

Lifecycle assessment of vacuum heat-insulation

Petr Zhuk

Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

E-mail: peter_05@bk.ru

Abstract. Vacuum insulated panels are becoming more and more common in building practices. Therefore, environmental analysis through vacuum insulated panels lifecycle and environmentally reasoned choice of components for their production are currently important. Rigorous research in area of vacuum insulated panels development were conducted by such organizations as Brunel University London, Chalmers University of Technology Gothenburg, FHBB Muttentz, TU München, Bayerisches Zentrum für Angewandte Energieforschung e.V., IfT Rosenheim, NIPTIS named after S.S. Ataev, etc. In Russian Federation the environmental analysis through vacuum insulated panels lifecycle was barely paid attention to, although there are interesting suggestions concerning utilization of different raw materials.

The goal of this research is to study the possibilities of vacuum insulated panels production projects in Russian Federation and their environmental assessment.

Such methods as ecoindicator-99, environmental restrictions and gross energy were used in environmental analysis through vacuum insulated panels lifecycle. The main method of lifecycle analysis is an integrated accounting of environmental criteria in accordance with the ISO 14000 international standard. In particular, the most important indicators of such account are greenhouse-warming potential (kg CO₂-equivalent), ozone layer depletion potential (kg CFC-11-equivalent), acidification potential (kg SO₂-equivalent), photooxidants generation potential (kg ethylene-equivalent), eutrophication potential (kg PO₄²⁻-equivalent), primary power consumption from renewable and exhaustible sources. The choice of environmentally preferable components suggests using qualimetry methods.

Results of the research confirm that environmental pressure of vacuum insulated panels functional unit (1 m²) through its lifecycle are compatible with pressure of other heat-insulating materials (like glass-wool). When examining different indexes of the ecoindicator-99 system, environmental impacts are almost identical. The attribute «human health» of vacuum insulated panels is a bit inferior to that of glass-wool and the attribute «resources consumption» are that many superior than that of alternative fibrose heat-insulation. In general, results of the research show wide horizons of vacuum insulated panels utilization in modern building construction from the environmental point of view, while there is a range of technological problems to be solved.

As a conclusion to the research, we suggest environmentally preferable constructive solutions with the utilization of vacuum insulated panels. Those solutions provide lowering the environmental impact and cost of vacuum heat-insulation systems, alternate solutions for joints due to utilization of back-up insulated systems and different heat-insulation materials, as well as protecting panels from depressurization by integrating them into building envelope.

Keywords: vacuum insulated panel (VIP), lifecycle assessment (LCA), environmental impacts, eco-indicator 99 method

1. Introduction

Vacuum insulated panels (VIP) are becoming more and more common in building practices as heat-insulation elements. Modern approaches to materials and constructions selection suggest environmental impact analysis during all stages of the product lifecycle. While doing that it is



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

important to pay attention not only to production methods and the most effective utilization of vacuum insulation panels, but also to their durability problems under impact of different operational factors. Rigorous research in area of vacuum insulated panels development were conducted by such organizations as Brunel University London, Chalmers University of Technology Gothenburg, FHBB Muttentz, TU München, Bayerisches Zentrum für Angewandte Energieforschung e.V., IfT Rosenheim, NIPTIS named after S.S. Ataev, etc. In Russian Federation the environmental analysis through vacuum insulated panels lifecycle was barely paid attention to, although there are interesting suggestions concerning utilization of different raw materials.

The goal of this research is to study the possibilities of vacuum insulated panels production projects in Russian Federation and their environmental assessment.

2. Methods

During vacuum heat-insulation materials environmental balance composition we can use such methods as ecoindicator-99, environmental restrictions approach, gross energy consumption approach [1, 2]. Each of these methods has a software for facilitation of calculations during the whole product lifecycle. The energy consumption approach considers such aspects as non-renewable resources and resources inconsistent with stability parameters; energy, derived from those resources; points of availability, demand and possibility of fuel replacement.

