Control of Thermal Energy in Membrane Structures

Univ.-Prof. Dr.-Ing. Bernd Baier
University of Essen, Germany
FB 10, Konstruktive Gestaltung, Leichtbau
D-45117 Essen
phone: 0201-183-2843/2845
fax: 0201-183-3543
email address: ikg030@sp2.power.uni-essen.de

1 Introduction

The tent was not the first shelter of humans, it has however always been stated as a building method - measured on the possibilities of the times - to the highest level or state of the art in each case. A tent is suitable for the task of repeated rapid erection and re-erection. It is easy to transport and is able to be adapted to a considerable degree to a particular climate and further, relative to more rigid, substantial building methods, it is economical.

Today's tents and modern membrane buildings such as meeting-, sport- or exhibition-halls likewise fulfill the characteristics specified above, although the mobility now plays a more subordinated role. They correspond to today's state of the art as space coverings only, if there are made increased measures for energy and environmental protection, using appropriate thermal insulation in connection with light permeability and noise control.

Membrane constructions generally react very rapidly to external energy influences due to their low storage mass. This means that both, inadvertent cooling due to winter thermal losses and excessive heating of the interior by solar radiation in the summer, only could be controlled by considerable expenditure of air conditioning.

Undesirable fluctuations of the interior temperature can be avoided with membrane constructions under certain conditions by active or passive controlling of the energy flows. Usable solar energy gains can even be made to contribute to a positive total energy balance.

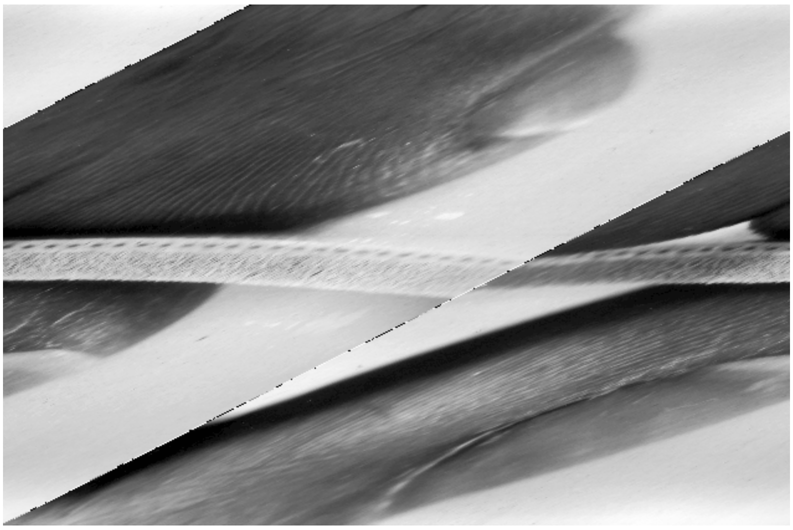
In this paper systematic solutions of membrane structures with different layers are shown, with which controlled effects are possible from guided daylight use to solar energy production.

2 Thermal insulation

2.1 Single layer membrane (Fig. 1)

The thermal insulating characteristics of single layer membranes are with a measured k-value of 5,7 W/m^2K [2] not sufficient for interiors permanently kept at a moderate temperature after the German Thermal Protection Standard WSVO. Sun exposure particularly can cause high temperatures under the membrane surface. Closed spaces result in air warming up in the summer due to the transformation of radiation energy into heat. At low night temperatures or during the winter time, a cooling of interior air results from thermal radiation.

Rapid heating and cooling are usually only controllable with large energy expenditure for ventilation, cooling and heating. The high translucence of the membrane material partiallly proves an advantage with this construction in an energy technical regard, since usually artificial lighting is to be provided during the day.



