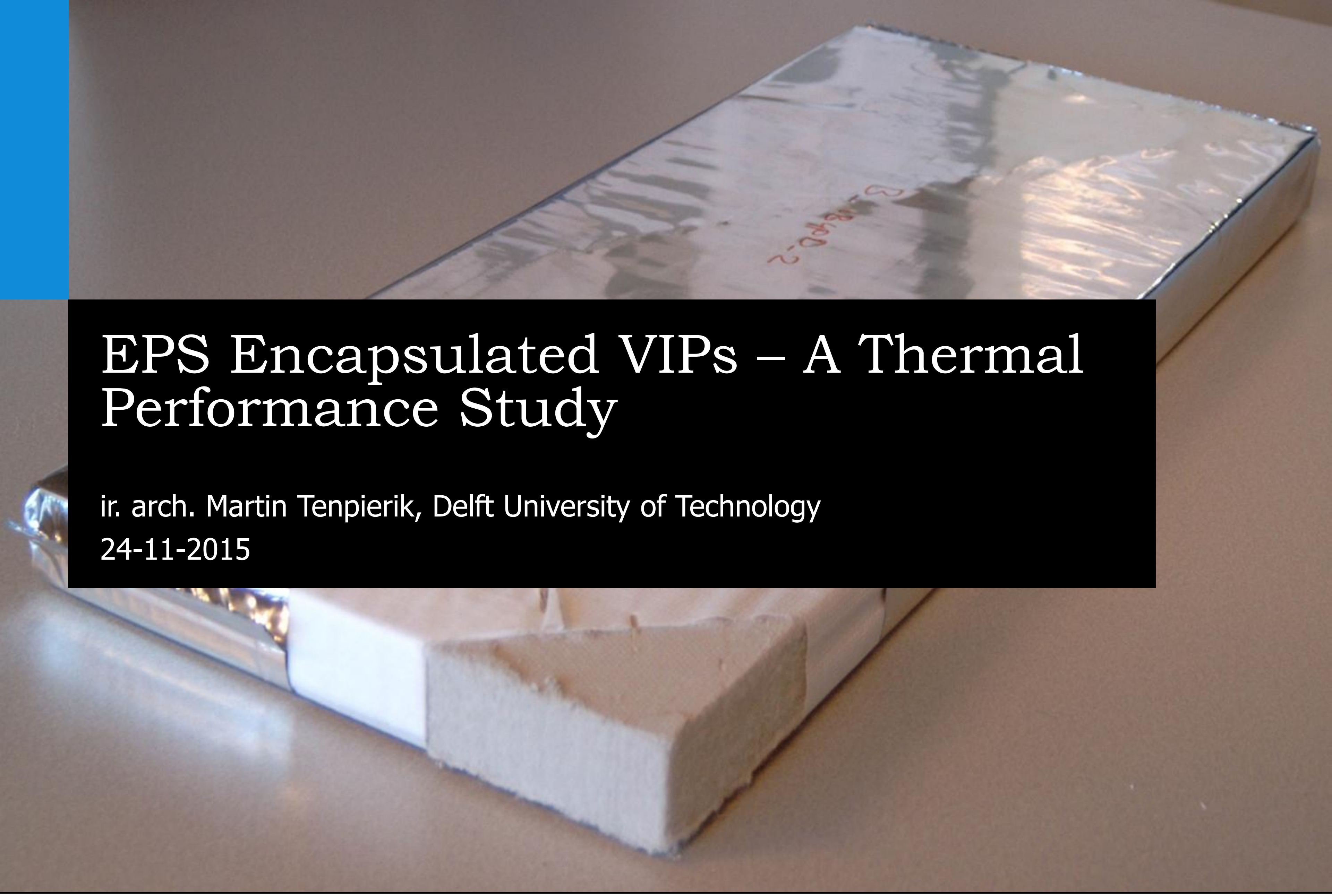

EPS Encapsulated VIPs – A Thermal Performance Study

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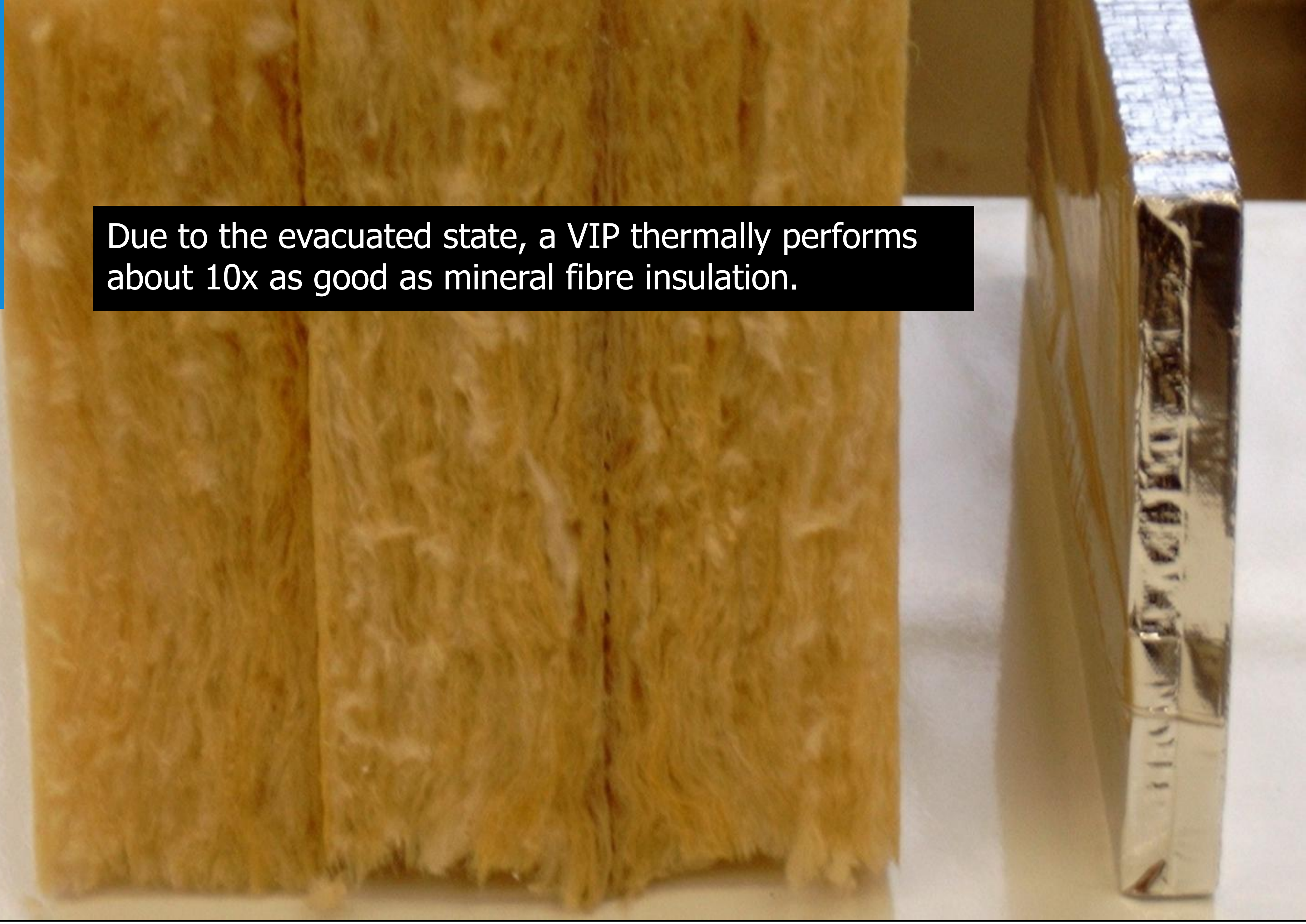
- Conclusion

Research Objective

To improve the thermal performance of EPS insulation boards using vacuum insulation panels.



Due to the evacuated state, a VIP thermally performs about 10x as good as mineral fibre insulation.

