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Advancements in Smart Windows: Triple Vacuum Insulated Glazing for Sustainable Low-Carbon Buildings

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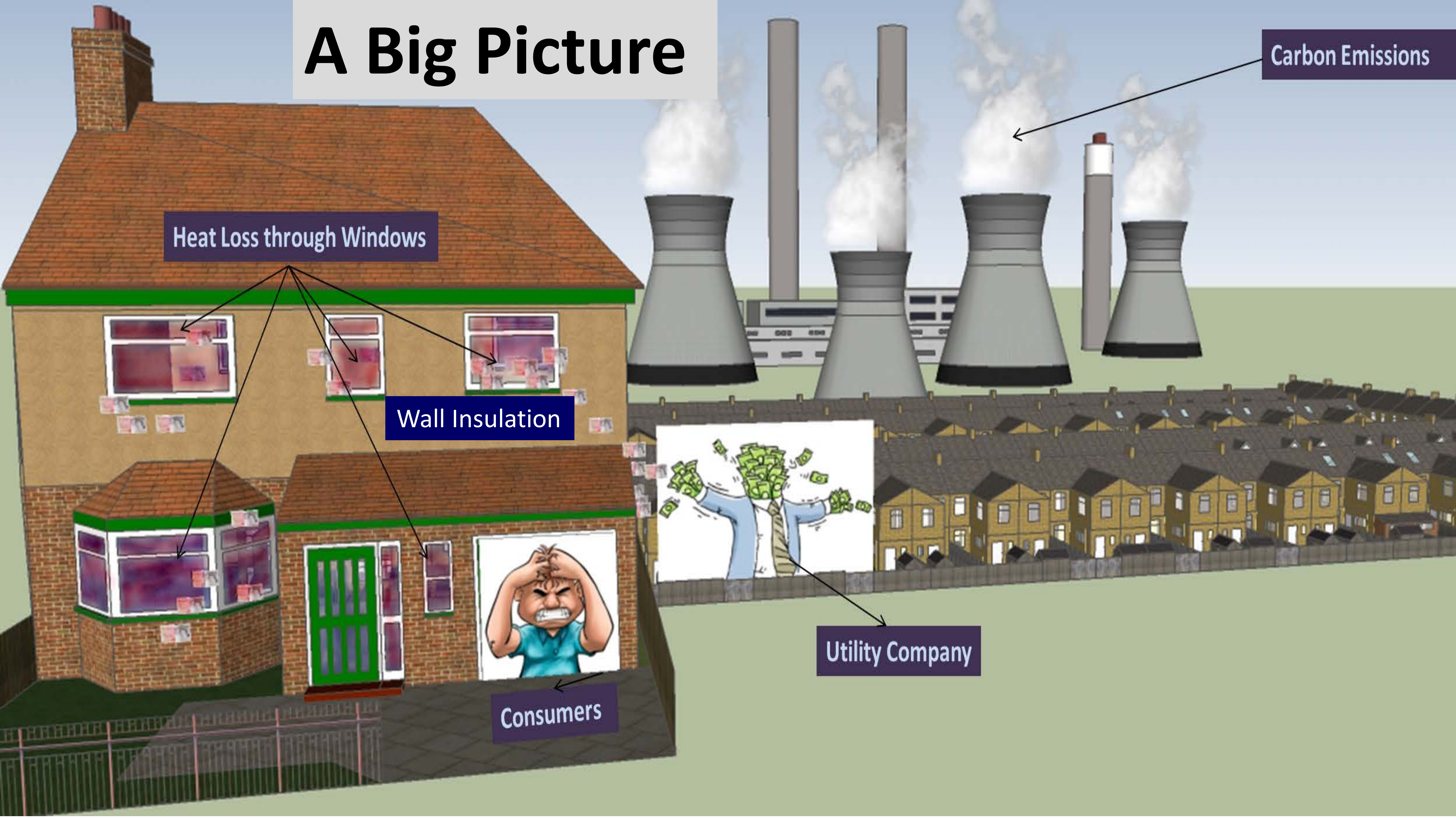
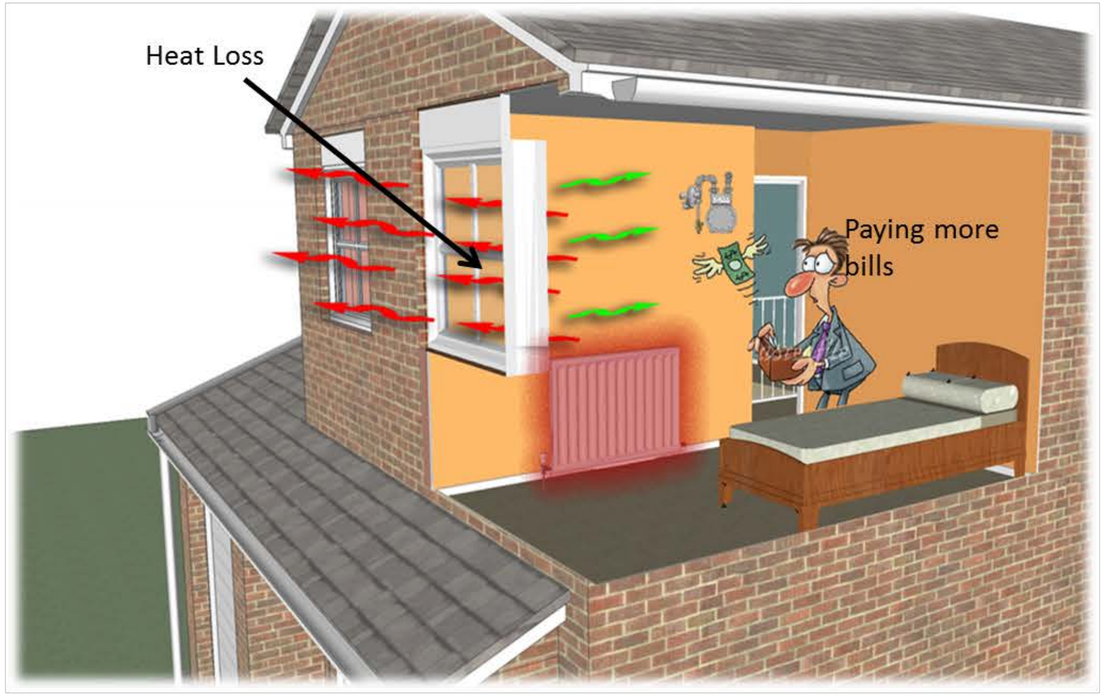
A Big Picture

