TRANSPARENT INSULATION

IN SOLAR ENERGY CONVERSION FOR BUILDINGS AND OTHER APPLICATIONS

Proceedings of the 2nd International Workshop
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For further information contact:

Professor A. Goetzberger
Fraunhofer Institut
für Solare Energiesysteme
Oltmannsstr. 22, D-7800 Freiburg, FRG

OR

Dr. L. F. Jesch
Energy Engineering (Birmingham) Ltd.
192 Franklin Rd.
Birmingham B30 2HE, UK

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INTRODUCTION

Professor A. Goetzberger

Fraunhofer Institute for Solar Energy Systems
Oltmannstrasse 22, D-7800 Freiburg
Federal Republic of Germany

Sixteen month ago we had the first international workshop on transparent insulation materials for passive solar energy utilisation. That first gathering in Freiburg made us realise that there is a strong international, mainly European, interest in the subject and that a large portion of the initial research and development work was being carried out in West Germany. The Fraunhofer Institute for Solar Energy Systems has been investigating the properties and applications of transparent insulation materials for some years and it organised the the first two workshops under the auspices of the German Section of the International Solar Energy Society.

The second workshop was held on 24 – 25 March 1988 and its theme was transparent insulation materials in solar energy conversion for buildings and other applications. More and better prepared papers were presented this time as all of us working in the field of transparent insulation learned more since 1986 and were able to see the directions our research should go into more clearly. Amongst the 26 presentations Canada (1), Denmark (1), Sweden (1), Switzerland (1), Great Britain (4) and West Germany (18) were represented.

We listened with great interest to the invited keynote address delivered by Professor Terry Hollands from the University of Waterloo, one of the earliest pioneers of heat transfer in honeycombs and transparent insulation materials.

There were five broad areas around which the presentations and discussions were focussed: materials, systems and components, simulation, architectural aspects, planned projects. This structure in itself was a small shift from that of the first workshop representing the changes of emphasis in the most recent work. There were papers presented from the same research groups and even by the same people as in 1986 reporting on most recent advances, but there were also new contributors some from new areas of activity, not represented before. Every session had a discussion period built into it which was always used to the full extent.

The closing session of the workshop provided an opportunity to evaluate our efforts and to get feedback from the delegates. By majority consensus we decided that the third transparent insulation workshop will be held in the late summer of 1989 in Freiburg and that the fourth workshop will be held in the Spring of 1991 in Birmingham.

During the technical sessions of the workshop we enjoyed the hospitality of the University of Freiburg and the City of Freiburg gave a civic reception to all participants in the historic building of the City Hall where the Deputy Mayor gave a welcoming address.

The burden of the preparation of the technical sessions was on Dr. V. Wittver and of the organisation of all details was on Dr. W. Stahl. The publicity, printing and publication was the responsibility of Ms. A. Pollock. They all worked hard and brought success to the workshop. As co-chairmen: Dr. Jesch and I are grateful to them.

Transparent insulation materials

V. Wittwer

Fraunhofer-Institut für Solare Energiesysteme
Oltmannsstrasse 22, D-7800 Freiburg, FRG

Abstract

Transparent insulation materials are characterized by physical properties which place them in a different class to both opaque insulation materials and conventional transparent systems. From the geometrical point of view, four different types can be distinguished.

Introduction

Transparent insulation materials are characterized by two physical properties. The first one is the solar transmittance τ_e, which sometimes has to be extended to the total energy transmittance g and the other one is the thermal heat loss coefficient u or the thermal conductivity λ. Both values are sensitive to a large number of variables which have to be defined exactly to get comparable results.

Different types of materials

From the geometrical point of view, four different types of materials can be distinguished:

- structures parallel to the absorber (multiple glazings)
- structures perpendicular to the absorber (honeycomb, capillary)
- scattering structures (foams, bubbles, fibres)
- homogeneous materials (aerogel) (fig. 1).

For all of these materials, specifically modified theories are necessary to describe their physical characteristics /1/2/3/. Most of these structures can be made from different materials such as glass or plastic, and can be filled with different gases or evacuated.

Solar transmittance and total energy transmission

As mentioned above, the characteristic data of such a material are dependent on a large number of variables. The total solar transmittance τ_e can be given by the double integral:

$$\tau_e = \frac{\int\int \tau(\lambda,\varphi)\, I(\lambda,\varphi)\, d\lambda d\varphi}{\int\int I(\lambda,\varphi)\, d\lambda d\varphi}$$

where λ denotes the wavelength and φ the angle of incidence and $I(\lambda,\varphi)$ is the incident intensity as a function of both of these variables.

The spectral transmittance $\tau(\lambda,\varphi)$ is dependent on the material itself and the geometry, while the incoming radiation is dependent on the angle of incidence, time and weather conditions. Figure 1 shows the angular dependence of different materials. For the total energy transmittance, the surrounding conditions also become important. Typically the g-value is 5 to 10% higher than the $\tau\alpha$-value. The exact determination of g is difficult and up to now there is no standard routine for measuring it.

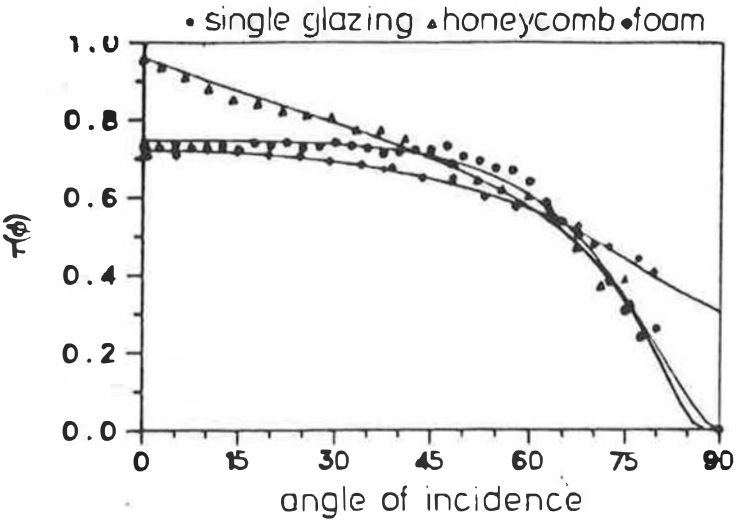

Fig. 1: Transmittance in dependence on the angle of incidence

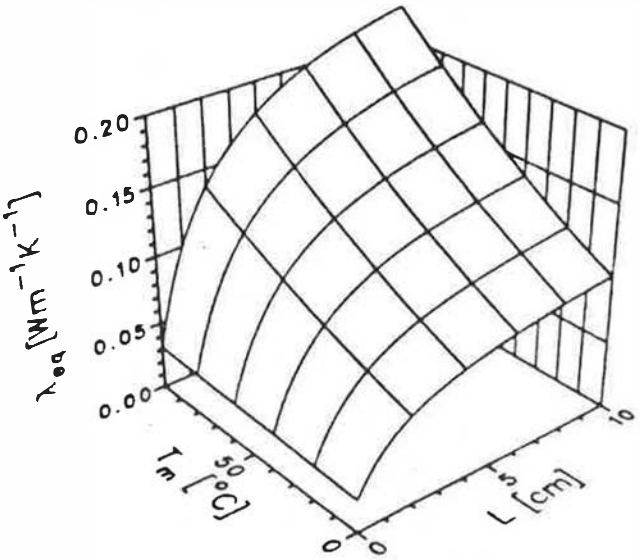

Fig. 2: Equivalent thermal conductivity of a honeycomb structure with ξ = 2 cm as a function of the mean temperature T_m and thickness L of the material.

Material	Thickness [cm]	τ_{dif}	Λ [Wm^{-2}K^{-1}]	ξ [cm]
Single glazing				
normal	0.4	0.78	-	-
low iron	0.4	0.84	-	-
Double glazing				
normal	1.6	0.67	5.20	-
low iron	1.6	0.76	5.20	-
selectively coated	1.5	0.50	2.10	-
PMMA foam				
Type A1K	1.6	0.58	3.60	1.23
Type A2K	1.6	0.48	3.10	0.76
Type C	1.6	0.60	3.50	1.12
" " plastic film coated	1.6	0.53	3.50	1.12
Capillary structure				
PC 1.7mm diameter	6.0	0.63	1.45	1.16
PC 1.7mm diameter	10.0	0.60	0.79	1.16
Honeycomb structures				
sinusoidal PS	10.8	0.66	1.28	3.0
hexagonal PS	4.3	0.75	2.21	2.2
hexagonal PA	9.8	0.61	0.97	1.6
sinusoidal PVC	10.8	0.45	1.12	2.4
hexagonal PVC	10.8	0.48	0.92	1.7
square PC 3.5mm diam.	10.0	0.71	1.10	2.0
Aerogel filled windows				
GRA 12968c	1.2	0.52	1.67	0.16
GRA 12968c	2.0	0.44	1.00	0.16

Tab. 1: Transmittance τ_{dif} for diffuse solar irradiation, heat loss coefficient Λ at 10°C mean temperature and thermal radiation penetration depth ξ of transparent insulation materials. PC = Polycarbonate, PS = Polystyrol, PA = Polyamide, PVC = Polyvinylchloride. For double glazings and aerogel windows, the distance between the two glasses is taken as the thickness.

Thermal conductivity and heat transfer coefficient

Similarly to the solar transmittance the thermal characteristics of these materials or material systems are dependent on many variables:

$$\lambda = \lambda(\text{mat, geo, d}, \Delta T, T_m, \text{gas}, \varepsilon_i)$$

where mat are the material characteristics
geo is the spatial distribution of the material
d is the thickness
ΔT, T_m are the temperature difference and the mean temperature
gas is the influence of the gas filling and
ε_i are the emissivities of the limiting surfaces.

For a homogeneous material with black surfaces, the thermal conductivity for a wide temperature range is given by the following formula, where ξ is a material constant valid for a specified temperature range. Figure 2 shows the results for a honeycomb material. The thermal heat transfer coefficient or the total heat loss coefficient can be calculated from the thermal conductivities.

$$\lambda_{eq} = \frac{4\sigma T_m^3}{\frac{1.22}{L} + \frac{1}{\xi}} + \lambda_{air}$$

Overview of existing materials

A number of materials are being produced now and some of them are available on a laboratory scale which allows first experimental measurements. The data are summarized in table 1. By combining different materials, air gaps and selective surfaces, an optimization for special applications is possible.

Possibilities for improvements in the future

Up to now, no material has been really optimized for a specific application. In real systems, not only the physical characteristics but also aspects such as the long-term stability and costs of the total system become important. Therefore, in the first economically useful applications, one has to accept some compromises. However, for the future there should be a large potential especially in improving a total system by optimizing the large number of parameters. The theoretical background for simulating such systems is now available.

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Optimization of transparently covered fibrous insulations

R. Caps and J. Fricke

Physikalisches Institut der Universität
D-8700 Würzburg, FRG.

ABSTRACT

Fibrous thermal insulation on house walls shows a drastically improved efficiency, if it is protected by a transparent pane instead of an opaque cover. The basic design parameters for the fibrous layer, e.g. optimal thickness, density, albedo and fiber diameter are presented.

INTRODUCTION

Recently, transparent or translucent thermal superinsulations have been discussed as promising systems for efficient passive use of solar energy [1] and thus for conservation of primary energy. The translucent wall concept which employs an evacuated aerogel insulation in front of a blackened house wall has been considered especially valuable to reduce the heating requirements in buildings.

Here we want to discuss a technically simpler insulation system [2]. It consists of a low-density fibrous insulation with a single glass pane as transparent cover. Solar radiation either is absorbed within the fibrous insulating layer or at the blackened surface of the wall.

SOLAR GAINS VERSUS THERMAL LOSSES

The solar flux $q_{SOL} \cdot t$ transmitted through the glass pane of transmissivity t partially compensates the thermal losses of the house wall. Thus we may describe the system with an effective loss coefficient

$$k_{EFF} = k_O - q_{SOL} \cdot t\,\eta\,/\,\Delta T\ . \qquad (1)$$

k_O is the loss coefficient of the opaque insulation, ΔT the mean difference between the temperatures inside and outside the house. q_{SOL} and ΔT are averaged over a certain timespan (month, heating period) to simulate stationary conditions. η is an efficiency, equivalent to the fraction of the solar flux which is absorbed and transferred into the house. The thermal losses from the interior to the environment vanish for $k_O = q_{SOL,O}/\Delta T \cdot \eta t$. If we introduce the solar gain coefficient $k_{SOL} = q_{SOL}/\Delta T$ and the solar gain coefficient $k_{SOL,O}$ for complete compensation of the thermal losses equ.(1) reads

$$k_{EFF} = k_O \cdot (1 - k_{SOL}/k_{SOL,O}). \qquad (2)$$

If the transmitted solar flux $q_{SOL} \cdot t$ is absorbed totally at the outer surface of the fiber layer, $k_{SOL,O}$ is determined by the thermal resistance $1/\Lambda_G$ of the air gap between the glass pane and fiber insulation: $k_{SOL,O} = \Lambda_G/t$. Assuming e.g. a $d_G = 12$ mm wide air gap and a low emissivity glass surface ($\varepsilon = 0.1$) we need a minimum solar input $k_{SOL,O} = 4.3$ W/(m²·K) for $k_{EFF} = 0$.

The total solar flux now is assumed to pass through the air gap and an insulating non-absorbing, but weakly scattering layer of thickness d_F. The absorption of the solar flux then occurs at the surface of the massive wall. As the resistances of air gap and fiber layer are in series, we have

$$k_{SOL,O} = \left\{ \frac{1}{\Lambda_G} + \frac{1}{\Lambda_F} \right\}^{-1} / (t \cdot t_F), \quad \text{with} \qquad (3)$$

$$\Lambda_F = \frac{(16/3)\sigma T_R^3}{1+(3/4)\tau_{IR}} + \frac{\lambda_{AIR}}{d_F}, \qquad \Lambda_G = \varepsilon \cdot (16/3)\sigma T_R^3 + \frac{\lambda_{AIR}}{d_G},$$

where T_R is a mean temperature, τ_{IR} the optical thickness in the IR, λ_{AIR} the air conductivity and t_F the transmission of solar radiation through the fiber layer. The latter can be calculated approximately according to $t_F = (1 + 3 \cdot \tau_{VIS}/4)^{-1}$, where τ_{VIS} is the optical thickness of the fiber layer in the visible.

The optical thicknesses τ_{VIS} and τ_{IR} of fibers with diameters D are derived from their relative extinction cross sections Q_{EXT} according to

$$\tau = (4/\pi) \cdot (Q_{EXT}/D) \cdot (\rho/\rho_O) \cdot d_F, \qquad (4)$$

where ρ and ρ_O are the density of the insulation and the solid density of the fiber material, respectively. We calculated the wavelength dependent cross sections from the IR index of refraction via Mie scattering theory assuming randomly oriented glass fibers and accounting for anisotropic scattering.

In order to allow a deep penetration of the solar flux into the fiber layer, but to guarantee strong attenuation of the heat flux, the ratio $\tau_{VIS}/\tau_{IR} = \gamma$ ought to be small compared to one. Mie scattering calculations for glass fibers show that for fiber diameters $D > 10$ µm the ratio γ is about 0.24 and the mean relative cross section in the IR about 0.82.

RESULTS

By optimizing equ.(3) with respect to τ_{IR} as variable we get the optimum $\tau_{IR,OPT}$ for a minimum $k_{SOL,O}$, which is depicted in Fig.1 as function of γ (assuming $d_G = 0$). For the design of the fiber insulation then the optimum ratio ρ/D is determined along equ.(4).

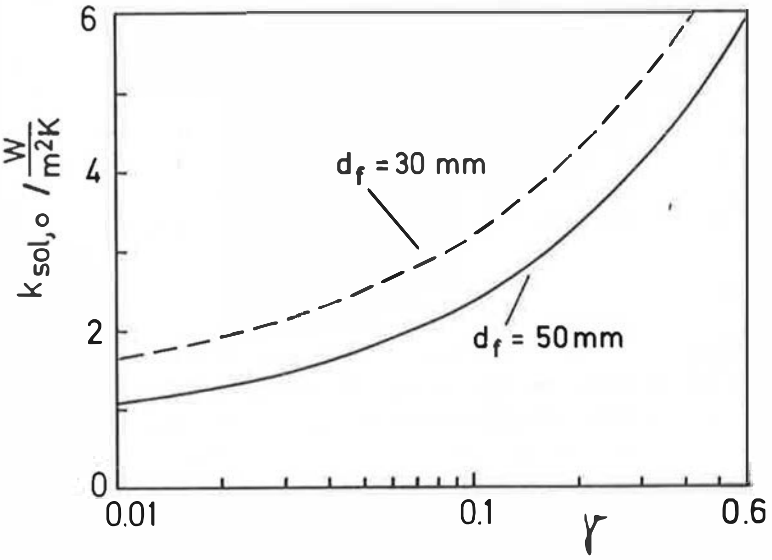

Fig. 1
Gain coefficient $k_{SOL,O}$ (for vanishing k_{EFF}) versus $\gamma = \tau_{VIS}/\tau_{IR}$ for fiber layers with thicknesses d_F = 30 and 50 mm

In the more general case with absorption in the fiber system the solar flux decreases multi-exponentially. We then performed calculations numerically by solving the coupled radiation-conduction transfer equations with the discrete ordinate method (see e.g. [3]).

In Fig. 2 the calculated dependence of $k_{SOL,O}$ on the reflectivity $R_{\infty,VIS}$ is shown ($R_{\infty,VIS}$ characterizes the reflectivity of a fiber layer which is optically thick in the visible). The total thickness $d = d_G + d_F = 50$ mm of the transparent insulation systems was kept constant. Either a 12 mm air gap was considered or no gap at all. The lowest values both for high and low emissivity glass covers are found for large fiber diameters (D = 30 µm) and low densities (ρ = 10 kg/m³). For a transparent insulation system including a low emissivity glass pane $k_{SOL,O}$ is as low as 2.9 W/(m²·K). Here the air gap is absolutely necessary: without the air gap $k_{SOL,O} \geq 4.1$ W/(m²·K) results (not shown in Fig.2). Systems with high emissivity glass panes ($\varepsilon_1 = 0.9$) either with or without an air gap provide a minimum $k_{SOL,O} \approx 3.3$ W/(m²·K) for non-absorbing fibers. Absorption in the visible, however, only moderately increases the necessary solar input for a zero net heat flux.

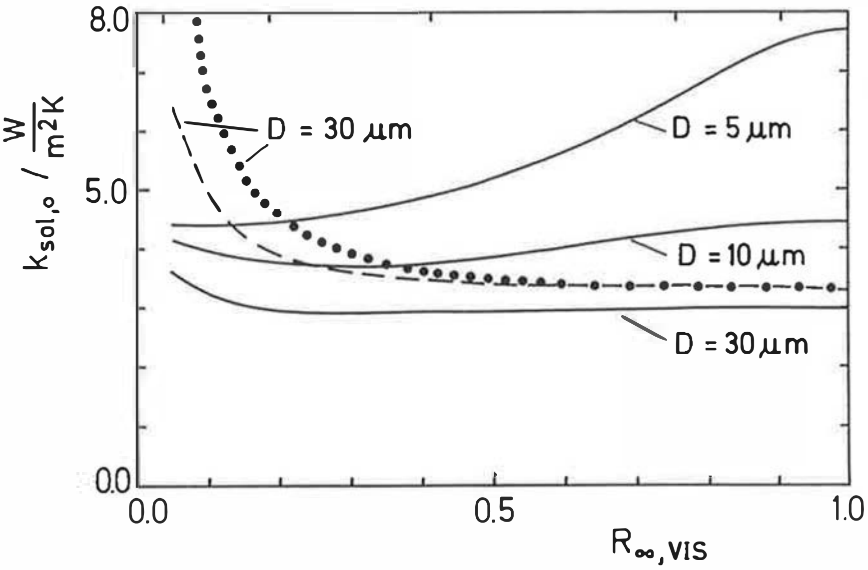

Fig. 2
Gain coefficient $k_{SOL,O}$ versus reflectivity of fiber layer in the visible spectral range, $R_{\infty VIS}$; full lines are for a coated glass pane (ε = 0.1) with 12 mm gap, the dashed line depicts the results for an uncoated glass pane (ε = 0.9) and the dotted curve gives gain coefficients for a system without gap

CONCLUSIONS

Transparently covered fiber insulations have a large potential to reduce heating requirements. We recommend a layer of about 50 mm thickness and a density of 10 kg/m³ consisting of weakly absorbing fibers with 20 - 30 µm in diameter and a non-coated glass pane as a cover.

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Hollow macro glass spheres in making fluorpolymer bonded transparent insulation

H. Fitz

Hoechst AG
Werk Gendorf, FRG

ABSTRACT

Hollow macro glass spheres, in the range of 1 – 20 mm diameter, can be inserted in certain fluorpolymer systems to produce a firm material which combines higher light transmission and interesting thermal insulating properties.

Hollow macro glass spheres in the range of 3 – 5 mm diameter and fluorpolymer bonding agents as PFA, ETFE and TFB will be examined.

The paper describes the method of production and the resulting physical properties of the material

The state-of-the-art development can produce thermal insulation panels which at 20 mm thickness have an overall transmittance of about 50 % and a U value of approximately 2 W/m^2, K.