Definition

(EPS) covered VIPs

(EPS) encapsulated VIPs

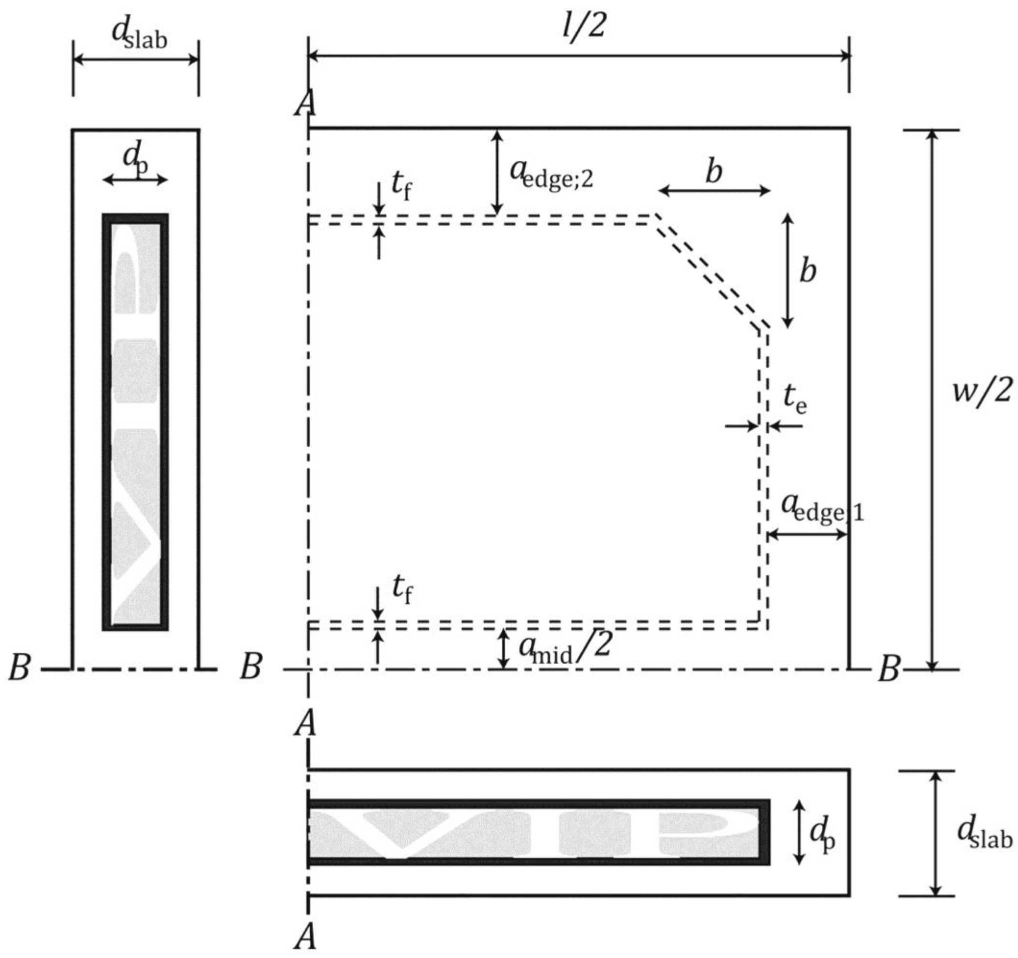
Starting Points for 3D Case-Study

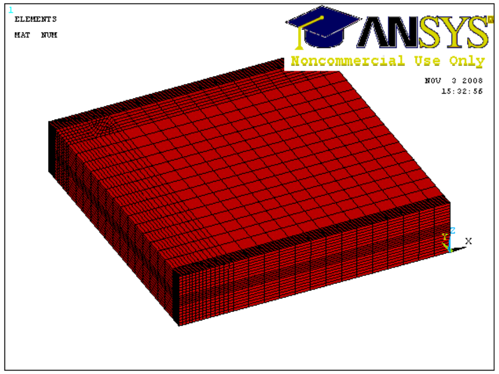
- EPS insulation boards of fixed size: 1000x1000x100 mm^3;
- 2 identical VIPs inside of variable thickness: 1 to 99 mm;
- Variable thermal conductivity core: 0.004-0.008 $Wm^{-1}K^{-1}$;
- Variable size of EPS strip along perimeter: 25 or 50 mm;
- Use of 40 μm aluminium foil based laminate;

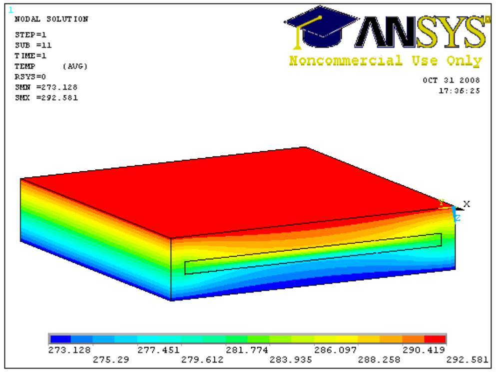
- Numerical computations;
- Thermal resistance calculated as

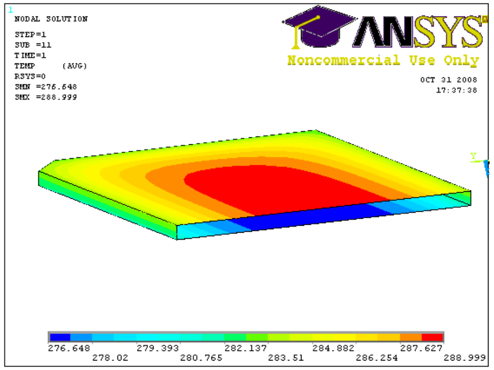
$$R_{c;eff} = \frac{S \cdot \Delta T}{Q} - \frac{1}{\alpha_i} - \frac{1}{\alpha_e} \quad .$$