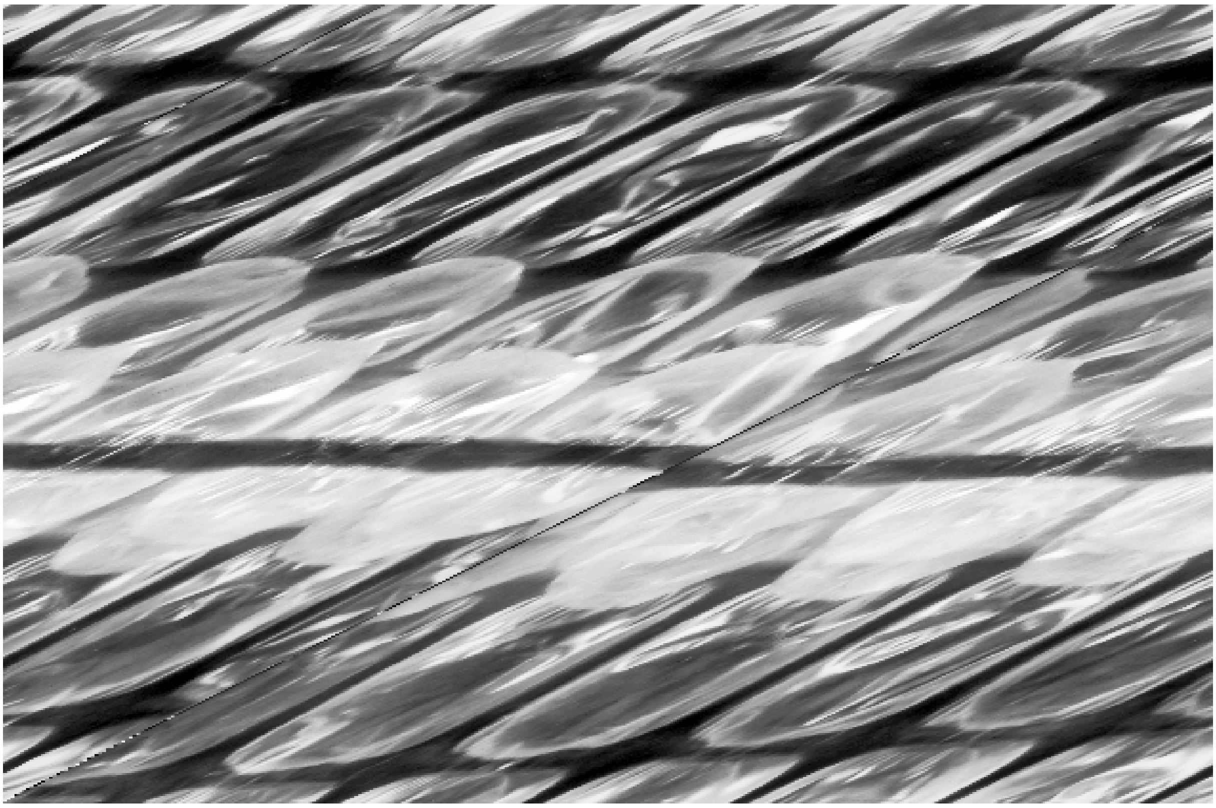
2.2 Single layer membrane with foam coating (Fig. 2)

Foam material from PVC or PU could be positioned underneath the structural membrane. Depending upon foam material thickness and material type thereby k-values to approximately 5.0 W/m²K can be attained [3], almost as with the single layer membrane. For spaces permanently kept at a moderate temperature this system is in energy technical respects not sufficient, not economical and ecologically not justifiable. Additional and different disadvantages come in to play: the membrane is hard to work with and difficult to transport, further it is not very translucent, with more additional energy on the lighting being spent during the daylight hours.

2.3 Double layer membrane with fibre insulating material (Fig. 3)

This construction is relatively frequently applied because of its favourable cost-benefit ratio. Between two membrane layers a filling of fibre insulating material is introduced, e.g. from mineral wool, which varies in thickness according to different demands. Solutions with a sufficient moisture insulation membrane beneath the thermal insulation layer are proved more successful than the freely hanging insulating material positions.

Depending upon material and insulating material thickness computational k-values up to 0,2 W/m²K (e.g. with 200 mm mineral wool) can be attained here [1]. Membrane constructions of this type are more suitable for rigid buildings, because this type only can be erected and re-erected frequently by additional measures for instance with the forming of prefabricated mats or mattresses. The translucence is limited by the thickness of the insulating material.



