Fachhochschule Dortmund
University of Applied Sciences and Arts

ULTRALIGHT

Further improvement of an ultra slim, energy efficient façade and window system based on fiber-reinforced plastics (FRP) and vacuum glazing (VIG) for optimum thermal insulation

SUMMARY REPORT

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Further development of an ultra slim, energy efficient façade and window system based on fiber-reinforced plastics (FRP) and vacuum glazing (VIG) for optimal thermal insulation.

Motivation

Aim of our research was the optimization of the window system developed in project ULTRASLIM (II 3-F20-10-1-062 / SF - 10.08.18.7-11.35) by means of a more detailed analysis of heat transmission and wind load stresses. We also investigated additional modes of opening and methods to further minimize heat transfer. In addition, we examined the refurbishment of an old window with vacuum glazing for reducing heat losses through windows in old buildings.

Items of research

As a first phase in project ULTRALIGHT, the profile geometry developed in project ULTRASLIM (3.2.10) for a window system with vacuum glazing underwent an in-depth analysis. A more detailed investigation of the thermal behavior was necessary, as vacuum glazing differs fundamentally from conventional – noble gas filled - multiple glazing units regarding heat transfer properties. While vacuum glazing offers extremely low center-of-pane U_g-values, the welded glass edge seal constitutes a thermal bridge comparable to the metal spacers in older insulation glazings. This thermal bridge must be compensated by the ULTRALIGHT window profile, which is made of glass-fiber-reinforced plastics with low thermal conductivity. Additionally, the behavior of the window exposed to wind forces was to be examined.

Both FEM simulation of heat transmission and differential climate indicated that, at low outside temperatures, condensation of moisture can occur around the edge of glazing on the room side ($\theta_{si,min}$ = 6.1 °C at θ_e = -5 °C). Filling the profile cavities with insulating material (WLG 030) showed little improvement. These limitations notwithstanding, the basic ULTRALIGHT profile allows for very slim windows with U_w-values of 0.8 W/m^{2}K. External FEM simulations (IB Kramer) of wind load stresses revealed that wind suction in particular could cause a displacement of the glazing and considerable torsion of the window sash. Consequently, high wind load stresses could force the rubber seal open.

Both FEM simulation of wind loads and considerations of thermal insulation suggested an increase in profile size. Accordingly, we developed a new and improved profile geometry (3.2.12.1) by way of intermediates. Having increased in height from 26 mm to 40 mm, the new, larger profile showed considerably smaller, noncritical distortions under wind load in FEM simulations. Thermal insulation properties of the window were also improved significantly ($\theta_{si,min}$ = 10.2 °C at θ_e = -5 °C). We again checked if filling the profile cavities with insulation material (WLG 030) could offer further improvement. While insulating the window frame showed little effect, insulating the window sash afforded lower U_w-values (ca. 0.7 W/m^{2}K), but also lower surface temperatures on the room side.

The new profile geometry also allowed for the placement of bulkier window fittings and thereby alternative modes of opening. Out of these, we examined pivoting top-hung windows and turn- and-tilt windows in detail. In order to facilitate a turn-tilt-window, the by far most common type of window in Germany, we developed a hybrid window concept (3.2.12.2). In the new FRP-wood hybrid window, the load-bearing fiberglass profiles are augmented with tailored wood components. The hybrid window also offers slightly improved thermal insulation (U_w about 0.7 W/m^{2}K, $\theta_{si,min}$ = 10.5 °C at θ_e = -5 °C).

We then further investigated the effect of expected short- to mid-term improvements to vacuum glazings on the ULTRALIGHT window system. We were able to show that a reduction in height of the glazing edge seal - already technically feasible according to the manufacturer Synergy - significantly improved obtainable U_w-values as well as surface temperatures on the room side. In a different approach, we were able to show that thermal insulation cladding on the outside could also strongly improve the heat transfer properties of the ULTRALIGHT window, especially in the zone around the glazing edge seal ($\theta_{si,min}$ = 12.1 °C instead of 10.2 °C at θ_e = -5 °C for 5 mm insulation cladding WLG 030).

