

Lightweight envelopes for old buildings

Textile membranes offer new opportunities for the energy-based refurbishment of existing buildings



Lightweight and transparent membrane structures enable large spaces, such as courtyards in old building complexes, to be roofed over. Supplemental to the additional space created, this also achieves savings in terms of the heating and lighting. Artificial light is not necessary and the heat losses from the adjacent buildings can be reduced. However, an intelligent building management system is essential in order to create a pleasant indoor environment. To ensure that this is achieved, scientists have developed new concepts and components for the use of film and membranes in old buildings.

The use of pneumatic cushions made of film opens up new approaches in tackling specific urban situations, whereby the air-filled cavity with an overpressure of approximately 0.2 bar provides an opportunity to optimise the thermal insulation. The cushions are very light and can be designed to be highly transparent. The light transmission is controllable, for example when the cushions are printed or flexible thin-film solar cells are applied to generate electricity. Their use for covering large atria or courtyards of buildings whose facades cannot be altered for architectural or conservation reasons enables the heat losses via the facades to be reduced. In addition, the considerable surface weight of glass roofs is another reason why it is beneficial to use a structure with textile materials, which can also be implemented more cheaply.

A diverse range of materials, coatings and components are now available in order to improve the thermal insulation properties of films and membranes.

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Researchers are improving the thermal properties

For successfully performing energy-based refurbishments by using membranes and films, materials and components with excellent thermal insulation properties are necessary. This requires basic knowledge of the structural physical characteristics. These include the infrared-optical properties, such as the transmission in the visible part of the spectrum, the solar transmission, the reflection in the solar part of the spectrum and the absorption of thermal radiation, which not only determine the visual appearance but also influence the energy-based properties of building envelopes made with this material. Since this data is not always available for membranes, scientists at ZAE Bayern have measured various types of materials with an identical procedure.

The use of an additional membrane layer already enables the thermal property of membrane cushions to be improved from 3.3 to 1.8 W/m²K (U-value). If an aerogel fleece is applied between the membranes, the U-value is approximately 0.4 W/m²K. Silica aerogel is translucent and is suitable for use in structures with pneumatic membrane cushions. Another option that has already been tested out is to coat the membranes with low-e coatings.

For realising high quality building envelopes using membrane materials, not only the membrane surface is important for the thermal protection but also the membrane edge. This particularly applies to cushion structures. Although the membrane surface offers considerable thermal protection, the overall U-value depends on the specific geometry of the structure. Here the cushion edge and, specifically, the clamping profile take on considerable importance. This, however, has unfavourable frame-related U-values, which can lead not only to heat losses but also to localised condensation problems. Nevertheless, the development of a prototype for a new clamp profile from the Hightex company has enabled the previously typical frame-related U-value to be halved (Fig. 1). A condensation channel that collects any condensation is still essential. The developers are working on further improvements in regards to the tightness of the cushions and the cushion connections.

Refurbishing buildings with membranes

Together with partners from industry, scientists at the Bavarian Center for Applied Energy Research (ZAE Bayern), Munich University of Applied Sciences and HFT Stuttgart have optimised the properties of membrane structures and developed concepts to enable the use of films and fabrics for the energy-based refurbishment of buildings. There are four basic application areas:

1. Facade and roof consist of a membrane.
2. Building-in-building principle: A membrane structure spans the entire building.
3. The membrane envelope acts as a second skin, comparable to a double facade made of glass.
4. Roofed-over atrium: A courtyard can be retrofitted with a roof.

All versions place considerable demands on the planning and technical building services equipment. However, during the course of the research project it has been shown that it is particularly worthwhile retrofitting courtyards with roofs. The improved A/V ratio of such building com-

