

Practical long-term experience with Vacuum Glass

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Abstract

The industrialization of Vacuum Glass VG after strong research in the past twenty years is now on track. A series of technical difficulties have been solved to start the first global mass production of high-quality vacuum glass within Company Synergy in Beijing.

High-quality means high performance and long-life which are interrelated. Finally widespread Vacuum Glass (VG) applications are now on the horizon. A mass production line must be able to achieve these two requirements if it is to produce vacuum glass products that can be accepted by the society. With U- values between 0,3 and 0,5 W/m²K based on Low E with an Emissivity of 0.03 till 0,06 the door is wide open for further advantages and hybrid solutions. Thinnest versions, with only 6 or 8 mm can be exchanged directly against single glazing's in windows and thus contribute enormously to renovation and historic heritage buildings.

Time, gradually to improve costs, maximize output and develop innovative solutions of advanced window and façade systems combining complete new features like smart glasses, intelligent lamella systems in Hybrid VG-IG solutions changing the building world towards "Energy or Active plus Houses". One can see, that market demand will rapidly increase in the following years with completely new options, also for roof windows and in the refrigeration industry. Demand will also come up in areas of trains, buses, sun-roofs etc.

Cost saving means to balance additional advantages for savings against system costs of window or façade elements, but also expensive HVAC-systems especially for cooling. Due to promotion of energy saving and emission reduction, both, subjective and objective conditions for a rapid application of VG is likely. The building world is waiting for it, since long. There is a lot to investigate and to gain for business success.

The Debugging of the fully-automatic Vacuum Glazing production line, recently built by Synergy Company in Beijing, with support by Dr. Hohenstein Consultancy is basically finished. This report presents technical evaluations on the pros and cons of the production line, based on testing data, and also introduce the first ideas of next generation production line.

The concept of energy saving buildings has promoted many green buildings, like active-houses, energy-plus houses, zero energy consumption buildings and passive houses. No matter, what kind of the green building is, it should have low energy consumption, which asks for the building envelope, especially the window, having good thermal insulation and solar shading properties. Under such demands, Vacuum Glass could show its advantages very well, like thermal insulation, good sound insulation, light weight, thin structure

and wide application and so on. This article introduces the production, the application and advantages of Vacuum Glass. It analyses some questions, about life time, costs, projects and industrialization. Vacuum Glass has comprehensive advantages in Green Building applications, and its industrialization need strong support from related industry and institutions, also from governmental research projects.

1 Introduction

As global energy-efficient building booms, some new types of green buildings, such as active house, energy plus house, zero energy consumption buildings and passive houses are constantly emerging. The design of these buildings integrates various energy saving principles and technologies, makes every effort to save non-renewable energy resources and make full use of solar, wind and other renewable energy sources creating energy and carbon savings, environmental protection and comfortable living environment.

In case of green buildings as a low energy consumption building, the envelope structure must have excellent thermal insulation and solar shading properties. The windows and doors are the key point and play an important part in energy saving of buildings. The window is counting for about one third energy loss. It should have coated glass with reasonable shading coefficient, lowest U value, and high-quality frame which can greatly reduce energy consumption.

2 Application of Vacuum Glass in Green Building

For high-level energy saving buildings, the main products of advanced glass are vacuum and triple insulating glasses. Insulating glass has been used for many years, and its technology is relatively mature. High-level products reduce its U-value by adopting high quality Low-E coatings, adding the coating layer, increasing insulating layer thickness, filling with argon and so on. For vacuum glass, the basic structure, two panes only, can get a lower U-value.

Now, VG has been designed in initial sample buildings by a number of domestic and international designers. For example, Werner Sobek, Professor at Stuttgart University Germany, Director of Architectural Design and Structure Research Institute, world famous glass engineering office, has adopted vacuum glazing products made by Beijing Synergy Company in one of his active houses. The structure of vacuum glazing is shown in table 1, the building is shown in figure 1. The building is located in the center of the Weissenhof Siedlung building group in Stuttgart, which is completed in 1920s, and memorable as “Weissenhof Siedlung” Building Exposition in the history of modern European architecture. Many famous European designers have been involved in the building design of this area. They designed modern urban living facilities with new building materials and new construction methods.

Werner Sobek has raised nearly € 3.9 million to support this project, with the help of government research grants and sponsors. The energy conversation house is fully recyclable, and can generate electricity through photovoltaic panels. It not only provides electricity for the surrounding residential communities, but also for the electricity grid. This energy model building is a unit with 85 square meters; it can save energy by large hybrid

vacuum glazing which is $2.5 \times 1.7 \text{ m}^2$, and retractable balcony, which is fixed in wooden front wall. It's the most energy-efficient method at present^[1].

