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Slim building envelopes using vacuum glazing and high-performance insulation

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Slim building envelopes using vacuum glazing and high-performance insulation

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Abstract. To get a slim building envelope with low thermal transmittance, and hence a low energy consumption, vacuum glazing and high-performance insulation material have been combined. Preliminary investigations both experimental and numerical have been carried out to determine thermal, hygric and mechanical properties of these building components according to either existing standards or to best knowledge procedures. This includes measurement of the center-of-glass U-value, the simulation of the influence of support pillars on the glass surface temperature and comparison of measured and calculated results. Several specimens were measured under different temperature gradients to get more information about accuracy and deviation in the production of the vacuum glazing elements. Further, mechanical stability of larger specimens was tested by the standard pendulum tests for flat glass and compared to identical tests on conventional double-glazing elements of the same size. Finally, a one-dimensional hygro-thermic analysis has been conducted to determine the temperature and moisture distribution within a thin wall construction containing high-performance insulation when submitted to climatic conditions in the Swiss Midlands.

1. Introduction

The idea of developing an evacuated glazing dates back nearly a century ago which was forwarded by F. Zoller who registered it as a German patent [1]. It took until the 1980's for a system to reach a desired performance. The first successful vacuum glazing has been reported in 1989 by Robinson et al. [2]. It was not before another 15 years' time that a larger interest in academia, industry and government for vacuum insulation panels grow. One major project started 2004 in Germany [3] covering almost all aspects from design to production. Updated reviews regarding basic concepts and sealing techniques followed soon [4,5]. Sophisticated 3D thermal models to determine the influence of support pillars and the edge seal [6], analysis of the temperature induced deflections [7] and the impact of extreme thermal cycling [8] have been reported soon after. The improvements continued with transparent supporting spacer arrays (pillars) using screen printing process [9] and the potential to reduce 50% heat loss compared to the identical area of double-glazing while enabling the same amount of heat gain [10]. Recently, more sophisticated models for support pillars for fully tempered vacuum glazing [11] and the optimized placement of support pillars have been tackled [12]. The edge sealing which represent the most vulnerable issue is still under investigation and difficulties encountered [13] might be the reason for the reluctance in the upcoming of large-scale industrial production. The present investigation is related to a project on the feasibility of a slim building envelope with low thermal transmittance leading to low energy consumption. Vacuum glazing and high-performance insulating materials are the best candidates as elements of a slim building envelope to fulfill this requirement. Several tests and calculations have been carried out in this preliminary phase to get a better and broader insight into the properties of these elements

2. The vacuum glazing

The vacuum glazing glasses used here are of Asian origin and have been shipped to Switzerland upon precise order on their dimensions to fulfill the size requirements of a multitude of testing equipment. They consist of two plane glasses of 6 mm thickness each and a gap of 0.2 mm sustained by an array of quasi transparent pillars at 40 mm from each other and a metallic sealing around the edge. No further information was provided by the producing company.

2.1. The center-of glass U-value

The thermal properties which define the total heat transfer through the glazing are the center-of glass U_g (undisturbed central region including the support pillars) and the edge loss due to the spacer and edge sealing on the periphery of the glazing. For the present investigation a guarded hot plate was used to measure the thermal resistance according to ISO 8302:1991 [14] using the single probe assembly. Thermocouples installed on a soft sheet were positioned on both sides of the glazing to measure the temperature directly at the surface. Due to the rigidness of the glazing a pair of compressible soft sheets were used to provide best contact between heating and cooling surfaces with the sample. All measurements were conducted at a mean temperature of 10°C with a temperature gradient of 15 K over the vacuum glazing. Figure 1 shows one of the samples (800mm x 800mm) installed in guarded hot plate apparatus before putting the heating plate and the compensation element on top of it. The circular copper plates with the thermocouples beneath them are clearly visible and positioned to fit into the metering area (500mm x 500 mm).

There is a laborious report on the design and validation of guarded hot plate for measuring evacuated glasses [15] which shows all the details to be kept in mind even for small sample sizes and hence, emphasize the adequacy of this measuring method for vacuum glazing.

