Multifunctional sun protection thermal insulation PV systems in lightweight construction for highly efficient energetic insulation of glazed building openings with integrated solar energy generation

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Abstract

Glazed surfaces on industrial and commercial buildings contribute disproportionately to heat losses due to their lower thermal insulation compared to the walls of the building. In addition, building glazing increases the energy consumption for air-conditioning of the building due to the high proportion of glazed surfaces in the building envelope, unless sufficient shading can be guaranteed in the case of high solar irradiation. The aim of the "EnShade" research and development project presented here was to significantly reduce the building's energy demand and to increase the use of renewable energies (PV) for glazed building envelope surfaces. For this purpose, multifunctional sun protection, thermal insulation and PV systems were developed within the framework of the project to increase the energy efficiency of glazed building openings. The conceptual designs and constructive designs developed were transferred and tested in functional and large-scale demonstrators.

1. Introduction

The innovative multifunctional window shutter segment serves both as effective thermal insulation and thus as compliance with the requirements to be derived from the EnEV from 2016 (cf. [1]) for minimising heat loss in winter, as well as for shading and as summer heat protection with the aim of reducing the energy required for air conditioning in buildings. Both aspects are binding components of the provisions of the Climate Protection Plan 2050 of the Federal Republic of Germany [2], which refers to the Paris Climate Protection Treaty [3] and underpins the central goal of this treaty - the reduction of the predicted global warming to an increase of less than 2 K in relation to the average global temperature - with concrete energy-saving measures to reduce CO_2 emissions. Fig. 1 illustrates this with the example of the increasing tightening of energy-saving requirements for the heating energy demand of new buildings (cf. [4]), which can only be met in the long term by consistently improving building insulation.

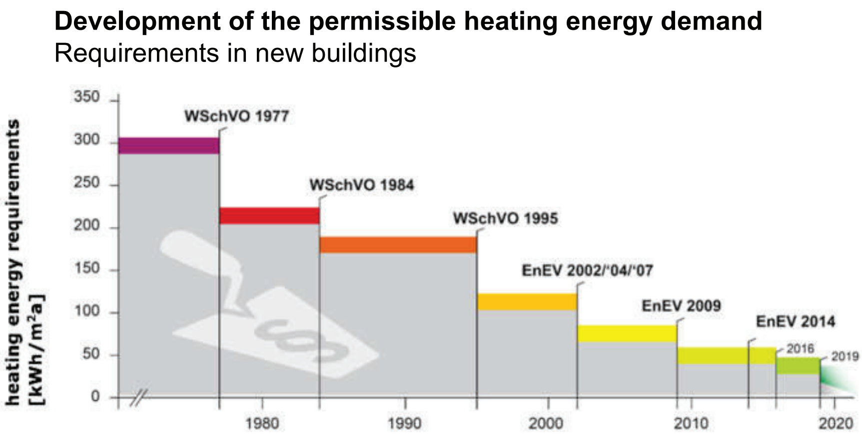

Fig. 1: Development of statutory energy-saving requirements for new buildings [4]

In the sense of these specifications, the developed system should make a significant contribution to improving the energy balance of buildings by counteracting the increase in heating and cooling loads required for temperature control - which is related to the increasing proportion of building glazing associated with modern architectural concepts ([5], [6]).

The state of the art in science and technology is characterised by individual solutions for the functionalities of thermal insulation, regenerative power generation by means of photovoltaics (PV) and shading. Fig. 2 provides a highly simplified overview of the individual and combined solutions available on the market at the start of the project.

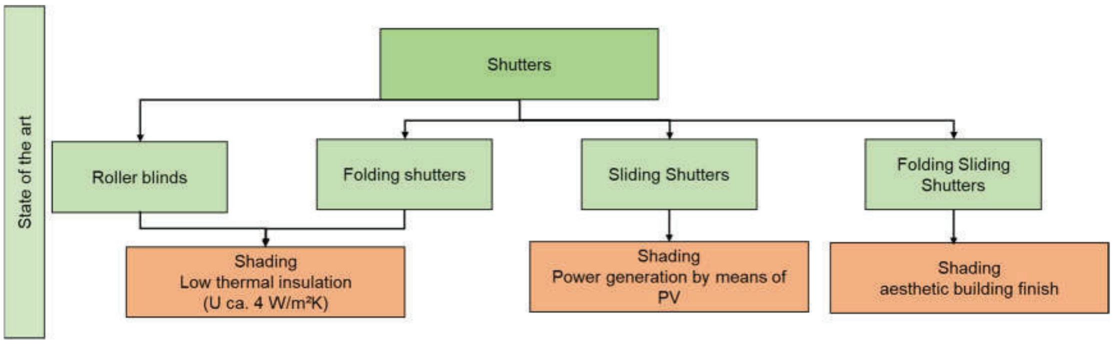

Fig. 2: State of the art of shutters available on the market at the start of the project

2. Objective

The overall objective of the project was the product and process development of an energy-efficient, thermally highly insulating solar shading system with integrated PV modules for solar energy generation, which can be installed as an upstream component on building glazing and significantly improves its energy balance (Fig. 3).