Figure 1: Vacuum glazing product data for Sobek's Active House Plus

Glass type outside inside	thickness mm	Visible light Transmittance τ_{vis} in %	Selectivity S	Total solar energy transmittance g-value	Emissivity of Low-E glass	U-value W/m ² K	Sound reduction index dB
Laminated + insulating+ heat strengthened vacuum glazing T5+0.76P+TL5+9A+ TL5+V+T5	29	61.13	1.6	0.382	0.17 0.059	0.463	39

Remark: 1. All data is calculated by Window 7 software according to NFRC 100-2010.
 2. T - tempered glass or heat strengthened glass, TL - tempered coated glass or heat strengthened coated glass, V - vacuum layer
 3. Definition of glazing selectivity coefficient [S] (other name: light-to-solar gain coefficient [LSG]): the ratio of transmitted visible light and total transmitted solar light energy. $LSG(S) = \tau_{vis}/g$ -value. At the same solar heat gain, the higher the index, the more visible light can one get into the room.

Vacuum Glass has also been applied in the "Water Front" passive low-energy consumption demonstration project, which is located in Qinhuangdao city. The project is one of first batch national level technology joint program, which is implemented by China Construction Ministry and German Energy Agency DENA And it may become the new generation standard in the field of building energy conservation in China as just recently discussed in the MoHURD (Ministry of Housing and Urban-Rural Development) Passive House Conference in Harbin 8th till 10th of January 2015, where VG solutions are very much encouraged for China.

"Water Front" project consists of four residential buildings which are designed according to the German passive and low energy consumption building standard, which is part of integrated project with 1.5 million m². Project picture is shown in figure 2. Each building has 18th floor, 45 suites, and a total of 6500 m². The building energy saving index is much higher than the current China energy conservation standards, such as door and window heat transfer coefficient U-value is less than 1 W/m²K^[2]. Figure 3 lists two kinds of glazing adopted by the project, one is hybrid vacuum glass (VIG) and the other is triple glazing with Argon. The solar transmission ratio and selectivity of glazing could be adjusted by Low-E glass and it's Emissivity.



Figure 1: Sobek Weissenhof Project



Figure 2: "Water front" Project

Figure 3: Vacuum Glass product data of "Water Front" Project

Build ing No	Structure outside inside	Thick ness mm	Visible light Transmit tance τ_{vis} in %	Selec tivity coeffic ient S	Total solar energy transmit tance g-value	Emissi vity of Low-E glass	U- valu e W/ m ² K	Soun d reduc tion index dB
13#	IG + Heat strengthened VG T5+16A+TL5+V+ TL5	31	63.7	1.16	0.55	0.17	0.54	41
15#	Tempered triple IG TL5+16Ar+TL5+ 12Ar+TL5	43	46.2	1.54	0.30	0.05 0.146	0.67	38

1. IG + heat strengthened VG in the table is provided by Beijing Synergy Vacuum Glazing Co., Ltd
2. The data's in the table are calculated by the Window7, the boundary conditions are chosen according to the JGJ151-2008 standard.
3. T - tempered glass or heat strengthened glass, TL - tempered coated glass or heat strengthened coated glass, V - vacuum layer, N - float glass, L - coated glass.

3. The advantages and disadvantages of Vacuum Glass applied in Green Buildings

Figure 4 shows that vacuum glass has obvious comprehensive performance advantages, as follows:

3.1 Low U value, even lower in the future.

Synergy's hybrid vacuum glass VIG has the lowest U value in "Water Front" project regarding the utilized Low E coating. Actually, if we use lower emissivity Low-E glass or use two or three Low-E glasses, the U value of vacuum glass could be even lower.

As shown in Figure 4, taking an example of "IG + heat strengthened vacuum glass" in "Water Front" project, if using single Low-E glass with the emissivity of 0.06 and 0.03, the U value can reach 0.50 and 0.41 W/m²K; if using double Low-E glass with the same emissivity, the U value can reach 0.41 and 0.35 W/m²K. At the same time, if we choose VG