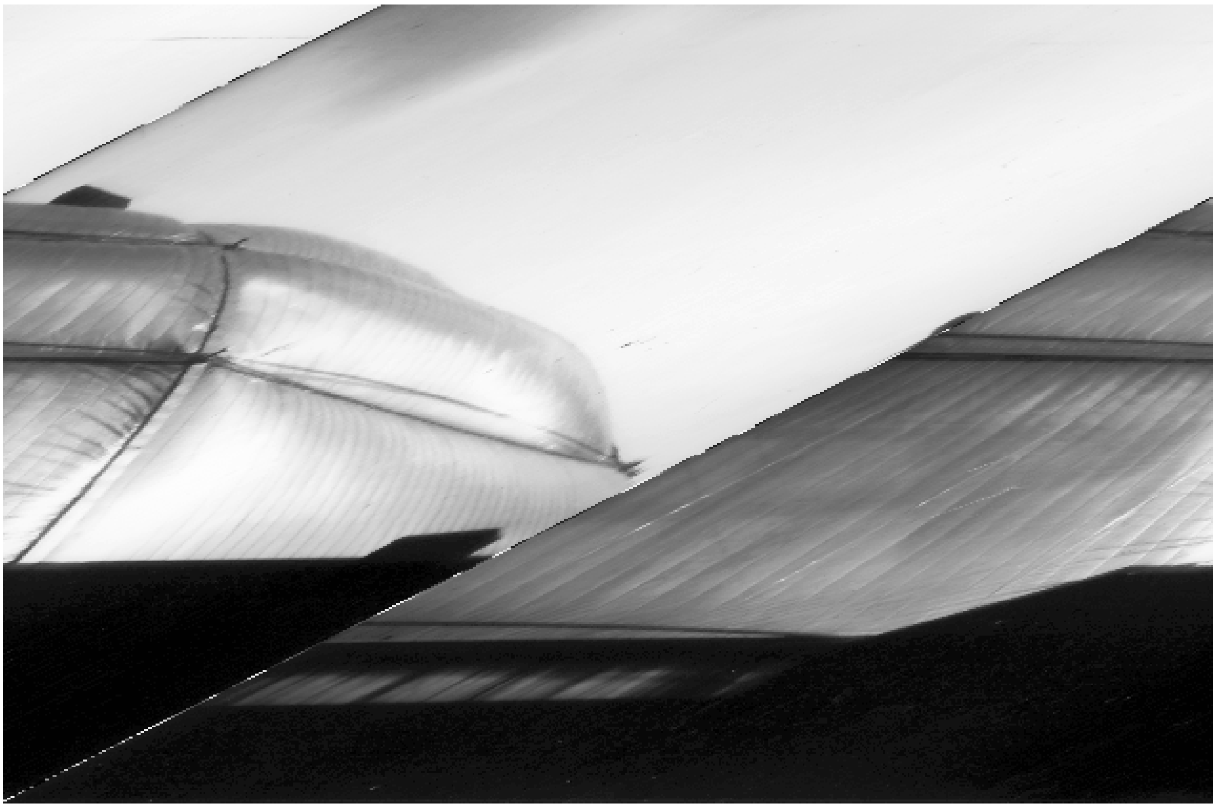
2.4 Double layer membranes with air cell filling (Fig. 4)

If the translucence of membrane materials is to be used for the natural lighting more strongly, air cells must provide the thermal insulation. Air cells can be tubular, with stitching or seamed like a pillow, or with single point attachments between the membrane layers like an airmattress. In addition, films forming self-contained air cells, so-called "blister films" between the two membrane or film layers result in a thermal insulating, translucent membrane construction.

A comparable effect have so-called "spacer fabrics". The air space between two membranes is produced by separating coils or loops in a double-layer fabric. The attainable k-values are, depending upon distance of the membrane layers, comparable to an insulating glazing and are situated with approximately 2.8 to 3.0 W/m²K.