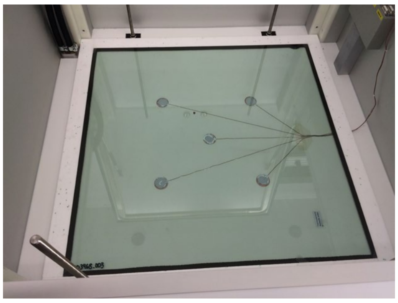

Figure 1. One of the vacuum glazing elements installed in the guarded hot plate

2.2. The standard pendulum tests

The pendulum according to EN 12600:2002 [16] is a method to ensure safety of glass panels against human impact. The method consists mainly of a pendulum impactor of 50 kg hanging from a steel cable which is left to bump into a framed glass panel from different heights. The sample is clamped into a steel frame with a prescribed force so that the setup of the test was according to EN 13049:2003 [17]. A concept drawing the test setup is shown in Figure 2.

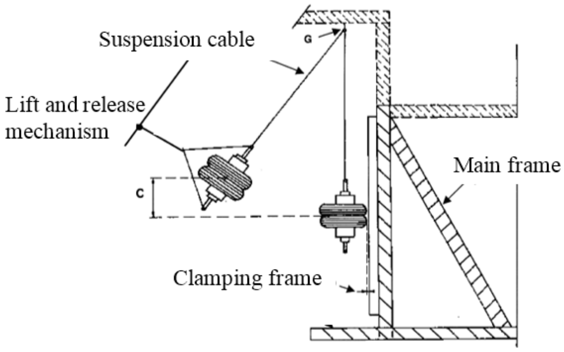

Figure 2. Setup of the pendulum impact test with the main parameter C

For the pendulum test 3 vacuum glazing samples and two conventional double-glazed samples (5-12-5 and 4-12-4) all of size 760 mm x 1409 mm were built in identical wooden frames (Fig. 3). This was to compare the 3 vacuum glasses with conventional ones under the same boundary conditions.

Figure 3. Three vacuum glasses (1,2,3) and two conventional double-glazed samples (4,5) and their installation into the clamping frame of the pendulum setup

3. The high-performance external wall

To keep pace with the slim vacuum glazing and its high thermal performance, an adequate slim and thermally equivalent wall construction is needed to comply with both the aesthetic requirements of architectural design and the reduction of the linear thermal transmittance due to the thermal bridge at the junctions between wall and window.

For this purpose, a ventilated wooden construction filled with a superinsulation material and protected by an external wooden layer has been chosen as external wall construction. The details of the construction and the different layers are shown in Figure 4.

3.1. Hygro-thermal simulations

A one-dimensional hygro-thermic calculation has been carried out to determine the moisture movement and accumulation in different layers of the above wall considering local weather data (Zurich cold year) as external boundary condition and normal internal boundary condition according to EN 15026. The model of the wall used for the calculation (WUFI®) is shown in Figure 5. The two wooden panels have been divided in three identical layers each to better localize the moisture accumulation, because otherwise the moisture content will be averaged over the total thickness of the wood panel. Here too, the air gap and the cladding have been neglected as the air in the gap can be presumed as the external air. For the calculation the influence of solar irradiation and wind driven rain on the external surface can be neglected as the cladding protects the underlying layer from both influences.

External wall		
Wooden cladding	21 mm	-
Air gap	27 mm	-
Kraft paper	-	-
Wood panel	30 mm	0.14 W/mK
Wooden bridge (locally)	100 mm	-
High-performance insulation	100 mm	0.019 W/mK
Wood panel	30 mm	0.14 W/mK
Vapor barrier	-	s_d = 10 m
Gypsum board	12 mm	0.30 W/mK
Total thickness (without air gap and cladding) = 172 mm U-value (calculated) = 0.17 W/m²K (R_i = 0.13 m²K/W and R_e = 0.08 m²K/W due to cladding)		

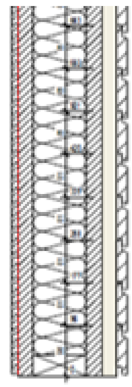

Figure 4. The external wall and its details

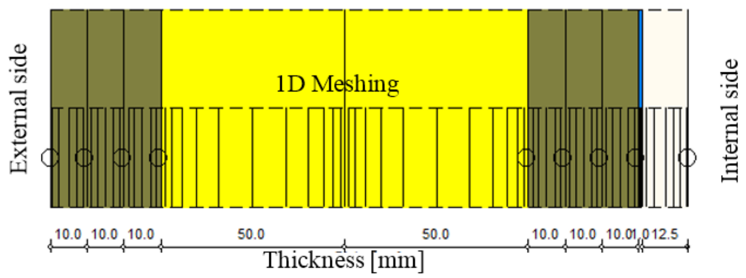

Figure 5. The external wall and its details

4. Results and discussions

The measured and calculated results according to the abovementioned methods and procedures are described in the following.