Quarter of 3D Model

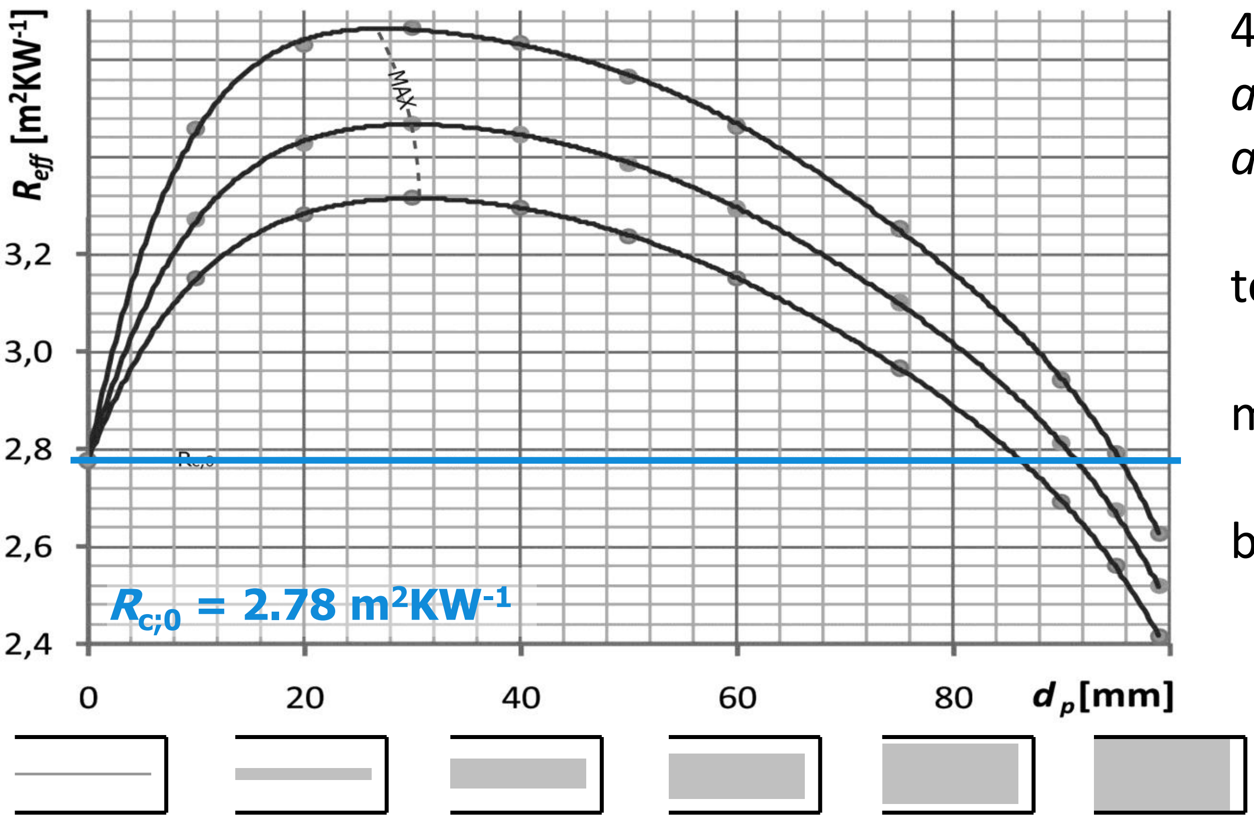








Subset of Results (3D)



40 μm alu. barrier;
$a_{edge;1}$ = 25 mm;
$a_{edge;2}$ = 50 mm;

top:
λ_c=0.004 Wm^{-1}K^{-1}
middle:
λ_c=0.006 Wm^{-1}K^{-1}
bottom:
λ_c=0.008 Wm^{-1}K^{-1}