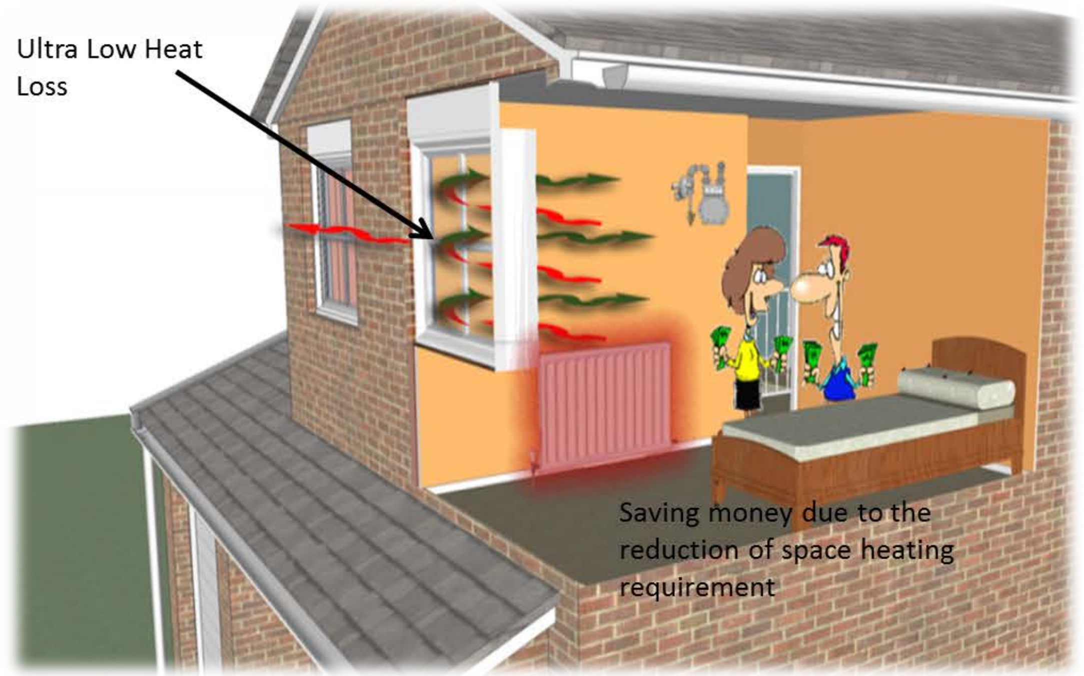


Problem



Heat loss through the windows of dwellings is a major concern due to the increase in use of natural gas in domestic boilers that not only increases the gas utility bills but also increases carbon emissions.

Solution



Vacuum glazing can not only reduce gas bills and CO_2 emissions but allows an increase in the window to wall area ratio that permits an increase in day light transmittance and solar gains.

Ref: *Memon, S., Eames, P. C. 2013. Fabrication of Energy Efficient Vacuum Glazing using a Novel Edge Sealing Material, 3rd International Low Carbon Energy Development Network (LCEDN), 24-25 Jun, London.*