In addition to these investigations into new window systems optimized for vacuum glazing, we also examined the feasibility of replacing the glazing in old windows with vacuum glazing in order to reduce building heat losses. As an example for this procedure, we chose an old coupled window with wooden frame and sash. In the course of the refurbishment one pane of float glass was replaced by vacuum glazing (U_g = 0.58 W/m^{2}K) and additional seals were added to the window. As a result, we were able to reduce the U_w-value of the window from 2.2 to 1.2 W/m^{2}K while retaining the optical appearance of the old window, especially from the outside.

Conclusion

After establishing the properties and limitations of the initial ULTRALIGHT geometry by means of FEM simulation and experiment, we were able to optimize the profile significantly using these results. The new ULTRALIGHT window system offers improved thermal insulation and the option of implementing different opening modes.

In addition to these results we were able to show that vacuum glazing can be a feasible means to reduce the heat loss in old windows without altering the outer appearance. This new option for a window refit should be checked for efficiency in individual cases and properly coordinated with other refurbishments.

Project data

Short title:	ULTRALIGHT
Researcher/project leader:	Prof. Armin D. Rogall
Basic project:	
overall cost:	123.243,10 €
federal funding:	86.043,10 €
project duration:	12 months 2013-09-02 – 2014-09-02
Extended project:	
add. overall cost:	73.650,00 €
add. federal funding:	50.850,00 €
add. project duration:	12 months 2014-09-02 – 2015-09-02 (extended until 2016-10-15)

Images

Image 1: Ultralight_01.jpg
edge seal in a triple glazing unit (top) and in a vacuum glazing (bottom)
optical microscope, magnification 20x

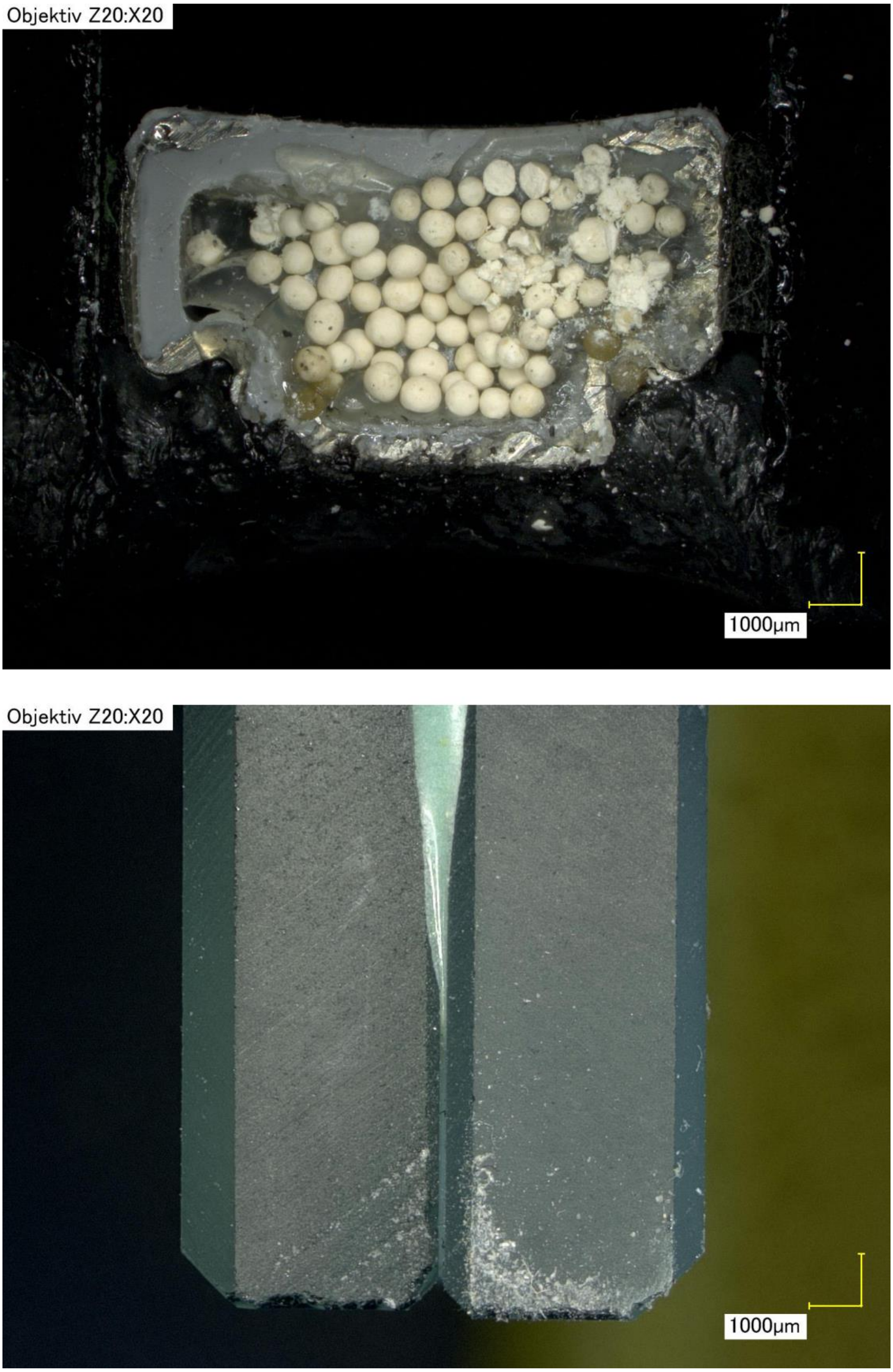
Image 2: Ultralight_02.jpg
Ultralight profile 3.2.10, parallel-stay window
simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