Conclusions from 3D model

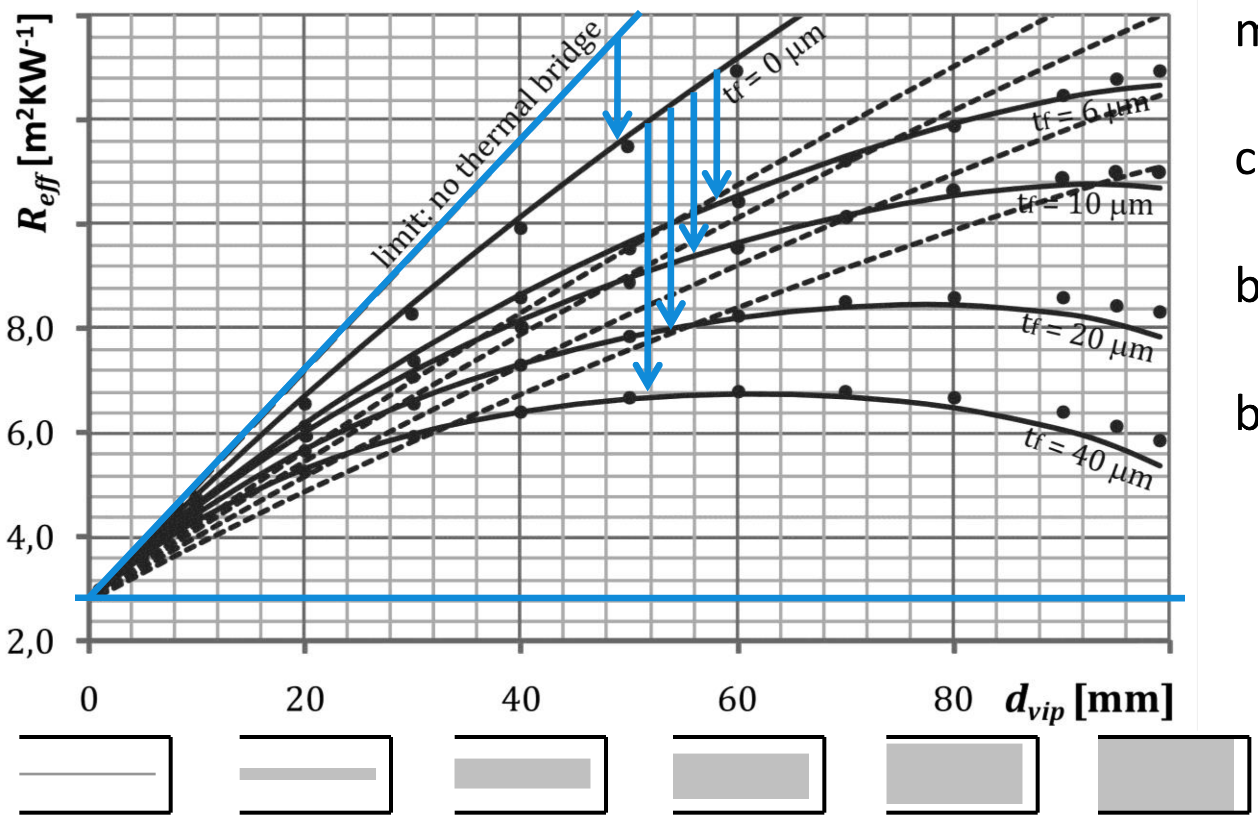
- Thermal performance decreases for increasing λ_c;
- Thermal performance decreases for increasing width EPS;
- There exists a maximum in thermal performance at a VIP thickness near 30 mm;
- Very thick VIPs result in a thermal performance worse than 100 mm EPS board.

Starting Points for 2D Analysis

- EPS boards of fixed size: 500 wide, 100 mm thick;
- One VIP inside of variable thickness: 1 to 99 mm;
- Constant thermal conductivity core: 0.004 $Wm^{-1}K^{-1}$;
- Constant size of EPS strip along perimeter: 25 mm;
- Variable thickness of alu. foil: 0 to 40 μm;

- Combination of numerical models, analytical models and ISO6946:2007.