Vacuum System Development

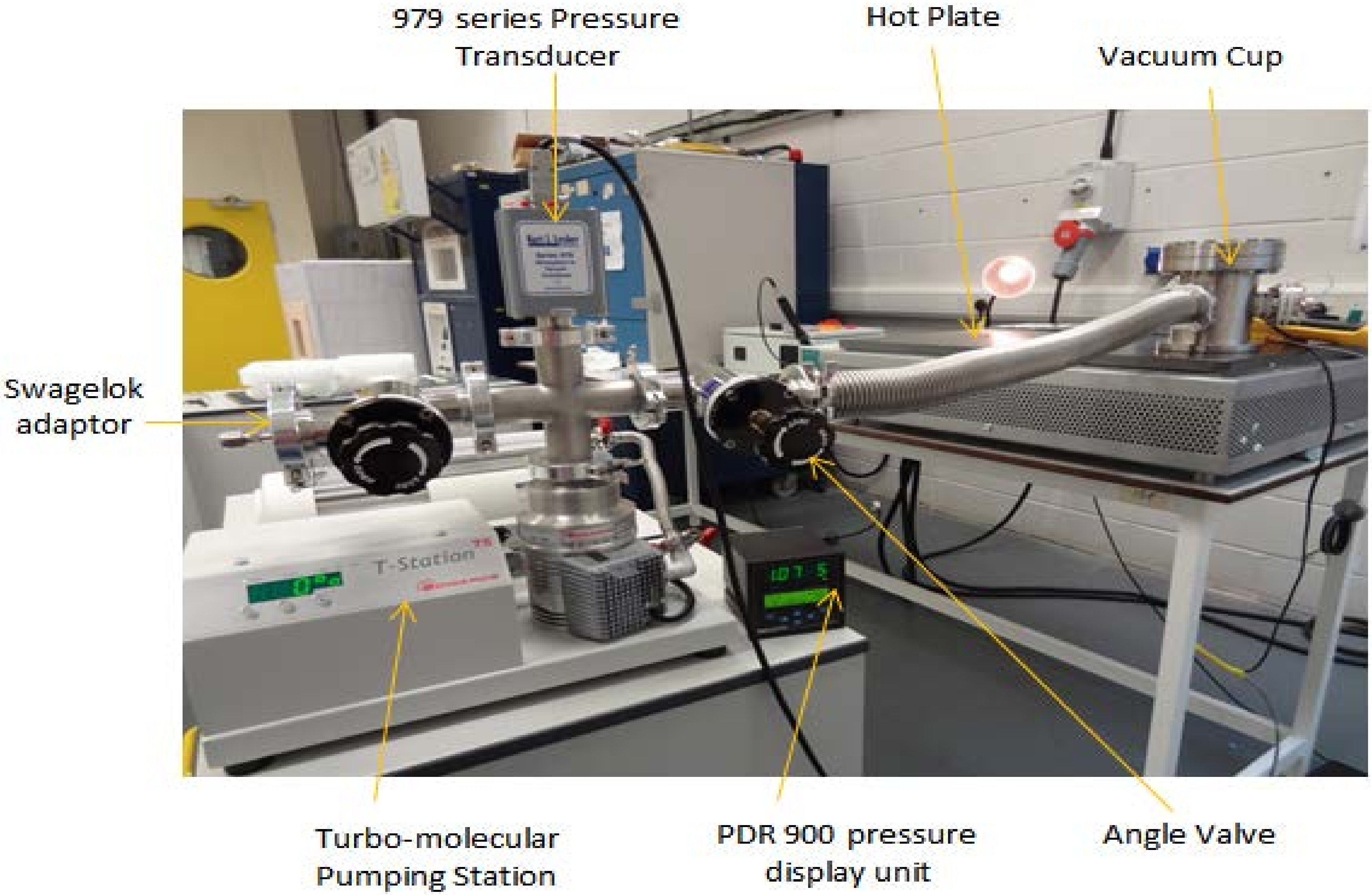


Figure: A photograph of the vacuum system developed based on the design presented in Fig.1.

Vacuum Cup Development

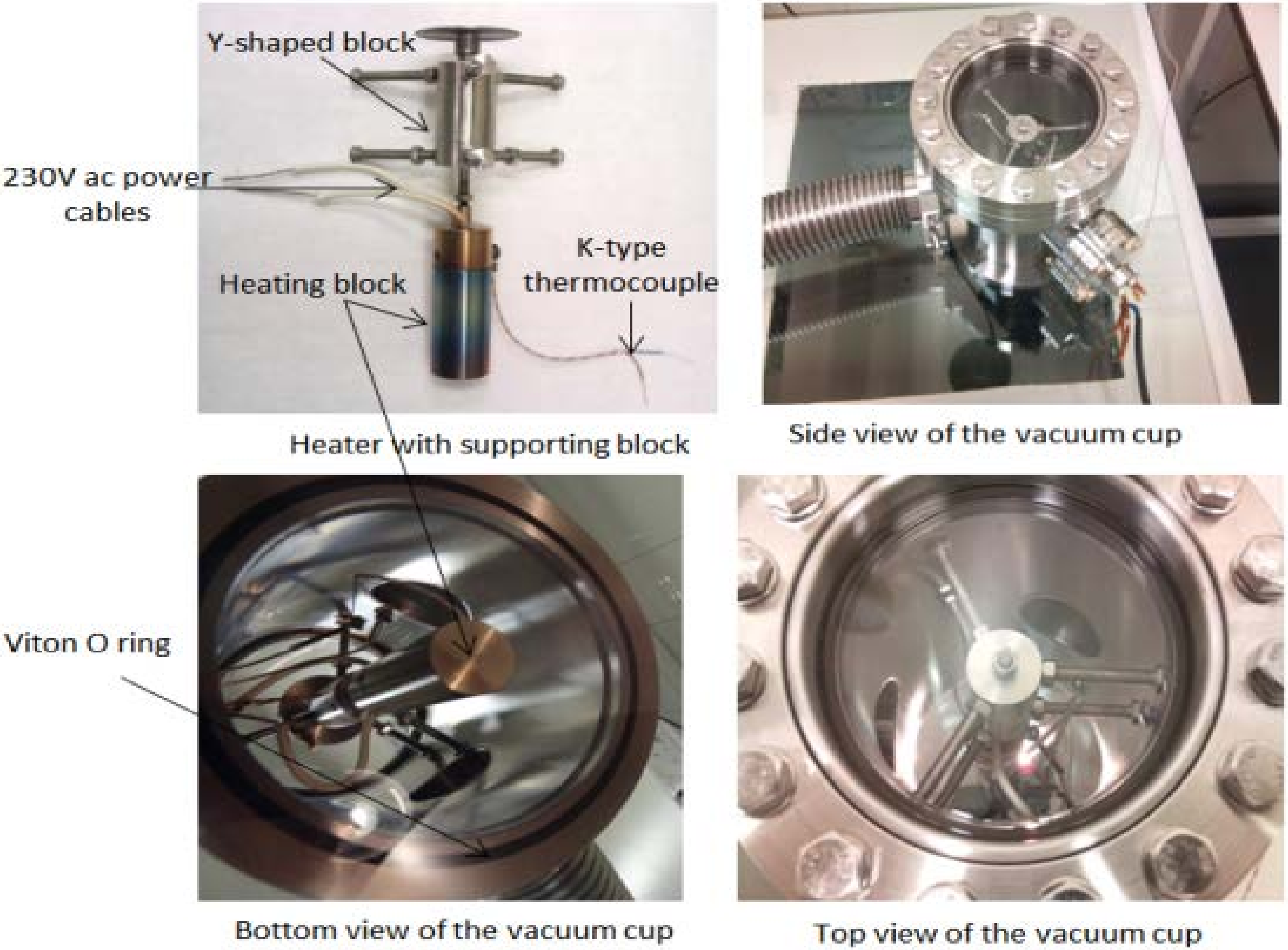


Figure: Photographs of the vacuum cup system for the evacuation and sealing of the pump-out hole of a triple vacuum glazing.