The new transparent insulation materials have densities in the neighbourhood of 0.2 - 0.3 g/cm^3, and display good mechanical properties.

P-Layer insulation (P-Folienplatte) a new transparent thermal insulation material

R.W. Peter

Peter-Consulting, Am Oeschbrig 22
Ch-8053 Zurich, Switzerland

ABSTRACT

A new transparent insulation material is presented, which is assembled of stacked selfsupporting layers of transparent film whose formed surface consists of closely adjoining cones or "pyramids". Solar radiation and heat transmission of P-layer, capillary and foam transparent insulation materials were measured and compared. P-layer and capillary insulation were found to be nearly comparable and superior in performance to foam insulation.

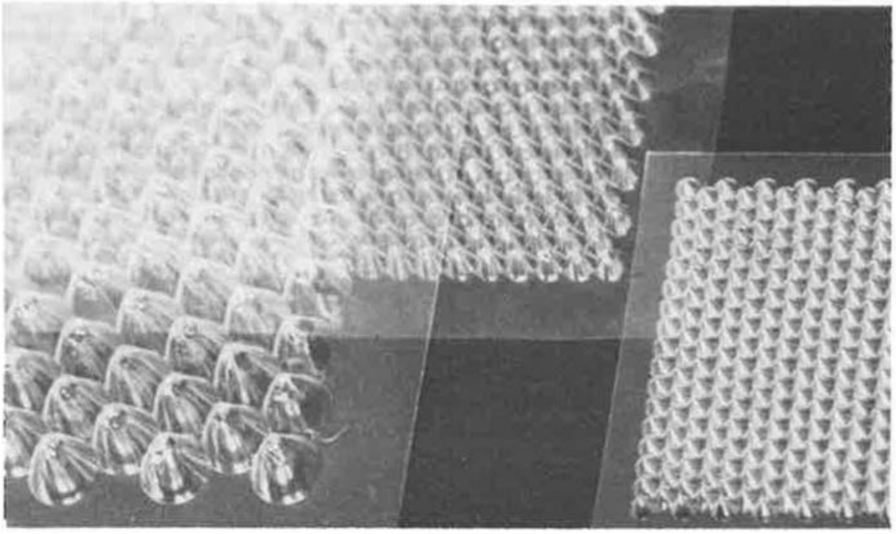
INTRODUCTION AND DESCRIPTION

A transparent insulation (TI) for a primarily solar energy heated house should admit much radiation, loose little heat. The ratio of radiation and heat transmission, τ/Λ, therefore may be regarded as a quality factor for TI materials.

P-layer insulation can be qualified as an excellent TI material on this basis. This new material is assembled of stacked layers of thin plates of transparent material, such as Polycarbonate etc (Fig.1). The plate surface consists of closely adjoining cones or "pyramids" without flat (reflecting) plate areas inbetween (Fig.3). The cones have an angle of less than 60° at the top and form a hexagonal edge, seen from the bottom. With the tops slightly rounded the plate layers can be stacked crosswise as the distance between tops differ sufficently in the two directions (Fig.3). Different types of P-plates are shown in Fig.2. The smaller the cone angle at the top, the larger is the angle, incoming solar radiation may differ from normal incidence onto the cones without being reflected to the outside.

ANALYSIS

To study the P-layer TI-material, a simplified model was used.
For the heat transmission Λ of the P-material, the following simplifying assumptions were made: 1) a P-layer stack can be replaced by a parallel-film stack;



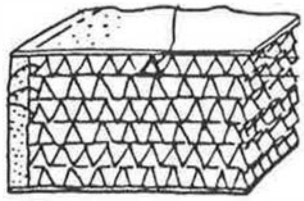


Fig. 1 Six layer P-insulatation

Fig. 2 P-layer samples with 5, 8 and 20 mm diameter cones and 60° cone angle

2) heat conduction is negligible;
3) no heat radiation through layer material;
4) layer thickness is $5 \leq d \leq 15$ mm.

Then the heat transmission for one layer can be approximated by

$$\Lambda' = \Lambda(\text{rad}) + \Lambda(\text{conv}) + \Lambda(\text{air cond})$$
$$= 4.8 + 20\,d + 0.025/d \quad (W/m^2K)$$

and of the n-layer insulation $\Lambda = \Lambda' / n$.

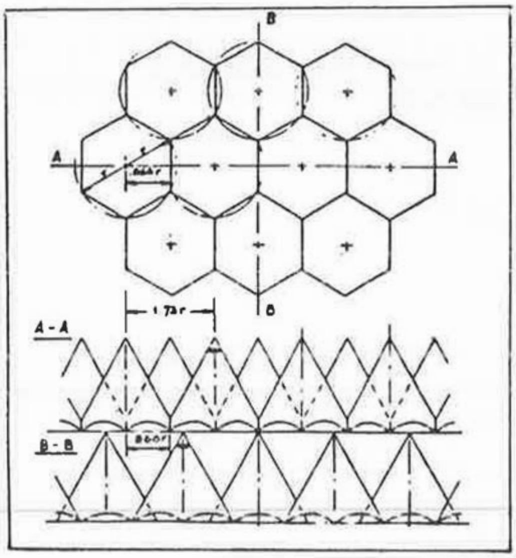


Fig. 3 P-layer cross sections and bottom view

For the solar radiation transmission, the maximum measured value at normal incidence was used, e.g. for a n-layer P-insulation with cone angle 60^{o}: $\tau(n) = (0.95)^n$.
Internally reflected radiation was assumed to be absorbed adding to internal loss q.
$g = \tau + q$ was not measured.

In Fig.5 heat and radiation transmission are shown for a number of layers n and total insulation thickness D = nd .
Fig.**6** shows the quality factor for P-insulation (cone angle 60^{o}) for various thicknesses D = nd. It is interesting to find a flat optimum τ/Λ of the number of layers for a given thickness D.

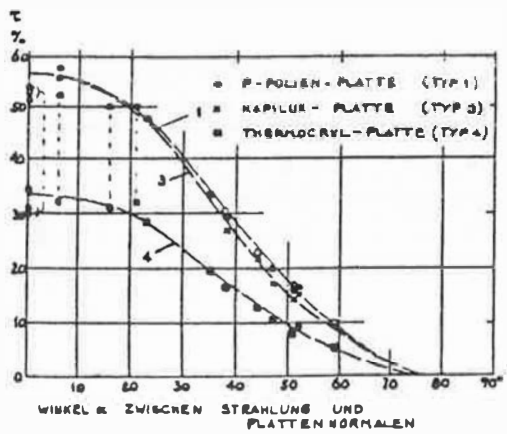


Fig. 4 Solar energy transmission of TI materials

MEASUREMENTS

Three TI-materials were measured, identically incased between two 3mm acrylic glass panes of size 600 x 600: 9-layer P-material (Polystyrol) (64mm thick), capillary material (two layers of Polycarbonate "Kapilux") (84mm thick) and acrylic foam material ("Thermocryl"). Along the sides, each material was enclosed in Polystyrol foam **(Fig.4)**.

The results of the thermal, light and solar transmission measurements are summerized in Table 1, together with published data for triple glazing and a "High Insulation Technology"

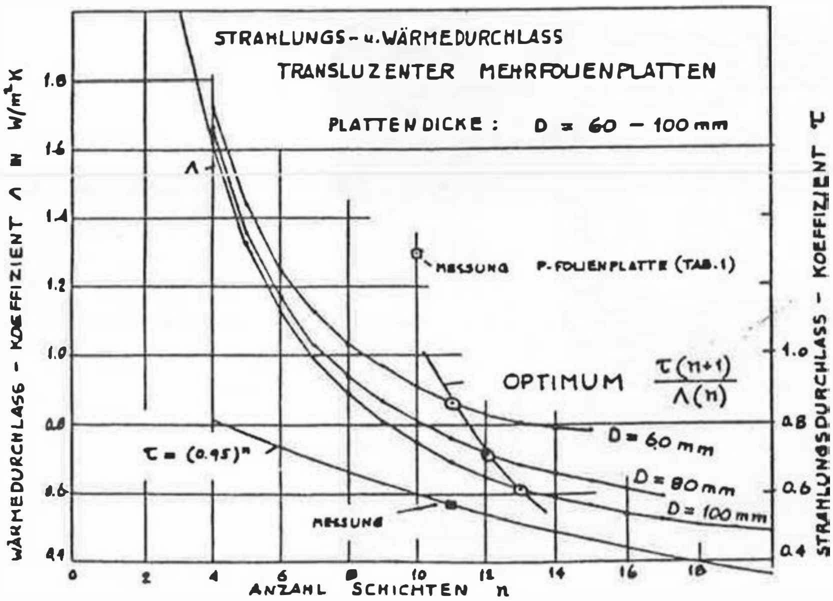


Fig. 5 Solar energy and heat transmission computed for P-layer insulation (cone angle 60^{o})

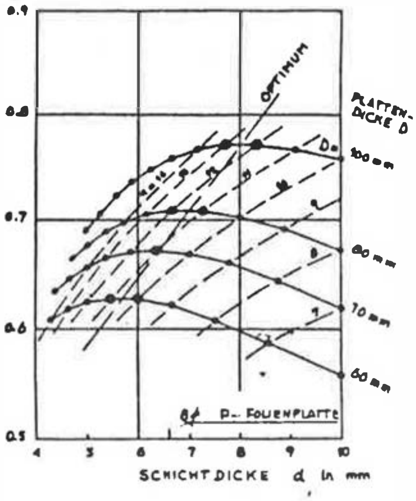


Fig. 6 Quality factor τ/Λ as a function of layer thicknes d and total insulation thickness D = nd

"HIT"-window with two IR-reflecting film layers. The bottom line of Tab.1 shows extrapolated values for a P-layer insulation comprable in thickness to the HIT and the capillary insulation.

The quality factor τ/k permits a limited comparison of transparent materials; as mentioned, it does not contain the contribution by the internal loss q as does the factor $g/k = (\tau + q)/k$.

The P-layer material tested approaches best capillary material; it is clearly superior to the foam material tested. The heat conductivity of foam is lower (which is valuable for buildings with only partial solar heating), but its radiation transmission is much lower than that of the P-material.

Fig.5 indicates the measured material results: the measured Λ-value is considerably higher than the simplified theory indicates. Leakage of heat radiation through the layer material (Polystyrol 0.1mm) might be a contributing factor.

Finally it should be mentioned that the radiation transmission measurements (Fig.4) were made with natural sunshine,

CONCLUSION

Our limited experimental information on the P-layer TI-material indicates that it looks promissing. It is an easily assembled, potentially cheaply produceable material. The tests made used the optimized 8mm-layer material (see Fig.6) with cone angle 60°. Further testing and optimizing is necessary to arrive at the inherent potential of the new material. Present results show that the new multilayer P-material approaches capillary material and is clearly superior to foam material in its quality factor for transparent materials.

Tab. 1 Compairison between transparent isolation materials

Transluzente Isolation	Dicke (mm)	Λ (W/m^2K)	k *) (W/m^2K)	Licht-transm. (%)	τ Global (%)	$q_{Wärme}$ (%)	$g = \tau + q$ (%)	g/k (τ/k)
3-fach Isolierverglasung	30		1.9	72	62	6	68	.36 (.33)
"HIT"-Fenster	90		0.65	56	31	9	40	.62 (.48)
P-Folienplatte Typ 1	64.1	1.30	1.15	78	57			(.50)
"Kapilux"-Wabenplatte Typ 3	84.3	0.918	0.85	78	57			(.67)
Thermocryl-Platte Acrylschaum, Typ 4	66.4	1.053	0.964	61	33			(.34)
P-Folienplatte (extrap.)	90	0.93	0.82		49			(.60)

*) $1/k = 1/\Lambda + 1/8 + 1/23$ $m^2 K/W$

Calculation of thermal conductivities from spectral data

A. Plüger

Fraunhofer-Institut für Solare Energie Systeme
Oltmannsstr. 22, D-7800 Freiburg, FRG

ABSTRACT

It is shown that for the approximative calculation of the thermal conductivity from spectral data of structured materials such as multifilm layers and honeycomb structures, the Planck mean of the spectral emittance of a layer may be used. - A new numerical algorithm is outlined, which allows exact calculation of thermal conductivity from spectral data and bulk material conductivity. First results are given.

INTRODUCTION

It Is often useful to calculate heat losses through hypothetical structures. A detailed knowledge of the thermal radiation transport is needed for correct calculations becouse it is usually the predominant heat loss mechanism in the materials. The number of approximative methods for the calculations is large but it is not possible to predict with certainty when they will fail. To avoid this imponderability, an exact numerical procedure was developed for homogeneous materials, which turned out to be fast and stable in all ranges of optical thickness.

A MEAN VALUE FOR STRUCTURED MATERIALS

The radiative heat transport through foam, multifilm layers or honeycomb structures can be described in terms of radiation exchange between a number of single sheets.
Each sheet has a spectral emittance ε_ν which is equal to the spectral absorptance α_ν. The total amount of emitted radiation is integrated over the whole frequency spectrum:

$$\int_0^\infty \varepsilon_\nu B_\nu d\nu \qquad (1)$$

where B_ν is Planck's blackbody radiation function. The irradiated spectral intensity on a sheet is I_ν. The total amount of absorbed radiation is

$$\int_0^\infty \alpha_\nu I_\nu d\nu . \qquad (2)$$

A general law is that in every cavity where the temperature difference between the walls enclosing the whole volume is small compared to the absolute temperature, the spectral distribution of intensity is very close to the blackbody radiation corresponding to the mean temperature, which means

$$I_\nu \approx B_\nu \qquad (3)$$

Inserting this and the equality $\varepsilon_\nu = \alpha_\nu$ into eqn.(2) leads to the result that the average absorptance of a sheet is about equal to the Planck average value of emittance:

$$\alpha_{ave} \approx \int_0^\infty \varepsilon_\nu B_\nu d\nu \; / \int_0^\infty B_\nu d_\nu = \varepsilon_{ave} \tag{4}$$

This value can then be used in non-spectral radiation theory.
Nevertheless it is not clear, at which temperature distribution inside the material the difference between α_{ave} and ε_{ave} becomes significant. This can only be checked by experiment or by an exact spectral solution of the radiation transport problem.
Using the Rosseland mean of the optical thickness of the sheets for example, instead of using eqn.(4) leads to completely wrong results.

SPECTRAL CALCULATION

Thermal radiation transport in homogeneous media and gases is described by

$$I = I_0 e^{-\tau} + \int_0^\tau B(\tau')e^{-(\tau-\tau')} d\tau' \tag{5}$$

Here, I is the spectral intensity per solid angle, I_0 is the intensity at the boundary and τ is the optical depth. The boundaries are assumed to be specular reflective. Eqn.(5) is solved for each frequency and angle seperately with a quasi-exact numerical integration. The solutions are interconnected by the equation for the conservation of energy, which is

$$\int_0^{2\pi} d\theta \int_0^\infty d_\nu \cos\theta \; \kappa_\nu (I_\nu(\theta) - B_\nu) = \frac{\partial q_{cond}}{\partial z} \tag{6}$$

θ is the solid angle, κ is the optical density and $\partial q_{cond}/\partial z$ is the divergence of the local heat flux density of the conductive heat transfer. The equation serves to find a selfconsistent temperature distribution by a Newton-Raphson procedure. The accuracy of the result is checked by the requirement of total flux conservation throughout the material [1].
Fig.1 shows the calculated thermal conductivity of granular aerogel in air. 200 frequency values and 3 angles were used. The choice of more angles does not result in better accuracy because Gaussian quadrature was used, which is exact to the order of 2×3–1=5. This means that one would abtain an identical result if $I(\theta)$ were approximated by a polynomial of 5th degree and subsequently integrated exactly.

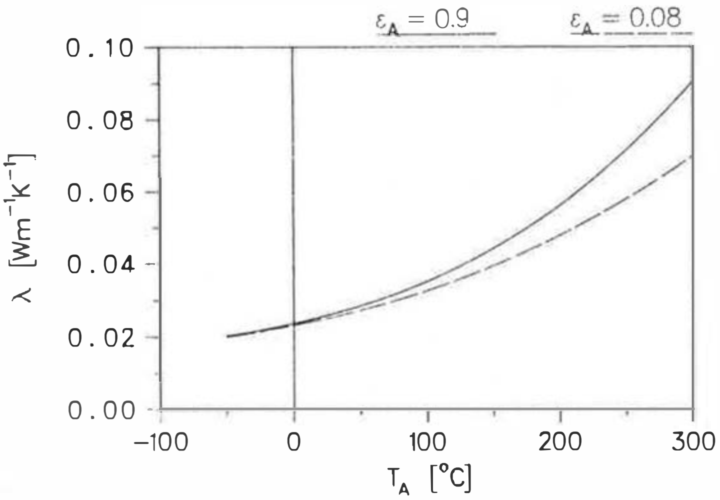


Fig.1.: Apparent thermal conductivity of a 2cm aerogel layer. The emittance of boundary A is ε_A and of boundary B is ε_B = 0.9.

[1] Pflüger A., Spektraler Strahlungstransport in transparenten Wärmedämmungen, Doctoral Thesis, Univ. Freiburg (1988), submitted

Optimization problems of transparently insulated systems

W. J. Platzer

Fraunhofer-Institut für Solare Energiesysteme
Oltmannsstr. 22 , D-7800 Freiburg, FRG

ABSTRACT

The optimization of a honeycomb transparent insulation material (TIM) combined with a selectively coated integrated storage collector (ISC) is discussed in this paper. In order to find the optimum material, characterized by the heat loss coefficient $\Lambda(T,D)$ and solar transmittance $\tau(\phi,\varphi;D)$, a theoretical model of the honeycomb absorber system for heat transport and solar transmission will be used. The modelling of the ISC itself is solved by a rather simple short-term simulation of representative days of each month (see SCHMIDT et.al. /1/ for a description of real ISC's). The optimization aim is to change parameters of the TIM in order to find the optimum balance between solar gains and heat losses, which results in a maximum yearly output or a minimum auxiliary energy demand for a one square metre collector. Two cases will be considered: The effect of two different scattering mechanisms in determining the combination of mass, mass distribution and both aspect ratios for rectangular honeycombs.

IMPROVEMENT AND OPTIMIZATION OF TRANSPARENTLY INSULATED SYSTEMS

Good TIM's combine low heat loss coefficients Λ (around 1 W/m^2K) and relatively high solar transmittances ($\tau_{dif} \geq 0.5$), so they can be used to improve glazed collector systems, where heat losses have to be reduced. This is the case when insolation levels are low (winter time), absorber temperatures are high (process heat) and/or storage of heat is wanted. A very promising type of structure is the absorber-vertical one (e.g. slats, honeycombs or capillaries), for which Λ-values below 1 W/m^2K can easily be achieved for example by increasing aspect ratios to values above 20. Improving the Λ-value is nearly always accompanied by a slight deterioration in transmittance. Thus an optimum material has to be determined by varying the material parameters influencing both properties, such as material thickness, cell wall thickness and aspect ratios. Other parameters might be used theoretically to affect only one mechanism (e.g. optical densities κ_{IR} or κ_{SOL}), and thus to improve the material (see /2/). These parameters will be kept constant here, which means that only values of one base material will be used.

THEORETICAL DESCRIPTION OF HONEYCOMB ABSORBER SYSTEM

A model to describe both the heat transport and the solar transmission of a honeycomb material has to be used for an optimization which includes the variable parameters. Details of the model used are described in PLATZER /3,4/. The advantage of this model is that it takes the geometrical structure of a honeycomb with a rectangular cross-section into account. With only a few approximations (linearization of radiation transport with respect to absolute temperature, neglection of radial temperature distribution within the honeycomb cells, no convection within the cells) it is possible to solve the coupled conductive-radiative heat transport equations analytically. Air gaps with convecting air and solar absorption within the material are included in the model. Because of the last feature, the total energy g*S reaching the collector absorber plate is calculated, which includes not only the transmitted, but also a part of the absorbed solar radiation.

OPTIMIZATION OF A PC-HONEYCOMB

Discussion of Scattering

The calculation of g depends on the relative strength of scattering as opposed to extinction, the albedo ω. Scattering might be due to impurities within the plastic films, surface roughness or dust on the surfaces. For a plastic film with d_F=55 μm ω has been crudely estimated from $\tau_{dif}(\lambda)$ and $\tau_{dir}(\lambda)$ as $\omega \approx 0.5$. The order of magnitude for experimental errors and the effects investigated, however, are the same, so there is still a large uncertainty. The total extinction has been chosen to yield the measured value of τ_{dif} for 10 cm PC-honeycomb material.

When varying the film thickness, another problem arises. If scattering is due to surface properties, then the albedo will increase for thinner films as scattering remains constant, whereas it remains constant for volume scattering. Moreover in practice, producing films of different thicknesses might result in different film qualities. In order to get an idea of the importance of these scattering properties, material optimization has been done for two limiting cases: Scattering proportional to film surface or to film volume, keeping absorption proportional to volume.

Volume Scattering

Because the albedo is constant, similarity considerations allow certain parameters to be excluded from the optimization. As the optical losses are proportional to the mass or film volume of the structure, τ remains constant, if one merely redistributes the mass. Finer structures with thinner cell walls and larger aspect ratios, however, reduce IR-transport appreciably compared to coarse structures, because the aspect ratio A is the dominant parameter /4/. Therefore structures should be produced to be as fine as possible. For this parameter no optimization has to be done.