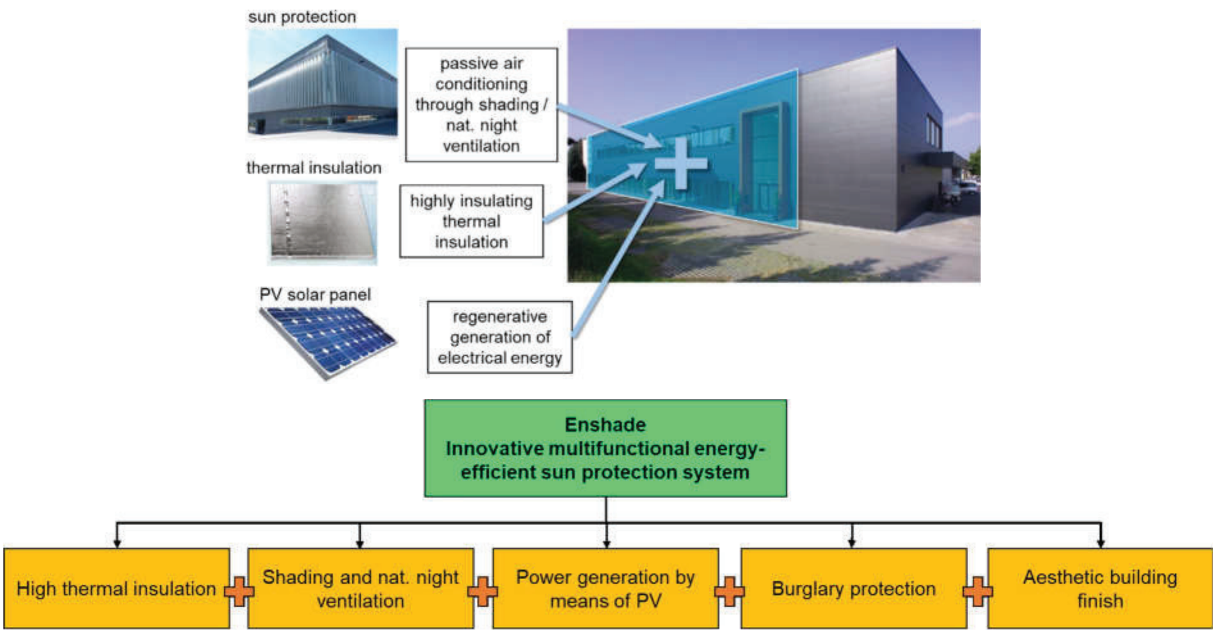

Fig. 3: EnShade: Multifunctional solar shading, thermal insulation and PV system for increasing the energy efficiency of glazed building openings

The project aimed to significantly improve the overall energy balance of buildings through innovative functional integration of highly efficient thermal insulation, effective (controlled) solar shading and PV power generation, which was achieved by developing a thermally optimised, PV-active shutter segment using innovative, This is to be achieved by developing a thermally optimised, PV-active window shutter segment using innovative, slim and highly insulating construction elements in the form of vacuum-insulated panels (VIP), integrated into an effectively sealing and thermal bridge-reduced frame construction with a new, smart drive and control technology to be specially developed for this purpose, which also supports seasonal natural night ventilation.

3. Concept solutions

For the targeted development of the EnShade system, potential use cases were analysed and evaluated and then user profiles were developed to derive the functional objectives. The selected use cases are non-residential buildings, in particular industrial buildings with continuous rooflights and office buildings with corresponding window measurements, which were chosen on the basis of the requirements and needs analysis carried out. As a result of the requirements analysis, an evaluation matrix was developed for selecting a suitable shutter principle for the EnShade system with the aim of checking the integrability of the individual functionalities and requirements in suitable shutter types. As a result, roller shutters and folding shutters were eliminated due to the impracticability of the desired multifunctionality of the EnShade system, and the development focus was placed on folding-lifting, sliding and folding-sliding shutters, as:

- Loads and stresses (dead weight and wind loads) can be transferred sensibly via bearings or guides close to the façade,
- the space required for folded-in shutters or the folding radius when folding and unfolding the system is only a fraction of the total area or length due to the division of the area to be shaded or thermally insulated into several individual segments and can therefore be constructed in a very space-saving manner, and
- the folding principle naturally supports the sealing process between the shutter segments and the building connection when closing.