Fabrication process for Triple Vacuum Glazing using Novel Dual Edge Seal

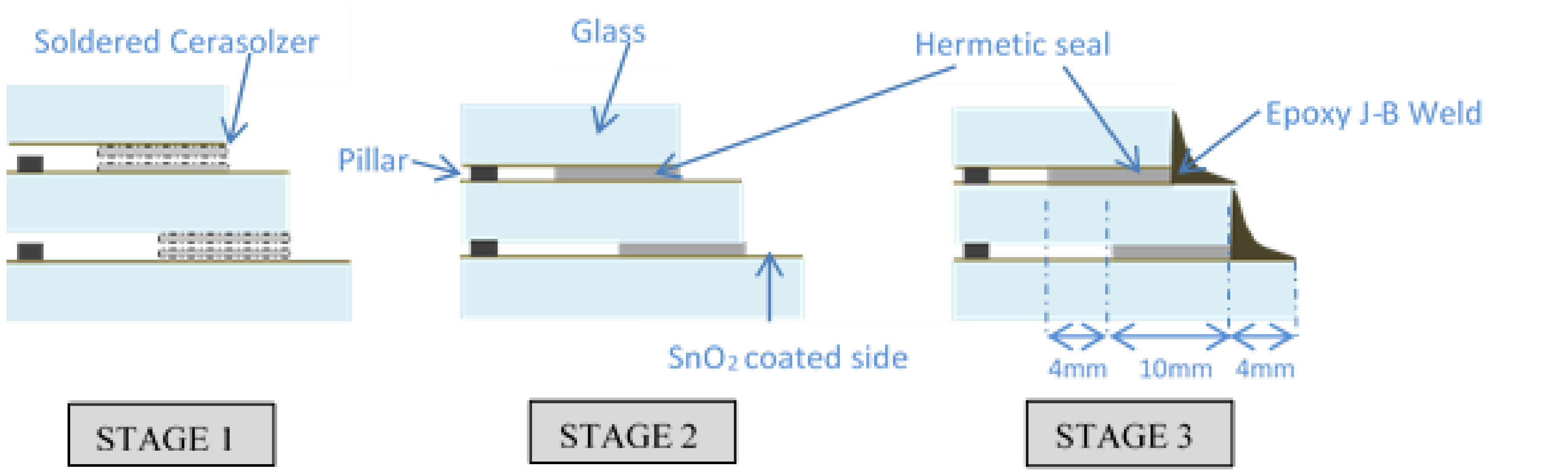


Figure: Three stage dual edge sealing design process for the fabrication of a Triple vacuum glazing.