2.5 Double layer cushions with stationary air filling (Fig. 5)

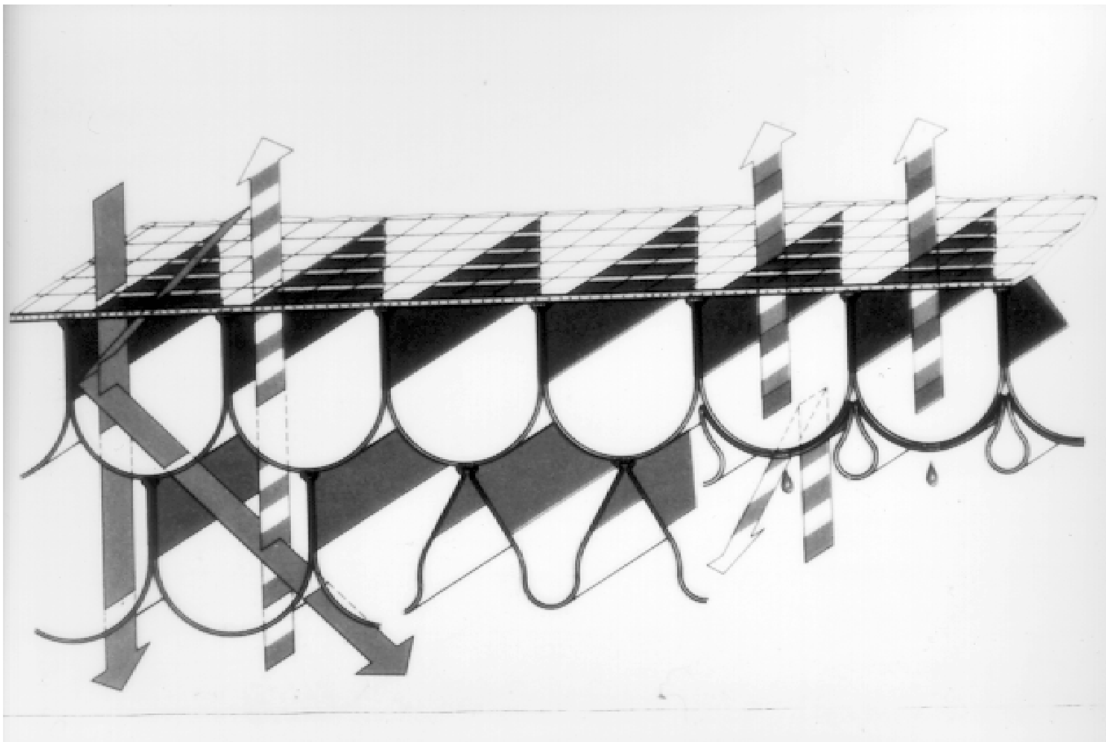
Large cushions constructed from membrane or film material with self-contained, constant air filling have been frequently used so far because of their translucence. They have worked satisfactorily in different climatic regions under changing conditions. With insufficiently dried and cleaned supporting air or with insufficiently moisture insulation membrane layers however, problems from condensate and fungal infestation at the inside of the cushions can result. Depending upon the distance of the membrane positions are attainable k-values of 2,7 to approximately 2.0 W/m²K [3].



2.6 Multi layer cushions with stationary air filling (Fig. 6)

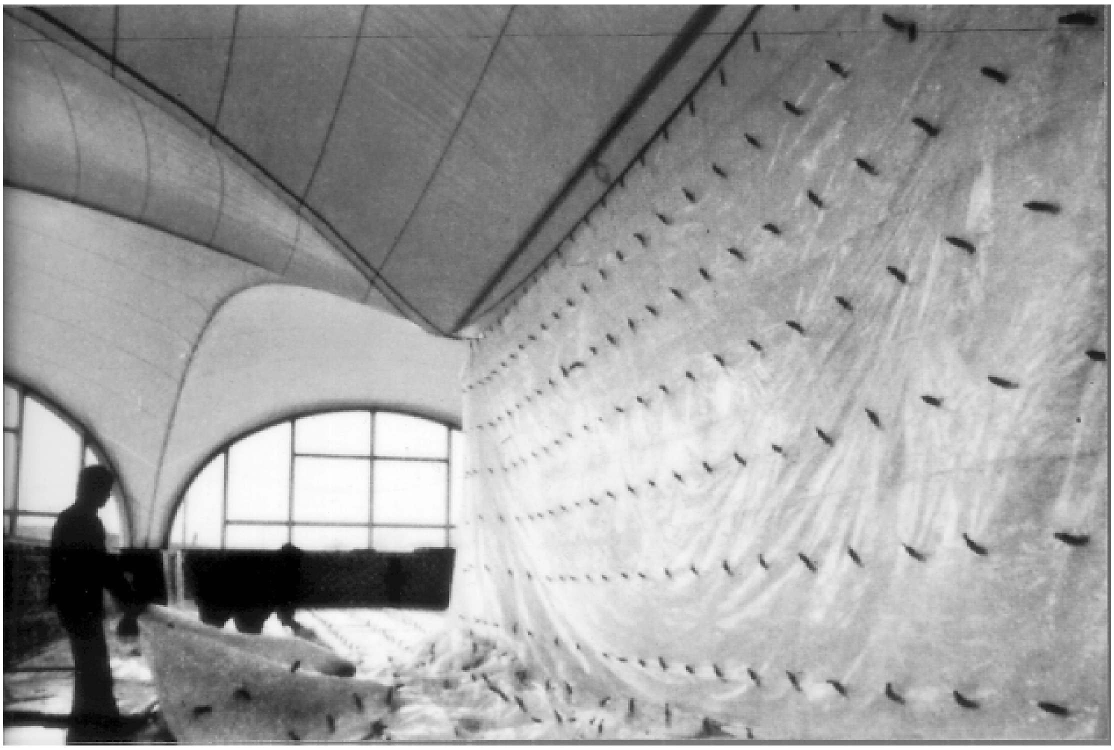
Multi-layer cushion constructions proved usable for decades because of the better thermal insulating characteristics opposite double layer cushions, their translucence is only insignificantly lower. Potential problems can occur with condensate and fungal infestation, in a similar manner as with the double layer cushions with constant air filling. As a function of the materials, the number (up to five) and the distance of the membrane positions, together with the air movement velocity between the membrane positions, k-values of 2,2 to approximately 0.8 W/m²K were determined [5].