The developed solution concept for the functional design of a folding lever wheel is shown in Fig. 4.

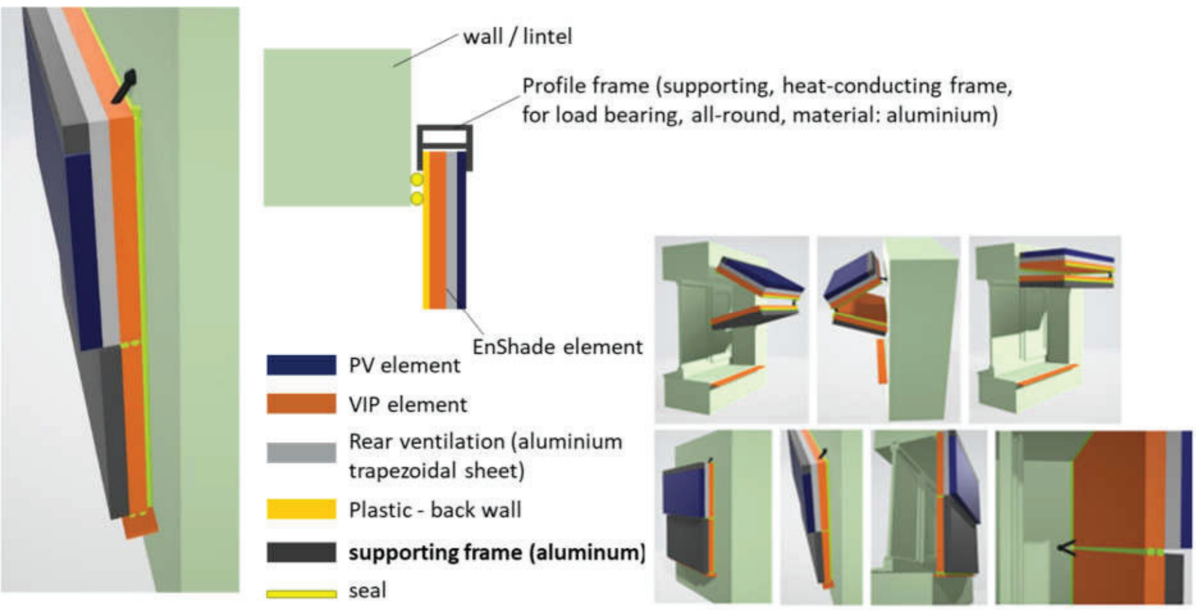

Fig. 4: Solution concept for the functional design of a folding lever wheel

In the case of folding lever shutters that are placed on the window rebate, the seals between the wall and the EnShade element can be arranged within the aluminium frame enclosing the EnShade element. If a rear wall made of a material with low thermal conductivity (e.g. plastic, aramid plastic composite or GRP) is used for the

EnShade element, thermal bridges at the upper edge and at the side edges can be largely excluded. The seal between the EnShade window shutter and the wall is designed as a triple seal and uses the heat-insulating properties of two enclosed air chambers.

As a solution to avoid a thermal bridge through the aluminium frame in the hinge axis of the folding shutter, the plastic rear wall of the EnShade element was extended to form a half-shell, i.e. the element was surrounded on the sides by a shell with only low thermal conductivity, which at the same time takes over part of the load-bearing function.

In addition, concepts and constructive solutions were developed for single- and multi-leaf sliding shutters, a sliding shutter with adjustable slats and a folding sliding shutter, which are not discussed in detail here.

Due to the thermal insulation on the back of the PV modules, it was not possible to exclude the possibility that the modules would heat up very strongly during high solar irradiation, which could potentially lead to a reduction in performance, the loosening of adhesive joints or damage to the modules (at module temperatures above 85 °C). For this reason, a concept for PV module rear ventilation was developed based on air flowing through natural convection: A trapezoidal aluminium sheet inserted between the back of the PV module and the VIP conducts the heat from the back of the module to the air flowing through, which enters at the lower end through openings in the frame and exits again at the upper end of the module.