Image 3: Ultralight_03.jpg
Ultralight profile 3.2.12.1, parallel-stay window
simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

Image 4: Ultralight_04.jpg
Ultralight profile 3.2.12.2, turn-and-tilt window
simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

Image 5: Ultralight_05.jpg
diagram: minimum room side surface temperature $\boldsymbol{\theta_{si,min}}$ over height of edge seal $\mathbf{h_{rv}}$
θ_i = 20 °C and θ_e = -5 °C or 0 °C, FEM-simulation (THERM 7.4)

Image 6: Ultralight_06.jpg
diagram: $\mathbf{U_w}$-value (window 1230 x 1480 mm, U_g = 0.42 W/m^{2}K)
over thickness $\mathbf{d_{ds}}$ of outside insulation cladding (WLG 020 - 040)
θ_i = 20 °C and θ_e = -5 °C, FEM-simulation (THERM 7.4)



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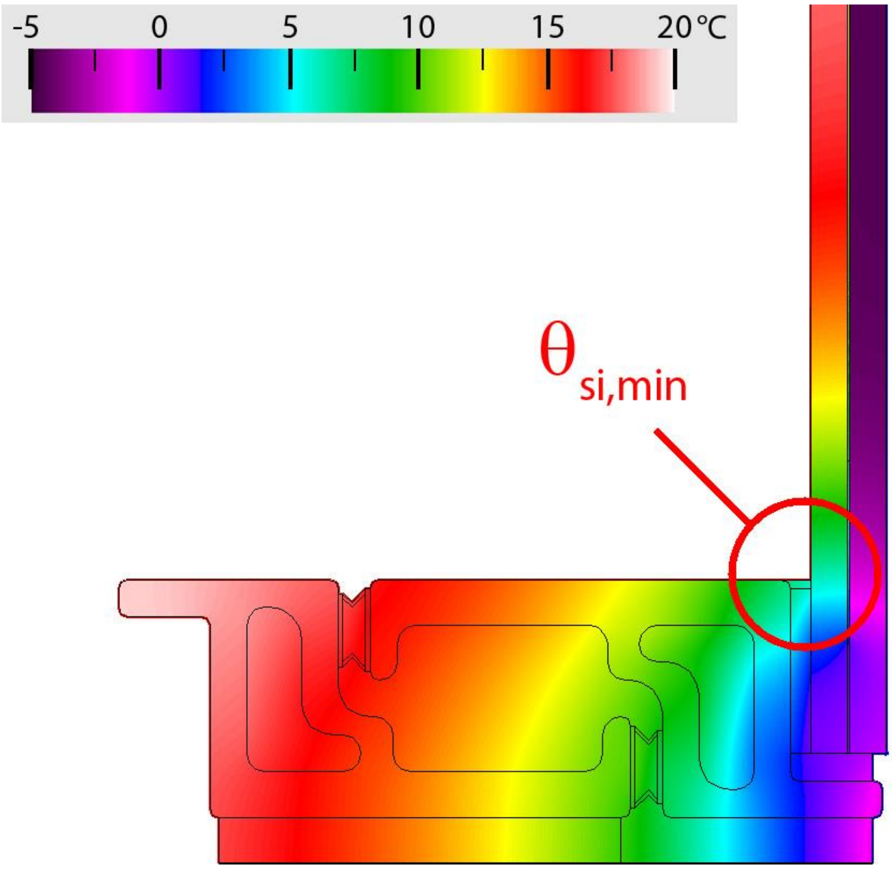