Triple Vacuum Glazing with cost-effective materials at Loughborough University, UK

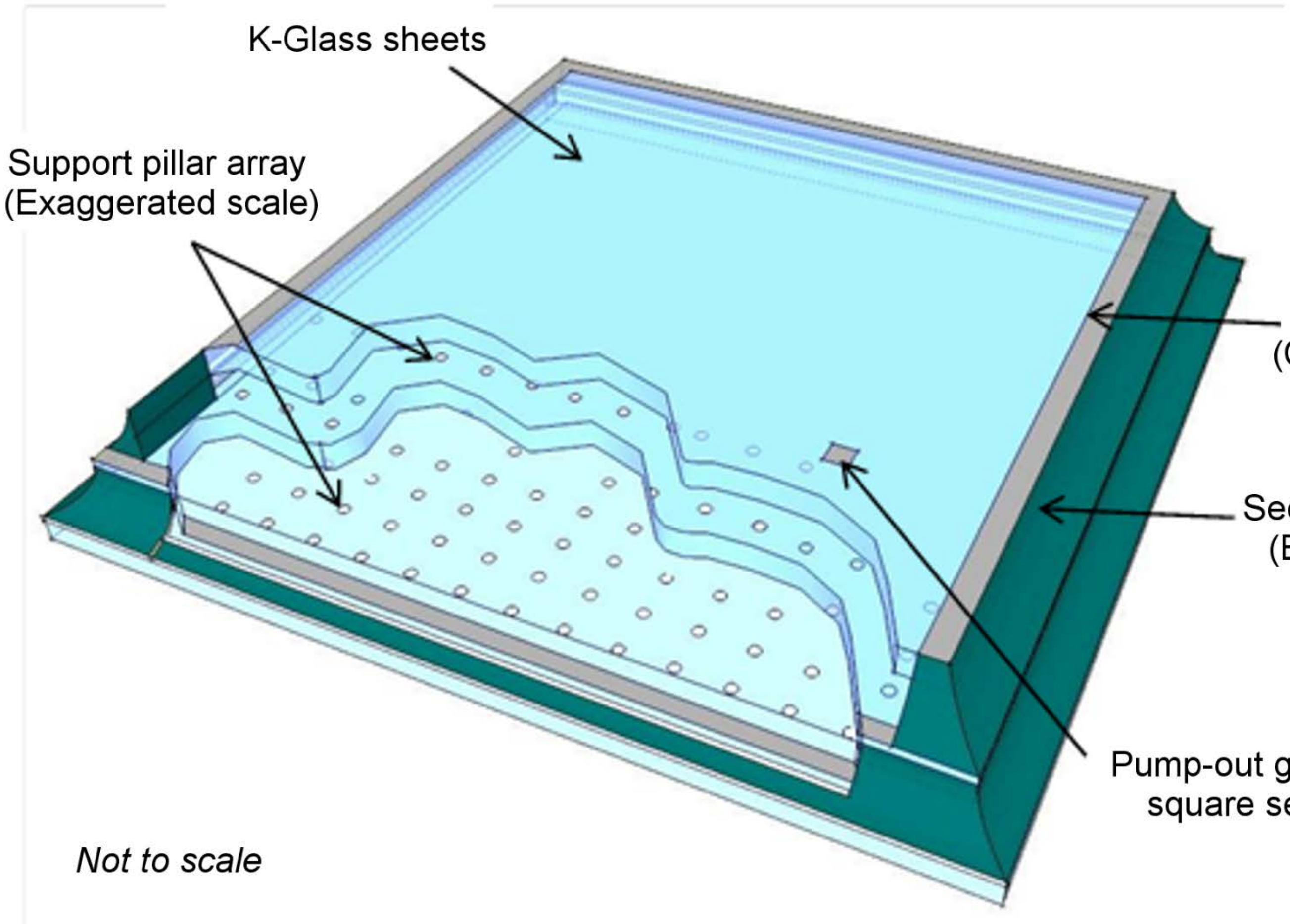
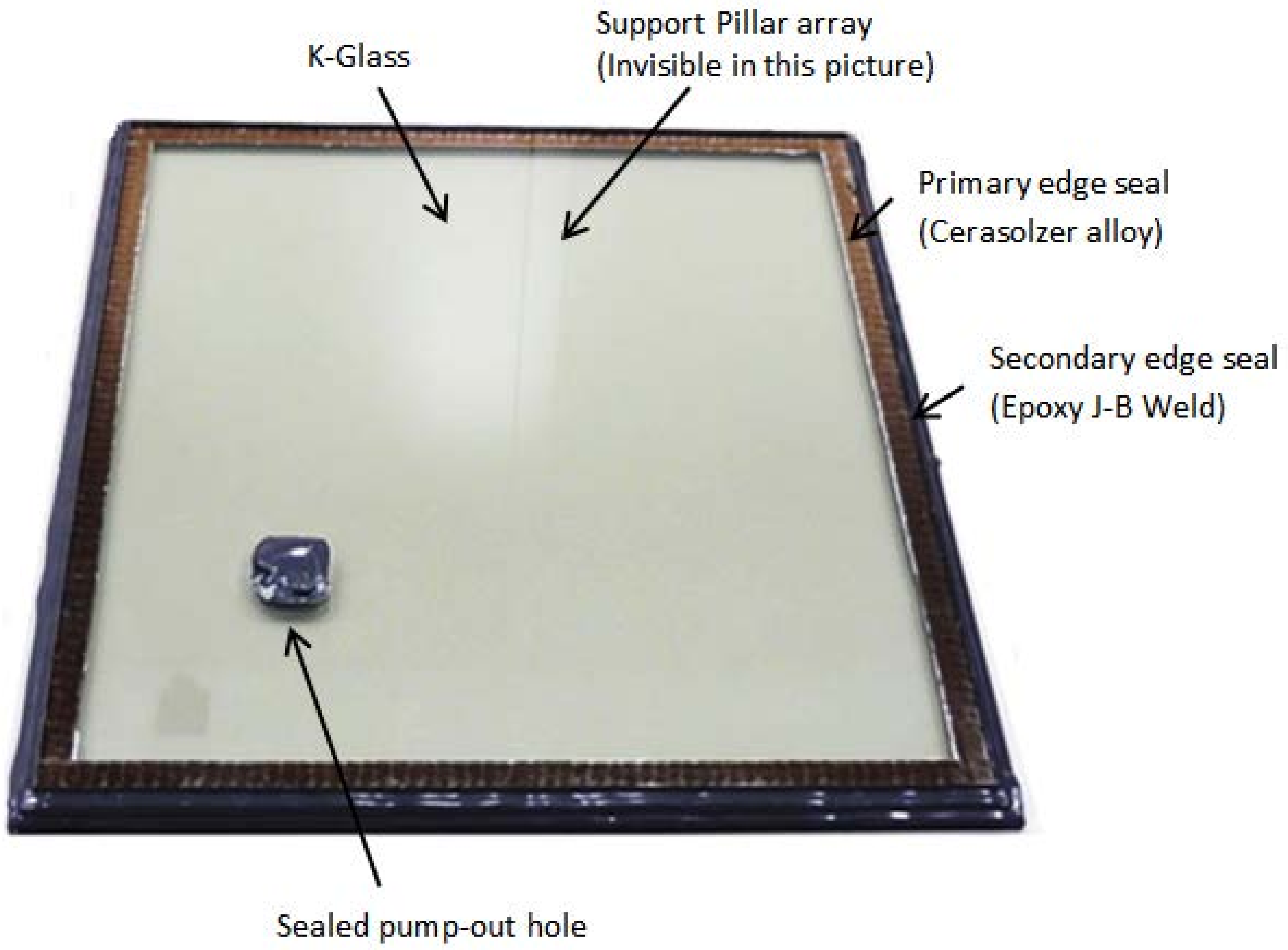