4. Construction and testing of demonstrators

Due to the diverse requirements placed on the EnShade elements on the one hand and on the overall functional construction of the shutters on the other, two functional demonstrators were initially designed and manufactured, which were mounted on a biaxially adjustable test stand in the ISE solar laboratory for the tests and tested for performance and heating and for deflection at different angles of inclination and under high solar irradiation (Fig. 5). One of the two systems was equipped with a cooling rear ventilation of the PV module, which enabled comparative measurements between rear-ventilated and non-rear-ventilated variants.

Fig. 5: Functional demonstrators installed in the solar laboratory (left) and frame load-deformation test (right)

Experiments on power and module temperature development were carried out at various angles of inclination relative to the earth's normal - with an exclusively southern orientation. Only measurements from days with high solar irradiation were taken into account. In a first test phase, the measured values of global radiation, module output, module temperature and outdoor temperature were recorded and evaluated over a period of 24 hours at constant module inclinations of 30°, 45° and 60°. In a second measurement phase - an in-termittent tracking measurement - the inclination of the EnShade function demonstrators was automatically adjusted by motor in time intervals of 15 minutes to the current position of the sun ("elevation") or to the "middle optimal angle" - the average optimal angle of inclination for the entire year. By alternately setting the angles, almost constant conditions can be achieved for the parallel measurements, so that good comparability was achieved. The results of the tests on the functional demonstrators proved that

- the joining technology solution developed in the form of adhesive bonding technology meets the requirements and can be transferred to the large-scale demonstrators,
- the load-related deformation (deflection) of the sandwich construction is reduced by approx. 45% compared to pure aluminium or GRP frames and this is sufficient to implement a uniform pressure force on the surrounding seals,
- cooling rear ventilation is not necessary, as the maximum temperature of the PV module of 85°C is not reached and a relevant increase in performance has not been proven.

The knowledge gained from the two functional demonstrators was incorporated into the conceptual design, the construction and the selection of the large-scale demonstrators intended for physical realisation. A sliding shutter and a folding lever shutter were realised as demonstrators. A container building was selected for the implementation of the individual development focal points of the project, on which the EnShade components were installed. The conceptual solution of the designed test stand is shown in Fig. 6.