Figure 4: Properties of hybrid vacuum glass VIG with different Low-E glass

No	Glass structure	Thickness mm	τ_{vis} %	Selectivity S	Total Solar Energy Transmittance g	Low-E Emissivity	U W/m ² K
1	IG+single Low-E heat strengthen vacuum glazing T5+6A+TL5+V+T5	21	42.46	1.41	0.302	0.06	0.50
2	IG+single Low-E heat strengthen vacuum glazing T5+6A+TL5+V+T5	21	56.54	2.21	0.256	0.03	0.41
3	IG+double Low-E heat strengthen vacuum glazing T5+6A+TL5+V+TL5	21	24.33	0.92	0.265	0.06	0.41
4	IG+double Low-E heat strengthen vacuum glazing T5+6A+TL5+V+TL5	21	43.12	1.82	0.237	0.03	0.35
5	Lamination+ single Low-E heat strengthen vacuum glazing TL5+V+T5+1.14P+T5	16	59.91	2.24	0.267	0.03	0.43

Note: 1. The data in the table are calculated by Window7 program, the boundary conditions are chosen according to the JGJ151-2008 standard.

2. Letter meaning: T - heat strengthen glass, TL - heat strengthen Low-E glass, V - vacuum layer.

with such low U values, we could reduce the frame - window ratio making lighter constructions, which could still result in a lower U value of the whole window, also could increase the whole light transmittance, and make living environment brighter.

Further it shows that we can adjust total solar energy transmittance and selectivity by selecting different Low-E or Solar Control glasses. Usually, the visible light transmittance,

selectivity, total solar energy transmittance need to be adjusted according to the region and especially in China with all climate zones.

3.2. Thin, even thinner in the future

From Figure 3, we can see that with similar U value, the thickness of the vacuum glass is far less than triple insulating glass. On the one hand, it can reduce the thickness of the whole window and building load, on the other hand it can increase the used space, the usable floor area of building could be increased.

Considering security, we use hybrid IG+VG in previous applications. If the security requirement is higher, we use EVA-Lamination on VG, which is thinner. Compared IG+heat strengthened VG in Figure 4 to triple IG, the thickness decreased 22 mm, if one uses EVA-laminated+ single Low-E heat strengthened VG, it is 27 mm.

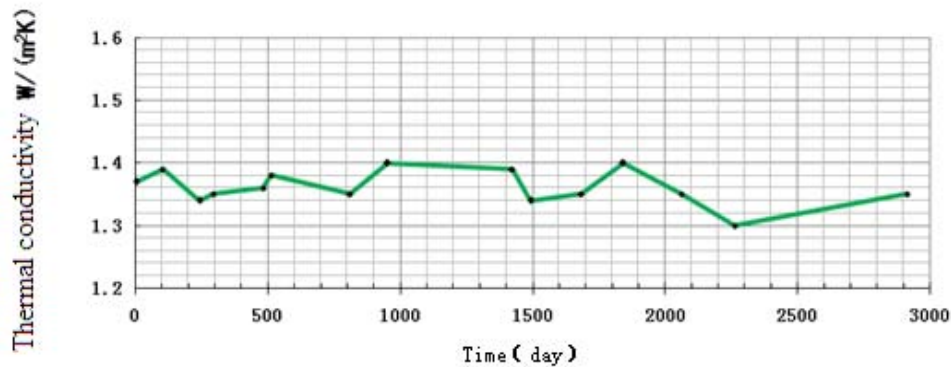


Figure 5: The variation of thermal conductivity of vacuum glass over 8 years

3.3 Long life time

VG is sealed with inorganic material, in this case with a glass frit. Besides, in the process of production, it has been strictly exhausted at high temperature. Under extreme environment like high temperature, low temperature, high humidity, ultraviolet light and so on, vacuum glass will keep the good performance and the problems such as attenuation of vacuum degree, aging performance failure and so on won't appear. Besides, there is a so-called getter used in these VGs. The lifetime is more than 50 years by theoretical calculation. Actually, after nearly 3000 days (9 years) tests in actual environment outside and in Beijing, thermal conductivity of VG samples changed very small, no more than 5% maximum, as shown in figure 3. For hybrid IG+VG-structure, U value will not change much even if IG-sealant in case of VIG fails.

On the other hand, Low-E coating is inside vacuum glass, vacuum can protect Low-E coating, which can guarantee the low U value of VG and increases the lifetime of the product.

3.4. Good performance of sound insulation^[3]

It can be seen from Figure 3 that the sound insulation property of VG is much better than for triple IG, Especially at middle and low frequencies. Better property of sound insulation grants us a comfortable life.

We can also improve the sound insulation property of VG by laminating or insulating. Hybrid VG; R_w value can reach 39 dB to 42 dB. In fact the total effect is not only influenced by the glass, but also the frame, so SYNERGY has cooperated with well-known sound insulation window companies and done lots of tests. Finally we got a good result of 42 dB as shown for No. 7 in Figure 6.