3. Results

In order to perform a thorough product lifecycle analysis we need to analyze main processes and methods of its production. In particular, it is very important to divide the production process into stages correctly. Moreover, each of manufacturing stages related to intermediary product manufacture must be thoroughly examined in accordance with system engineering principle considering energy and material flows at the input and output. Researchers from the Energy Institute, FHBB, Muttentz suggest the following method of dividing vacuum insulated panels production into stages: silicon tetrachloride production, silicon carbide production, hydrogen (H_2) production by methanolysis, fumed silica production, covering vacuum panels elements with metal foil, connecting film production [1]. Manufacturing panels from separate elements, in turn, includes connecting reinforcing fibers from glass of cellulose with fumed silica as well as silicon carbide. It is followed by pressing, using electricity for power source, and then by assembly and drying, which also use electricity as well as natural gas. A cloth made of polypropylene fiber with connecting film as an envelope is used to protect particles. The process is concluded by vacuumizing, which requires considerable amount of electrical power (Figure 1).

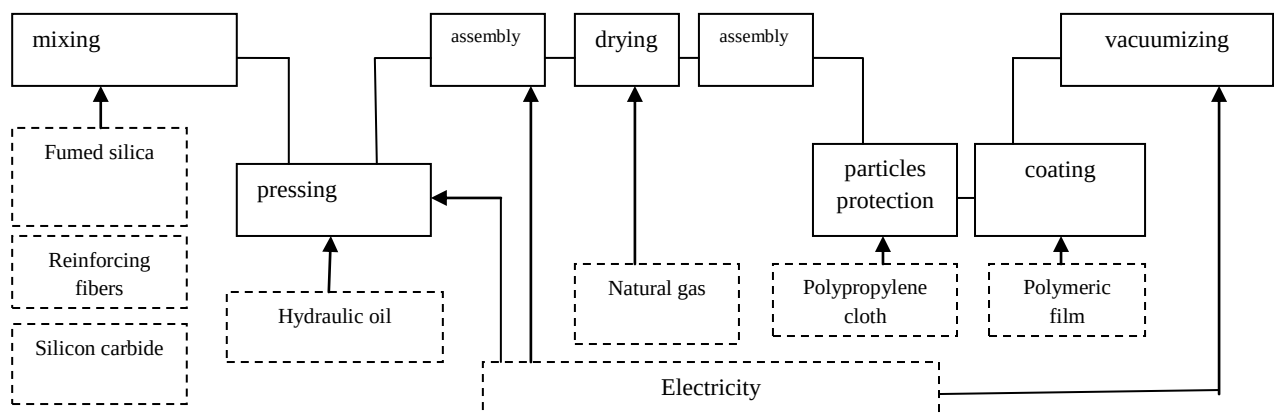


Figure 1 Vacuum insulated panels production scheme

All of the vacuum heat-insulation systems used in building practice can be divided in two main types: separate items of easier installation (for example, flat panels); building envelope parts (often multilayered), which separate exterior space using vacuum (for instance, sealed insulating glass units).

Modern vacuum panels consist of porous filler and multilayer envelope, with each of its layers performing a certain function. In particular, these functions include barrier function (providing gas-proofiness), reflection of infra-red radiation (foil layer), securing construction durability and integrity (weld-fabricated) [3]. Vacuum heat-insulation panels can have different fillers. Alternatives of fillers and envelopes combinations are set out in the Table 1.

Table 1. Vacuum heat-insulation panels classification features

Classification feature (column – base filler; line – gas-proof envelope)	Metal sheets	Plastic films	Multilayer combined films
Aerogel	–	+	+
Glass-fiber	+	–	–
Organic foam materials	–	+	+
Microporous silicone dioxide	+	+	+
«–» combinations is not used in practice			
«+» combination is used in practice or is supposed to be used in the future			

Among organic foam fillers there are extruded polystyrene, polyurethane or polyimide, all of these materials have open-cell structure. In addition to fillers mentioned in the Table, a porous rock – perlite – can be used. In all, the optimal filler by structure and pores size is fumed silica, and in order to use it as a powder in panels reinforcing components (like glass- or cellulose fiber) must be introduced. Fumed silica is the most widespread filler for vacuum insulated panels due to such qualities as low density, advanced specific surface area and low thermal conductivity [4]. Films made from synthetic polymers with metal spraying combined with metal foil or silicon oxide coating are used as multilayer combined films.

Under this research a comparative environmental analysis of vacuum insulated panels filled with fumed silica production by different manufacturers, namely *Microtherm* (Belgium) and *Porextherm Dämmstoffe* (Germany), the latter belonging to the British corporation *Morgan Advanced Materials*. Results of products environmental declaration calculated using functional unit 1 m² are set out in the Table 2.