Results (2D): with EPS coverings

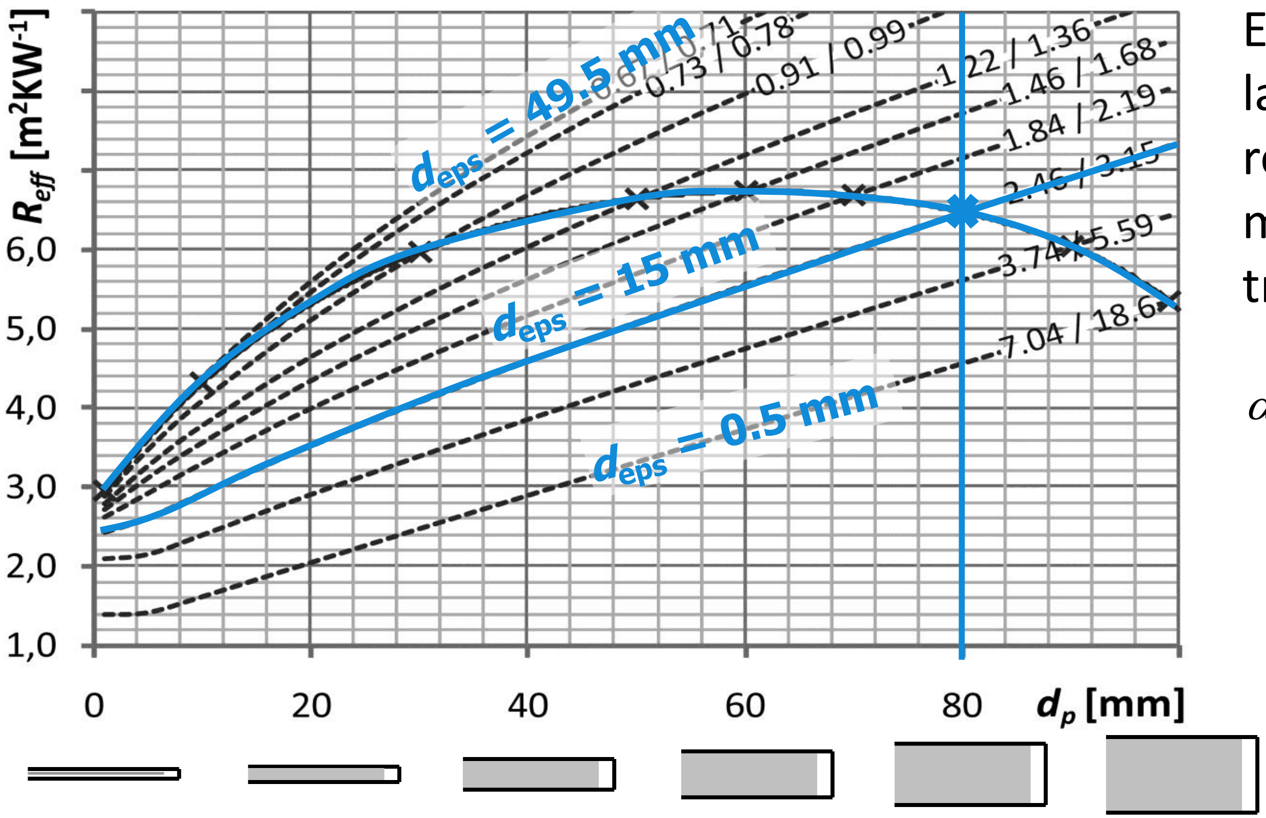


markers:
numerical data;
continuous lines:
analytical model;
broken lines short:
ISO 6946;
broken lines long:
limiting case.

Observation 1

The thickness of the barrier laminate, or in fact the product of thickness and thermal conductivity, seems to influence the occurrence of a maximum in thermal performance of EPS encapsulated VIPs.

Results (2D): no EPS coverings



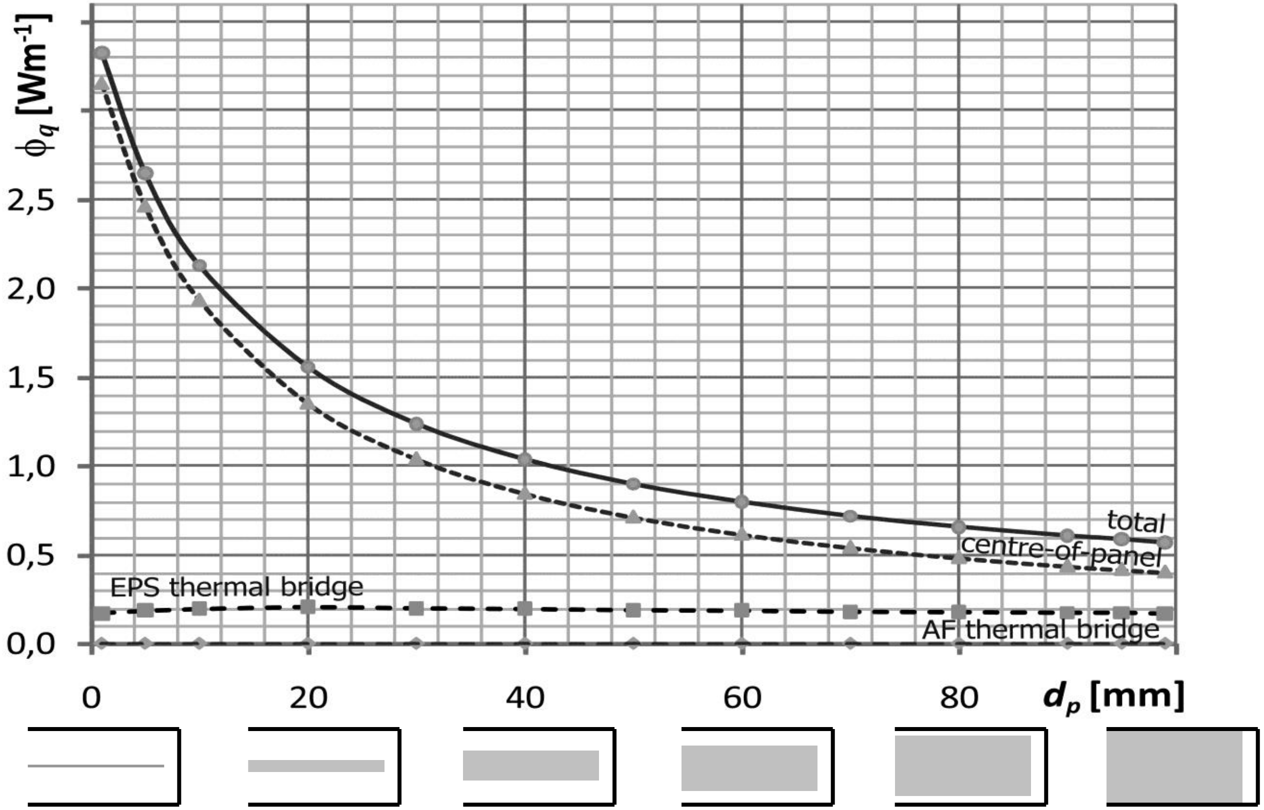
EPS top and bottom layers can be represented by modified boundary transfer coefficients