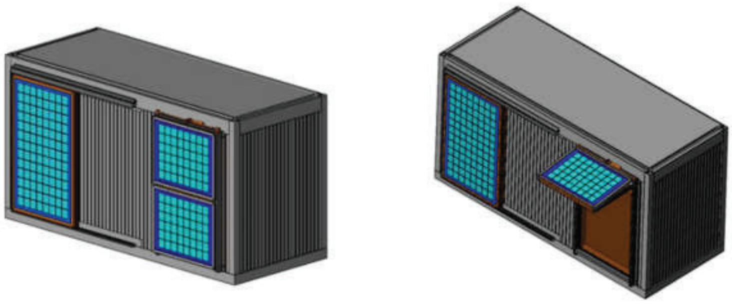

Fig. 6: EnShade test stand for large-scale demonstrators

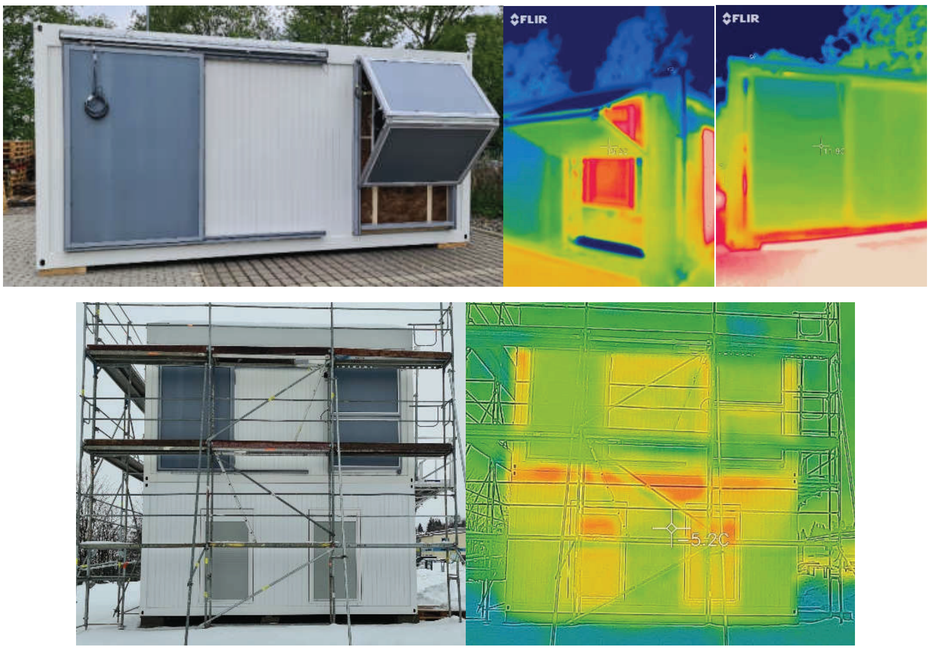

Fig. 7: EnShade container building - installed demonstrators (left half of the image) and thermographic images of the heat loss or insulation properties of the two EnShade shutters compared to the rest of the container building (right half of the image).

After fabrication and installation (Fig. 7, top left) of the two EnShade demonstrators on a thermally insulated container and later integration of the container into a container building (Fig. 7, bottom left), orienting measurements and thermographic recordings were carried out in autumn (Fig. 7, top right) at outside temperatures of approx. + 5°C and in winter (Fig. 7, bottom right) at outside temperatures of approx. -7°C. The indoor temperatures were about 20 to 25 K higher than the respective outdoor temperatures in the thermographic recordings. The graphs show that the U-value of the thermal insulation of both EnShade shutters is below the U-value of the rest of the container building.

The thermal insulation properties of the EnShade elements have also been proven mathematically. An effective U-value of 0.278 W/(m²*K) could thus be determined for the demonstrator sliding shutter.

The PV power curve was recorded over a period of several weeks in late summer and autumn. The sum of the real outputs of both EnShade elements reached peak values of approx. 380 W and average outputs of between 150 and 300 W. Based on this performance data, it was possible to roughly extrapolate an annual yield. Thus, depending on the location of the installed building as well as the possibility of readjusting the PV module by changing the inclination of the folding lever edge, the targeted annual yield of approx. 90 kWh per year and m² of PV-equipped shop area could be proven to be realisable.

5. Resume

The development goal of an energy-efficient, thermally highly insulating solar protection system with integrated PV modules for solar energy generation, which can be installed as an upstream component on building glazing and significantly improves its energy balance, was achieved. To this end, various approaches were pursued, some of which were implemented only conceptually, others conceptually and constructively, and in two cases exemplarily physically realised and tested. All the desired properties of the EnShade system could be achieved conceptually. The fulfilment of many of the intended goals could also be proven by means of the demonstrators.

The EnShade element being developed can make a significant contribution to improving the energy balance both by reducing the heating and cooling loads required for buildings and by generating solar energy. At the same time, it can protect the glazing behind it against vandalism and burglary.

6. References

[1] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB), „Wirksamwerden der Anhebung der energetischen Anforderungen an Neubauten am 1. Januar 2016,“ 14 01 2016. [Online]. Available: http://www.bmub.bund.de/themen/bauen/energieeffizientes-bauen-und-sanieren/energieeinsparverordnung/.

[2] Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), [Online]. Available: https://www.bmu.de/fileadmin/Daten_BMU/Download_PDF/Klimaschutz/klimaschutzplan_2050_bf.pdf. [Accessed 04 01 2022].

[3] Europäische Kommission, „Pariser Übereinkommen,“ 04 01 2022. [Online]. Available: https://ec.europa.eu/clima/policies/international/negotiations/paris_de.

[4] S. Kersten, „Die Energieeinsparverordnung (EnEV 2014/2016), Vortrag auf dem Praxistag des Energiezentrum Willich,“ 04 01 2022. [Online]. Available: http://www.energiezentrum-willich.de/downloads/Praxistage/2015-09-25_EnEV_EZW.pdf.

[5] S. Wirtz und M. Wirths, „Pfosten - Riegel - Konstruktionen / Elementfassaden,“ 04 01 2022. [Online]. Available: http://www.architektur.uni-siegen.de/aktuelles/brett/bauko_wi/pdf/reader_fassadensysteme_2010_05_10.pdf.

[6] Oberster Rechnungshof Bayern, „Jahresbericht 2007, TNr. 19: Staatliche Gebäude mit hohem Glasanteil in der Fassade,“ 04 01 2022. [Online]. Available: https://www.orh.bayern.de/berichte/jahresberichte/archiv/jahresbericht-2007/beitraege-zu-baumassnahmen/262-tnr-19-staatliche-gebaeude-mit-hohem-glasanteil-in-der-fassade.html.