3 Active control of light and thermal transmission



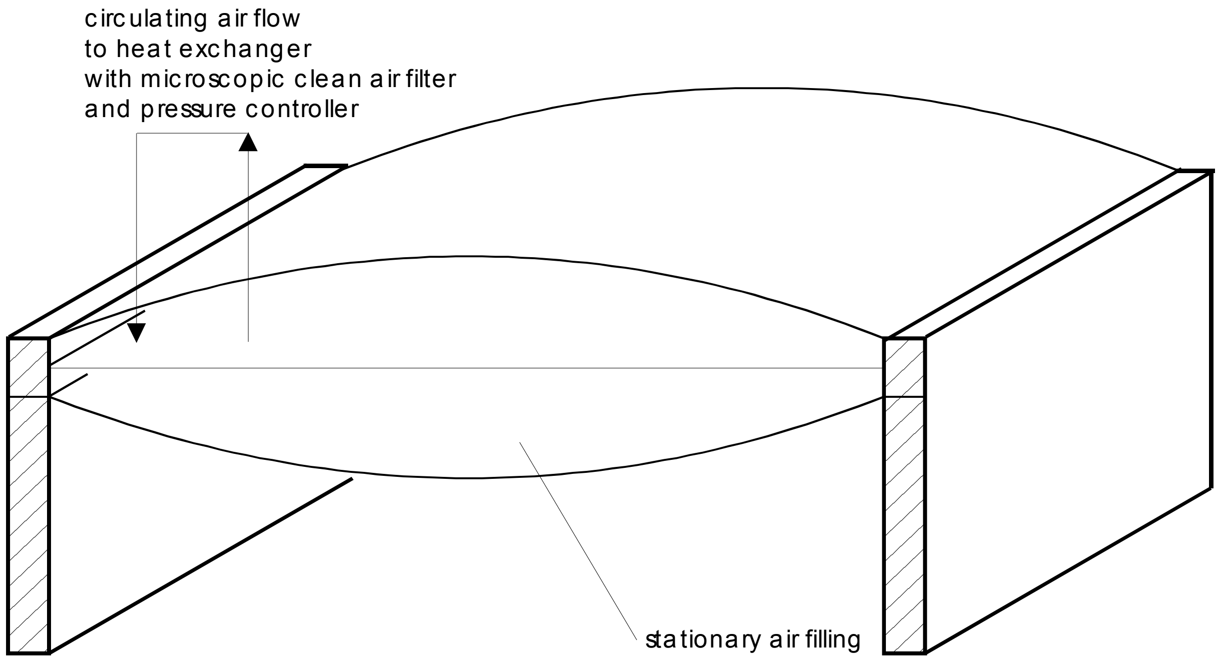
3.1 Active systems for the air condition of pneumatic coverings (Fig. 7)

For the first time N. Laing published [4] a dynamic computing method for systems showing the improvement of the room climate of pneumatic coverings, with which he wanted to prove that "tropical climate in Newfoundland and temperatures down to freezing point were possible in the Sahara". The systems suggested by him operated with parallel, partly metallized or blackened hose cells from film material. These could control, and depending upon position of the cell walls, thermal insulation, thermal storage, air-drying or moisture formation, operate different levels of radiation from total reflection to total transmission.