$$\alpha^* = \frac{1}{1/\alpha + d_{eps}/\lambda_{eps}}$$

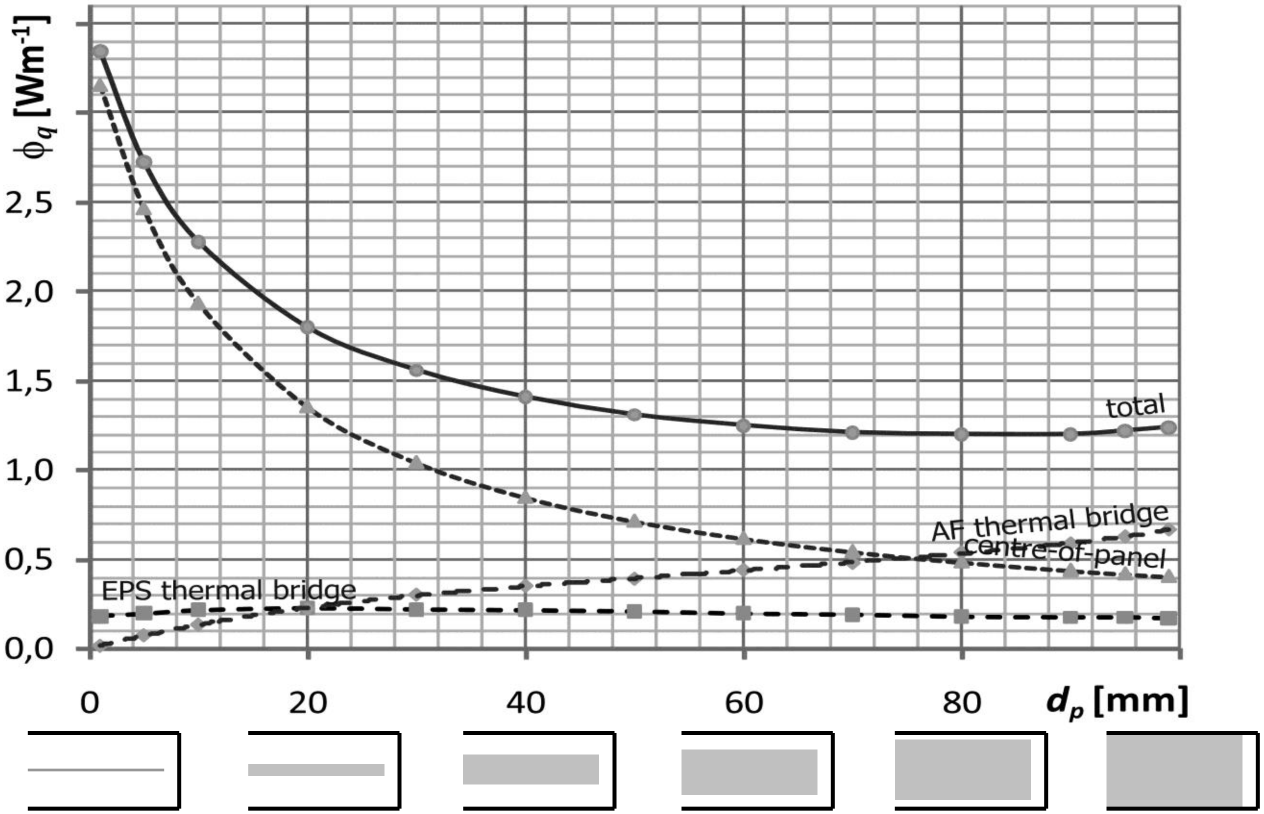
Observation 2

The varying thickness of the EPS top and bottom layers, or in other words the modified boundary heat transfer coefficients, also seem to influence the occurrence of a maximum in thermal performance of EPS encapsulated VIPs.

