive
- Radiative heat transfer minimized by use of six low emissivity surfaces (shiny stainless steel)



Physibel modelling (BISCO):

Conduction occurs along the panel skins and through the edge detail. Edge detail design is critical



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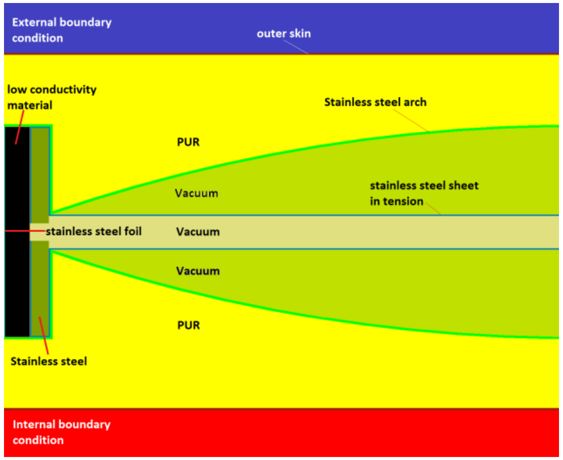
Design development: Thermal assessment

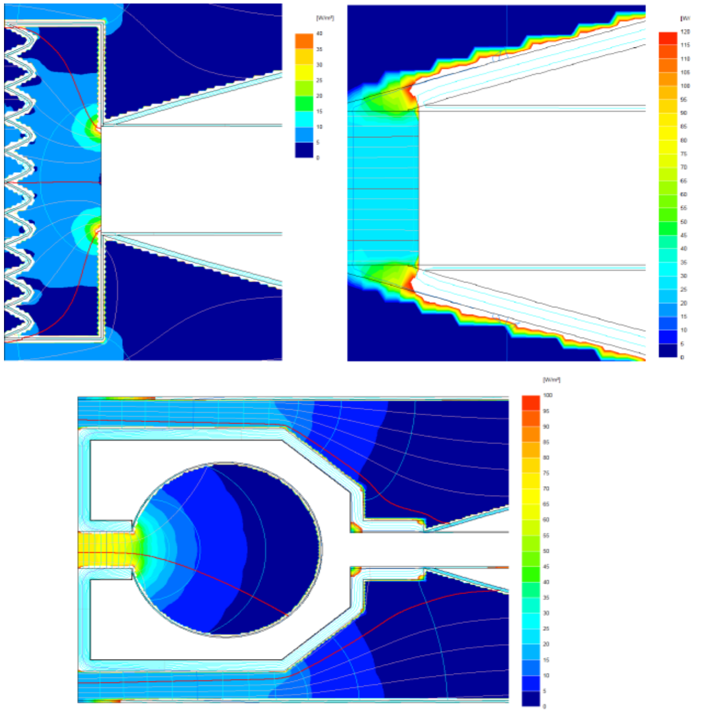
- Thermal engineering of edge detail to keep edge losses to a minimum.
- Conduction is the main heat flow mechanism:

- External panel face to foam fill
- Foam to arch and arch edge detail
- Edge detail to foil through stainless steel and support material
- Edge detail to edge detail through the load carrying contact points



Design development: Engineered Edge Detail

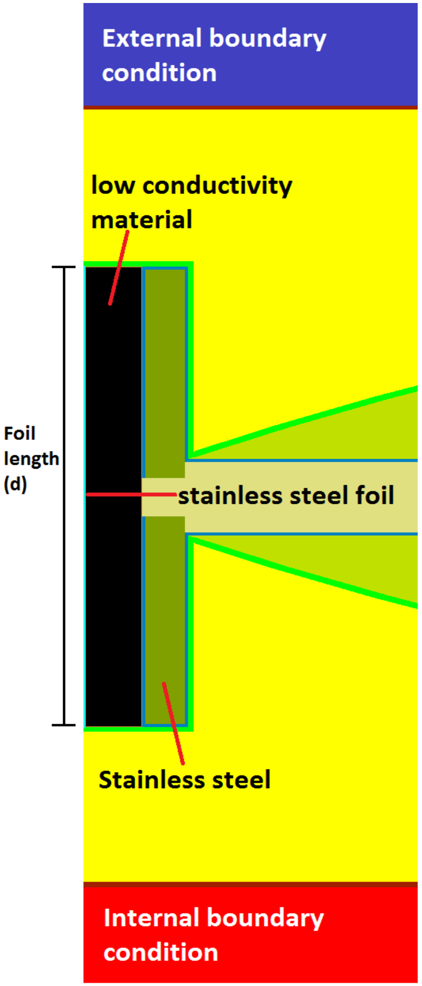
- A variety of edge detail designs were investigated.
- Objective was to maintain vacuum with minimal conduction
- Minimal foil thickness
- Maximum conduction path length



Design development: Engineered Edge Detail

- The final design as chosen:
- 60mm conduction path is required for target U-value

Foil length (d) (mm)	U-Value without considering the heat loss through the structural elements between arches ($W/m^2.K$)	Additional heat transfer through the structural elements ($W/m^2.K$)	Effective U-value ($W/m^2.K$)
20	0.101	0.006	0.107
30	0.098	0.006	0.104
40	0.096	0.006	0.102
50	0.095	0.006	0.101
60	0.094	0.006	0.1
70	0.094	0.006	0.1



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Conclusions

- A coreless vacuum panel has been developed and assessed both structurally and thermally.
- A U-value of $0.1W/m^2K$ can be achieved with a thickness of 100mm
- Next steps: prototyping to evaluate structural and thermal performance
- High performance building cladding with very low embodied energy