In order to examine the effects of the main parameters, namely the lateral aspect ratio A_{lat} and the mass density itself, a constant thickness of D_0=10cm has been chosen. The variations therefore are $A_{lat}=A_{lat}(f_0,d_{F0},D_0;A_x)$ and $f=f(A_{lat,0},D_0,d_{F0};A_x)$. The optimum choice of A_{lat} is not critical at all; the cross-section should be rectangular (longer in East-West-direction) with $A_{lat} \approx 2$ nearly independent of the choice of f_0. For $A_{lat}=2$ the optimum volume densities have been identified for film thicknesses d_F=30μm and d_F=100μm. If one takes into account that the corresponding optimum choice of A_x for d_F=100μm would be A_x=8, which is already critical with respect to convection, densities of about 20 kg/m^3 are recommended.

Surface Scattering

For this case scattering increases if one reduces the film thickness for constant mass. Therefore finer structures are not automatically favoured and the mass distribution also has to be optimized. This has been done for square honeycombs with different densities, the results being shown in Fig.1. Although the scattering mechanism is different, densities around 20 kg/m^3 also seem to be optimal (12 kg/m^3 is critical because the aspect ratio is too small). The optimum film thickness then is about 60μm ($A \approx 14$), but the whole range between 40μm ($A \approx 21$) and 80μm ($A \approx 11$) is acceptable.

An optimization of the lateral aspect ratio for constant mass and film thickness showed a different behaviour to the case of volume scattering. When using thick films (50 to 100μm), the favoured lateral aspect ratio is again about 2, but for thin films it increases. So for 10μm films slat structures would be favourable ($A_{lat} \approx 20$).

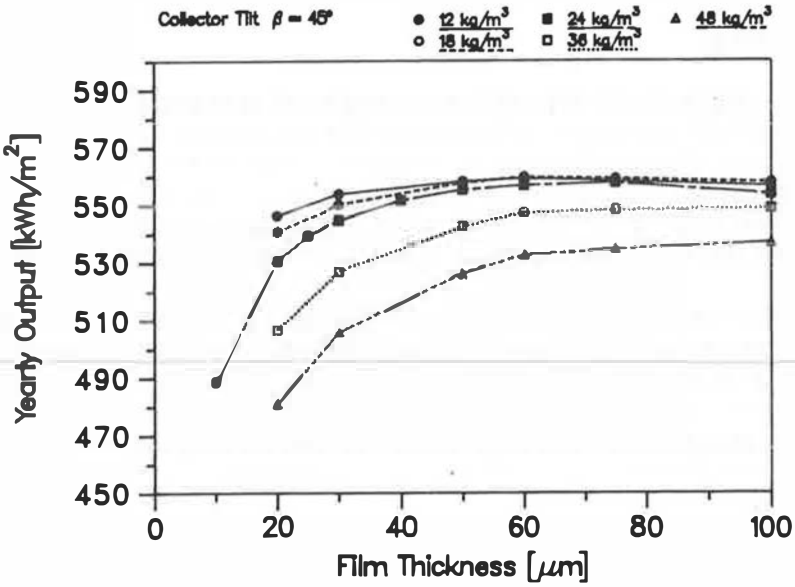


Figure 1 : Optimum mass distribution and film thickness

CONCLUSIONS

The optimization of rectangular honeycomb structures for a given application is possible with the procedure described here, if the input data for the plastic films are known. Here the critical points are the exact determination of scattering coefficients and of the scattering mechanisms. Depending on these data different optimum designs will result. However, optima are relatively flat, so the choice of the material parameters volume density, aspect ratio and lateral aspect is not that critical. To choose the mass distribution, i.e. the film thickness used, more knowledge about the scattering mechanism is needed. As mentioned before, the production of thinner films may also change the optical film properties. Therefore a recommendation of an optimum mass distribution cannot be given safely. These questions have to be resolved experimentally in the future.

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Aerogel window panes – energy savings in houses

N. B. Andersen

Technological Institute, Department of Energy Technology
Taastrup, Denmark

ABSTRACT

The influence of evacuated and non-evacuated silica aerogel windows on the energy consumptions of a traditional detached house and a low energy house in Denmark was investigated.

Small evacuated aerogel window panes in the laboratory have given experience in evacuation and sealing.

INRODUCTION

The main purposes of windows in houses are mainly to transmit light and to make it possible to look at the surroundings from the inside of the house. This performance is satisfied by standard double pane windows, which on the other hand contribute strongly to the heat loss of houses, even when they are south- facing and making best use of solar gains.

During the last decade several energy panes have been introduced into the market, some of them able to reduce the heat losses considerably (1). The night-time U-values of standard double pane windows can be lowered from 2.9 W/m^2, ^{o}C to about 1.3 W/m^2, ^{o}C using coatings with low emissivity. Taking into account the transmission of solar energy through the panes by means of a resultant U-value, calculations can present heat gains instead of losses.

Using silica aerogel tiles as spacers in double pane windows even better U- values can be obtained.

AEROGEL WINDOW PANES

The advantages of aerogel materials for window applications are (2, 3, 4):

- good solar transmittance
- acceptable visual transparency
- low heat losses (U-values)

Using thicker aerogel tiles it is possible to obtain as low U-values as required. However, thicker tiles at the same time reduce the amount of transmitted light and energy, which can be seen on Fig. 1, where the U-values are shown for evacuated panes (10 mbar absolute pressure) as well as non- evacuated panes.

The overall normal transmittance takes into account all reflected and absorbed energy and it is assumed that half of the scattered light is transmitted in the room. The U-values are computed for an average temperature of 10^{o}C, at which temperature only a small amount of infrared light is transmitted through the aerogel (4). The true temperature in the aerogel exposed to solar insolation is possible at a higher level, introducing increased radiation losses and it could be preferable to implement low emissivity boundaries (8).

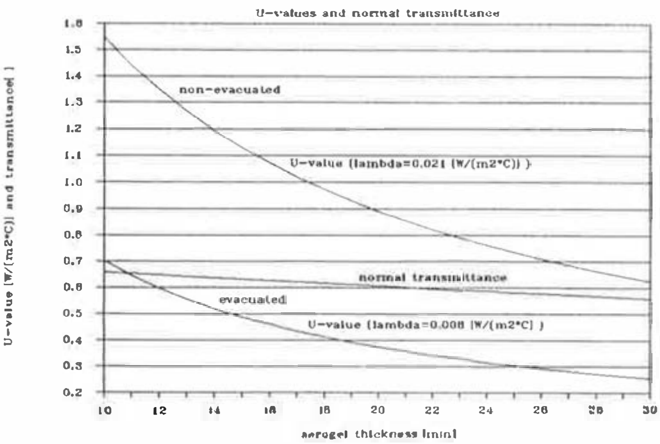


Fig. 1 Aerogel window panes: U-values and normal transmittance

As seen on Fig. 1, the evacuated aerogel panes are very attractive, giving U- values in the area of 0.25-0.70 W/m^2, ^{o}C, which for the lower values are comparable to the values for well-insulated walls.

PROTOTYPE AEROGEL WINDOW

A small aerogel window was made for laboratory purposes to obtain experience in the behaviour of aerogel samples in a vacuum and to explore possible sealing methods for the edges. The 16.16 cm^2 aerogel tile was put between two glass panes and a stiff edge of EPDM-rubber, 10 mm in thickness. The proofing between rubber and glass was provided by a polyisobutylen product making the construction airtight on a short term basis.

The window sample was evacuated through small pipes in the edges to an absolute pressure of about 10 mbar which was reached after 2 days. During the following three weeks the pressure rose to 100 mbar, apparently because of diffusion through the rubber and other leakages.

The evacuation process was rather slow, but one of the possibilities is to mount the second glass pane in a vacuum chamber, making the process less sensible to the window area at the same time.

A new sealing method is being developed in order to secure tightness at the edges without introducing cold bridges. The seal must keep the pressure below 100 mbar for 20-30 years.

ENERGY SAVINGS IN HOUSES

For computational purposes it can be suitable to describe the performance of the windows using a resultant U-value which incorporates the solar gains. This U-value is specific to the actual window construction and the orientation and surroundings of the window. Thus the values are only valid for a certain window in a certain building.

On Fig. 2 are shown the resultant U-values for south-facing aerogel windows with the heat capacity factor of the house as a parameter. This heat capacity factor equals unity for a house with extremely high heat capacity and equals zero for a house with no heat capacity. The three upper curves cover non-evacuated aerogel while the lower curves cover evacuated aerogel.

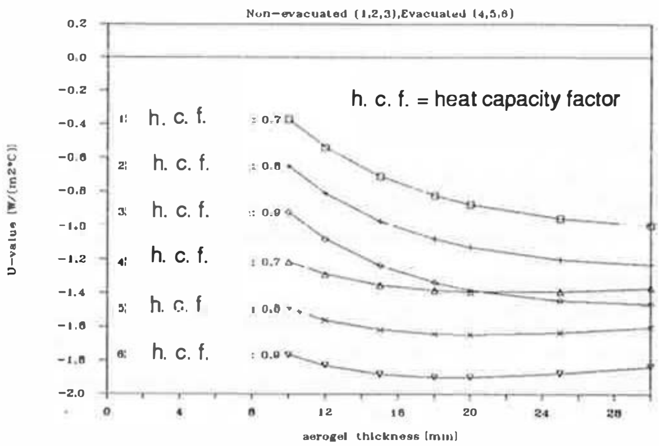
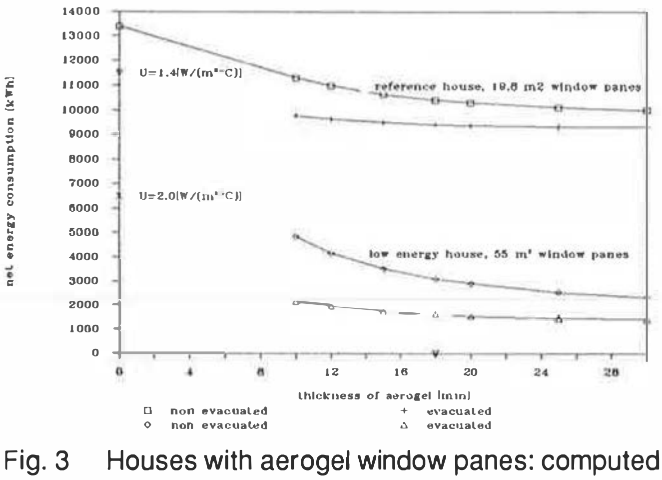


Fig. 2 Resultant U-values for aerogel panes

Based on the solar insolation in the Danish Test Reference Year (5), the solar heat gain through standard double pane windows in the heating season is found (6), yielding the maximum of 280 kWh for south-facing windows and a minimum of 80 kWh for north-facing windows. These values have been modified due to the aerogel layer and the degree of energy utilization according to the heat capacity of the house in order to give the theoretical curves in Fig. 2. It can be seen that an adequate aerogel thickness from an energy stand-point will be 16-20 mm.

In order to evaluate the effect of aerogel windows on the annual net energy consumption in a traditional detached house and a low energy house, several simulations have been made using a newly developed menu-based PC-programme for passive solar computations (7). The programme assumes the internal heat production from people etc. to be used before it takes advantage of the passive solar gains. A reduction factor equal to 0.85 has been used in order to include the shading effects of trees and walls around the window.



	Reference house	Low energy house
Floor area	145 m^2	145 m^2
Heat capacity factor	0.5	1.0
Window panes	19.8 m^2	55.0 m^2
Percent of floor area	13.7 %	37.9 %
South-facing windows	9.7 m^2	37.0 m^2

Fig. 3 Houses with aerogel window panes: computed annual net energy consumption

The main results are shown in Fig. 3. Also shown is the consumption of the reference house with energy windows, U= 1.4 W/m^2, °C and the consumption of a low energy house with standard triple pane windows with U= 2 W/m^2, °C. The net energy consumptions cover only the energy for heating and therefore do not include the domestic hot water or the electricity. Some of the main parameters are given beside the figure.

The theoretical savings are about 4000 kWh/year in the traditional detached house provided with evacuated aerogel panes instead of standard double pane windows. Aerogel window panes in low energy houses yield extremely low energy consumptions for heating in the order of 1500–2000 kWh/year.

Problems concerning overheating of the house during the summer have not yet been investigated, but it is evident that cooling loads will occur which may introduce an increased consumption of electrical power.

CONCLUSIONS

Silica aerogel windows can be produced which provide night-time U-values as low as 0.26 W/m^2, °C with 30 mm of evacuated aerogel. Aerogel window-panes will remarkably reduce the net energy consumption of detached houses. Using 12 mm of aerogel in windows of detached houses the calculated consumptions for space heating are in the range of:

13400 kWh/year:	standard house, standard double-pane windows
11000 kWh/year:	standard house, non-evacuated aerogel panes
9500 kWh/year:	standard house, evacuated aerogel panes
4000 kWh/year:	low energy house, non-evacuated aerogel panes
2000 kWh/year:	low energy house, evacuated aerogel panes

A small evacuated aerogel window has been made. Some of the remaining problems are:

– development of a seal for the edges without cold bridges

– studies on aerogel windows exposed to shock and vibration

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HITH Energy saving double window with control of solar transmission using special blinds

H. J. Gläser

Interpane E & B
D-3471 Lauenförde, FRG

Abstract

The performance and in-situ ageing of a double window with a heat saving insulating glass on the inner frame and a Venetian blind with as well sun reflecting as low emissive slats in the window space are investigated. This window construction has a low k-value (0,9 W/m² K with closed blind at night), a variable solar transmission (g = ~20 - 53 %) and light transmission (τ = ~15 - 64 %). There are no problems with the in-situ ageing.

Introduction

The investigated window construction performs on the one hand today's trend in architectural physics by further reducing the k-value (1) and, on the other hand shading against exessive sun irradiation. The last point gains in importance the lower the k-value of the window and the whole facade to avoid the greenhouse effect in the buildings. A further reduction of the k-value of the whole outer skin of a building as in the case of the "low energy house" recommended these days can be taken for granted.

Window construction

Fig. 1 shows the investigated window construction with a heat insulating double glass (iplus: k = 1,3 W/m² K; g = 62 %, τ = 75 %) on the inner frame and a single clear glass pane on the outer frame. In the window space between there is a Venetian blind with slats which have high sun reflection to the outside and, at the same time, low emissivity to both sides. This is achieved by an aluminium coating on the slats which has a high solar reflection (ϱ_e ~ 80 %) and, at the same time, a low emissivity (ε ~ 0,15).

Technical values

In table 1 are compared the essential light, solar radiation and thermal data relating to this window construction with one of the usual single frame windows with glazing of conventional insulating glass and "iplus".

Table 1

No.	Window	τ (%)	g (%)	k (W/m²K)	k_F** (W/m²K)	k_{eq} (W/m²K)
1	Single frame window with conv.insulating glass	80	75	3,0	2,6	1,70
2	Single frame window with "iplus"	75	62	1,3	1,5	0,76
3	Double window with "iplus" and special Venetian blind	~15-64	~20-53	1,1/0,7*	1,1/0,9*	0,35

*with closed Venetian blind (at night); ** 25 % frame area part and optimal k-value of the window frame.

Due to the low emissive surface of the slats the investigated double window works with closed blind and in combination with the heat insulating double glass as quadruple glazing with a low emissive coating facing all three spaces of the panes; i.e. in this case the k-value of the glazing (k) is 0,7 W/m²K, respectively that of the window (k_F) is 0,9 W/m²K. With open blind the k- and k_F-value is 1,1 W/m²K. The k_{eq}-value of the double window amounts to 0,35 W/m²K and has nearly the same value as a high heat insulated wall. Trough using the Venetian blind the solar transmission (g) and the light transmission (τ) can be controlled.

Thermal behaviour

Fig 2_{a+b} shows the annual heat consumption of the windows of table 1 on the south and north facades, dependent upon the window area part. (We take this opportunity to thank Prof. G. Hauser form the Gesamthochschule, Kassel, for carrying out these caluculations; see (2) for the calculation method). You can see that the single frame window with conventional insulating glass (1) has the highest heat consumption. The single frame window with "iplus" glazing shows much better results (2) however, the heat consumption is the lowest in the case of the double window we investigated (3). It is noticeable that the minimum of the energy consumption is much lower the lower the k-value of the glazing although, at the same time, the g-value of the panes sinks from 75 % to 53 %. In the case of the investigated double window on the south facade the minimum of heat consumption no longer exists; i.e. the heat consumption sinks when the window area part is increased. On the north facade the minimum is nearly disappeared. This is why we can use the double window for large window areas at a low heat consumption rate, whereby the danger of a greenhouse effect is eliminated by the Venetian blind; i.e. normal air exchange rates of a room are sufficient to guarantee high comfort even by strong sun irradiation. These days the control of the sun irradiation by closing the blind and adjusting the slats can be carried out automatically.

Influence of the reduced light transmission

Furthermore Fig. 2_{a+b} shows that the differences in light transmission between conventional insulating glass (τ = 80 %), "iplus" (τ = 75 %) and the double window (τ = 64 %) hardly have any influence on the energy consumption of the artificial lighting in the rooms. The energy consumption curves of the artificial light using "iplus" and conventional insulating glass are close together; the double window in question only differs slightly. This means that the times for swichting on the artificial lighting do not vary much when the τ-value of the glazing falls in the range between 60 - 80 %. This is quite understandable as the human eye adapts itself to the level of daylight in a room by opening and closing the pupil so that, with the exeption of special-purpose rooms, a room lit by natural daylight is equivalent with the abovementioned τ-value variation of the glazing. As Fig. 2_{a+b} shows, it is of great importance for optimal heat consumption using highly heat-insulated glazings that the window area part is greater than 40 %.

Ageing behaviour

The in-situ ageing of the investigated double window showed that there is a danger of breakage due to overheating of the pane next to the Venetian blind using "iplus" glazing (inner pane of the inner frame). The main reason for this is the heating up of the blind by sun irradiation, which, in turn, heat up the inner pane. We have gone through this problem together with the IFT Rosenheim (3) over a summer and autumn/winter period with natural sun irradiation on a southwest and southeast facade taking into consideration the

- position of the Venetian blind (closed or open)
- position of the slats (horizontal or nearly vertical)
- surface of the Venetian blind (colour, IR-reflection)
- dimensions of openings for water vapour compensation in the window space.

The results were as follows:

1. The position of the slats and the dimensions of openings for water vapour compensation necessary to reduce the danger of water condensation in the window space have very little influence on the behaviour of the temperature of the inner pane.

2. Comparing the situation whether the blinds are open or closed, exactly opposite results are achieved (see Fig. 3). While in the case of the open blind the edge of the pane has a higher temperature than in the middle, when the blinds are closed the temperature in the middle of the pane is higher than the reading at the edge of the pane, independent of the colour (solar absorption) of the slats.

3. The colour (solar absorption) of the slats decisively influences the maximum temperature. As Fig. 3 shows, using solar absorbing slats (a brown or grey tone) max. temperatures of up to 90°C are possible, whereas using solar reflecting slats in white the temperature can only reach a maximum of 60°C. The difference in temperature on the edge of the pane rises to 60°C using coloured slats compared with only 25°C using white ones. In the case of flate glass it is well known that there is a danger of breakage when there is a difference in temperature of 40°C across the pane (see DIN 1249, Part 10). This means that when,using blinds with absorbing coloured slats there is a danger of breakage from intensive sun irradiation. Therefore it is very important that the Venetian blind has a high solar reflection.

SUMMARY:

The investigated double window performs the future trend of a high heat insulating window ($k_F \leq 0{,}9$ W/m² K) for the realisation of a "low energy house" recommended these days by the architectural physicists. The danger of the greenhouse effect at this low k_F-value and relatively high g value (g = 53 %) can be eliminated by the Venetian blind so that, with normal air exchange rates, a high standard of comfort in a building is guaranted even by high sun irradiation. The blind also ensures glare protection and a privacy effect. These last two requirements are proving to be more and more important on the window sector. Because the blind has a high solar reflection no dangerously superelevated temperatures occur, even when there is intensive sun irradiation. With window parts more than 40 % the investigated double window can be installed at unlimited sizes and practically indepedent of the orientation of the facade. Instead of the Venetian blind the roller blind system developed by the ISE (Freiburg) (4) can be used with the same efficiency. We are convinced that by today's state of art the investigated window is the most economical solution for an optimal heat insulated window with, at the same time, controlled sun irradition to ensure high comfort inside a building. It is worth mentioning that the technology for manufactoring of this window is known and in the hands of several firms especially in the Vienna area in Austria.