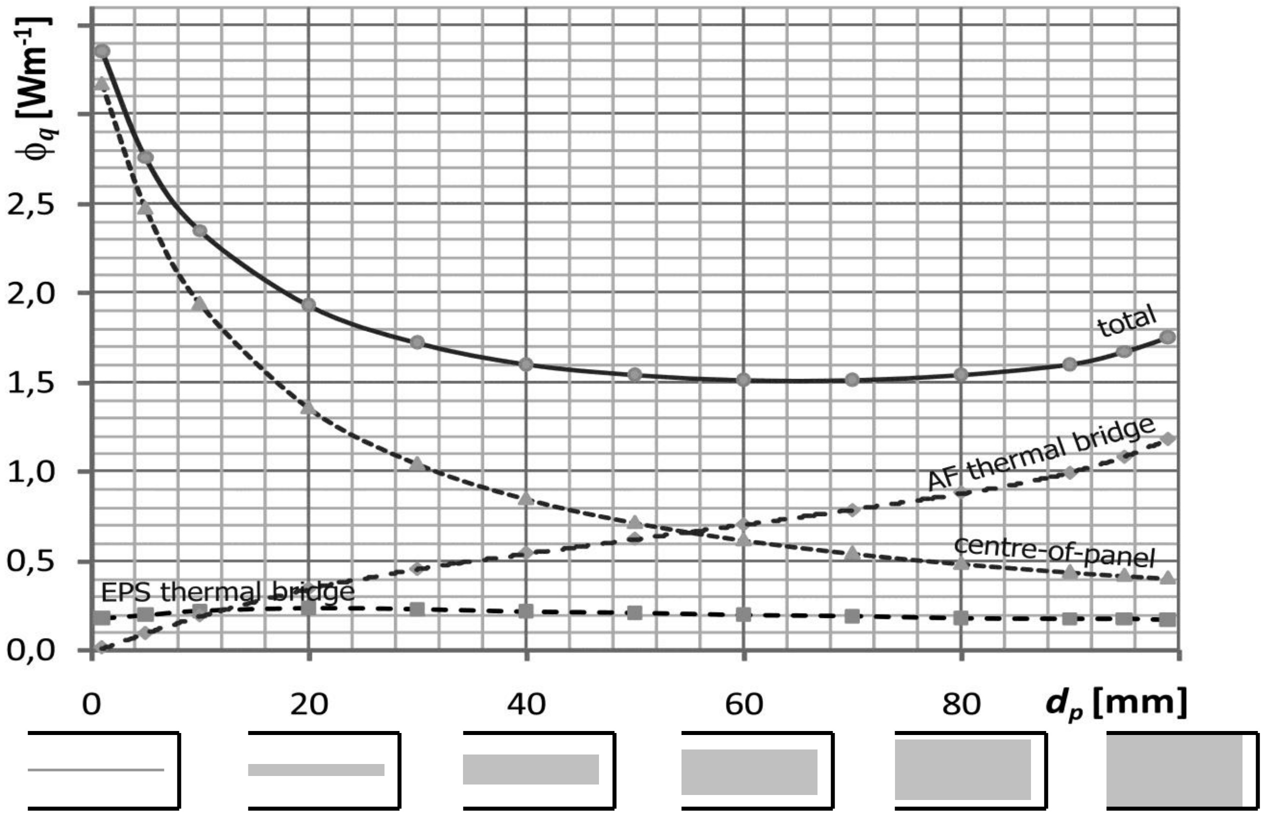
Results (2D): heat flows – 0 μm AF



Results (2D): heat flows – 20 μm AF



Results (2D): heat flows – 40 μm AF



Final Conclusion

If thick metal foil based barrier envelopes are used and the thickness of the entire insulation layer is fixed, it is not always wise to maximise the thickness of a vacuum insulation panel encapsulated by polymeric foam insulation.

Closure

Thank you very much for your attention!

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Maximum Performance – Math.Proof

Assumption: The heat flow through the thermal bridge can be computed using the equation for the linear thermal transmittance of a VIP with λ_c = 0 $Wm^{-1}K^{-1}$

$$\frac{\phi_{q,kobru}}{\Delta T} = \psi_{vip,edge,0} = \frac{1}{\frac{d_p}{t'_f \lambda'_f} + \frac{1}{\sqrt{\alpha_1^* t_f \lambda_f}} + \frac{1}{\sqrt{\alpha_2^* t_f \lambda_f}}}$$

with

$$\alpha_j^* = \left(\frac{1}{\alpha_j} + \frac{0.1 - d_p}{2\lambda_{eps}} \right)^{-1}$$

Maximum Performance – Math.Proof

The heat flow trough the centre-of-panel area follows from

$$\frac{\phi_{q,cop}}{\Delta T} = \frac{b}{R_{cop}} \approx b\left(\frac{d_p}{\lambda_c} + \frac{1}{\alpha_1^*} + \frac{1}{\alpha_2^*}\right)^{-1}$$

Maximum Performance – Math.Proof

The sum of both heat flows is the total heat flow which has as derivative

$$\frac{d}{dd_p}\left(\frac{\phi_q}{\Delta T}\right) = -\psi^2_{vip,edge,0}\left(\frac{1}{t'_f\lambda'_f} - \frac{\sqrt{\alpha_1^*}+\sqrt{\alpha_2^*}}{4\lambda_{eps}\sqrt{t_f\lambda_f}}\right)$$

$$-b\left(\frac{1}{\lambda_c}-\frac{1}{\lambda_{eps}}\right)\left(\frac{d_p}{\lambda_c}+\frac{1}{\alpha_1^*}+\frac{1}{\alpha_2^*}\right)^{-2}$$

Where this derivative equals zero, a maximum in thermal performance occurs.

Maximum Performance – Math.Proof