3.2 Multi layer air supported membrane coverings with controlled air flow (Fig. 8)

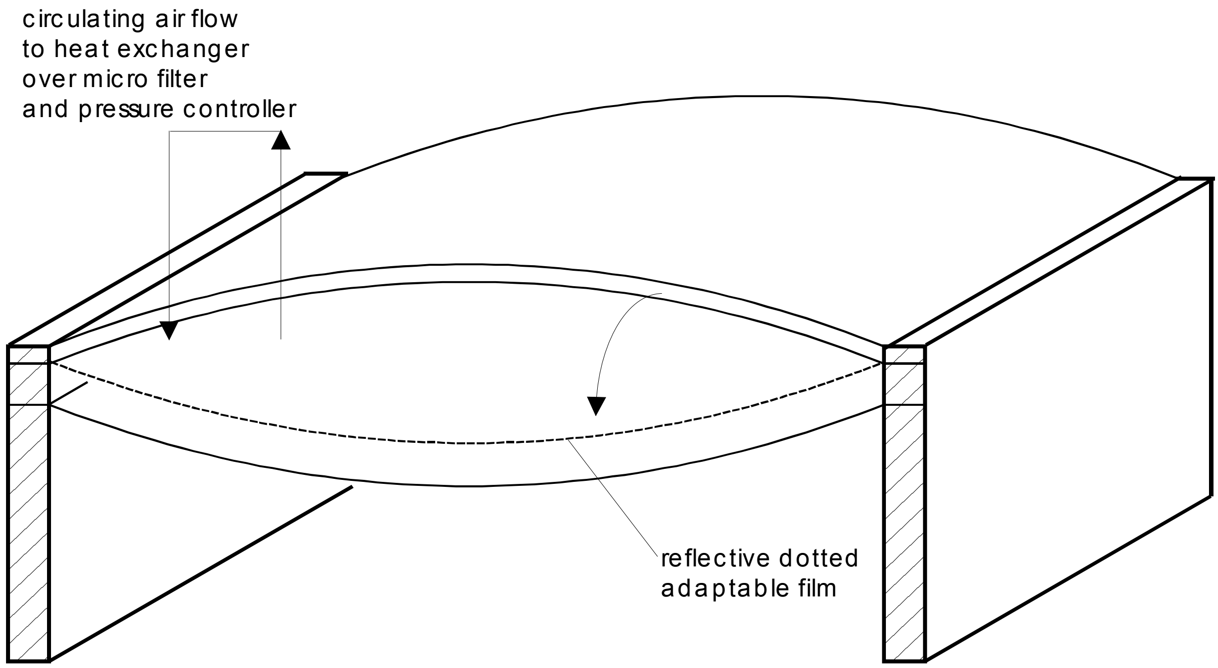
J. Linecker could achieve comparable effects as with the systems of Laing [5]. He used three to five layered membranes for the air-supported covering of swimming pools. The special advantage of these constructions was the possibility of supplying supporting air for the pneumatically stabilised halls after their loading with solar energy to a heat exchanger which then preheated industrial water for pools and showers, and thus saved energy. The flow rate of air in the gaps of the membrane positions was thereby variable, and could be controlled by valves in such a way that in the summer solar energy could be won or be used in the winter with the insulating efficiency of the outside standing air layer.



3.3 Triple layer film cushions with controlled air flow (Fig. 9)

More recently, a cushion system was used several times, a system which consists of three film layers and gaps through which air flowed, in contrast to example 2.6, where the air is a stationary filling. Important constituents of this system are blowers with a micro filter, appropriate pressure control systems and heat exchangers.

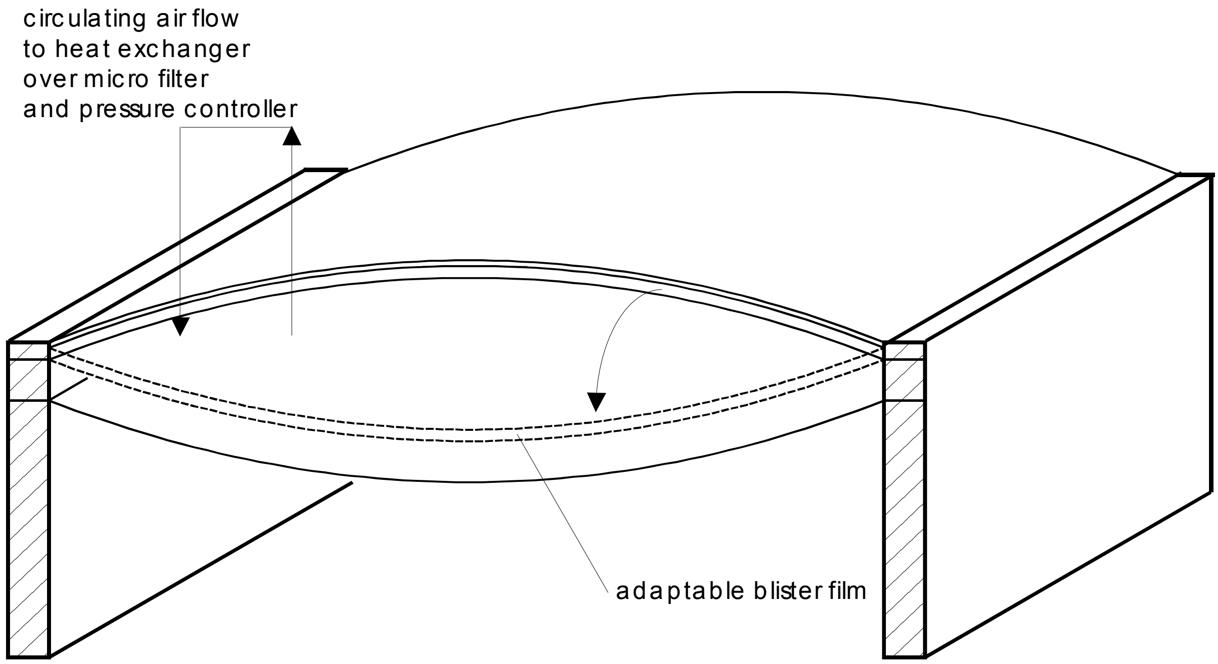
A further favourable and special feature is that the return air from the gaps transports thermal energy, which can be supplied either to a heat exchanger, or be ventilated with a heat energy surplus in the summer during high sun exposure. Likewise a mass storage with cold night air can be fed, in order to diminish thereby during the day room air temperature points. In the yearly energy balance an energy surplus results from the use of the sun exposure, which positively affects the economy of this system.