Figure: A schematic diagram of a triple vacuum glazing showing the primary edge seal made of Cerasolzer alloy and a secondary edge seal of epoxy steel resin.*

Ref: **Memon, S.** 2013. *Design, Fabrication and Performance Analysis of Vacuum Glazing Units Fabricated with Low and High Temperature Hermetic Glass Edge Sealing Materials*. PhD Thesis. Loughborough University: UK. DOI: https://dspace.lboro.ac.uk/2134/14562

A fabricated triple vacuum glazing of dimensions 300x300mm with dual edge seal.



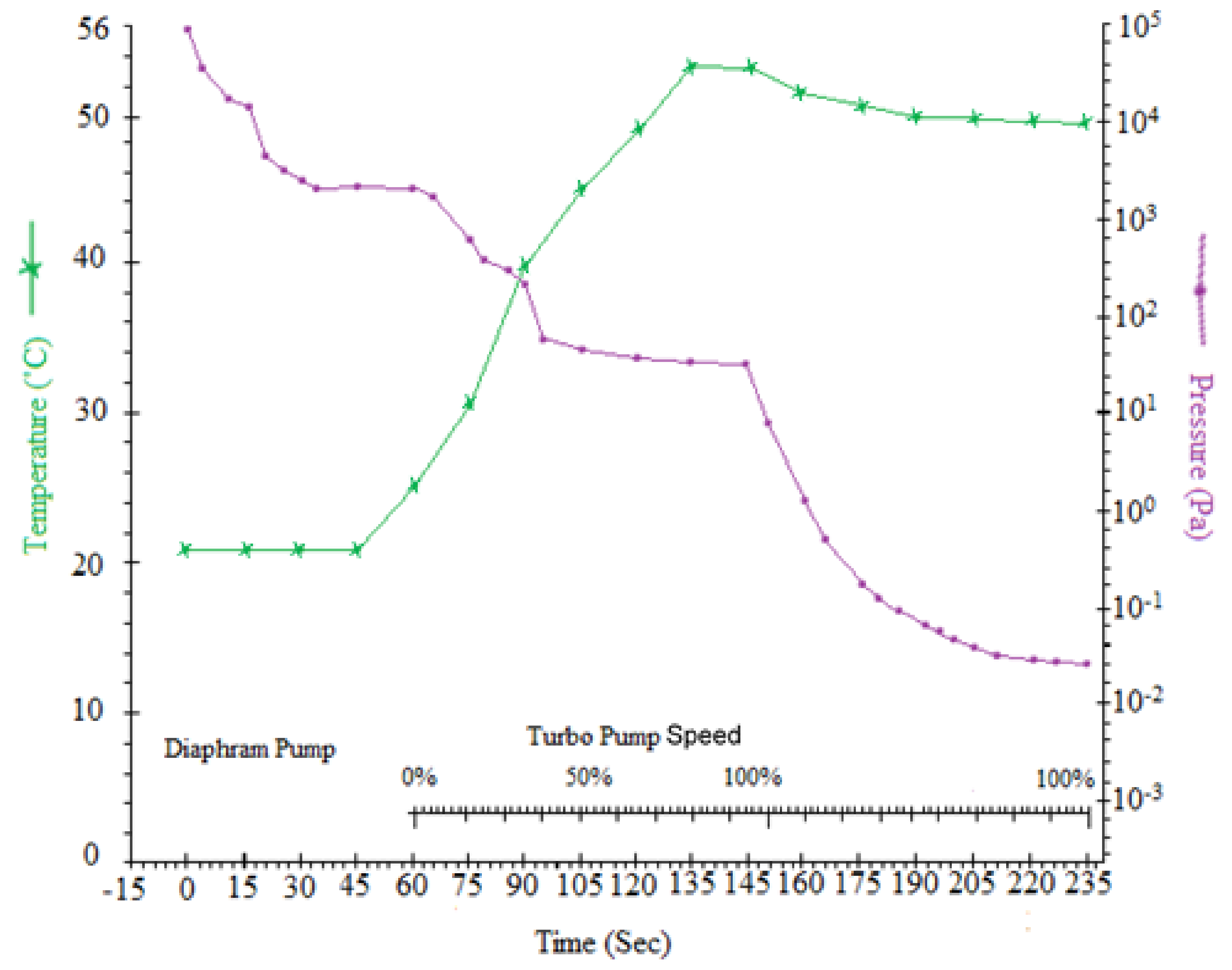
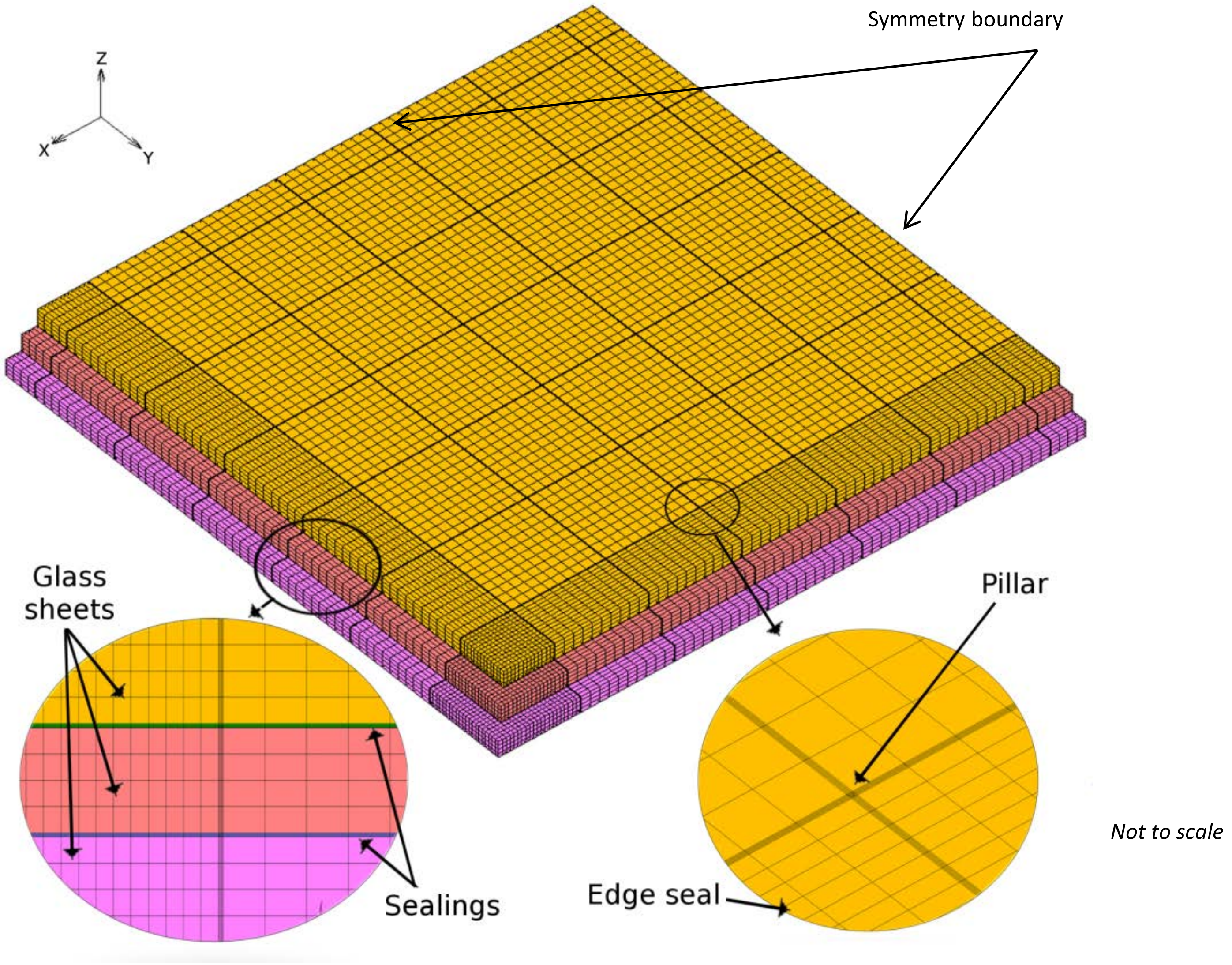


Figure: Typical temperature/pressure profiles for evacuation and heating of triple vacuum glazing

Finite element mesh of a quarter (150x150mm) of the triple vacuum glazing.