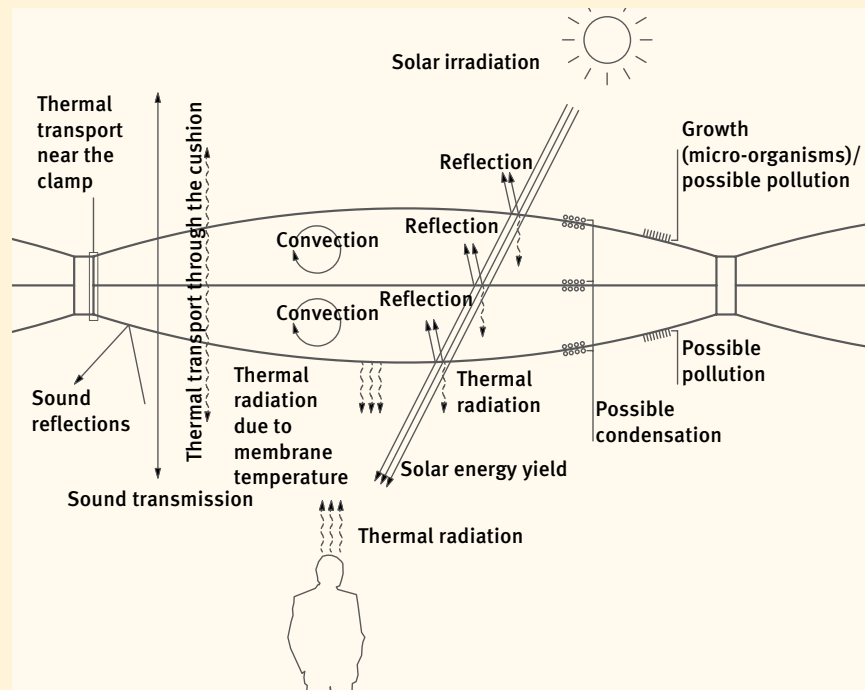


Fig. 1 Structural aspects of membrane cushions.

Source: Jan Cremers

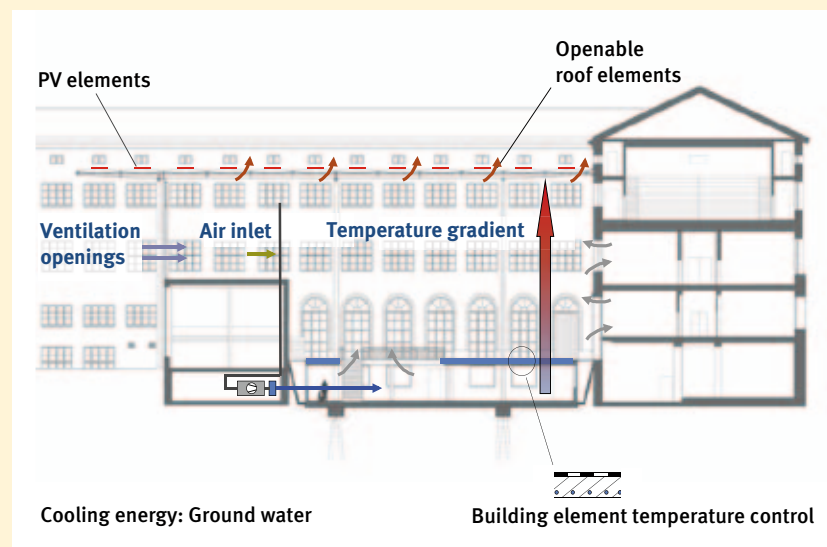


Fig. 2 Depiction of a recommended operational mode in summer, TU Munich.

Source: Ebert Ingenieure and Lang Hugger Rampp GmbH

plexes in itself provides advantages relative to the initial situation in terms of the energy use. This application area was therefore examined more closely.

Roofing over atria

The scientists developed a concept for roofing over courtyards for two properties belonging to the HFT Stuttgart and TU Munich (Fig. 3, 4).

The research work focussed on the thermal flow conditions and the daylight situation in the atrium and adjacent rooms. The results show that ventilation possibilities need to be provided via the membrane roof since the indoor temperature constantly rises in summer with the height. Cushions that can be pushed upwards provide an option here. A variable gap is created in accordance with the lifting height. A sufficient number of controllable air inlets provide the necessary air exchange.

The daylight situation depends on the geometry and size of the roofed-over courtyard. In the case of the HFT Stuttgart, the small and narrow surface



Membrane materials

Materials predominantly used in membrane structures include polytetrafluorethylene (PTFE)-coated glass fibre fabrics (Olympic Stadium Berlin), polyvinylchloride (PVC)-coated polyester fabrics (Rothenbaum Tennis Arena) and ethylene tetrafluoroethylene films (ETFE) (Small Palace Courtyard, Dresden). The materials have a fire protection class of at least B1. Characteristic features of ETFE films and PTFE-coated fabrics include their high self-cleaning effect, low soiling characteristics and high UV and weather resistance. These flexible membrane materials weigh between 0.2 and 1.5 kg/m². The low weight offers advantages in terms of the lifecycle of buildings. The 0.2 mm-thick ETFE films are particularly light and are used with pneumatic cushions.