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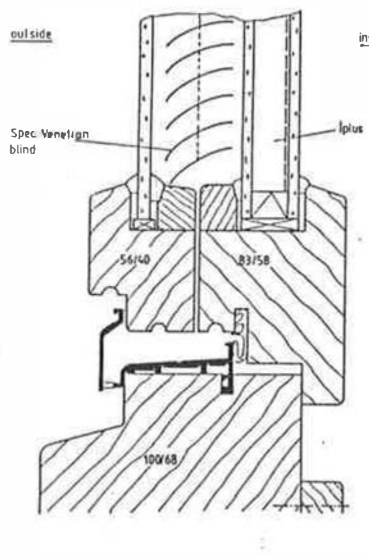

Fig.1 Investigated double window with special Venetian blind

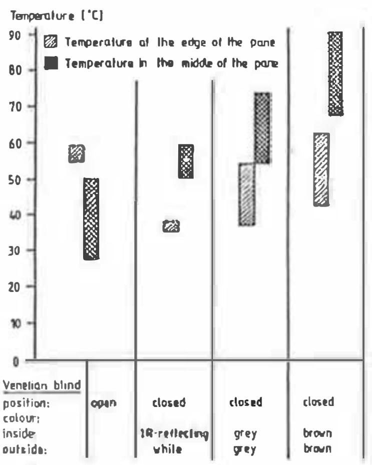

Fig.3 Temperatures of the pane next to the blind of the "iplus"-glazing, dependent upon the position of the blind and the colour of the slats.

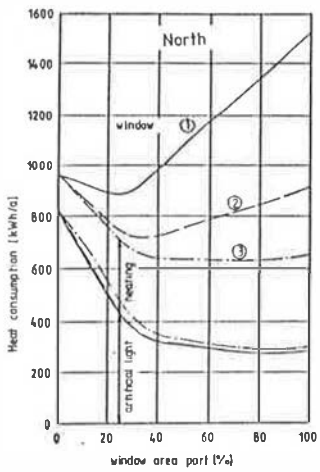

Fig. 2b Heat consumption of the investigated windows, dependent upon the window area part.

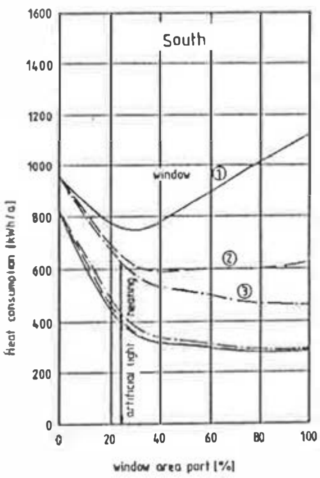

Fig. 2a Heat consumption of the investigated windows,dependent upon the window area part.

Highly insulated window systems with controllable performance

H.F.O. Müller

Fachhochschule Köln
Fachbereich Architektur, D-5000 Köln 21, FRG

ABSTRACT

The thermal performance of windows can be improveded by transparent films or fabric in the air gap between glazing layers [1]. If roller blinds are used, the window can be controlled regarding the daily and seasonal variation of thermal insulation, sun- and glare control, and visibility. Principle solutions for construction of casements, number of layers, and coating of glass and roller blind are discussed.

WINDOW DESIGN

The roller blind system is integrated in the double casement of the window, which ist separated for cleaning and maintenance purposes only. The junction between roller blind and frame is airtight, either by a gasket or simply by a groove.

The construction material for the frames can be timber, plastic, metal or combinations. Fig. 1 shows the principle of a metal-timber solution. For the modernisation of existing windows metal casements with single glazing and integrated roller blind can be applied, as Fig. 2 shows. In order to avoid water of condensation, there must be a controlled air change between gap and outside.

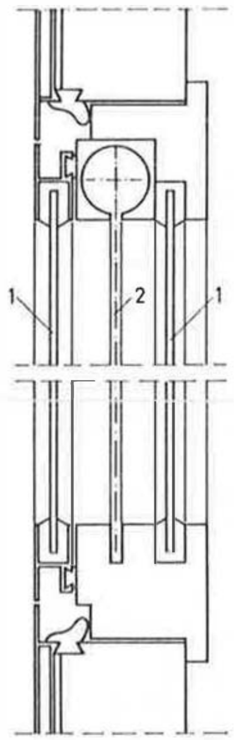

Fig. 1
Example of timber-metal-window with single glazing (1) and roller blind (2) in air gap

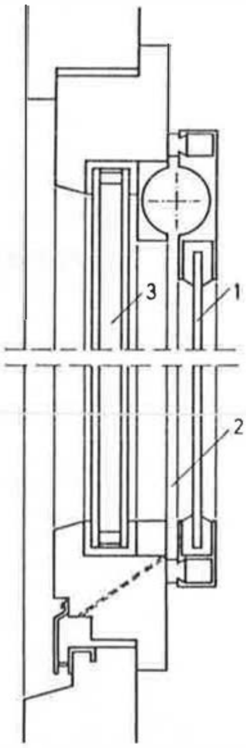

Fig. 2
Example for modernization of double glazed (3) window by attached frame with roller blind (2) and single glazing (1)

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AIR GAPS AND COATINGS OF LAYERS

One air gap is the minimum for thermal insulation, while two or more gaps clearly improve the U-value, as Fig. 3 shows. The optimal width for the air gaps is 20 to 25 mm. The layers, separating the gaps, can be of different materials. The outer ones should be glass paines because of mechanical resistance, while the intermediate layers are preferably plastic film or fabric in respect of weight and flexibility.

IR-low-emissivity-coatings on respectively one surface of each air gap clearly reduce the U-values, as Fig 3 shows. On single glazing transparent hard coatings (S_nO_2) have to be applied. Products with $\varepsilon < 0.2$ and $T > 0.6$ are on the market. The kind of coating on the roller blind surfaces depends upon the intended performance (visibility, sun control e.g.). Emissivities of about 0.1 can be reached.

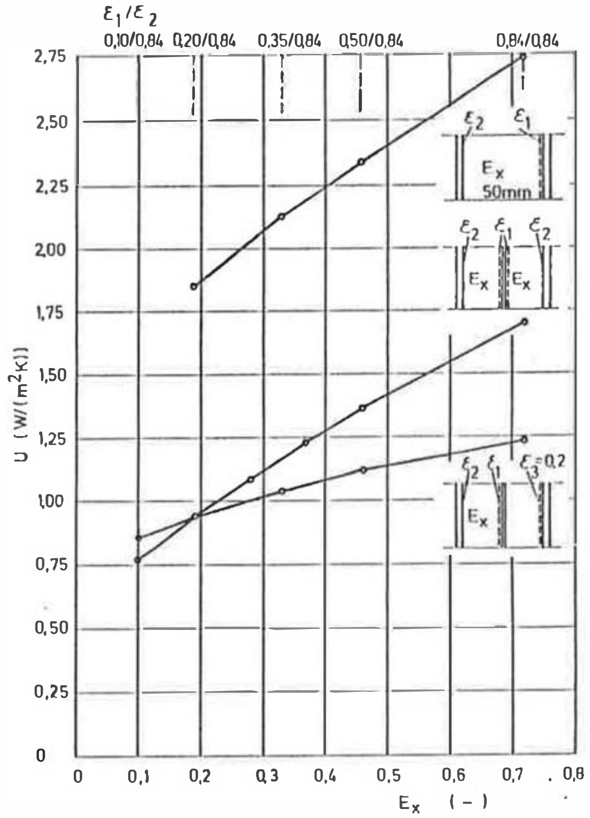

Fig. 3
Influence of the number of air gaps and their effective emissivity Ex upon the U-Value of window systems
$Ex = 1/(1/\varepsilon 1 + 1/\varepsilon 2-1)$
ε IR-Emissivity, calculation by "Window 2.o" [2]

The U-value of windows with low emissivity-coating is influenced by the ambient temperature. With falling external temperature it is rising.

OVERALL THERMAL PERFORMANCE

A comparison of window varitions in Fig. 4 shows the equivalent U-values, taking into account temporary insulation, solar heat gain and influence of the window frame. Systems with two air gaps and two low-e-coatings, one on the glass surface and one on the roller blind, show excellent results (No. 4).

By the addition of a fourth layer (glass or film), which ist closed permanently during the heating season, the heat losses of the glazed window area can be minimized.

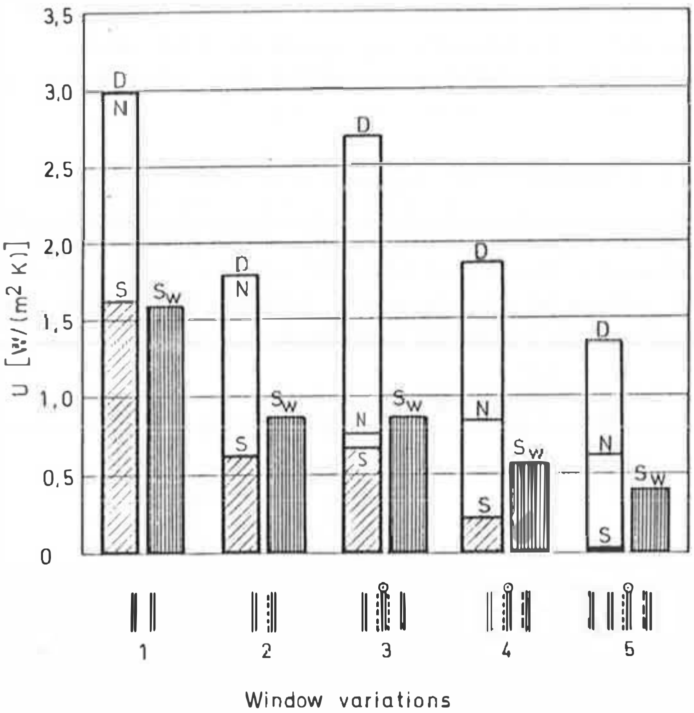

Fig. 4
U-values for different window systems with regard to thermal performance of the frame.

U-values: D Glazing by day
N Glazing by night
S Glazing under consideration of insolation (E/W) [3]
S_W Total window with 25% frame area
U-value of frame 1.6 $W/(m^2K)$

IR-Emittance: $\varepsilon = 0.1$ $\varepsilon = 0.2$

The influence of the thermal insulation of the frame proves to be of strong influence upon the overall U-value of the window, and the demand for insulation adequate to the glazed area (U 0.80 $W/(m^2 K)$) becomes evident.

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Integrated solar element (ISE) – collector, storage, radiator for heatng and hot water systems

W. Balk

FB Physik/ c.o. FB Bauingenieurwesen
Gesamthochschule Kassel, Mönchebergstr.7, D-3500 Kassel, FRG

ABSTRACT

Radiators belonging to an usual hot water heating system are black coloured and situated in mirror boxes with transparent insulation, which are part of a facade facing the sunradiation. The radiators are warmed alternatively by the heating system or by the sun.

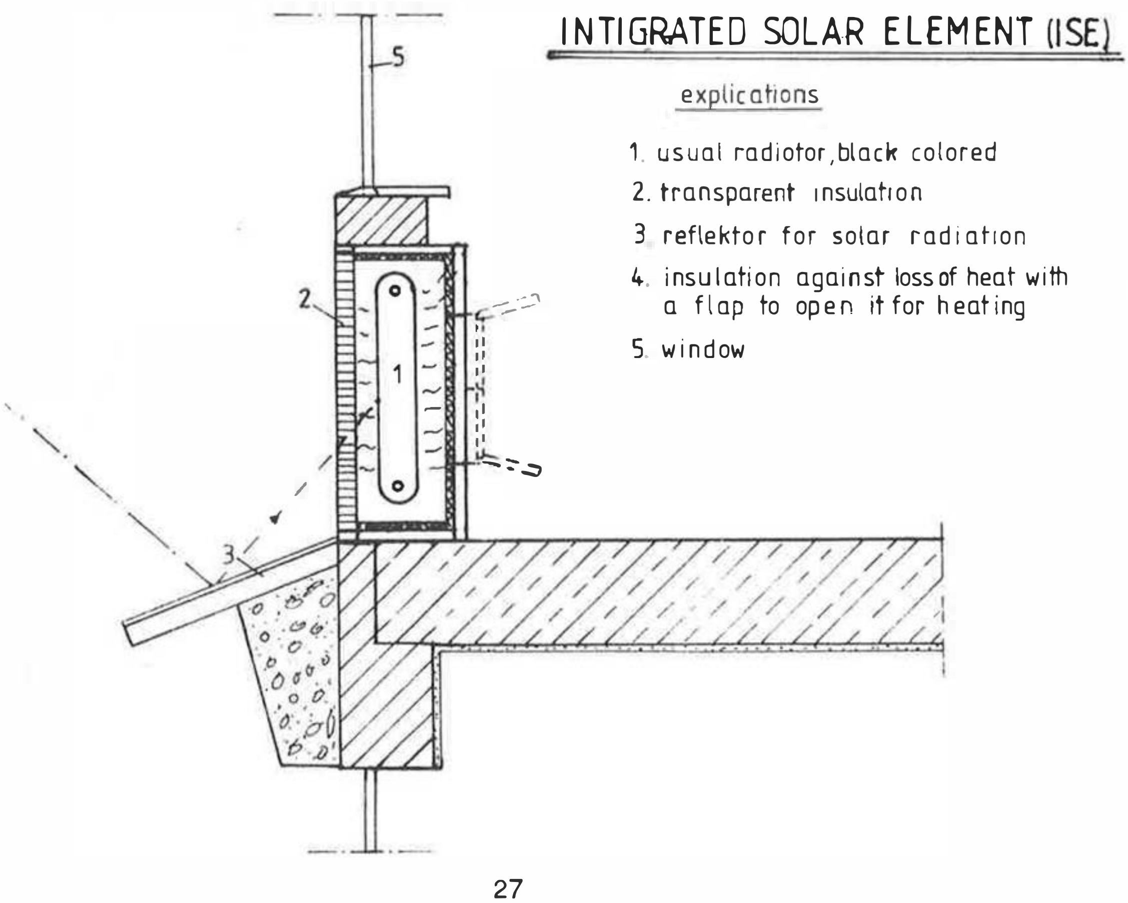
In wintertime the radiators are giving their heat directly to the rooms they belong to.

In summertime the heat is given to a domestic water boiler.

At the facade there are reflectors being part of the mirror boxes, which are giving shadow to the windows under them in summertime at noon, so that there is a little cooling effect, too.

INTRODUCTION

Beginning in 198o we built, together with project groups of students of the Civil Engineering Faculty some models of ISE's and Prof. Balk is using ISE's in his private house. But these first constructions had no transparent insulation, so that there had to be a mirror flap at the facade. - The new construction is not including any movable details at the outside of the facade.



SYSTEM DESCRIPTION

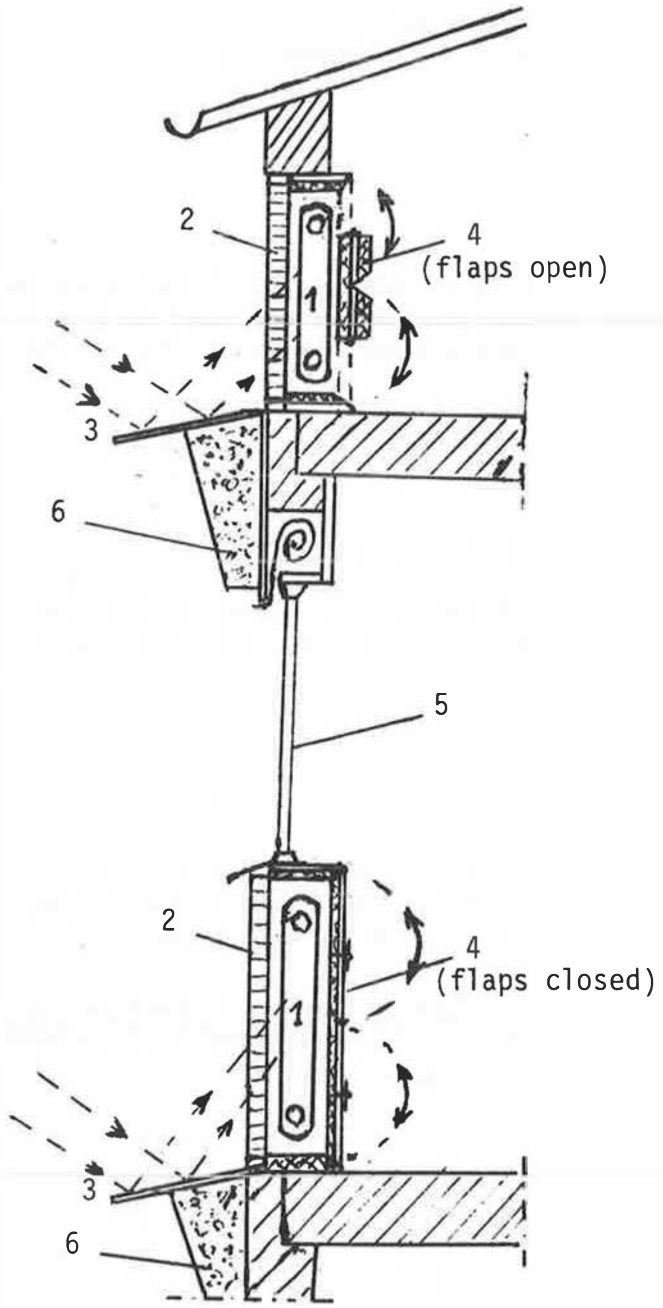


Figure: Integrated Solar Elements (ISE) in a facade

explications:

1. usual radiator, black colored (absorber, storage)
2. transparent insulation
3. reflector for solar radiation
4. insulation against loss of heat with flaps to open it for heating
5. window
6. thermal insulation (outdoors)

The system is based on an usual central heating with radiators.

The 3 functions:

1. heat collection:

A reflector outside (3) concentrates the radiation to the black painted radiator in a box insulating against loss of heat (4). The hot medium in the radiator (absorber, short time storage) flows by natural circulation (thermosyphon) - through the two holes usually closed - to another storage tank above.

2. storing and warm domestic water:

The heat is stored in the radiators (1) and in the tank above (under the roof or in a room faced to the north side). The storage tank above is filled with domestic water and a heat exchanger brings the heat from the medium to the domestic water.

3. heating and cooling:

When heating is needed, the flaps (4) are opened. There is a little cooling effect too in summer, for the reflectors (3) then give shadow to the windows under the INTEGRATED SOLAR ELEMENT.

Test results and optimisation of integrated collector storage with a transparent insulation cover

Ch. Schmidt, A. Goetzberger, J. Schmid

Fraunhofer-Institut für Solare Energiesysteme
Oltmannsstrasse 22, D-7800 Freiburg, FRG

ABSTRACT

Transparent Insulation Material (TIM) has been used in integrated collector storage (ICS) prototypes developed at the Fraunhofer Institut für Solare Energiesysteme (ISE).
Two prototypes (1st generation) without a second, freeze-protecting circuit, have been investigated under stagnation conditions and with water withdrawal during one year at the ISE outdoor test site (/1/, /2/). No damage due to freezing occurred.

The second optimised generation of ICS with TIM consists of a single cylindrical tank with a selectively absorbing surface, an involute reflector behind it and an optimised TIM cover. The test results show a significant improvement of performance.
A detailed computer program for ICS has been developed in order to make parametric runs.

LONG TERM MEASUREMENTS

Since 1986 two ICS prototypes which only differ in the tank construction have been tested at the ISE (ICS A and ICS B). The first prototype incorporates 7 pressure resistent cylindrical subunits which are connected in series (fig.1). For a water withdrawal rate of 40l/m^2/day ICS B had a yearly efficiency of 28% and a solar fraction of 58% (req. hot water temperature 50^{o}C; measured from 11/86 to 10/87). ICS A has an aluminium flat tank and was run under stagnation conditions during the some period. No damage due to freezing occurred despite snow coverage for about one week during a very cold (t_{min} = -17^{o}C) period. In summer 100C was only reached a few times.

With a computer simulation program the yearly ICS performance can be predicted with an accuracy of 4%.

OPTIMISATION OF ICS

A second ICS generation (ICS C) has now been developed. The ICS C basically consists of one single cylindrical tank with a selectively absorbing surface and an involute reflector behind it. This type of reflector has an acceptance angle of 180. That means that even diffuse light (or light which is scattered by the TIM material) is reflected onto the absorber.
The ICS is covered with a 10cm AREL layer under an iron-free glass pane (fig. 2). The main advantages of this construction are:

- very simple construction of the pressure resistent tank and very good stratification of the tank if mounted vertically (e.g. between rafters or integrated into a wall, see fig. 6).

- low heat losses because the surface of the tank is almost completely used as an absorber.

A prototype of such an ICS has now been constructed (/3/). First measurements show that, compared to the 1st generation of ICS the mean heat loss coefficient could be lowered by 15%, the heat loss coefficient at lower temperatures and temperature differences could even be lowered by more than 25%. The measured product was slightly improved too, despite the supplementary reflector losses (60.2% instead of 59.8% from Dez '87 to Feb '88).
Inevitably the overheating problem becomes more significant if the heat loss coefficient of the ICS decreases and increases.

Fig.3 shows the yearly maximum and minimum temperatures of ICS C as a function of water volume per square meter absorber surface for a daily water withdrawal rate of 40l/day/m^2 (data basis is the test reference year for Freiburg). The corresponding tank diameter (ICS C) is indicated in parentheses. The temperature never exceeds 100^{o}C for a water volume of more than 75 l/m^2 and never drops below 8^{o}C (inlet water temperature 10^{o}C). As the yearly performance of the ICS (yearly efficiency and yearly solar fraction) is relatively insensitive to the thermal inertia of the ICS, it can be chosen in such a way that the ICS is neither damaged due to freezing nor due to overheating (upper temperature limit for AREL-TIM material: 140°C).