Figure 6: R_w value of hybrid vacuum glazing

NO.	Type	Structure	Testing Organization	R_w /dB
1	Hybrid structure vacuum glazing	T5+V+T4+1.14PA+T5	Tsinghua	39
2	Hybrid structure vacuum glazing	N6+V+N4+0.38+N4+12A+N6	CABR	42
3	Hybrid structure vacuum glazing with 86PVC frame	T5+26A+T5+V+T4+1.14PA+T4	Greentec	40
4	Hybrid structure vacuum glazing with 86PVC frame	T8+26A+T5+V+T6	Greentec	40
5	Hybrid structure vacuum glazing with 86PVC frame	T8+26A+T5+V+T6	CABR	40
6	Hybrid structure vacuum glazing with 60 thermal broken frame	T6+12A+T5+V+T4+1.14PA+T5	Tsinghua	41
7	Hybrid structure vacuum glazing with 86PVC frame	T6+25A+T5+V+T6+0.76 PVB+T4	Tsinghua	42

3.5. Wide application

Vacuum glass could be used in building and cold chain industry because of its excellent thermal insulation property. What's more, it can be transported from low altitude area to high altitude area because the vacuum layer could avoid cavity expanding and breakage lacking any convection and gas expansion by atmospheric conditions – resulting with higher altitude applications and transport, lower stress, more safety. When one installs IG in building roofs and overhead, the gas convection conduction would increase, but VG wouldn't. So the application is well extended for its unique structure and perfect performance.

3.6. High wind pressure resistance strength

In application, the most common pressure is wind pressure. VG has high strength under wind pressure. That is because the two panes of VG are connected rigidly by soldered glass. Non-deformability is better than single glass. For example, under the same wind

pressure, the deformation and tensile stress in the center of VG with 10mm thickness (5+5) is equal to a single glass of 8.5mm thickness, at least.

Vacuum Glass is a relatively young product. There seem to be some disadvantages as follows:

1. There are support pillars in VG with size of 0,3 mm. Even if they are very tiny, if you are very close to the glass, you still can see the little dots. But normally people do not see them at all;
2. The support pillars transfer heat and sound, when they are called “heat bridge” and “sound bridge”. As stated above the good values are reached inclusive these effects. Without “heat bridge” and “sound bridge”, the heat insulation and sound insulation of VG will be even better; there is a realistic chance, to increase the distance of such pillars in future and thus get an even better U- and sound-value.
3. Because of the support pillars, when VG is impacted, there is stress concentration around the pillars which will cause that the impact strength of VG is somewhat reduced.

4. Several issues about Vacuum Glass

As a new product, VG has aroused wide discussions, meanwhile, some people may be confused in some aspect, so we introduce several common concerned issues.

4.1. Vacuum Life time of VG

The life time of VG consists of two aspects, one is vacuum life, and the other is mechanical life. As introduced above, the process ensures the vacuum life. It should be noted that regular manufacturers have to check each piece of VG strictly before it leaves factory, in order to prevent the inferior-product quality flowing into the market. Relevant departments must keep strict supervision on shoddy VG products, such as without high temperature exhaust, no getter - even fake getter; only completely eradicate these cases, to assure the VG public acceptance.

4.2 Mechanical Life Time

In order to increase mechanical lifetime, on one side we should design and produce VG products scientifically and strictly, one has to manufacture heat strengthened or tempered VG to improve its mechanical strength. On the other hand, one shall use hybrid VIG like insulating or laminating methods to improve its safety. To what extent VG can be used for safety requirements should be carefully followed up.

4.3 Cost problem

Cost is the most important problem, VG has better performance compared with triple IG, but with higher price. Material costs of VG might be lower than triple IG, but process cost and investment is higher. The price of VG will decline by improving yield and capacity as well as using new materials and technology, but probably never to the same level. Besides this one has to consider the costs of windows and facades, which includes glass, frame, hardware and metal joint connectors. Vacuum glass is light and thin, the frame could also be light and thin and metal joint connectors also could be less expensive, even more façade

construction saving additional weight. There are more cost advantages considering the whole benefit for new designed houses with VG