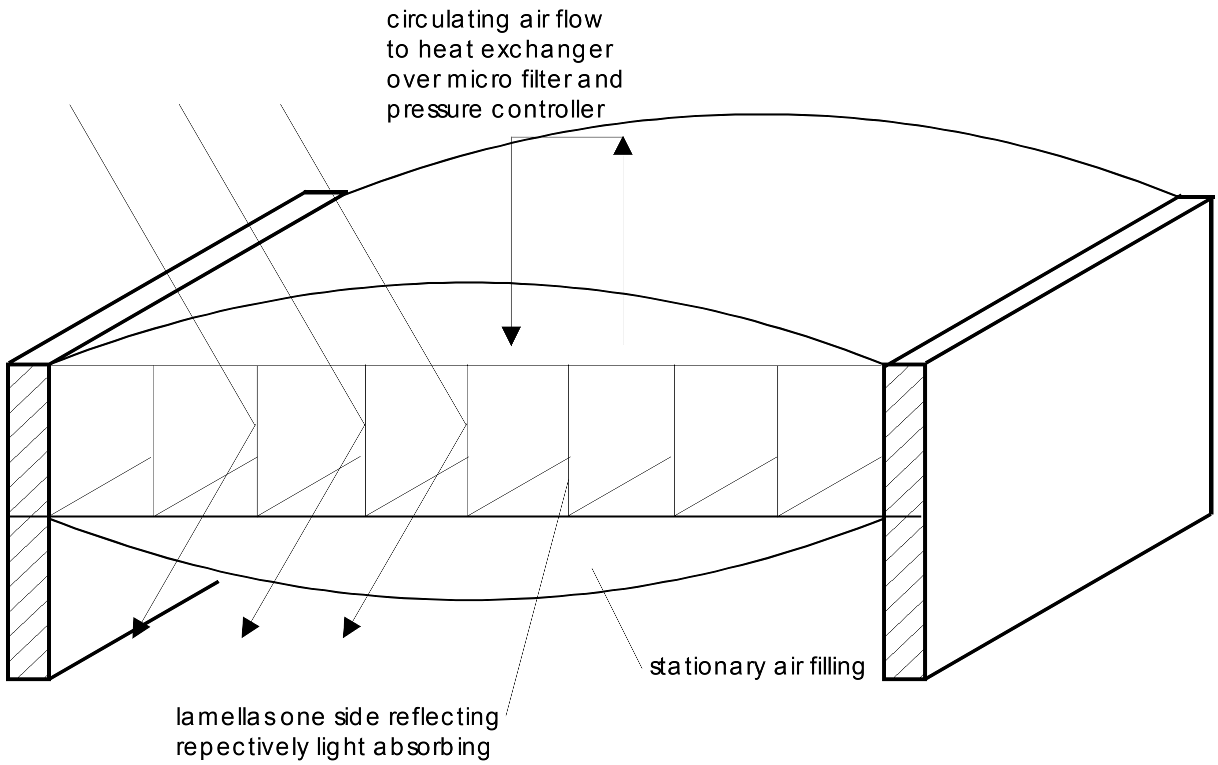


3.4 Multi layer film cushions with active controlled air flow (Fig. 10)

A combination of an active system (as in 3.1) and multi-layer film cushions (as in 3.3) offers all possibilities of an optimal controlling of the energy flows, whereby the following functions can be influenced by these and used synergetically:
- lighting: of total light permeability over light scattering up to the black-out
- sun exposure: from transmission to reflection
- nocturnal thermal radiation: unhindered permeable or shielded
- thermal insulation: controllable with air gap and air speed
- thermal energy use: over heat exchangers or from mass storage
- heat storage: in different media such as water or stone.