Image 2: Ultralight_02.jpg

Ultralight profile 3.2.10, parallel-stay window

simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

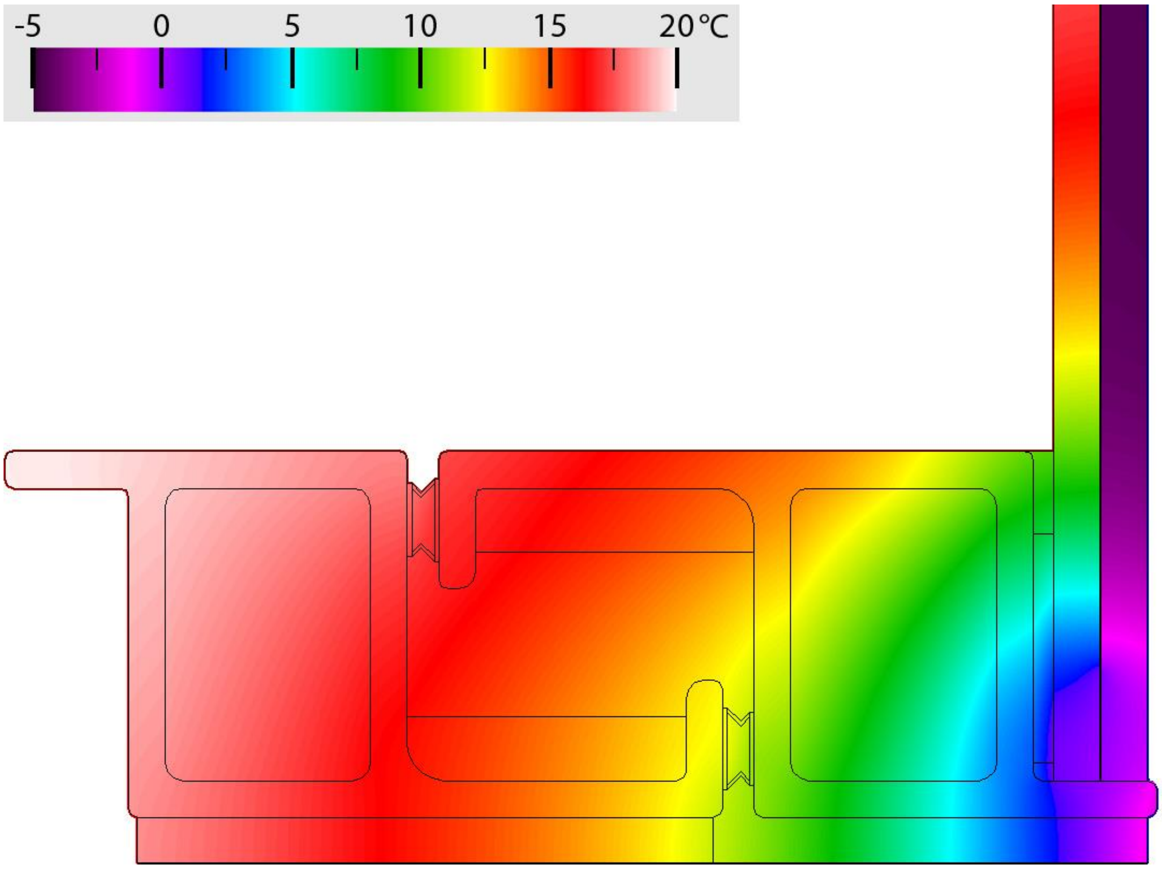


Image 3: Ultralight_03.jpg
Ultralight profile 3.2.12.1, parallel-stay window
simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