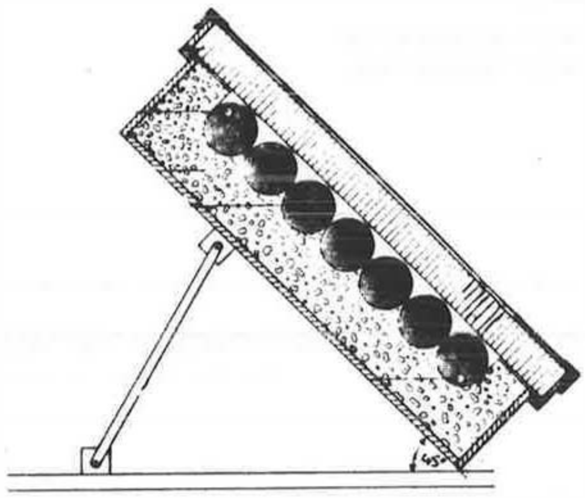


Fig. 1 Cross-section of the first prototype (ICS B; tank: 7 pressure-resistent subunits in series)

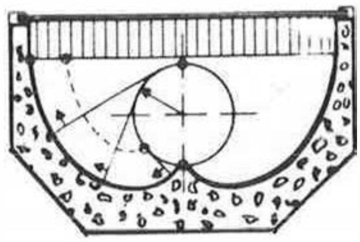


Fig. 2 Cross-section of optimised prototype (ICS C; tank: one single cylindrical unit with an involute reflector behind it)

The minimum thermal mass of an ICS has to be determined by studying its stagnation performance. In order to predict the ICS performance under extreme conditions, two extreme weather periods have been included into the test reference year (2 weeks in winter, mean ambient temperature -9.2°C, 1.08 kWh/m^2/day and -7.0°C, 0.38 kWh/m^2/day; 8 days in summer, mean ambient temperature 22.8°C and 7.05 kWh/m^2/day).The risk of freezing for ICS C is still lower than that of ICS B. It has to be mentioned that damage due to freezing only occurs if more than about 20% of the water content of the ICS is frozen. This would correspond to another temperature drop of about 16 K. Fig. 4 shows that the ICS temperature may significantly exceed 100°C so that additional measures such as temperature controlled cold water flow through the tank may become necessary because of security demands. The calculations have been made with a u-value as a function of temperature but without considering the dependence on the geometry of the ICS. In reality for ICS C, the u-value tends to decrease with the tank diameter because of the larger air layer between the tank and the insulation. For ICS B it tends to increase because of the larger ratio of tank surface to absorber surface.

Fig. 5 shows the yearly performance of ICS C in comparison to ICS B as a function of the angle of inclination. For vertical installation (e.g. integrated into a wall), the yearly efficiency of ICS C reaches its maximum at almost 90°. This is becouse of the lower insolation onto a southern wall than onto a 45° tilted south orientated surface: for a constant water flow of 40 l/m^2/day the yearly mean ICS temperature and therefore the heat loss becomes lower, whereas the mean transmission of the optimized TIM cover is still high even for small incident angles (such as in summer).

Fig. 6 shows a comparison of different TIM covers for ICS C. Up to now, aerogel granulate does not seem to be suited for use in ICS systems because of its optical properties. The difference in the yearly performance of the ICS with 10 cm AREL cover (as tested) and a 5 cm AREL cover is remarkably low and is due to the large air space between the tank and the insulation (see fig. 2). However the thermal inertia of the system with 5 cm AREL cover is lower so that the risk of freezing and overheating increases again. This shows that the thickness of the TIM layer still has to be optimized. The use of AREL TIM with tilted Honeycomb structures seems to be interesting too (especially for vertical installation) and will also be investigated.

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/2/ Test results and evaluation of integrated collector storage systems with highly transparent insulation; to be published in 'Solar Energy'; Ch. Schmidt, A. Goetzberger, J. Schmid

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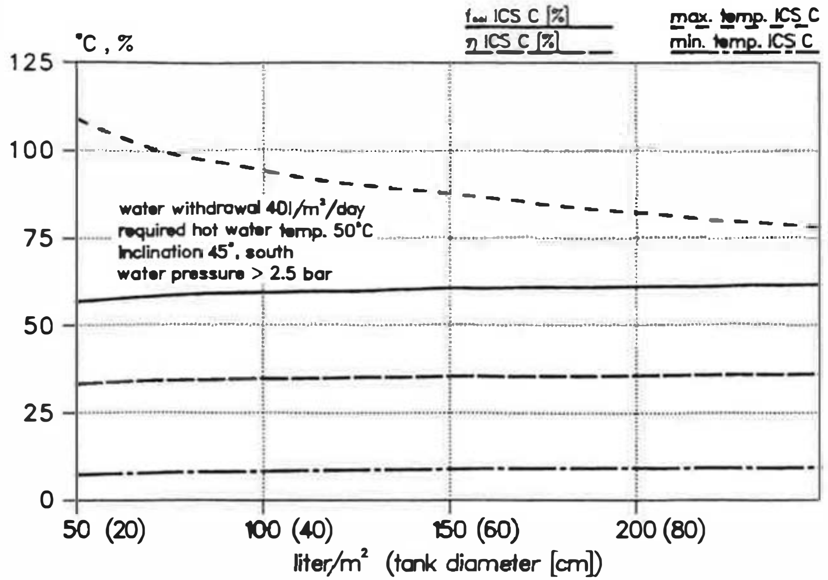

Fig. 3 Yearly maximum and minimum temperature (water withdrawal) of the ICS C, yearly efficiency and yearly solar fraction as a function of the amount of storage (water) volume per m^2 absorber surface (tank diameter in parentheses)

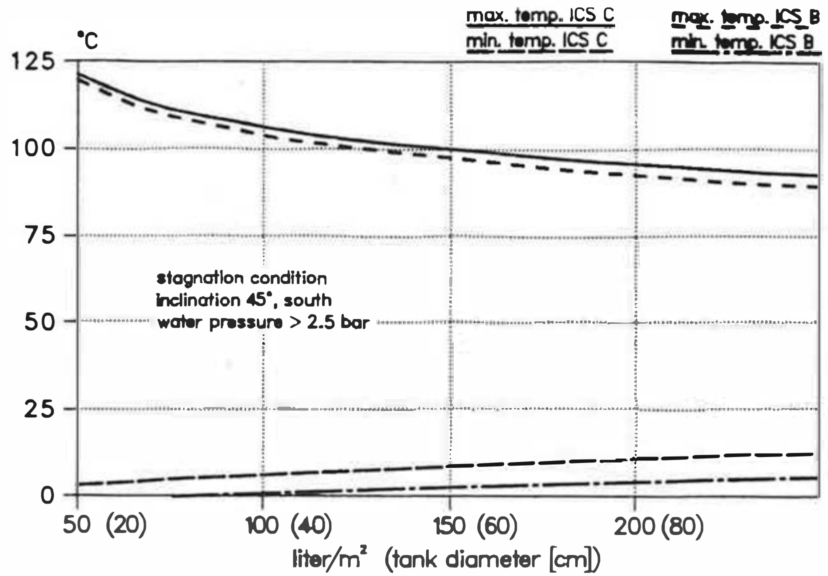

Fig. 4 Yearly maximum and minimum temperature of the ICS C and ICS B (stagnation condition), as a function of the amount of storage (water) volume per m^2 absorber surface (tank diameter in parentheses)

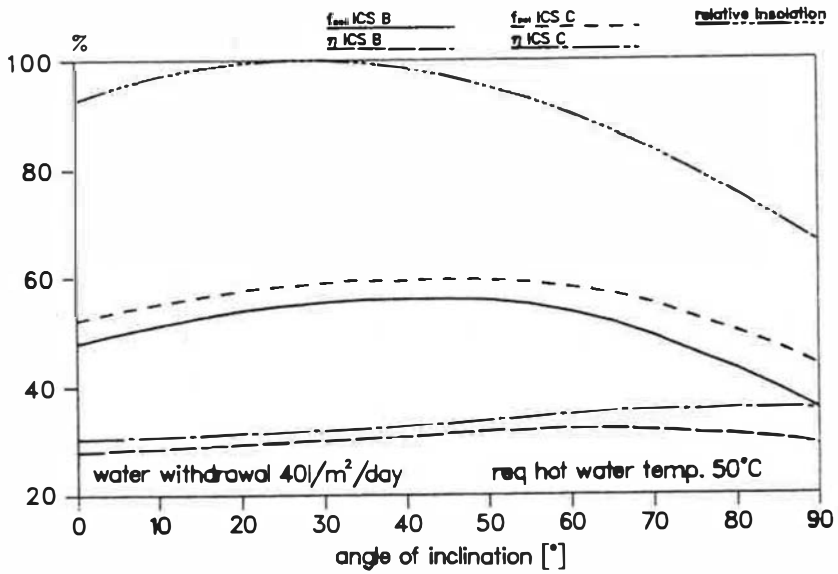

Fig. 5 Yearly solar fraction, yearly efficiency and relative insolation on the aperture as a function of the angle of inclination Comparison between ICS B and ICS C

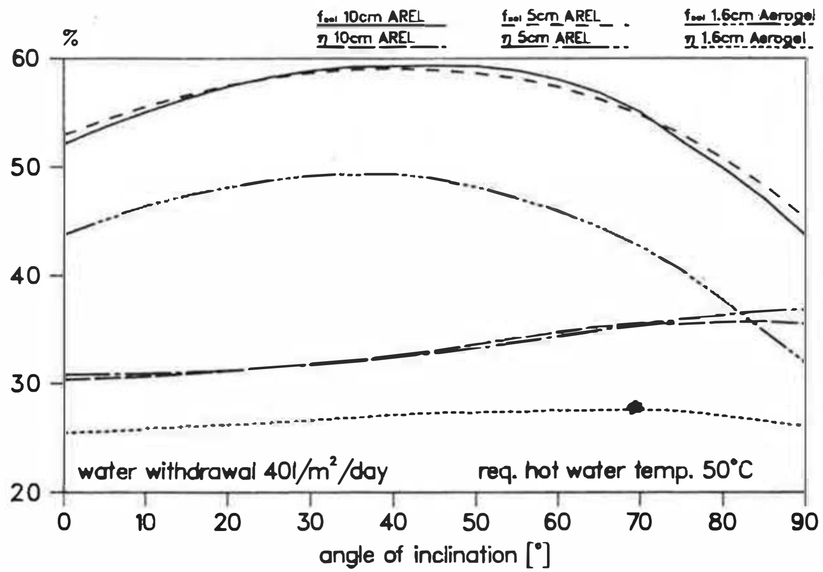

Fig. 6 Yearly solar fraction and yearly efficiency as a function of the angle of inclination, comparison of 3 different TIM covers

Energy saving coatings on flexible substrates

W. Müller, V. Neveling, W. Siefert

Renker GmbH & Co. KG
D-7800 Freiburg, FRG

ABSTRACT

Energy saving coatings, so called low-e-, as well as solar control-coatings are developed on transparent flexible substrates in an industrial scale at a web width of 1.6 meters by application of sputter technique. The resulting optical data of a silver-based low-e-coating on polyester-basefilm (PETP) developed in our lab are presented and the development program is scetched.

The state of the art of web coating is shown and some advantages of using flexible substrates are discussed. There are advantages in the production of the film as well as in the handling and in the application.

INTRODUCTION

The state of the art of direct sputter coated glass are glass panes with neutral color and highly selective surfaces with an emissivity of thermal radiation of about 0.1 and a visible transmission of about 85 % + 1 %.

By web-coating such small tolerances could not be maintained till now. Because of a better machine concept and a highly sophisticated fiberbased optical in-line-monitoring technique it is now possible to control the simultaneous coating process of up to 6 cathodes at web width's of up to 2 m. This gives the sputter-rollcoating technique the chance to produce high quality low-e-type coatings in a quasi-continuous process. If this coating can be made environmental-stable a wide field of applications opens up, especially in the window renovation market.

STATE OF THE ART OF FLEXIBLE WEB COATING BY SPUTTERING

Modern sputter-rollcoating machines are multicathode machines, where up to 6 sputtering cathodes are placed around one large sized thermally controlled coating drum. The cathode chambers are separated by each other in such a manner that different atmospheres can be handled in the different cathode chambers without cross-contamination. For simultaneous operation of all cathodes a highly sophisticated in-line process control is essential. State of the art is control of the electrical conductivity as well as the control of spectral transmission and reflection of the coated film.

Since the geometry of the cathode surroundings in a rollcoater is completely different from a glass-coating machine and since the polyester basefilm cannot withstand high temperatures, the coating process must be adjusted to the special conditions during web coating. This optimisation process we have now under development and present first results in the case of a silver-based low-e-type coating with SnO_2 as dielectric material as an example for the potential of this technique and our special know-how.

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ADVANTAGES BECAUSE OF USING FLEXIBLE SUBSTRATES

Because of the continuous production a high quality can be expected. After sputter coating further processing steps can be made economically in a continuous process. Environmental protective coatings or self adhesive coatings can easily be applied by industrial machines. Keeping large quantities of coated film on stock is very easy and needs only a small volume. The coated film can easily be distributed also via large distances. There is no waste of glass during the whole coating process.

Because of the total decoupling between coating process and final product the coating can be optimised separately and the coated film can be combined with different glasses, even with uniaxially curved glasses. An environmental stable coated film might be the only economic way for renovation of old buildings.

Because of the light weight of the coated film 3- or 4-pane windows can easily be made by stretching 1 or 2 coated films between 2 outer glasspanes. On this way U-values below 1 W/cm^2 can be realized. If necessary the coated film can be used as or combined with a roller blind and the radiation transmission of the window can be adjusted on this way.

LOW-E-COATINGS ON POLYESTER-BASEFILM

Low-emissivity coatings are characterized by high solar transmission, especially where the human eye is sensitive and high IR-reflection in the range of room temperature radiation (5 - 50 µm). This behaviour is basically coupled to free electrons in the coating which react with the incoming electromagnetic wave of solar or thermal radiation in different manner. The free electrons make the material electrically conductive and as a matter of fact the surface resistivity of low-e-coatings is within the range of 5 - 30 Ω/□. This low resistivity can be obtained either by semiconducting oxides, or by extremely thin metall coatings which must be sandwiched between dielectric coatings to reduce the high visible reflectance and to protect the metall against corrosion respective for better adherence.

Indium-Tin-Oxide (ITO) is the most prominent semiconducting material for this application. To get the low resistivity, the material must have a thickness of 0.2 - 0.3 µm. Such thick coatings are hard to realize by sputtering and have a strong tendency to interference-color. On the other hand this material is stable against corrosion and the interference-color can be eliminated by a further antireflective coating. Furthermore, this material has a very high solar-energy-transmission, because the plasma edge lies according to the relatively low density of free electrons in the NIR between 1 an 2 µm, where the power density of the solar spectrum has slowed down.

The most interesting material is a silver-based sandwich structure. The silver is in charge of the electrical conductivity, has a neutral color because of the position of the absorption edge in the UV-region and allows a high transmission, because of its low absorption. The whole thickness of the sandwich-system is below 0.1 µm and is therefore much more economic compared to the semiconducting coatings.

In our lab we have developed a tinoxide/silver/tinoxide sandwich structure (fig. 1) on PETP-basefilm - 50 µm thick. The coating is optimised for maximum

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transmission at 550 nm. The measured transmission is 86.6 % and the measured reflection at this wavelength is 9.6 %. Because of a systematic error of the Ulbricht-sphere at speculiar reflectance the true reflection is 6.4 %. Therefore, the absorption is 7 %. The reflection of the coated surface is 1.1 %, which has to be compared to the reflection of the uncoated surface of 5.3 %. Between 350 and 640 nm the coating acts as antireflective coating. The total solar radiation-transmission is 61 % at AM 1.5, the emissivity is below 0.15, as measured in the IR-reflection.

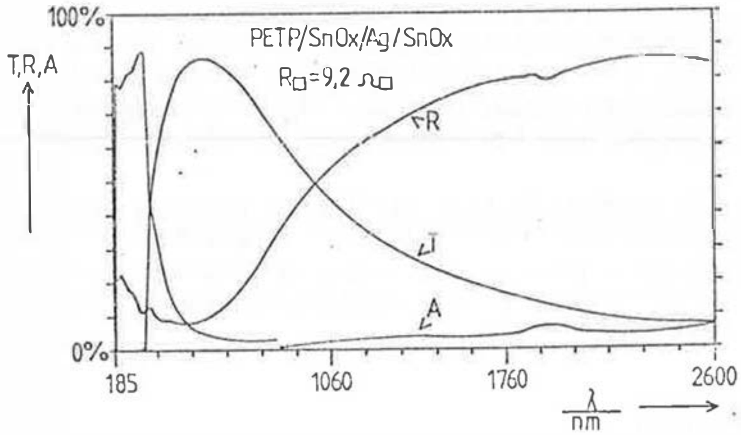

Fig. 1:

Spectral transmission T, reflection R and absorption A of a low-e-coated PETP-basefilm

Within some limits the optical characteristics of the coated film can be changed by using different dielectric materials. At a transmission of the basefilm of 88,3 % and an absorption loss because of the metallic layer of 7 % a maximum transmission of 86.6 % can be expected. This demonstrates that the state of the development is very near to the physical limits. The short-coming of the film is - similar to the direct-coated glass - the missing longterm stability under environmental conditions. One way to overcome this problem is the deposition of a thin organic coating. Experiments with different lacquer coatings resulted in highly improved corrosion stability when treating a lacquercoated film in a QUV intermittently with condensing water and UV- illumination. Because of the small thickness of the lacquer coating of only 1 µm the emissivity rises only by 0.05.

FURTHER PROGRAMM AND CONCLUSION

By our research and development efforts we intend to optimise the optical characteristics of the film as well as to improve its longterm stability. For this purpose we study a five-layer-system. This allows a better matching of the refractive indices as well as the use of material combinations which protect the silver layer moreeffectively.

Simultaneously, we are installing in May 1988 a mulitcathode sputterrollcoater with a coating width of 1.6 m which allows the deposition of the above described low-e-film developed in our lab, as well as the homogeneous deposition of ITO. After transfer of the developed coating process to the production machine we will offer a whole family of low-e-coatings specially designed for high/low energy-transmission, or high visible transmission. Furthermore, we develop environmental-stable solar control films. Pure metall coatings as well as sandwich coatings are of interest for this application.

Concluding, we have demonstrated, that we have as the first European supplier all equipment and the necessary know-how for development and production of highly sophisticated multilayer coatings on flexible subtrates for window application.

A new thermo-optical regulation system – suited for transparent insulation ?

E. Boy. and S. Meinhardt

Fraunhofer-Institut für Bauphysik Institutsbereich Wärme/Klima
Dir.: Prof. Dr.-Ing. habil. K. Gertis
Nobelstr. 12, D-7000 Stuttgart 80, FRG

ABSTRACT

In the present contribution a new material whose light transmission properties change by clouding depending on its temperature will be presented. Its function, characteristic properties, and physical behaviour will be featured. As a self-regulating solar screen, this material can be applied to components used in passive solar engineering. Its clouding point may be regulated with an accuracy of 1.5 K within a temperature range of 9 to 90°C. Being initially transparent, the substance is clouded when the temperature of reaction is passed. In its clouded state, a layer of less than 1 mm thickness is sufficient to reduce solar transmission to less than 40%, the transmitted light being highly diffused. The clouding effect is achieved by way of a reversible thermochemical dissolution of water and a thermally induced modification in the molecular chain dimensions of the organic polymer material.
When applied in thin layers between glazing elements, this new material acts as a temperature-dependent, self-regulating screen. The wide potential of possible applications in combination with transparent thermal insulating material is self-evident.

INTRODUCTION

There is evidence suggesting that people prefer natural light to artifical light. Modern glass architecture enhances the quality of life by supplying living and working rooms with natural sunlight. But the intensity of sunlight varies. Too much solar radiation often causes dazzling and cooling problems. To regulate sunlight intensity, a lot of shading devices are available: shutters, rollers, blinds, curtains etc. For passive solar strategies and, of course, for transparent thermal insulation, there are other ways to enable architects to create passive solar buildings. To control solar heat gains in buildings it is however recommended to utilize the glazing or transparent insulation itself. With a good window design and intelligent use of sun controls, not only a good daylight distribution can be achieved in spaces but also solar heat gains. The control of the right quantity of heat and light in the building is coupled to outside conditions. The exploitation of solar energy for heating purposes in winter and the regulation of sunlight intensity in summer is necessary. The new development of automatically controlled roller blinds [1] will not satisfy the requirements put to long-life applications. The acceptance of architects and users for those systems seems to be very low. Traditional shutters are too expensive in case of transparent insulation and need a careful design. Such shading devices do not reduce the heating consumption significantly. On the other hand, they do increase the costs for the system so that with the present price for energy economically viable applications of transparent insulation systems are difficult to realize.

SWITCHABLE GLAZINGS

Solar shading could also be managed with optically switchable glazings. To exclude undesired solar energy, we know three basic types of switchable glazings where the control depends on the glazing itself [2]: chromogenic, physio-optic and electro-deposition systems. Chromogenic energy control sheet materials, also called "optical shutters", change the absorption or reflection of the glazing in response to heat, electricity or light. Windows will darken or lighten to vary the amount of solar radiation and heat entering the building. The materials are classified as thermochromic in case that change of colour responds to heat, electrochromic if the change of colour is the reaction to an applied electric field or current, and photochromic if it responds to light only.