Figure 7: Office building and workshop of Synergy



Drying oven



Edge sealing oven



Vacuum oven



Robot for pillar setting

Figure 8: Pictures of fully automatic production line

4.4 Supply problem

The supply problem will be solved with the development of VG industrialization. The automatic production line of Synergy has entered into final debugging stage, once completed and launched, the design capacity will allow 500,000 m² per year. The

factory is shown in Figure 7 and 8. The next generation of a medium sized capacity line of about 250.000 m² is in design, which is probably more suitable for initial producers. Synergy is willing to grant license and rights to interested parties. The Co-author of this paper, Helmut Hohenstein is the representative for international projects and any requirements also for sample projects and technology exchange. Please contact: helmut.hohenstein@hohenstein.biz

5. Applications

Application is the best way to test a certain product in practice. The VG/VIG of Beijing Synergy has been used since 2005 in many buildings. Some of them are the “firsts” of domestic, even international. For example, the Tianheng Building is the first project of which all the glass units are VIG. And also it is the first time that large area glass curtain wall of VG is used in actual project. By now, Beijing Synergy has provided the most vacuum glazing units and actual projects all over the world. The main applications of vacuum glass of Beijing Synergy are listed in Figure 9 and shown in Figure 10.

Figure 9: Vacuum Glazing application projects

No.	Project Names	Glass area m ²	Glass type	Application type	Time
Domestic projects					
1	Water front building of Qinhuangdao in Hebei	830	heat strengthened vacuum glazing	Glass wall	2013
2	Great glory century building in Shandong	3000	heat strengthened vacuum glazing	Window	2013
3	Exhibition Centre Zhongguancun, Beijing	1200	VG; heat strengthened vacuum glazing	Glass wall Sunny roof	2012
4	Zhengzhou library	10000	VG; heat strengthened vacuum glazing	Glass wall	2011
5	Culture park of Changsha in Hunan	12700	VG; heat strengthened vacuum glazing	Glass wall	2011
6	Hebei province land and resources office building	3000	vacuum glazing	Window (reform)	2010
7	Science and Technology Bureau of Hebei	4000	vacuum glazing	Window (reform)	2010
8	Tiantaitongbai library	1500	vacuum glazing	Glass wall	2009
9	Construction service center, Hebei prov.	3000	vacuum glazing	Window	2009

10	Meilinqingcheng residential house	10000	vacuum glazing	Window	2009
11	Micro Energy Consumption Kindergarten, Beijing	Sunny roof 500, Window 1000	vacuum glazing	Window; Sunny roof	2008
12	The college of life science	Glass wall 600 Sunny roof 600	vacuum glazing	Glass wall; Sunny roof	2006
13	Long river high-grade residential house	1000	vacuum glazing	Window	2006
14	Sky plaza building in Beijing	10000	vacuum glazing	Glass wall; Window	2005
15	Ultra-low power demonstration bldg., Tsinghua University	1000	vacuum glazing	Glass wall	2004
International projects					
16	Switzerland	28	heat strengthened vacuum glazing	Window (reform)	2012
17	Qatar	13	heat strengthened vacuum glazing	Window (reform)	2012
18	Germany (Frankfort)	73	vacuum glazing	Window (reform)	2011
19	Germany (Stuttgart)	63	heat strengthened vacuum glazing	Glass wall (active building)	2014



Exhibition Centre of Zhongguancun in Beijing



Great glory century building in Shandong



Zhengzhou Library, Henan



Sky Plaza building



Low energy consumption building, Tsinghua Univ.



Tiantaitongbai Library



Construction service center of Hebei Province



Culture park of Changsha, Hunan



Micro energy consumption Kindergarten of Beijing

Figure 10: Beijing Synergy Vacuum Glass Projects

5. Summary

In the extending and application area of “Green Buildings”, Vacuum Glass has more general performance options than classic and any advanced Insulating Glass. Chinese vacuum glazing industry is leading in the world, the highest industrialization level, and the most applications, which is worth of enough attention. We hope that the governmental bodies and the relevant authorities give more support on VG industrialization worldwide, as it contributes dramatically to energy saving in hot and cold climates and also to environmental savings of carbon emissions and last but not least offers many advantages for comfort and building options.

After nearly 2 decades of no real innovation within the glass industry, Vacuum Glass can offer all involved parties and the users a better benefit and at the same time better earnings in a wider application field, first in new generations of green buildings, but also in conventional sectors for direct exchange in refurbishment projects.

There is so much to do and so much to achieve. This industry should have a general concept to utilize vacuum glass in order to satisfy the present architectural requirements and future expectations. The architecture and glass engineering world is asked to develop innovative solutions. In Germany there is a new movement towards so-called Active Plus Houses, where just recently an alliance with leading architects and institutes was founded. Also the government is focusing in future on it.

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