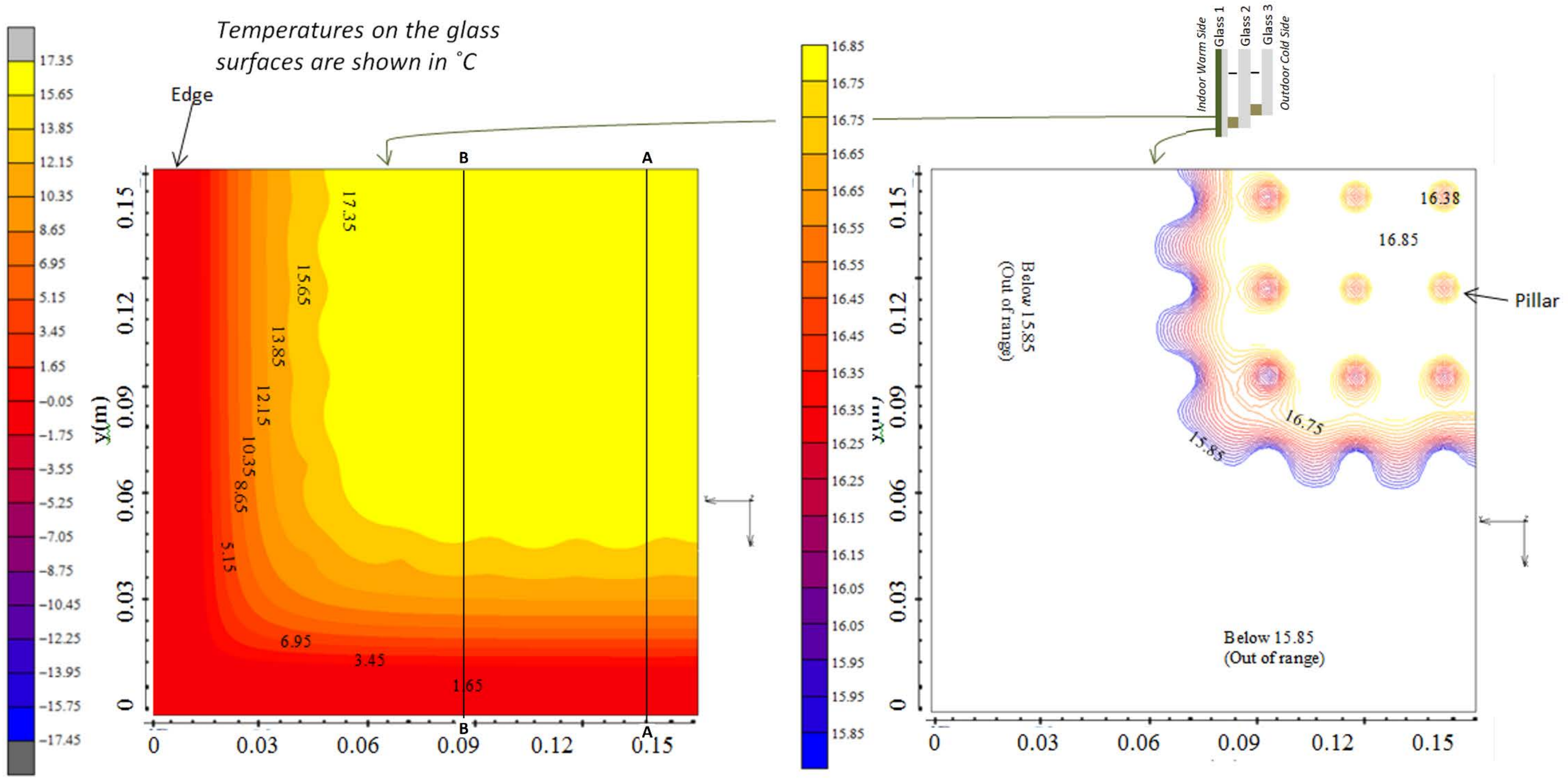


Figure: Predicted isotherms on the warm (indoor side) glass surface showing (A)the temperature variations from the edge area towards the central area and (B) the temperature variations around the centre-of-pane support pillar area for the simulated triple vacuum glazing