Fig. 3 Simulated courtyard perspective for the HFT Stuttgart building. Source: Lang Hugger Rampp GmbH



Fig. 4 Simulated interior perspective for the TU Munich building with a converted basement. Source: Lang Hugger Rampp GmbH

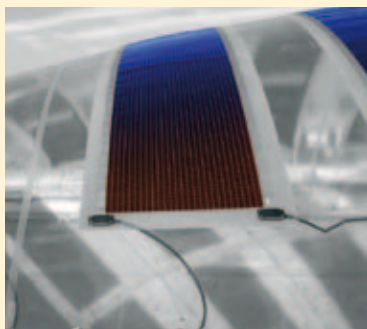


Fig. 5 Prototype of an ETFE cushion with flexible PV modules. Source: Jan Cremers, Hightex GmbH



Fig. 6 Residential Palace, Dresden, membrane roof. Architect: P. Kulka, P. Stamborski. Source: Jochen Manara

area with a roof surface of 400 m² means that the adjacent office spaces are already supplied with insufficient daylight at a room depth of 2 metres. In Munich, with a roofed-over surface area of 1,300 m², the offices have sufficient daylight.

The climate concept places high demands on the technical building services equipment. Atria behave in a similar fashion to air collectors, whereby the air temperatures vary considerably in accordance with the air exchange and solar irradiation. Natural ventilation through suitable openings in the roof and air inlets near the ground is not suitable for all weather situations. It is therefore recommended to use mechanical ventilation with an air exchange rate between 2.5 and 4 h⁻¹.

The use of the courtyard should already be decided upon before the planning starts. This determines the technical measures and the concept used for the technical building services equipment. The desired room temperatures are an important criterion. Depending on the use, these vary between 14 °C (for

circulation and exhibition spaces) and 22 °C (for office and conference areas). The technology used must be able to deal with continuously changing conditions. Sufficient sensors for the temperature, air movement, etc, need to be planned in for this purpose. A good example is the concept for the Small Palace Courtyard in Dresden. The roofed-over inner space provides a vestibule for the ticket counter and a foyer for exhibitions, which means that the thermal comfort requirements are clearly defined.

If the atrium is to be used as a workspace, it needs to be heated. This utilisation presupposes that the membrane roof is well insulated. This heating, however, can cancel out the saving effects achieved. The researchers have therefore developed a model that can calculate the temperature of the atrium at which the savings effect is lost. They have proposed combining building element activation with a ventilation system to provide the heating system. The heated air can also be blown into the atrium at a greater height when needed via jet nozzles. This system can also be used for cooling in summer. The building element activation needs to be connected to ground water cooling for this purpose (Fig. 2).

Primary energy balance

Compared with glass roofs, membrane structures have a considerable advantage in terms of the primary energy. This is because they use less material for the supporting structure and the roof skin. By way of example, the primary energy consumption for both a glass roof and a membrane structure with cushions was calculated for the project in Munich. The membrane roof requires 50% less energy. If the building's usage period is also taken into consideration, the savings effect depends on the electricity consumed to operate the membrane cushions. Ideally, the power consumed should not be more than 0.4 W/m². With 1.2 W/m², the advantage over glass in regards to the energy use would no longer exist after an assumed usage period of 80 years.



Membrane structures with new functions

The energy efficient operation of buildings with membrane structures requires measures that reduce the heat influx in summer and provide good thermal insulation in winter. In combination with excellent control technology that takes into account optimum air exchange rates via openable roof elements and which enables efficient solar shading, the use of membranes for energy-based refurbishment provides an interesting concept for specific urban situations. Flexible thin-film solar cells made of amorphous silicon, embedded in fluoropolymer films, enable the use of photovoltaics on textile roofs (Fig. 5). A favourable side effect is that the PV modules provide shading for the space underneath. The installation is complex because the flexible roof structure causes stresses in the roof envelope. This has an impact on the PV modules that cannot generally move with the expansions. The Hightex company has developed a method that technically works – although it is still considerably time consuming. Two single-sided laminated PTFE/glass membrane strips are welded to the support membrane. Hook-and-loop strips are bonded to it, to which the PV modules are fixed. The reversible connection enables the replacement of faulty modules. Further research work needs to determine the durability and UV resistance of the adhesive connections. Could the loosely supported reverse side of the PV modules become dirty? Is the fixing permanent or is damage caused to the modules?

Further research and development are also required in regards to improving the energy efficiency of membrane structures. Light emitting function layers can be applied to the material surface or switchable/self-switching function layers integrated for controlling the g-values. Textile structures are becoming increasingly important and are used to a high extent in large-scale construction projects. Spectacular examples that showcase the new possibilities include Bangkok's new airport, the BC Place stadium in Vancouver, Canada, and the Gerontology Centre in Bad Tölz, Germany.

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ETFE-film facade at the Gerontology Centre in Bad Tölz. Arch. D. J. Siegert.
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