THERMOCHROMIC SYSTEMS

The most cost-effective technology seems to be the heat-changing thermochromic materials. There are a lot of different developments known from all over the world. Thermex [3], a German invention was on the market in the 60s, Thempshade [4] is a development from USA, to give just some examples. At the present state-of-the-art another development [5], a thermotropic gel, is the most interesting material for architectural purposes in passive solar engineering. This material is called TALD.

THE THERMOCROMIC "TALD" GEL

TALD gel contains polyether compounds with ethylene oxide groups, mixed with wetting agents containing 5 to 10 ethylene oxide groups in the molecule. Added to this mixture are further carboxyvinyl copolymers with a molecular weight in the range of 250,000 and 4,000,000. The result is a stiff and stable gel with a freezing point below -50°C. The reversible temperature-dependant clouding effect is achieved by way of two different reactions. The first mechanism is the temperature-dependant control of watersoluble filamentary macromolecules. In the initial phase (transparent) the macromolecules are completely dissolved in water in the form of long chains. In this state their diameter is smaller than the wavelength of light. With increasing temperature molecular chains begin to form, the dimensions of which are larger than the wavelength of light. Clouding occurs due to the refraction of light by the chain particles (see Fig. 1). The 'clouding point' can be regulated with an accuracy of 1.5 K within the temperature range of 9 to 90°C. The wetting agents in the gel contain water due to polar interaction.

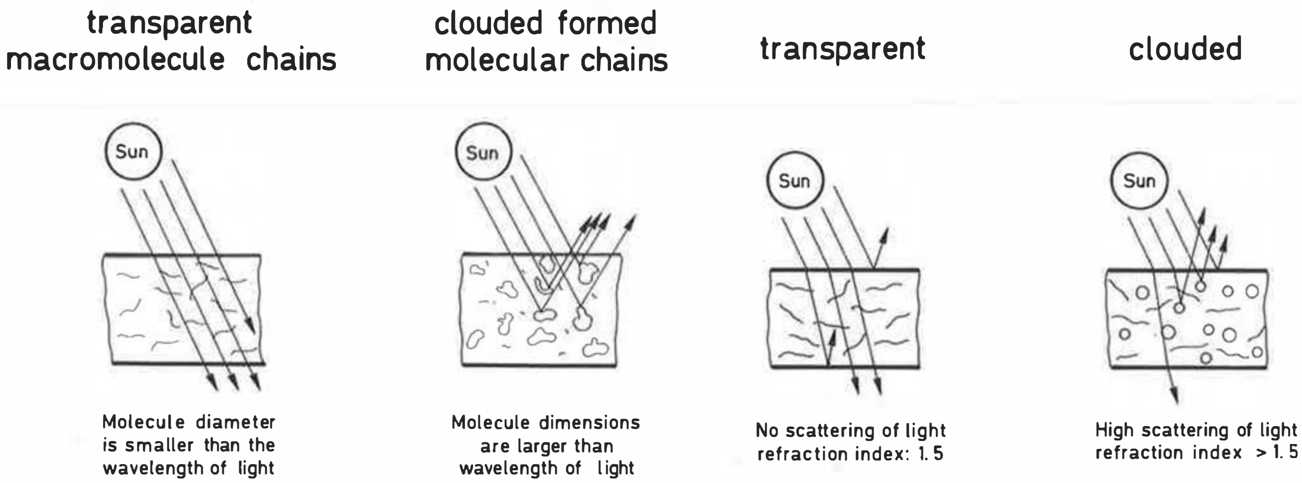

Fig. 1 Schematic presentation of the first clouding mechanism of TALD (left) depending on the molecular dimensions and the second clouding mechanism (right) occuring with the temperature dependance of water solution by means of polar interaction on wetting agents.

In the second clouding mechanism, the polar bound water is released and forms a highly light-diffusing dispersion of minute droplets of water in the plastic gel. This process is also reversible and temperature-dependant. By adding different substances to the plastic gel its properties can be adjusted so that the precise temperature at which water is set free can be regulated. The combination of these two mechanisms is the characteristic feature of TALD and has been proven in durability tests. Fig. 2 shows an example.

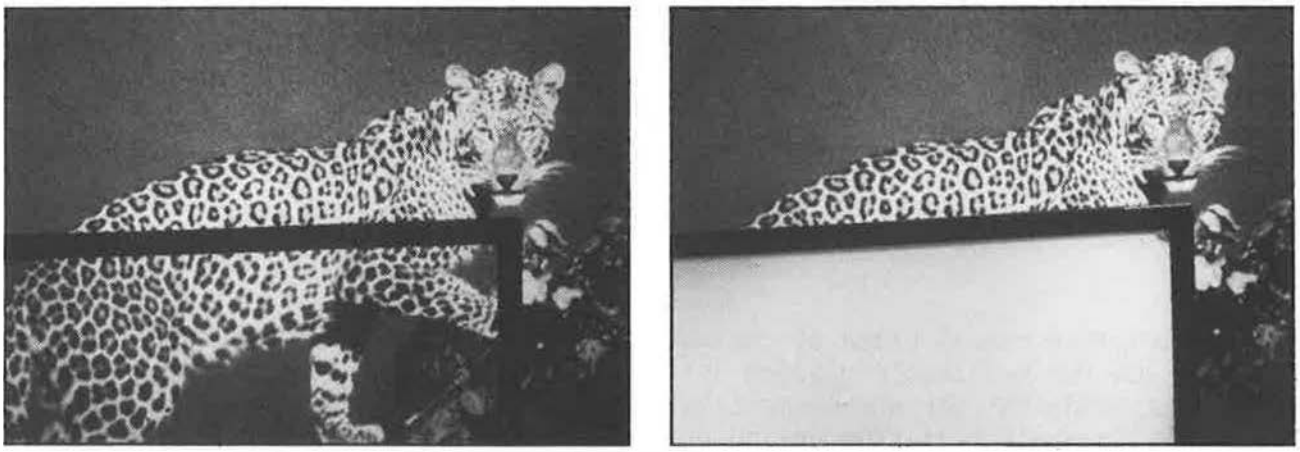

Fig. 2 Example of the transparent state of a TALD pane (left) and the same pane in the clouded state (right) at a higher temperature

TALD gel is chemically stable, UV-resistant and light stable. It is nontoxic, biodegradable and physiologically neutral. It is also fungus neutral, i.e. it does not provide a nutrient medium for fungal growth. Glass surfaces act as sequestering agents with the gel. During use it had to be prevented from drying out. Layers of less than 1 mm thickness are sufficient to achieve optimum cloud-effects. They do not reduce light transmission in the transparent state. With layers of 10 mm, a 25% reduction of light transmission occurs (see Fig. 3). The transmitted solar radiation of approximately 34% is highly diffused. In comparison with the widely available conventional sunshade panes, i.e. gold-tinted, low-emissivity glass, which keep out 34% of the light and over 50% of the heat even when outside temperatures do not require the latter, the shading properties of TALD are substantially superior. Compared to a gold-tinted low-emissivity glass TALD has excellent properties for applications in solar techniques, as indicated in Fig. 4. 84% or more transmission of incident solar radiation is possible in the normal state. In clouded state this drops to 34% or less.

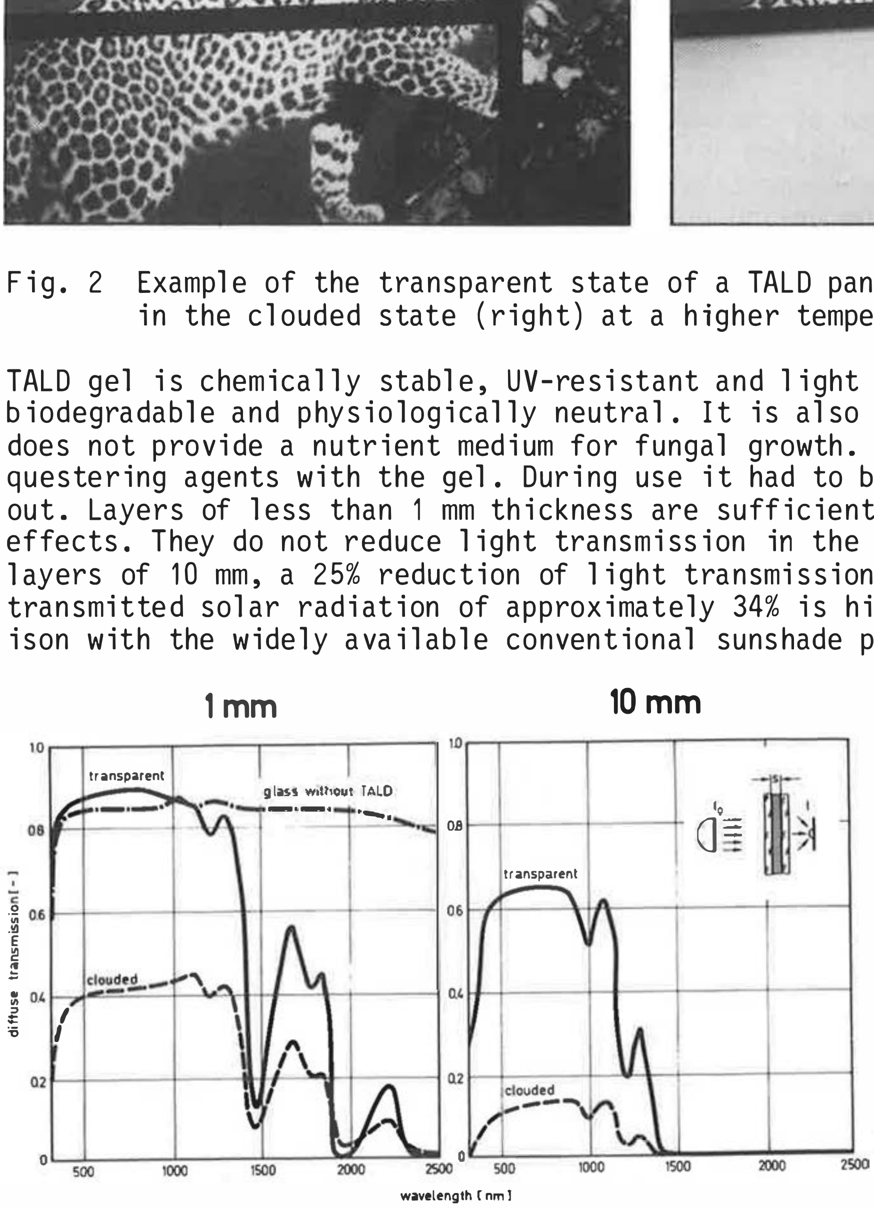

Fig. 3 Diffuse transmission of a TALD-Pane (clouding Temperature level 33°C) in transparent and clouded state for TALD gel layers of 1 mm (left) an 10 mm (right). In the visible range of solar radiation the transmission of glass without gel is lower tan with TALD gel.

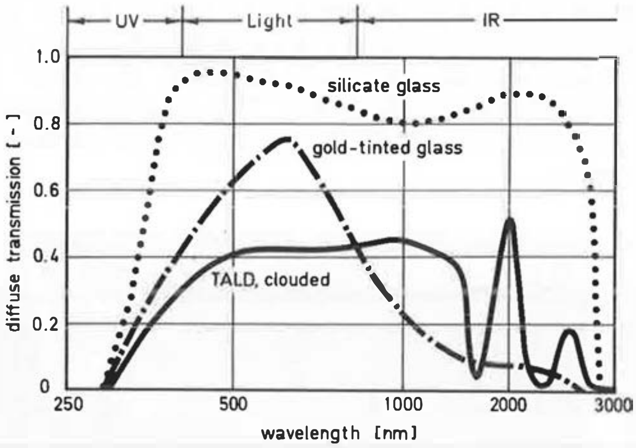

Fig. 4

Comparison of spectral diffuse transmission of TALD with a solar control glass (gold-tinted, low-emissivity glass) and with silicate glass

The anticipated retail price of the material will be less than 3 DM per m² which is very low for switchable glazing systems. A preferred application of this product is a sandwich-type arrangement between glass panels or other transparent materials to protect it from drying out. The edges have to be sealed in an air-tight and water-vapour resistant fashion like e.g. by special rubber gasketing. Before large-scale manufacturing is ventured, some problems must be solved.

CONCLUSIONS

TALD is an optically neutral thermochromic gel that undergoes an internal reversible chemo-physical change when its temperature is changed. This chemo-physical change results in a change of optical transmittance. Through control of TALD composition the following parameters may be adjusted to suit specific applications: Light and energy transmittance ratio between clear and clouded states, the temperatures at which transition begins, the temperature range over which the complete transition occurs, the speed of reaction and the optical properties (reflectance or absorptance) of the clouded material.

TALD may be suitable to a wide variety of glazing envelopes available to architects. Control of transmission by TALD may be accomplished by exterior or interior surface temperatures, solar flux through the panel or active control elements (electric heating) included within the panel at the time of manufacture. The material also behaves as a fire retardant since it contains water at a high percentage of mass.

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Transparent insulation for high temperature flat plate collectors

B. Karlsson

Älvkarleby Laboratory. Swedish State Power Board
S-810, 70 Älvkarleby, Sweden

A very Long Ground Based flat plate collector is developed. This so called LGB-collector is supposed to be connected to the district heating net-work which requires operating temperatures between 60 and 90 °C. This means that the flat plate collector has to be well insulated and equipped with some kind of transparent insulation between the glass and the absorber.From a detailed knowledge of the climatic conditions this paper discusses the expected performance of a number of different transparent insulation materials.

It is shown that the plane of a collector tilted 45° from the horizontal and pointed towards south during 1985 received 794 kWh/m² of irradiation of intensities exceeding 300 W/m², at an irradiation weighted mean angle of incidence of 30°, during 1273 hours at a mean ambient temperature of 14 °C. This means that the annual heat production of the flat plate collector in a simplified manner can be written

$$E=(\eta_0*794-U_L*(T-14)*1.273)*C$$

where the C-constant is a correction factor for correlating the simple relation to actually measured data. This factor which basically takes account of effects of the thermal inertia of the collector is normally set to C=0.90.

This simple but well verified formula allows us in a straigth-forward way to evaluate the performance of collectors equipped with transparent insulation materials of given solar transmittances and heat-loss coefficients.

The developed collector is furnished with a double glazing composed of a low-iron glass and a flat teflon film. In the paper the performance of this glazing is compared with double teflon films, V-corrugated films of teflon, tedlar and mylar and also of the newly developed AREL-honeycomb. The characteristic parameters of these materials needed for applying the relation above are obtained from measurements of solar-transmittances in a large intgrating sphere and heat loss factors from a hot-box.

The analysis shows that the most of structured materials shows a better performance than the flat teflon film, but that it from a cost effective point of view is difficult to compete with the high transmitting teflon film.

Designing honeycombs for minimum material and maximum transmission

K. G. T. Hollands

Solar Thermal Engineering Centre, Department of Mechanical Engineering
University of Waterloo, Waterloo, Ontario, Canada N2L 3GI

ABSTRACT

This paper briefly discusses a key problem facing the designer of honeycombs, or "transparent insulation of the forward-reflecting type—TIFT". What should be the cell size? From the point of view of minimizing the material content and the solar transmission, the larger the cell size, the better. To suppress convection requires a minimum cell size of typically about 10 mm for the hydraulic diameter. To effectively suppress radiation, on the other hand, requires a cell size of about 3 mm. From the point of view of minimizing the material content, it may be better to obtain the radiant reduction through the use of a low emissivity surface at the bounding faces, rather than through the honeycomb itself.

INTRODUCTION

The recent European (and Israeli) surge of interest in transparent insulation, as witnessed, for example, by this conference, is very encouraging. I am particularly pleased with the newly-adopted name: transparent insulation. During the 1970's and early 80's there was considerable activity in this area in North America and Australia, where it went under the name of "honeycomb" and later (at least by some) "convection suppression devices".

But "transparent-insulation" has the assets of being both easily understandable and descriptive of the goal, rather than a particular solution. The goal is to make a heat insulation that transmits—or is transparent to—solar radiation. A honeycomb is one solution to the problem of realizing that goal.

NOMENCLATURE

The McGraw-Hill Dictionary of Scientific and Technical Terms describes insulation as a "material that retards the passage of heat". Since a vacuum per se is not a 'material', it can be eliminated from our terms of reference. The three classes of transparent insulation receiving the most attention—namely aerogel, parallel transparent sheets, and honeycomb—all work by dividing up space into compartments or cells which trap a gas, forestalling the gas's tendency to convect when given enough room to do so, and which has walls that shield the long-wave radiation while remaining transparent to solar radiation.

What I have meant by the word "honeycomb" in my publications has been a compartmentalization in which the walls are perpendicular to the plane of the insulation slab, i.e., parallel to the direction of the applied temperature gradient. This meaning applies regardless of the pattern the walls form in planform: hexagonal, square, or rectangular. The supreme advantage of this orientation is that the solar radiation impinging on the slab is reflected, and re-reflected, by the walls in a forward direction. Thus if reflections are perfectly specular, and there is no scattering or absorption in the walls, the solar transmission will be 100 percent. In the parallel transparent sheet arrangement, on the other hand, the reflected energy at the walls goes back out, and therefore is lost. Since this forward reflection is the key to the honeycomb's advantage, perhaps we should coin (yet?) another name for the honeycomb: transparent insulation of the forward-reflecting type, or TIFT. The parallel wall arrangement would then be transparent insulation of the rear-reflecting type, or TIRT. Aerogel, as I understand it, succeeds in transmitting solar radiation by having the length scale of the compartments of the order of the wavelength of the solar radiation. This changes the relevant laws of reflection and scattering to those which apply to a material which, as seen by the radiation, is a quasi-continuum. Perhaps we should call this type "transparent insulation of the continuum type", or TICT.

THE 'FORK' IN THE DESIGN PROCESS

When confronted with the concept of TIFT, a host of questions naturally arise in the mind of the would-be designer: what size should the cells be? What is the best cell shape? What is the best material from which to make the walls? One guiding light in answering these questions is the amount of material that must go into making the TI. Material content is very important for two reasons. First, the amount of absorption and scattering of solar radiation inside the wall is proportional to the material content; so is the heat transfer by conduction through the cell wall. Second, materials cost money; indeed in mass production, the material cost will be the controlling item in this ultimate product cost. Using this guiding light, the walls should be as thin as possible and the cells as large as possible (the solid fraction of the TIFT is twice the wall thickness over the cell hydraulic diameter).

At this point the design process reaches a fork in the road: are we using the honeycomb primarily to suppress convection, or primarily to suppress long-wave radiation? For radiant suppression we need a small cell size, and we also need a minimum thickness of wall, depending upon the extinction coefficient of the wall material for long-wave radiation; in brief, we need a minimum solid fraction. For convection suppression, on the other hand, we need only a minimum cell size below which no added advantage is gained. The two required cell sizes—one for radiation, one for convection—are not usually the same.

The problem is focussed somewhat by considering two idealized cases of a square celled TIFT, the first totally dominated by radiation, the second totally dominated by gaseous conduction and convection. In case 1, the faces of the slab of TIFT and the cell walls are all radiantly black in the long wave region, and the slab is evacuated; in case 2, the faces of the slab and the cell walls have zero emissivity, the cells are filled with atmospheric air, and the cell walls are so thin that they do not conduct appreciably in the direction of the applied gradient. In each case we calculate the cell-size that will make the slab conductance U equal to 0.52 W/m^2K, when the slab thickness is 50 mm and when the slab faces are at 293 and 313K respectively. For case 1, the cell size needs to be 3.3 mm (3) and for case 2, 12.2 mm, the latter being the size that will "just" suppress convection in the horizontal orientation of the slab (2). In other words, as a general rule, for the same slab conductance, radiant suppression requires smaller cells than convection suppression.

In addition, the radiant suppression requires a minimum wall thickness to establish the required degree of opaqueness. Convection suppression, on the other hand, demands only that the wall should be there to stop fluid motion; any wall thickness (other than exactly zero) is acceptable. It is the radiant suppression that is demanding of material.

This being the case, should we not give the radiant suppression "a hand" by giving the bounding faces of the slab a low-emissivity? For example, by putting low-ε coating on window panes or selective surfaces on the absorber plate? This is the fork in the road. If the answer is yes, one has to pay the cost of low emissivity surface(s) and deal with the fact that the radiant and conductive fields are coupled, and an air gap will have to be left between the selective surface and the slab—forming a "compound honeycomb" (4). If the answer is no, we will have to put more material into the honeycomb. Which approach will win out? In the best of worlds, both will find a place.

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#5390

Heat-losss through transparent honeycomb insulation

J.A. Chattha and L.F. Jesch,

Solar Energy Laboratory, Mechanical Engineering Departament
University of Birmingham, Birmingham B31 2TT, U.K.

ABSTRACT

The use of a transparent honeycomb structure for insulation is viable because it suppresses convective and radiative losses while increasing passive solar gains. The development of reliable methods for calculating the overall heat transfer through honeycomb materials helps predicting and optimising the thermal performance of honeycomb insulated buildings. Mathematical models have been created which yield design parameters for optimal geometry, material selection and application of honeycomb transparent insulation. The effects of these parameters on the U value is discussed.