Figures 10.1 to 10.3 show three examples of active controlled cushion systems proposed by the author.


circulating air flow
to heat exchanger
over micro filter
and pressure controller
adaptable blister film


circulating air flow
to heat exchanger
over micro filter and
pressure controller
stationary air filling
lamellas one side reflecting
repectively light absorbing

4. Energy expenditure for production and operation (Tab. 1)

system	layers, material	production (incl. structure) [kWh/m^2]	operation (incl. utilisation) [kWh/m^2a]	usable energy profits [kWh/m^2a]
2.1	1 x PVC/PES membrane	42	202	0
2.2	1 x PVC/PES + 30 mm PU foam	58	172	0
2.3	2 x PVC/PES + 200 mm mineralwool	74	118	0
2.4	2 x PVC/PES + ETFE blister film	88	157	0
2.5	2 x PVC/PES membrane	68	157	0
2.6	2 x PVC/PES + 3 x ETFE film	128	129	0
3.1	3 x ETFE film	80	143	-190
3.2	2 x PVC/PES + 3 x ETFE film	134	129	-190
3.3	3 x ETFE film	80	143	-190
3.4	3 x ETFE film	80	143	-190

5 Summary

In table 1 the primary energy input for the production of the membrane is calculated per m² including the supporting structure, but without foundations. The operation energy input is calculated per m² and year (see [2]), including proportionate costs for the heating, for auxiliary energy, maintenance and the general use (lighting).

Under the passive systems the double layer membrane with fibre insulating material filling (system 2.3) is most economical, although because of the translucence lacking, in relation to other systems, higher annual energy expenditures for the artificial exposure must be taken into consideration.

In the comparison of the expenditure values of all described systems it is to be stated that the passive systems differ from the active systems by the fact that with them the solar energy gains can be included into a yearly energy balance also.

The time of the energy gains in the summer is however shifted in relation to the highest losses of energy in the winter seasonally, therefore the sum total of the theoretically usable solar energy gains does not state everything over the actual height of the annual energy saving. Only a long-term heat storage would bring remedy here, only then could the energy gains with the losses of energy become partly balanced.

This lecture has shown which effects are possible with the active control of energy flows in multi-layer translucent membrane systems.

From the comparison of the energy expenditure values it is clear that with certain cases (e.g. with swimming pools, sports sites and commercial systems) it is useful to apply the solar energy gains partly for the heating and for the industrial water preliminary heating. Thus show up together with the advantages, resulting from the controlling of the sun exposure for natural lighting, clear alternatives to conventional structures of glass and metal

If into a wholistic evaluation of building constructions criteria are likewise included such as variability, adaptability at different climatic conditions and exposure request, such as financial, energy and ecological economy, then multi-layer membrane constructions with active control of light and thermal flows offer optimal solutions.

Bibliography:

1. Baier, B.: Sind Membrankonstruktionen Energieverschwender?; in: Bubner, Baier, Koenen, Oelbermann (Hrsg.): Membrankonstruktionen 2, Köln-Braunsfeld 1981
2. Baier, B.: Energetische Bewertung luftgetragener Membranhallen im Vergleich mit Holz-, Stahl- und Stahlbetonhallen, Membrankonstruktionen 3; Köln-Braunsfeld 1982
3. Bubner, E.: Zur konstruktiven Ausbildung der Wärmedämmung bei Bauwerken aus textilen Membranen; in: Bubner, Baier, Koenen, Oelbermann (Hrsg.): Membrankonstruktionen, Köln-Braunsfeld 1979
4. Laing, N.: The Use of Solar and Sky Radiation for Air Conditioning of Pneumatic Structures, in: Proceedings of the 1st International Colloquium on Pneumatic Structures, Stuttgart 1967
5. Linecker, J.: Mehrschichtige Membrankonstruktionen zur Energieeinsparung und -gewinnung; in: Bubner, Baier, Koenen, Oelbermann (Hrsg.): Membrankonstruktionen, Köln-Braunsfeld 1979