Table 2. Environmental impact of vacuum insulated panels production

Environmental impact indicators	Units of measurement	<i>Microtherm</i>	<i>Porextherm Dämmstoffe</i>
Greenhouse effect	kg of CO ₂ - equivalent	2.24E+01	42.2
Depletion of ozone layer	kg of CFC- equivalent	1.54E–05	4.22E–09
Ground acidification	kg of SO ₂ - equivalent	8.71E–02	1.46E–01
Eutrophication	kg of PO ₄ ²⁻ - equivalent	4.45E – 02	1.64E–02
Photochemical oxidation	kg of ethene- equivalent	6.33E – 03	1.27E–02

Distinctions in indicator values for different manufacturers are due to more detailed accounting of raw materials extraction and transportation problems in *Porextherm Dämmstoffe* products declaration, and by distinctions in manufacturing process and used equipment. It should be noted that in Russia only precipitated silica (white carbon) is produced, fumed silica, which requires flaming hydrolysis of voltaic siliceous substances, is manufactured in Belarus and Ukraine. Moreover, in Russian Federation this raw material is required by such industries as pharmaceuticals, elastomers production (as fillers for rubber resins), paint and coatings. Lack of the one of the most prospective raw materials greatly limits vacuum insulated panels production in Russian Federation.

An important stage of vacuum insulated panels lifecycle is their installation in building constructions. Heat-insulating materials being studied under this research are used for heat insulation in building and renovation of different constructions. In particular, they are used for heat insulation of floors, building fronts, roofs and terraces, as well as sandwich-panels component. Vacuum insulated panels allow creating envelopes 8-10 times thinner than walls in which regular heat-insulation materials are used. For a long time vulnerability to mechanical impact has been considered their main disadvantage. At present, there are sandwich-systems which allow minimizing possible mechanical damage of vacuum insulated panels or their quick replacement in case of losing effectiveness [5]. Vacuum heat-insulation panels are most effective when used in combination with other materials. There are examples of successful combinations of vacuum panels and wood, when planks protect panels and form a construction with increased resistance for heat conductivity in living buildings. Living house usable space can be increased due to vacuum panels' shallow thickness. Vacuum panels with thickness of 20 mm combined with polyurethane foam can be used for walls heat insulation in an office building with concrete envelopment.

4. Discussion

Panels installation is often made using glue joints. Some durability researchers perform heat-insulation elements durability tests by the following directions: contact with glue joint (both hardened and not), contact with alkali solutions, thermal and mechanical fluctuating loads [6]. Under all of the mentioned loads, such crucial for vacuum panels criteria as internal gas pressure, envelope permeability for gas, breaking strength upright to panel surface and heat conductivity were measured. Internal gas pressure in all of the studied panels grows with time under load. Results of internal gas pressure measurement are in accordance with heat conductivity index measurements. Panels aging led to increase in their heat conductivity. In general, vacuum insulated panels aging modeling demonstrated relatively high indexes of possible working lifespan (approximately up to 25 years). This being said, due to the fact that vacuum panels heat conductivity index is 10 times smaller compared to rock wool, even after mechanical damage of vacuum systems they are still more effective than other heat insulation materials. Nevertheless, the most optimal way of using vacuum insulated panels is combining them with other heat insulation materials.

As for the concluding stage of panels lifecycle, the following options are possible: 1. Vacuum insulated panels' components mechanical separation followed by thermal treatment of envelopes and return of powder filler directly into manufacturing process; 2. components separation and recycling, film must be made of recyclable polymeric material; 3. disposal by burning all panels with power generation.

Research results confirm that vacuum panel functional unit (1 m²) environmental burden on lifecycle are comparable with the environmental burden of rock wool. If we look into different parameters of the ecoindicator-99 system, we will see similar environmental impact. By the «human health» parameter vacuum insulated panels are slighter inferior to rock wool, but by the «resource spent» indicator they are as many superior to alternative fiber heat insulation. Research findings demonstrate vast horizons of vacuum insulated panels in modern building from the environmental point of view, since their utilization from an operational point of view is out of question.