MATERIAL DESIGN

A honeycomb structure divides the air-filled enclosure into a large number of cells. Due to the reduced dimensions of each cell in comparison to the single enclosure the viscous forces acting on the air in each cell are increased. If the cell is dimensioned correctly the onset of natural convection can be shifted to larger temperature differences. This also gives the opportunity to increase the distance bewteen plates which improves the insulating contribution of the air layer trapped in the cells.

The honeycomb walls should be made thin so that the loss of radiation and the conductive heat loss through the material could be kept very small compared to the benefit which is reached by the suppression of natural convection. The selection of the material used for making the honeycomb is also important from an optical point of view: the refractive index has to be chosen correctly.

SIMULATION

Hollands (1984) showed a strong coupling between the radiation and conduction modes of heat transfer. In our work a coupled mode heat transfer model adjusted with an air gap between the absober and transparent insulaton has been used to determine the dependence of U-value of honeycomb insulation on different dimensional and material characteristics. Selected parameters such as cover plate emissivity (e_c), absorber plate emissivity (e_a) and air gap in four assumed and near limit configurations are listed below.

Configuration	*Cover emissivity*	*Absorber emissivity*	*Airgap*
1	0.9	0.9	no
2	0.9	0.1	no
3	0.1	0.1	no
4	0.9	0.	yes

For sample calculations a honeycomb structure similar to AREL's Thermode has been chosen with an average cell size of 3.5 by 3.5 mm, cell length of 100 mm, and wall thickness of 0.03 mm, made of polycarbonate . All the calculations have been made at constant average temperature of 15 °C and at a temperature difference of 10 °C between the end plates.

The overall U-value has been calculated as a function of the emissivity of the sidewalls and conductivity of honeycomb shown in Fig. 1. The nature of the curves can be best understood by considering separately the dependence of radiation and conduction heat transfer as a function of sidewall emissivity (Fig. 2).

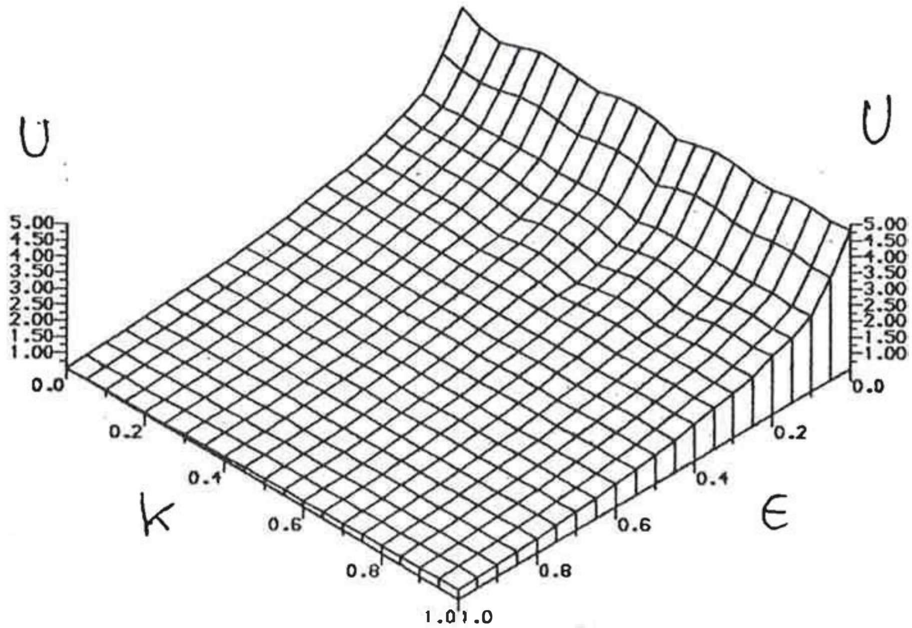

Fig. 1 U-value as a function of conductivity (k) and emissivity (e)

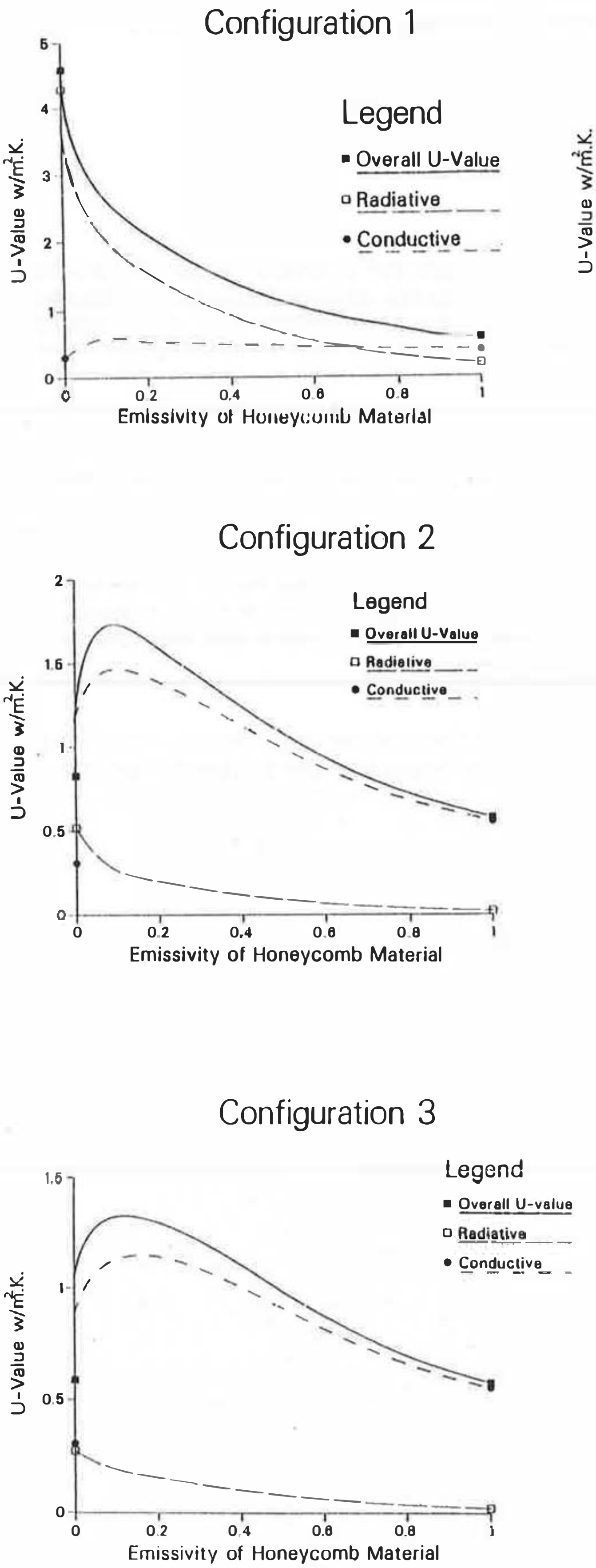

Fig. 2 U-value as a function of emissivity for configurations 1, 2, 3

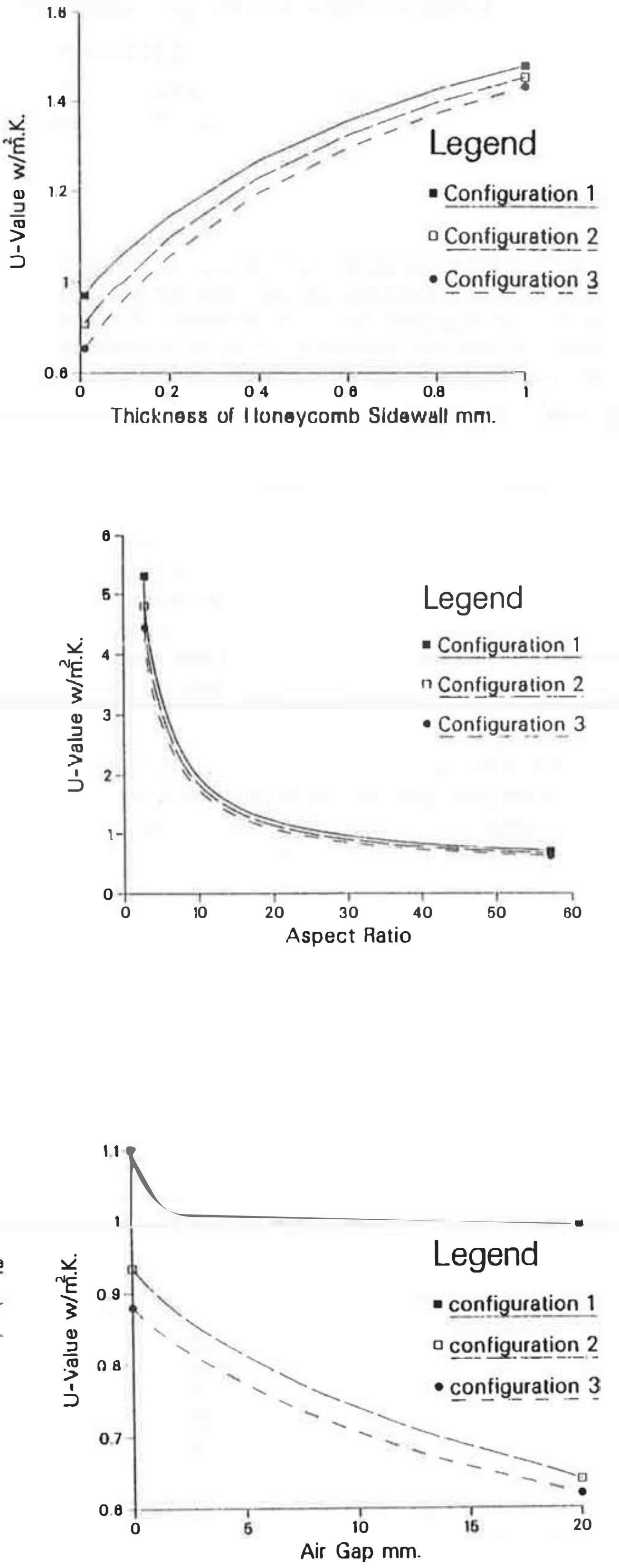

Fig. 3 U value as a function of structural geometry for configurations 1,2,3

COUPLED MODE HEAT TRANSFER

Radiation heat transfer through the honeycomb decreases with an increase in sidewall emissivity as a result of an increase in radiation shielding by the sidewall. No radiation shielding occurs when the sidewall emissivity is zero and the maximum shielding occurs when the sidewall emissivity is one.

Conduction heat transfer through the absorber surface, when the sidewall emissivity is zero, is equal to the independent mode conduction heat transfer since no radiative-conductive coupling exists. When the sidewall emissivity is increased from zero: the radiative-conductive coupling causes the heat conducted through the absorber surface first to increase to a maximum value and then to decrease as the sidewall emissivity increases.

The initial increase at low sidewall emissivities is a result of an increase in radiation assisted conduction coupling. As the sidewall emissivity is further increased the increase in resistance to radiation transmission becomes stronger resulting in decreased conduction heat transfer as the sidewall emissivity increases.

As seen in Figure 2 for configurations 2 and 3 the overall U-value for low emissivity sidewalls increases with an increase in emissivity. This increase in overal U-value results from the greater increase in conduction with increase in emissivity compared to the reduction in radiation as a result of the increase in radiation shielding. For configuration 1 it can be seen from Figure 2 that the heat transfer due to radiation is more dominant thus the increased conduction with increase in emissivity has a weaker effect on the overall heat transfer. Hence it can be concluded that there will always be a decrease in over all U-value with an increase in sidewall emissivity for high emissivity honeycombs since both conduction and radiation heat transfer decreases with an increase in sidewall emissivity.

It can also be concluded that if a honeycomb has plates such as black paint or glass then the greater the honeycomb emissivity the lower the heat losses will be. If however one or both of the bounding sufaces have a reduced emissivity then design curves similar to the ones shown for configuration 2 and 3 should be studied before selecting a cell emissivity configuration.

The size of the cell was fixed at 3.5 mm and the aspect ratio has been varied by changing the cell length of honeycomb. It is noted from Figure 3 that the U value of honeycomb decreases with an increase of aspect ratio. This effect has been expected since both the conductive and radiative heat transfer decreases with increase of the cell length.

The thickness of the sidewall has been varied from 0.01 to 1.0 mm keeping all other parameters constant. The first three configurations show qualitatively the same dependence of U-value on sidewall thickness. The conclusion is that overall U-value will be lower with thinner sidewalls.

THE INFLUENCE OF AN AIR GAP

The large effect that the mechanism of coupled heat transfer has on the total heat transfer can be reduced by the introduction of a gap between the honeycomb structure and the absorber wall i.e. at the place where the largest temperature gradients are expected. For a selective surface absorber large temperature gradients exist in the air and the honeycomb structure wall near the absorber. This induces large conductive heat transfer. Application of a gap shall decrease coupling between the heat transfer mechanisms locally and reduce overall heat transfer. Moreover the gap introduces an air layer which has a smaller thermal conductivity than the thermal conductivity of honeycomb structure wall. Figure 3 shows the effect of air gap thickness on U-value for configurations 1, 2 and 3. It is important however that the air gap thickness be restricted to prevent convection heat transfer to take place.

CONCLUSIONS

The best transparent insulation has high emissivity and thin walled honeycomb material with high aspect ratio and an air gap of about 20 mm thickness in front of a selectively absorbant mass wall.

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Comparison of measurements on transparent thermal insulation systems with numerical simulations of building envelopes

E. Boy

Fraunhofer Institute of Building Physics Department of Heat/Climate
(Dir. Prof. Dr.-Ing. habil. K. Gertis)
Nobelstr. 12, D-7000 Stuttgart 80, FRG

ABSTRACT

An existing simulation program has been improved in such a way that it is now possible to analyze the thermal behaviour of transparent insulated building facades. The comparison of numerical calculations performed using this model and of associated experimental investigations shows good agreement concerning the system's thermal behaviour, maximum surface temperatures, and long-term mean values. These calculations are based on the assumption that material properties are known and that multi-dimensional effects caused by cold bridges, frames, fans, etc. are describable with equivalent values of thermal properties. Actually, even minor uncertainties regarding indoor air temperature are liable to reduce the agreement of measured and predicted heat flow densities. As could be verified by error analyses, these variances are however still remaining within the range of measurement accuracy.

Another result of the comparison is that the characteristic heat gains achieved by transparent insulated walls are strongly depending on the seasonal variations in climate. In connection with heat gains through windows and internal heat gains, the temporary gains due to the transparent insulation system are only useable to a certain extent since they are obtained in times when they are not needed, as well. This is the reason why results of calculations performed on wall constructions using ideal boundary conditions are not implicitly transferable to real buildings. With indoor climate conditions, user behaviour, and different thermal zones in buildings varying widely, actually useable gains in buildings are not necessarily predictable from numerical investigations of wall constructions.

INTRODUCTION

The numerical simulation program SUNCODE [1] is a general purpose thermal analysis program for residential buildings. In SUNCODE, the mathematical representation of the building is a thermal network with non-linear temperature dependent controls. The mathematical solution technique uses a combination of forward finite differences, Jacobian iteration and constrained optimization [1]. This program allows not only to conduct an accurate thermal analysis of buildings, rooms and building components, but also to quantify the energy gains of passive solar constructions. Special provisions have been made for the analysis of attached sunspaces and Trombe walls.

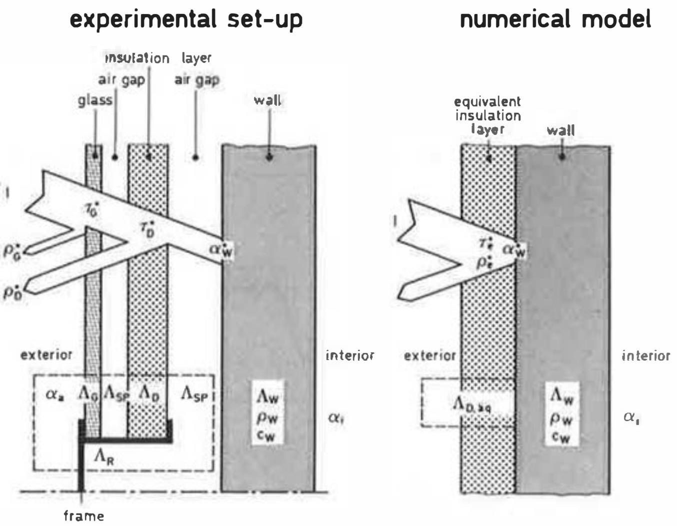
The data input used for improving the existing simulation code [1] has been provided from the research and development work carried out within the framework of "LEGIS" [2], a project investigating transparent thermal insulation systems in a series of detailed experimental analyses of test walls, test rooms, and an entire test house.

BRIEF DESCRIPTION OF THE PROGRAM

A thermal model of the building or of building components is created by the program user. Subsequently it is translated into mathematical form by the program. The mathematical equations are then solved repeatedly at time intervals of one hour or less for the period of simulation. The program calculates the dynamic performance of the building or building component in great detail and reports the input quantities of energy and power that the heating and cooling equipment must supply in order to maintain comfort conditions. Effects of long-wave or infrared radiation transfer between surfaces in a room have to be regulated by means of other parameters, for example surface coefficients. Shading of external surfaces and windows is allowed by overhangs und vertical offsets. The program also provides for sidefins and shading caused by faraway objects that obstruct the skyline. Simplifying assumptions and approximations have been made throughout the program, such as one-dimensional heat flow through each part of the building's envelope. Temperature dependence of material properties is described using mean values. Time-dependent parameters or parameter-dependent material properties such as transmissivity of transparent insulation layers are approximated by way of effective mean values. The optical and thermal behaviour of windows and transparent insulations or any layer of partially transparent material could be approximated with a set of different parameters like e.g. U-value of glazing or layer, shading coefficient, extinction coefficient, index of refraction, thickness of layer and number of layers. Time-dependent parameters may also be scheduled to describe additional night insulation or to allow for solar control during the summer. Shading of only direct radiation is possible if the sun is obstructed by the overhang or sidefins. Effects on interior thermal comfort conditions can be studied either without heating and cooling devices or with equipment of specified maximum capacities. Air change rates may be either constant, scheduled or temperature-dependent.

COMPARISON OF MEASUREMENTS WITH NUMERICAL CALCULATIONS

Results of experimental investigations of different transparent insulated test walls [3] have been validated with numerical calculations [4]. Fig. 1 shows the test wall in a schematic presentation and also the approximation accomplished in the calculation model. The individual layers of the transparent insulation system, including frames, are assumed as one equivalent homogeneous layer. Existing multidimensional effects have been approximated in one dimension only (see Fig. 2).



I	solar radiation
τ_G^*, τ_D^*	transmissivity of transparent weather protection (of transparent insulation, respectively)
ϱ_G^*, ϱ_D^*	reflectivity
a_w^*	absorptivity of wall surface
α_a, α_i	surface coefficient exterior and interior
Λ_G, Λ_{Sp}, Λ_D, Λ_R, Λ_w	thermal resistance layers
ϱ_w, c_w	bulk density of wall and specific heat capacity
τ_e^*, ϱ_e^*	optical properties of insulation system
$\Lambda_{D,äq}^*$	equivalent thermal resistance of insulation systems

Fig. 1 Schematic presentation of the experimental set-up and of the numerical model

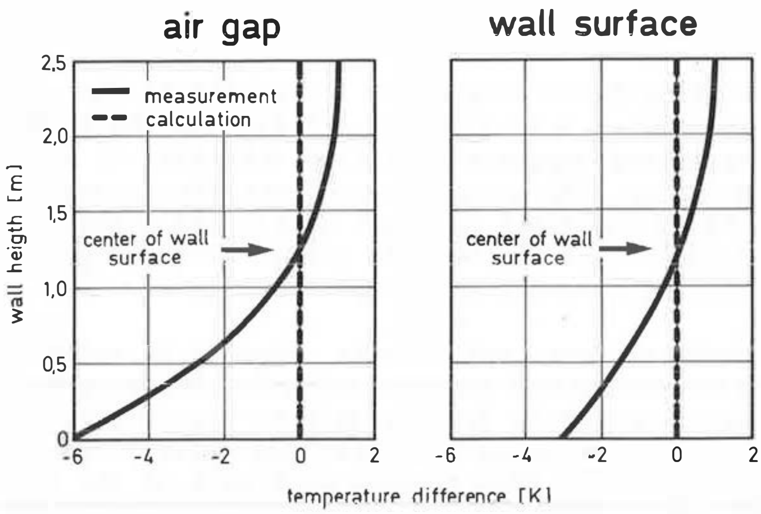


Fig. 2 Multi-dimensional effects measured on a test wall and numerical approximation

The weather data input to the program was supplied by measured hourly mean values of solar radiation and ambient air temperature. Fluctuation of surface coefficients has been neglected. During measurements, the room air temperature was kept constant at 20°C within an absolute accuracy of ± 2 K and a mean accuracy of ± 0.2 K. Fig. 3 shows an example of the results obtained in a six-day comparison of measured and calculated data. Since the program requires unshaded horizontal and direkt normal radiation as data input, there is a minor difference between measured and calculated radiation on the south-facing wall as shown in the top diagram in Fig. 3. The second diagram in Fig. 3 illustrates the fluctuation of outdoor air temperature. These measured data could be used as direct input to the program. The third and fourth diagram present the exterior respectively interior wall surface temperature as measured compared with the calculated fluctuation. Both diagrams show excellent agreement. In the last diagram of Fig. 3 there is a slight difference to be stated between measured and calculated values for heat flux density. Error analysis indicates, however, that within a period of three months an uncertainty of only 0.2 K in temperature measurements eventually results in an uncertainty of more than 2 kWh/m² in heat flux calculation. Table 1 includes the measured and calculated mean values of a three-month period. Again, the results show good agreement between measurement and calculation.