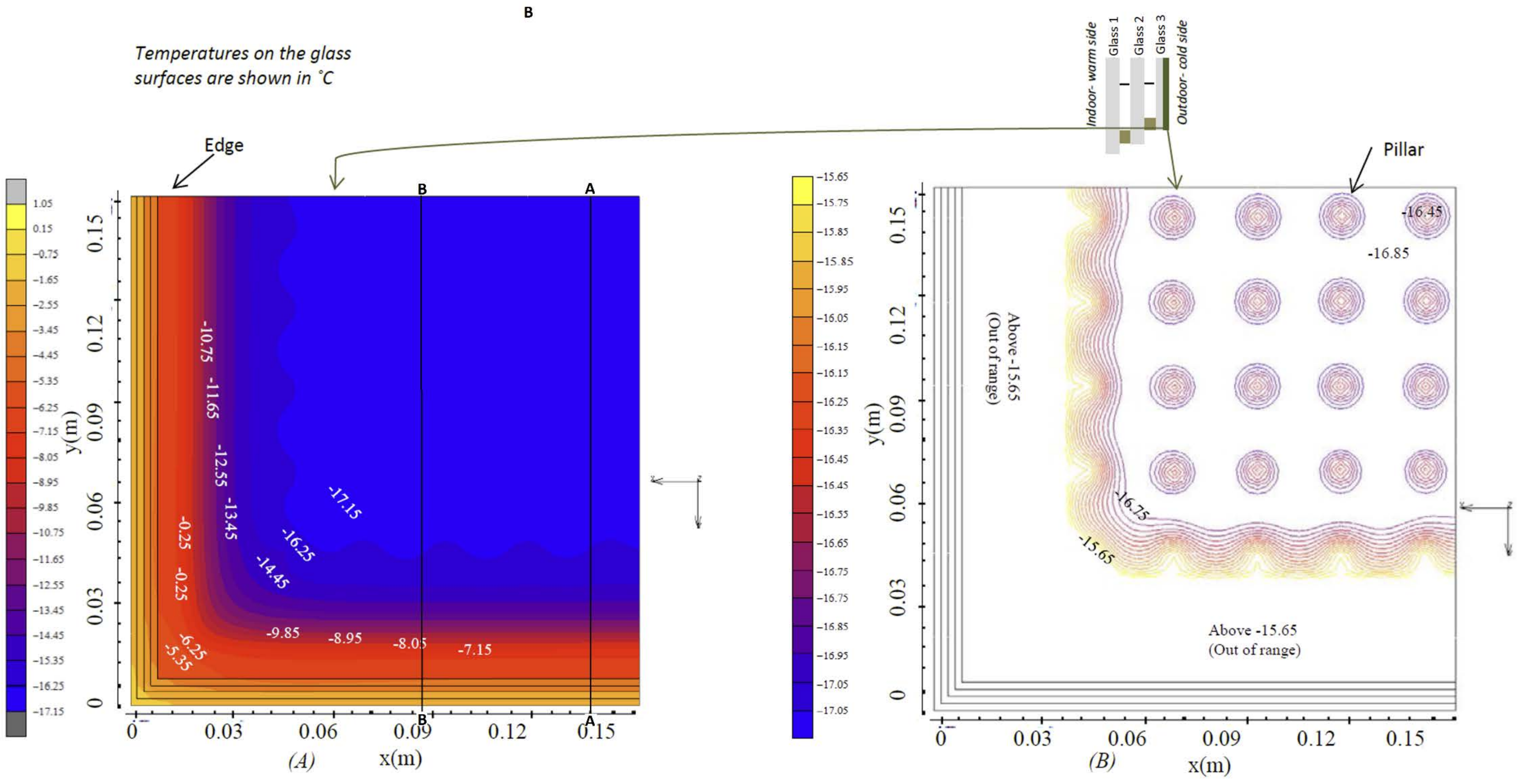


Figure: Predicted isotherms on the cold (outdoor side) glass surface showing (A) the temperature variations from the edge area towards the central glazing area and (B) the temperature variations around support pillars on the central glazing area of the simulated triple vacuum glazing.

The calculated costs of the glass edge sealing materials used for the fabrication of double and triple vacuum glazings.

Sample	Glazing dimensions (mm)	Edge seal width (mm)	Material quantity used (grams)								Total cost of materials in GBP	Calculated cost in GBP per m^2
			Cerasolzer alloy wire CS186 (10mm layer)	Indium-1 metal wire (8mm layer)	Indium-2 metal wire (8mm layer)	Epoxy J-B Weld	Pump-out hole Seal*					
							Cerasolzer alloy wire CS186	Epoxy J-B Weld/ Araldite	Indium-1 metal wire	Indium-2 metal wire		
Double Vacuum Glazing (X1)	300x300	14mm	9.53	-	-	14	0.65	0.42 Araldite	-	-	9.98	31.81 Cost based on the prices of materials in the European Union
Double Vacuum Glazing (X2)	300x300	8mm	-	8.1	-		-	-	0.5	-	65.44	209.28 Cost based on the prices of materials in the European Union
Double Vacuum Glazing (X3)	300x300	8mm	-	-	8.1		-	-	-	0.5	8.57	27.39 Cost based on the prices of materials in China
Triple Vacuum Glazing (Y1)	300x300	14mm	17.31	-	-	26	0.65	0.42 J-B Weld	-	-	17.63	57.36 Cost based on the prices of materials in the European Union
Triple Vacuum Glazing (Y2)	300x300	8mm	-	16.8	-		-	-	0.7	-	133.18	431.49 Cost based on the prices of materials in the European Union
Triple Vacuum Glazing (Y3)	300x300	8mm	-	-	16.8		-	-	-	0.7	17.43	56.47 Cost based on the prices of materials in China

*The amount of material required for the pump-out hole sealing is the same for all sizes of the glazing unless specified.

Summary of Glazing Technologies compared to commercial Vacuum Glazing Units

Window Category	*Total Thickness*	*Low-emissivity coating*	*Centre-of- pane U values $Wm^{-2}K^{-1}$*
Single	4mm	No coating (ε=0.89)	5.75
Double glazed Air-filled	20mm	SnO_2 (ε=0.15-0.18)	2.85
Double glazed Argon gas filled	20mm	SnO_2 (ε=0.15-0.18)	2.67
Triple glazed Air-filled	36mm	SnO_2 (ε=0.15-0.18)	1.89
Triple Vacuum Glazed	12.26mm	SnO_2 (ε=0.15-0.18)	0.33

Conclusions

- The experimental testing results have shown the achievable vacuum pressure in the vacuum system to be **4.35×10^{-5} Pa.** This deviates by 7.7% with the ultimate vacuum pressure of the turbo molecular pump due to the molecular air flow conductances through the vacuum system.

- A vacuum cup designed to **reduce the risk of dislocation of the heating block and the degradation of O rings** due to continuous heating with the pump-out hole evacuation.

- The outcome of the design and development of high-vacuum system was the **successful fabrication of ultra-low heat loss triple vacuum glazing with a pump-out hole sealing material using Cerasolzer CS-186.**

- A **new method** of fabricating triple vacuum glazing based on a low melt temperature (186ºC) dual-edge seal was designed and experimentally validated, consisting of Cerasolzer CS186 alloy as a main seal and J-B Weld epoxy steel resin as a support seal.

- A vacuum pressure of **4.8×10^{-2}Pa** was achieved.

- A 3D FEM of the fabricated design of triple vacuum glazing was developed in which the centre-of-pane and overall U-values of a triple vacuum glazing (300mm x 300mm) were predicted to be **$0.33 Wm^{-2}K^{-1}$ and $1.05 Wm^{-2}K^{-1}$**, respectively.

- **Triple vacuum glazing has the potential in future, if manufactured at the mass production level, because of its slimness (12.6 mm) compared to the conventional glazings and due to its lowest achievable thermal transmittance value.**