4.1. Thermal property, U_g value

The total thermal transmittance (U_g) of three samples has been determined based on the thermal resistance measured, the total thickness of the sample and the assumed standard internal and external surface resistances ($R_i + R_a$= 0.17 m²K/W).

Vacuum glazing (11.9 mm)	U_g [W/m²K]
Sample 3468-001	0.52 ± 0.01
Sample 3468-001	0.52 ± 0.01
Sample 3468-001	0.67 ± 0.01
All at mean Temperature T_m =10° C and gradient of ΔT = 15 K	

Table 1. Results of the measurements in the guarded hot plate

4.2. Stability of the glazing to human impact

Results of the pendulum tests are summarized in table 2. The numbers in this table represent the height C (Fig. D) from which the pendulum impactor was released to bump into the glazing. The red numbers indicate the height where the glazing broke away. The vacuum glazing falls extremely short compared to the conventional double-glazing samples. This is mainly due to the support pillars which act as a point of concentration of the impact onto a very small surface which results in a very early failure. In the conventional samples there is only gas between the panes and hence the impact is easily dissipated. Numerical simulations have been conducted for conventional structural glass [18] and need to be extended to vacuum glasses in order to get improvements in this respect.

Vacuum 1	Vacuum 2	Vacuum 3	Double 5-12-5	Double 4-12-4
50	50	50	150	100
100	100	100	200	150
150	150	150	250	200
	175	200	300	250
 			400	300
			450	350
			500	450
			550	500
			600	550
			700	600
			800	700
			900	750
				850

Table 2. Results of the pendulum tests carried out on the five samples. The two inlays show the front and the rear side of the broken vacuum 3 (front fracture lines red, rear fracture lines black)

4.3. Hygrothermal conditions of the slim wall

The most critical part of the construction with respect to moisture accumulation is the external side of the external wood pane. This is because of the low temperature on the outer surface induced by the very low thermal conductivity of the high-performance insulation layer which acts as an internal insulation leaving the outer shell of the envelope at low temperatures during the cold period of the year.