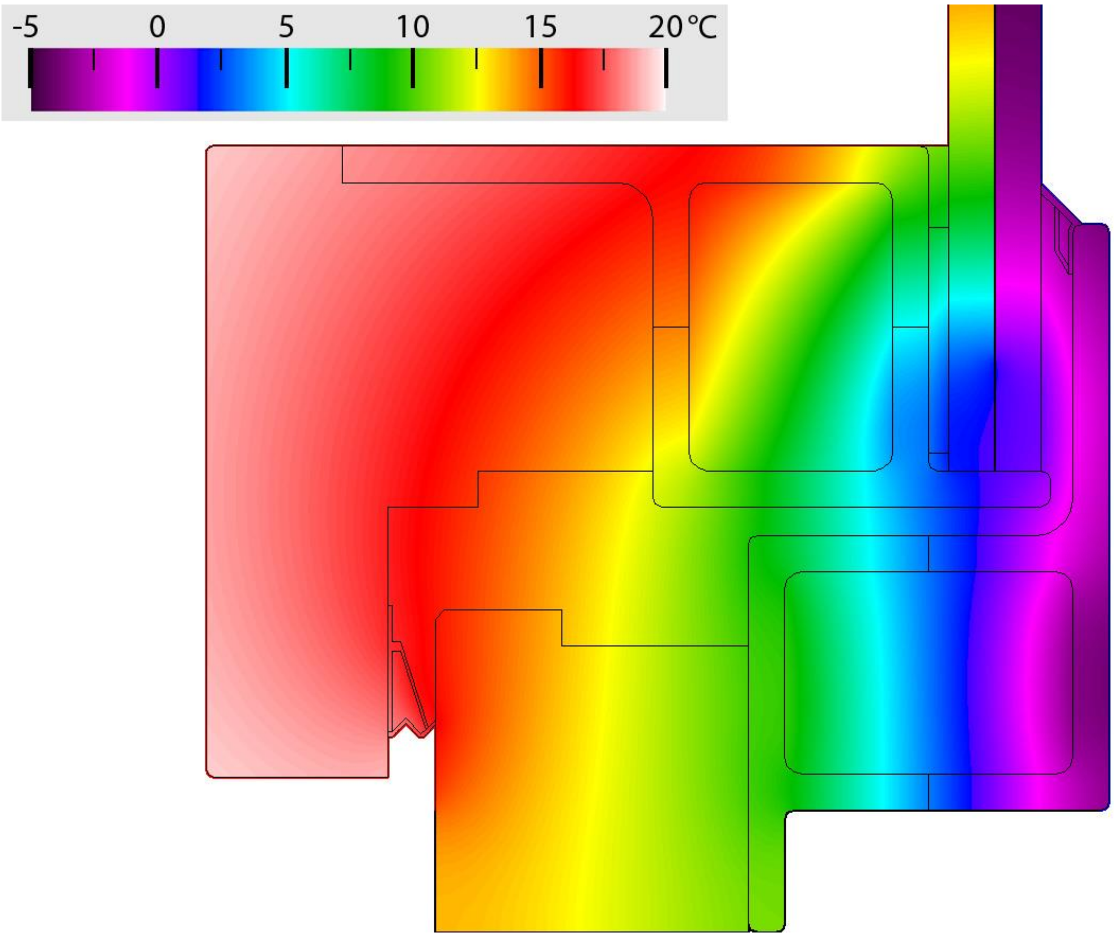


Image 4: Ultralight_04.jpg

Ultralight profile 3.2.12.2, turn-and-tilt window

simulated heat transmission at θ_i = 20 °C and θ_e = -5 °C (THERM 7.4)