The VIPs are prone to damages and has to be handled with great care during the process of building. To increase the durability of panels, different approaches have been suggested and tested. A more robust version of the panels is the vacuum insulated sandwiches which are covered by a stainless steel casing.

It is calculated the thermal bridges created by the robust protective casing around the VIS and found that the thermal bridge could be reduced by using insulation materials adjacent to the VIS.

Such panels can be used even without additional protection. Vacuum insulating panels, as a rule, are used in the whole system of enclosing structures, including with additional or equalizing thermal insulation. The analysis of environmental impacts of structures using VIP was not the purpose of this work.

In the study, vacuum insulating panels were considered as an independent unit in order to simplify comparison of them with each other as an element of the future enclosing structure.

5. Conclusion

Vacuum insulated panels durability is the major criteria of their lifecycle assessment. VIP durability is provided by enveloping the panel with the metalized multilayer polymer film as well as by the way of fastening the panel to the construction. The durability of the VIP depends on a well thought out design where the VIP is protected both during the construction phase and the service life.

Another issue is the environmental impacts of VIP which depend on the core material. Those impacts can be reduced by using environmentally efficient filler material for the VIP. From this point of view the best option is the use of pyrogenous silicon dioxide.

VIP can be used in new buildings, both in light-weight timber frame walls and in heavy concrete walls. In old buildings, VIP can be used on the exterior or interior of the existing wall. So far, the most common utilization of VIP is on the exterior of the existing wall. It is also possible to integrate the VIP in a structural sandwich panel, e.g. made of concrete, to increase the protection of the VIP. The best way of the VIP utilization from the lifecycle assessment point of view is a combination of these systems with other heat-insulation materials.

Minimum useful life of the VIP is 25 years, which is comparable to service life of the main enveloping structure but requires certain maintenance and repair expenditures, which in some degree influences total lifecycle costs [5]. In case a hole is made in the VIP, its thermal conductivity increases fivefold, but still remains half the thermal conductivity of mineral wool. One way of protecting the VIP from damages is enveloping it with EPS boards. This measure increases the thickness of the insulation layer, but decreases risk of damages.

Despite the obstacles on the way of using VIP in building applications, it is an interesting component that can play an important role in reducing energy use for heating of buildings. It is recommended to integrate the VIP in such a way that they are easy to replace after their service life has expired. By doing so and by educating builders and designers to consider special aspects of working with VIP, the energy use for heating in the existing building stock can be reduced.

The LCA calculations show that the VIP is worse than glass wool and EPS in terms of embodied energy. Eco-indicator-99 method shows that VIP has lower environmental impact than EPS which is 42% higher than VIP, while mineral wool is only half compared to VIP. The analysis shows that 90% of the energy used in VIP production is consumed by the filler production while only 4 % was used for the film production.

The generally recognized approach of treating the VIP wastes has not yet been developed. Therefore, one must include the probability of returning panels to manufacturing site with possible thermal recycling of polymeric film components. While doing that it is important to secure controlled separation of mineral and organic components.

References

- [1] Schonhardt U, Binz A, Wohler M, Dott R and Frischknecht R 2003 Ökobilanz eines Vakuum-Isolations-Paneels (VIP) (Muttentz/ Uster: Institut für Energie FHBB ESU-services) p 67
- [2] Eco-indicator-99 2000 Manual for Designers A damage oriented method for Life Cycle Impact Assessment (The Hague: Ministry of Housing Spatial Planning and the Environment) p 49
- [3] Danilevsky L *Architecture and Construction* vol 5 Vacuum heat insulation and the prospects for its use in construction pp 114–117
- [4] Alam M 2015 Development of Vacuum Insulation Panel with low Cost Core Material A thesis submitted for the degree of Doctor of Philosophy (London : Department of Mechanical

- Aerospace and Civil Engineering College of Engineering Design and Physical Science Brunel University) p 140
- [5] Johansson P 2012 Vacuum Isolation Panels in Buildings Literature Review Report in Building Physics (Gothenburg: Department of Civil and Environmental Engineering Chalmers University of Technology) p 27
- [6] Rose A, Sack N, Koppold S and Albrecht W 2014 Dauerhaftigkeit von Vakuum-Isolations-Paneelen in der klebetechnischen Anwendung (Rosenheim: Institut fuer Fenstertechnik) p 19