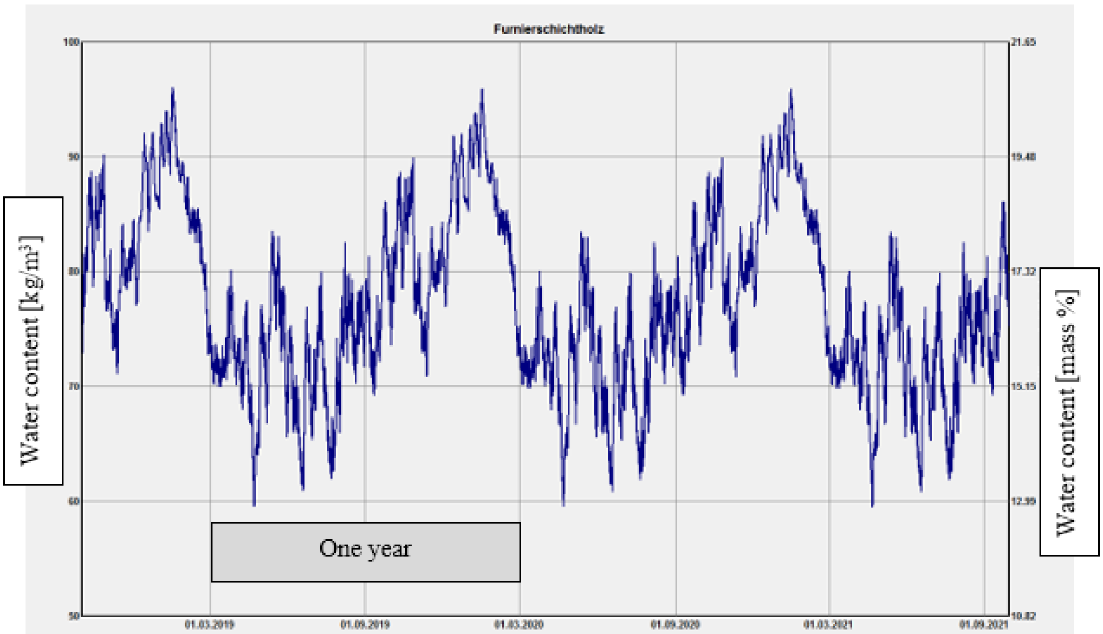

Figure 6. Evolution of moisture content in the first third of the external wood panel over a period of 3 years under the climatic conditions of Zurich (cold year)

Figure 6 shows the water content in the first third of the external wood panel for a period of 3 years under the climatic conditions of Zurich. The peaks occur as expected around January of each year but do not reach critical values. The situation is stable and there is no accumulation over the years (peak height constant). This is mainly due to the ventilated façade which neutralizes the effect of driving rain and the vapor barrier on the internal side which prevents moisture transport from indoor.

5. Conclusions and outlook

The U_g values measured are well beneath the values reported by many suppliers of vacuum glazing. But there is still need for improvement of vacuum glazing panels with respect to their production quality regarding thermal insulation as well as safety aspects. The result of the pendulum impact test showed a major shortcoming with respect to conventional glazing due to the presence of punctual stress accumulation at the site of the transparent pillars needed to keep the two glass sheets parallel. The present preliminary results are going to be completed with acoustic tests and guarded hot-box tests to determine the edge effect which is a major factor regarding heat loss and to deliver a measured value for an equivalent thermal conductivity to be used in thermal modellings to make their results more realistic. The present investigation will go further with the determination of the acoustic properties and the linear thermal transmittance due to the sealed edge.

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References

[1] Zoller F. German Patent 1924:387655
[2] Robinson S J, Collins R E 1989 *ISES Solar World Congress*, Japan, Kobe
[3] Glaser S, Weinläder H, Hippeli S, Weismann S, Ebert H P, Kron J, Durschang B, Arnten M, Graf W, Faber T, Kübler R, Friedel W, Brandber H, Pätz W, Stempfhuber D, Mikolaschek R and Faisst F 2007, Vakuum-Isolierglas (VIG) Abschlussbericht (in German), VDMA, Germany.
[4] Eames P C 2008 *Vacuum* **82** 717
[5] Manz H 2008 *Renew. Energ.* **33** 119
[6] Fang Y, Hyde T, Hewitt N, Eames P C and Norton B 2009 *Sol. Energ. Mat. Sol. C.* **93** 1492
[7] Wullschleger L, Manz H and Ghazi Wakili K 2009 *Constr. Build. Mater.* **23** 1378
[8] Fang Y, Hyde T, Eames P C and Hewitt N 2009 *Sol. Energ.* 83 1723
[9] Zhao J, Luo S, Zhang X and Xu W 2013 *Vacuum* **93** 60
[10] Ghosh A, Norton B and Duffy A 2016 *Appl. Energ*. **177** 196
[11] Hu D, Li Y, Liu C and Li Y 2018 *Adv. Mech. Eng.* **10** 1
[12] Kim J, Kim Y and Jeon E S *J. Mech. Sci. Technol.* **32** 5653
[13] Koebel M, El Hawi N, Lu J, Gattiker F and Neuenschwander J 2011 *Sol. Energ. Mat. Sol. C.* **95** 3001
[14] International Standard ISO 8302 Thermal insulation - Determination of steady-state thermal resistance and related properties - Guarded hot plate apparatus, 1991, ISO geneva, Switzerland
[15] Dey C J, Simko T M, Collins R E and Zhang Q C 1998 *Rev. Sc.i Instrum.* **69** 2939
[16] European Standard EN 12600, Glass in Building – Pendulum test – Impact test method and classification for flat glass, 2002, CEN, 1050 Brussels, Belgium
[17] European Standard EN 13049:2003 Windows - Soft and heavy body impact - Test method, safety requirements and classification, CEN, 1050 Brussels, Belgium
[18] Pelfrene J, Van Dam S, Kuntsche J, Van Paepegem W 2016 *Challenging Glass 5, Conference on Architectural and Structural Applications of Glass*, Ghent University, June 2016.