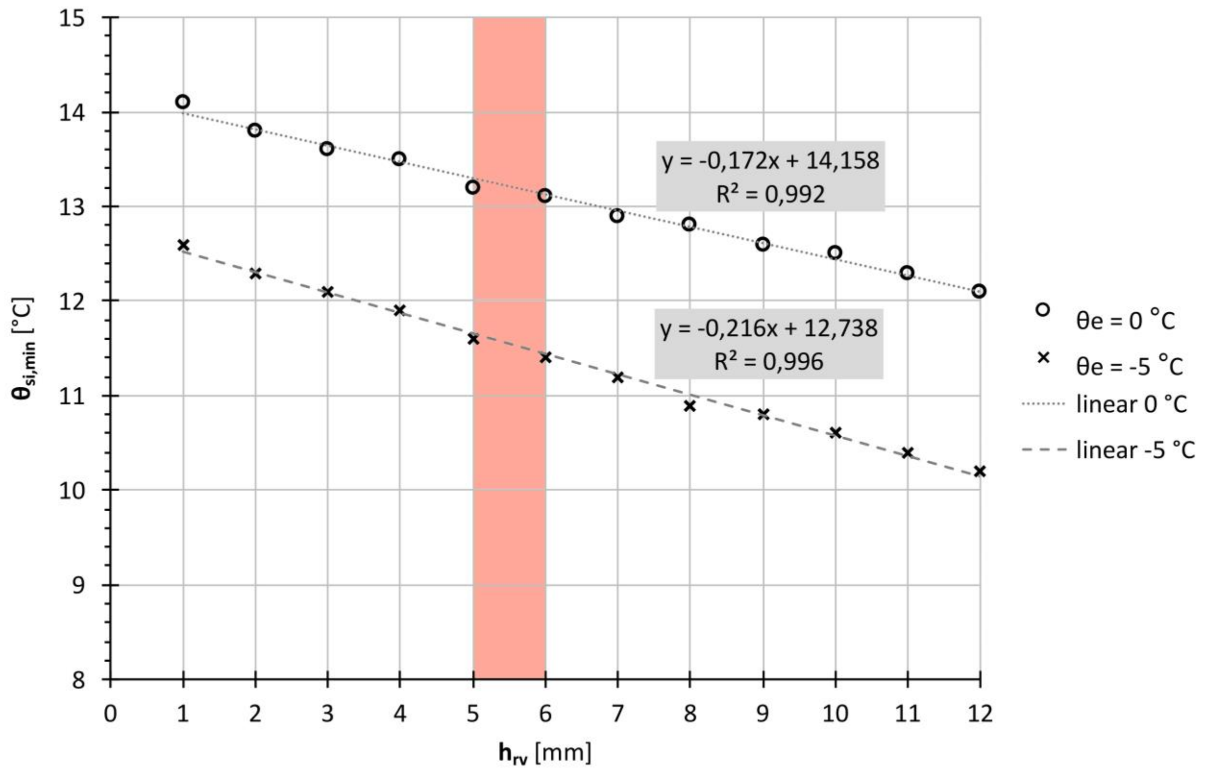
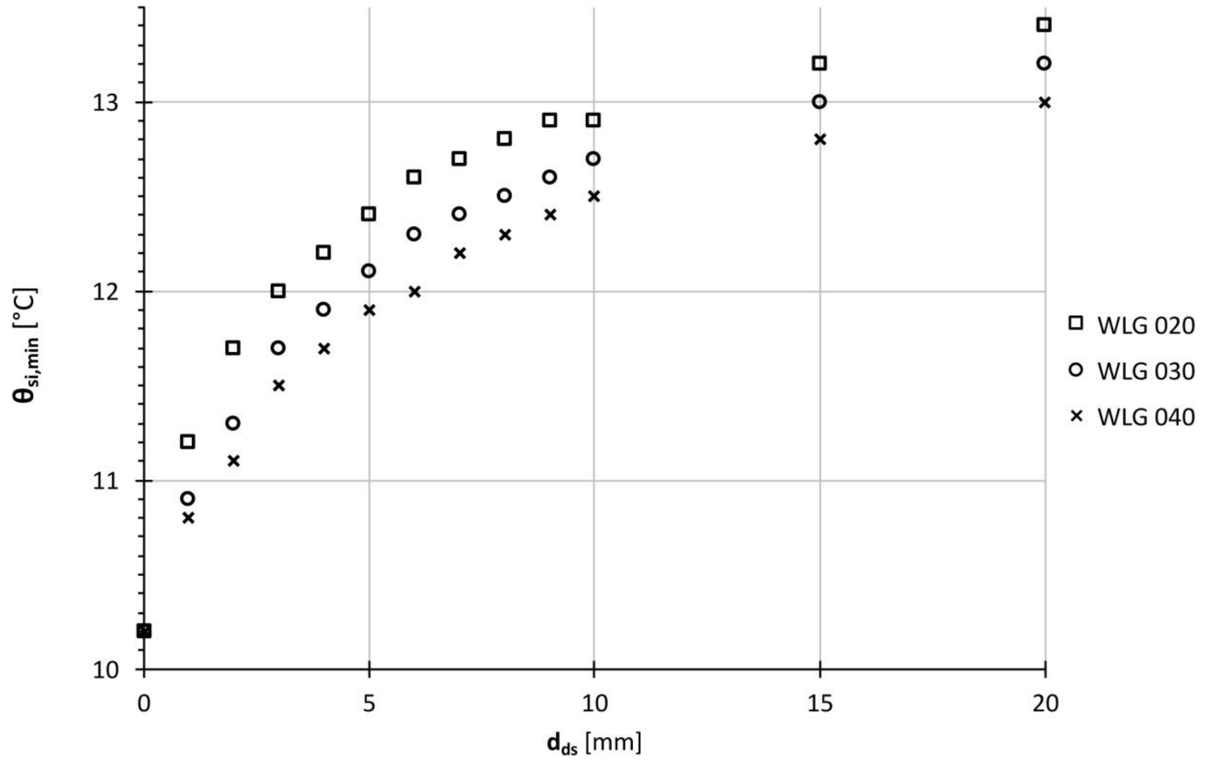


Image 5: Ultralight_05.jpg

diagram: minimum room side surface temperature $\boldsymbol{\theta_{si,min}}$ over height of edge seal $\boldsymbol{h_{rv}}$

θ_i = 20 °C and θ_e = -5 °C or 0 °C, FEM-simulation (THERM 7.4)



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θ_i = 20 °C and θ_e = -5 °C, FEM-simulation (THERM 7.4)