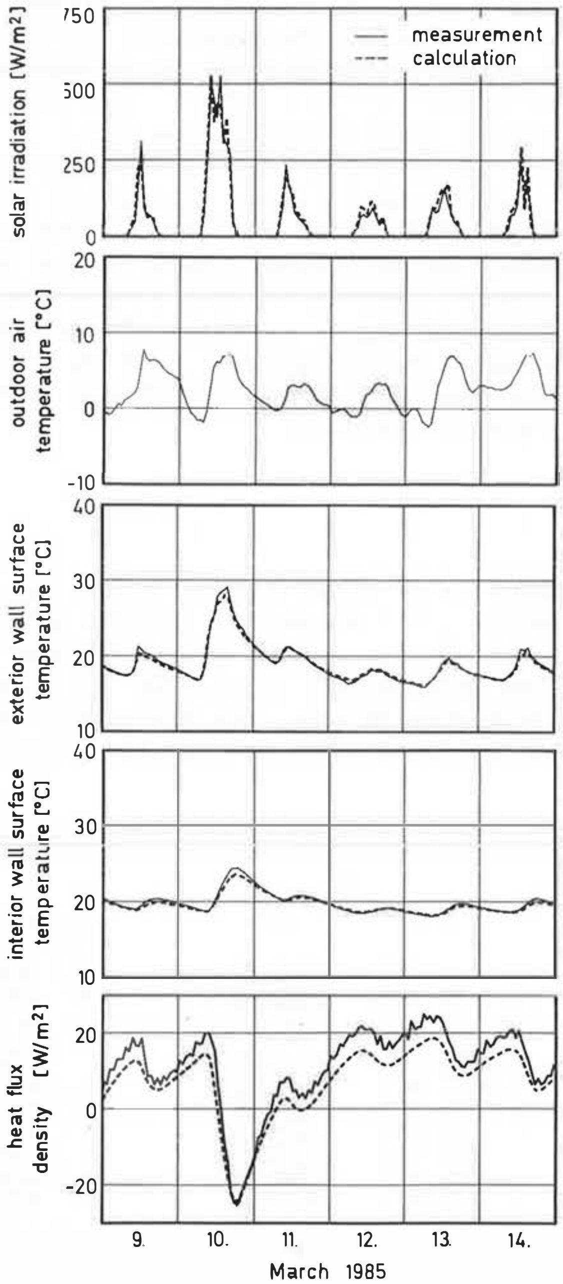


Fig. 3 Six-day example for the comparison of measured and calculated data of a transparent insulated wall

Table 1 Comparison of measured and calculated data (mean values) for a transparent insulated wall over a three-month period

comparison		measurement	calculation	difference	
				absoloute [unit]	relative [%]
solar irradiation [kWh/m²]		130.3	133.3	2.9	2.2
surface of wall [°C]	exterior	22.9	23.1	0.2	0.8
	interior	22.0	22.0	0.0	0
areal heat flux [kWh/m²]	losses	5.40	3.62	1.77*	33
	surplus heat	17.35	19.14	1.78*	10

*An uncertainty of 0.2 K results in an uncertainty of heat flux of more than 2 kWh/m²

Further comparisons of measurement data obtained for one test room and a test house show the same agreement if multi-dimensional effects of material properties are taken into account.

CONCLUSIONS

The comparison of numerical calculations performed using the improved building energy analysis simulation program SUNCODE with associated experimental investigations shows good agreement concerning the system's thermal behaviour, maximum surface temperatures, and long-term values. The calculations are based on specified assumptions and simplifications of system parameters and material properties, which is in fact a result of several years of experience gained in investigating different transparent insulation systems. If material properties are known this improved program allows calculations with an accuracy of $\pm$ 1 K for the thermal behaviour of transparent insulated walls.

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A simple method for the estimation of energy savings through application of transparent insulation materials

B. C. Alexa, A. Kerschberger*, A. Lohr**, B. Weidlich***

***Büro fur energiegerechtes Bauen, Oldenburger Strasse 68, D-5000 Köln 60, FRG*

**Weidlich Ingenieurgesellschaft, Giesebrechtstrasse 10, D-1000 Berlin 12, FRG*

ABSTRACT

A simple method for estimating the effects of transparent insulation materials in buildings is presented. Based on monthly mean climatic data and a spreadsheet calculation, the method allows possible energy savings to be visualized in a diagram of transmission versus U-value. The method is meant for architects during the first phases of a design process.

INTRODUCTION

The calculation of the solar gains of a building using transparent insulation material (TIM) should be performed on three levels. On the two levels of scientific research and engineering detailed simulation is necessary on an hourly basis. On a third level, a simple method for architects has been developed for first estimates of auxiliary heating demands, based on monthly meteorological data. A personal computer and a spreadsheet calculation (Framework) have been used.

Good performance of a TIM is characterized by high solar transmission and a low U-value. In a diagram showing the transmission versus the U-value, best performing TIMs will be found in the upper left corner (see Fig. 1). However this information is not sufficient for the validation of different TIMs for different types of buildings in a specific climate.

INPUT: GIVEN PARAMETERS

For this estimate, a simple set of building parameters for a one-zone building is used with:

		U-value (W/m^2K)
–floor / roof area	10x10=100 m^2	0.55 / 0.30
–total wall area	88 m^2	1.75 (without insul.)
–windows (half N and S)	22 m^2	3.00
–air change rate	0.7 /hr	
–base temperature	20 °C	
–internal gains	15 kWh/d	

With a conventional opaque insulation of 3 cm of polystyrene this building fits the German insulation standards (WSVO). According to these standards, which do not allow solar gains to be taken into account, the use of any TIM having a U- value higher than 1.5 W/m^2K has to be excluded for this particular building. This is indicated in Fig. 1 by the limit "minimum insulaton". Further calculations have only to be performed with TIMs left of this limit.

Monthly data of mean outdoor temperatures (1) and global irradiation on horizontal and vertical surfaces facing west, north, east and south (2) of the weather station of Trier, Federal Republic of Germany, have been chosen.

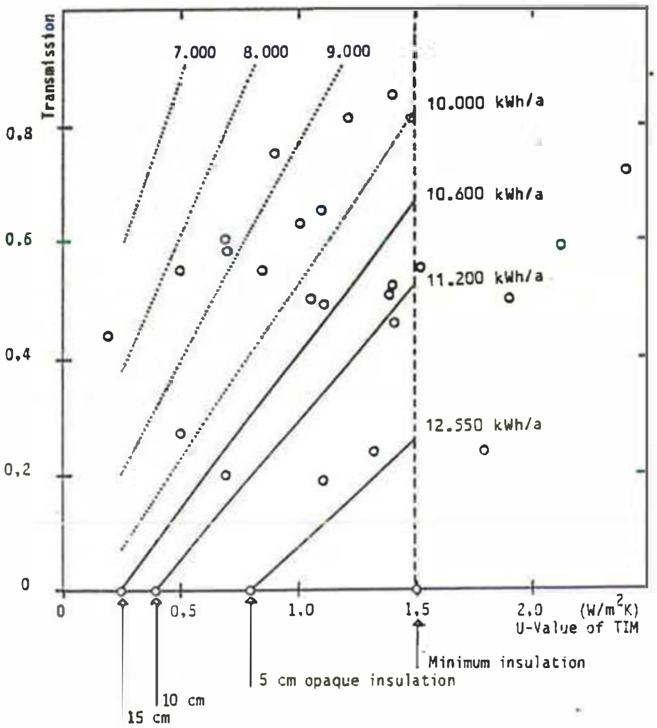

Fig. 1 "Curves" of equal auxiliary heating demand

OUTPUT: ENERGY BALANCE

The monthly total gain (including internal and solar gain) has been calculated and related to the total load using the <u>G</u>ain <u>L</u>oad <u>R</u>atio (GLR, instead of the solar load ratio, SLR).

The simple formula

$$FU = (1-\exp(-GLR)) / GLR$$

used here was given by Heidt (3). It is an estimation on the usable fraction FU of gains. According to Platzer (4,5) the formula seems to predict slightly conservative results with respect to the possible energy savings.

ZEITRAUM :	JAN	FEB	MAR	APR	MAI	JUN	JUL	AUG	SEP	OKT	NOV	DEZ	JAHR	HEIZZEIT
Heiztage :	31	28	31	30	31	0	0	0	30	31	30	31	273	273
Heizgradtage: :	570	512	434	321	195	102	47	84	165	316	426	512	3684	3452
V E R L U S T E (alle Energiewerte in kWh)														
SÜD Fenster :	452	406	344	254	155	81	37	66	131	250	337	405	2918	2734
WEST Fenster :	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NORD Fenster :	452	406	344	254	155	81	37	66	131	250	337	405	2918	2734
OST Fenster :	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fenster Summe :	904	812	687	508	309	162	74	133	261	501	675	810	5835	5468
SÜD Wand :	131	117	99	74	45	23	11	19	38	72	98	117	844	791
WEST Wand :	218	196	166	123	75	39	18	32	63	121	163	195	1407	1318
NORD Wand :	131	117	99	74	45	23	11	19	38	72	98	117	844	791
OST Wand :	218	196	166	123	75	39	18	32	63	121	163	195	1407	1318
Wand Summe :	697	626	530	392	239	125	57	102	202	386	521	625	4502	4218
SÜD gesamt :	582	523	443	328	199	104	47	85	168	323	435	522	3762	3525
WEST gesamt :	218	196	166	123	75	39	18	32	63	121	163	195	1407	1318
NORD gesamt :	582	523	443	328	199	104	47	85	168	323	435	522	3762	3525
OST gesamt :	218	196	166	123	75	39	18	32	63	121	163	195	1407	1318
W+F Summe :	1601	1438	1218	901	548	286	130	235	463	887	1195	1435	10337	9686
:														
BebauteFläche B:	376	338	286	212	129	67	31	55	109	209	281	338	2431	2278
Dachfläche D:	411	369	312	231	141	73	33	60	119	228	307	368	2652	2485
Gesamtaußenfl.A:	2388	2145	1817	1344	818	427	195	350	691	1324	1783	2141	15421	14449
:														
Lüftungsverlust:	914	821	696	515	313	164	75	134	265	507	683	820	5906	5534
GESAMTVERLUSTE :	3302	2966	2512	1858	1131	590	269	485	955	1831	2466	2961	21327	19983
P O T E N T I E L L E G E W I N N E (aller Flächen und interne Gewinne)														
Interne Gewinne:														
Zelle mit 100m2:	465	420	465	450	465	450	465	465	450	465	450	465	5475	4095
Sol.Gew.Fenster:														
SÜD :	202	335	467	519	542	506	558	566	546	409	209	177	5035	3406
WEST :	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NORD :	57	94	171	257	365	397	393	302	209	124	63	43	2475	1383
OST :	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fenster gesamt :	259	429	638	776	907	903	951	868	755	532	272	220	7510	4789
Solar.Potential:														
SÜD :	197	327	456	506	529	493	544	552	532	399	204	172	4913	3323
WEST :	153	291	527	748	914	940	977	853	655	380	167	125	6730	3960
NORD :	56	92	167	250	356	388	383	295	204	121	61	42	2415	1349
OST :	153	291	527	748	914	940	977	853	655	380	167	125	6730	3960
Wände gesamt :	560	1002	1677	2253	2712	2760	2882	2553	2047	1280	599	464	20788	12593
Dach :	28	51	97	144	188	195	202	170	123	69	31	22	1319	752
Solar Gesamt :	847	1482	2412	3172	3807	3858	4035	3591	2925	1881	902	705	29618	13133
GEWINNE Gesamt :	1312	1902	2877	3622	4272	4308	4500	4056	3375	2346	1352	1170	35093	22228
B I L A N Z (Solar-Last-Verhältnis, Nutzungsgrad, Heizbedarf)														
anrech.(Heidt) :													Summe:	
nur interne Gw.:	434	392	425	400	381	315	221	299	359	411	411	430	4477	3642
Int.Gw + D + F :	673	777	954	969	846	548	269	463	717	808	649	629	8300	7021
(alle Gewinne) :														
SLV :	,40	,64	1,15	1,95	3,78	7,30	16,72	8,37	3,53	1,28	,55	,40		
N (Heidt) :	,83	,74	,60	,44	,26	,14	,06	,12	,27	,56	,77	,83		
anrechenbar:	1082	1404	1713	1594	1105	590	269	484	927	1322	1041	967	12499	11155
davon TWD-Wände:	410	628	759	625	259	43	1	22	210	514	392	338	4199	4134
Rest-Heizbedarf:	2220	1562	799	265	26	0	0	0	28	508	1425	1994	8828	8828

Fig. 2 Calculation table

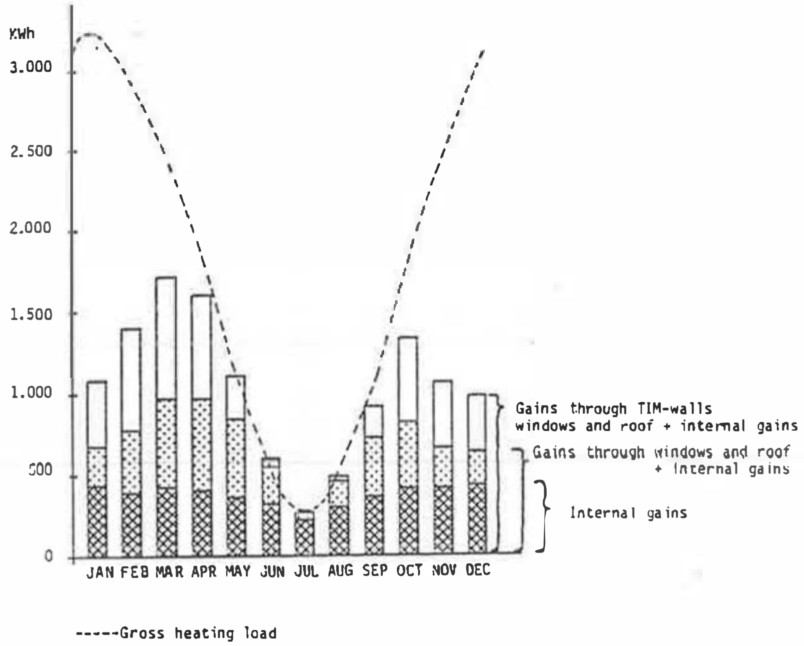

Fig. 3 Bar diagram showing the net gains and gross heating loads

Loads minus usable gains provide the monthly auxiliary heating demand which can be summed up to a yearly amount. Fig. 2 shows an example of a calculation table containing losses, gains and balances for every month, the entire year and the traditional heating period of the year (Sept. to May). Fig. 3 shows the distribution of monthly loads and usable gains.

DISCUSSION OF FIRST RESULTS

For this particular case, TIMs with different combinations of transmission and U-values that lead to the same yearly amount of auxiliary heating demands are shown as lines in Fig.1.

Full lines denote TIMs that render a result equal to an opaque insulation of 5, 10 and 15 cm (see circles on the x-axis). Beyond the range of conventional insulation, additional energy savings are possible (regime of dotted lines). The amount of savings is given by the spacing between any two curves of equal auxiliary heating demand.

It must be noted that the lines do not have to be straight lines but can be curved in other cases. Positions and spacings of the lines visualize a classification scheme of different TIMs for a special building and climate: they depend on the chosen formula of estimating the usable fraction of heat gain.

FUTURE DEVELOPMENTS

Subject to a final estimation formula, found by fitting results of applications and simulation programmes, an economic validation can be given.

TIMs falling within the full lines have to compete with the corresponding opaque insulation in price. Additional savings can be evaluated economically by attaching (current or expected) energy costs to the corresponding curves of equal auxiliary heating demand. Thus the method presented provides a quick evaluation of possible energy and cost savings of a TIM application for a particular building.

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Analysis of over-heating of wall structures in transparent insulation applications

L. Jankovic and L.F. Jesch

Energy Engineering (Birmingham) Ltd.
192 Franklin Road, Birmingham B30 2HE, U.K.

ABSTRACT

An experimental installation of transparent insulation retrofitted on parts of the south and west facing walls of the corner room of a 100 year old building in Birmingham, UK has been monitored since 1986. The two exposed walls receive different shading and in the winter the west facing wall does not receive direct beam radiation from the Sun. The temperatures on the outside surface of the south facing wall behind the transparent insulation, where it is exposed to most radiation and for the longest periods of time, have never reached a level which would be damaging to the building fabric. Samples of the monitored temperature data are shown in statistically reduced form. They indicate both the transparency benefits and the insulating benefits of the installation and give no evidence of overheating.

INSTALLATION

The installation of the transparent insulation reported by Jesch (1987a) and (1987b) was carried out on the building in 1986. The south facing wall is partially insulated by Arel honeycomb material and covered by a polycarbonate sheet. The west facing wall is partially insulated by the same material and covered by clear glass. All transparent insulation panels are in wooden frames.

MONITORING

Sensors are placed in 7 locations each having a group of K type thermocouples measuring the temperatures of ambient air, outside wall surface, inside wall surface and inside air at acarefully selected position of the area. Five of the seven locations are marked A - E on Fig.1 which gives the view of the two corner walls from the inside of the room. The other 2 locations are on the west wall and the window, but they are not part of the present study.

Kipp & Zonen CM 11 type solarimeters are used to record the solar radiation arriving on the vertical surfaces of the south and west walls. The information obtained from these instruments is augmented by climatological measurements monitored a few hundred meters away on inclined and vertical plus horizontal total and horizontal diffuse radiation for comparison and correlation purposes.

A Microdata 1600 microprocessor based datalogger is used for recording all thermocouple and solarimeter signals. The thermocouples are connected to an isothermal junction box and the solarimeters feed information into an integrator which allows both instantaneous and time integrated values to be recorded. Time interval between scans of all data is 6 minutes, thus the resolution of data is based on 10 readings per hour.

EVALUATION

The industry - standard tape cartridges containing monitored data are removed periodically from the datalogger and information is transferred to an IBM PC AT machine for processing and analysis. Graphics are produced directly from the files containing reduced data via a Polaroid Palette and an HP plotter.

The present study limits itself to the subject of overheating in structures covered by transparent insulation. Energy balances of the building calculated by the Transparent Insulation Computer Aided Design (TICAD) program, which was specially developed for modelling transparent insulation applications, are not discussed here.

TEST RESULTS

Figures 2 – 6 give sample results of the correlation between the three major parameters (solar radiation, outside wall surface temperature and inside wall surface temperature) measured during the test. The conditions in the five areas where temperature was measured are shown below

Area	*Trnsp.Insul.*	*Outer cover*	*Radiation condition*
A	none	none	Most shading throughout the year
B	yes	polycarbonate	Most shading throughout the year
C	yes	polycarbonate	No shading, maximum radiation
D	yes	clear glass	No direct beam radiation for 6 months
E	none	none	No direct beam radiation for 6 months

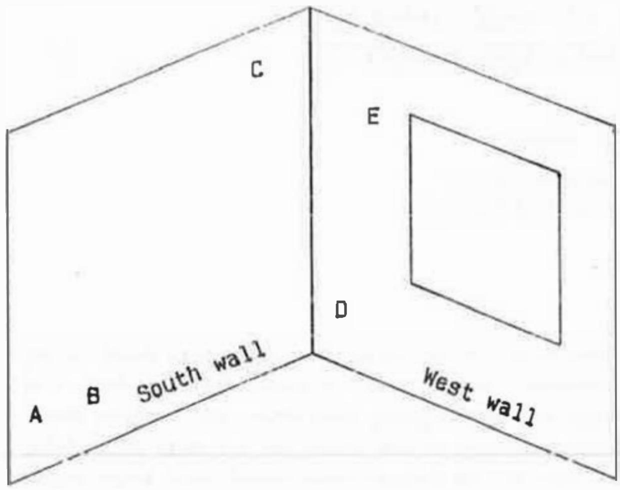

Fig. 1 Axonometric view of sensor location from inside

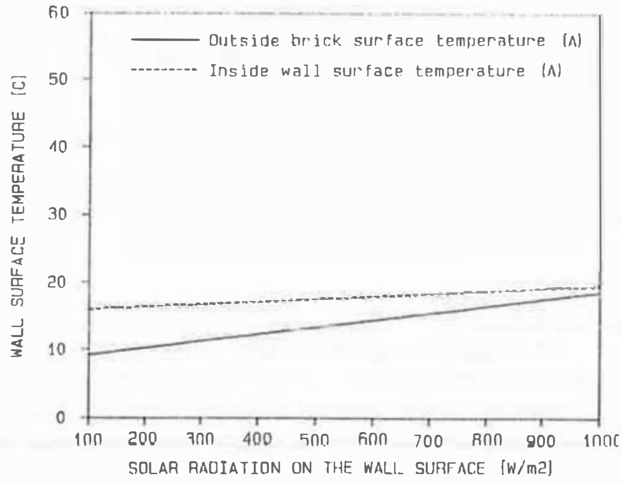

Fig. 2 South wall surface temperature: position A

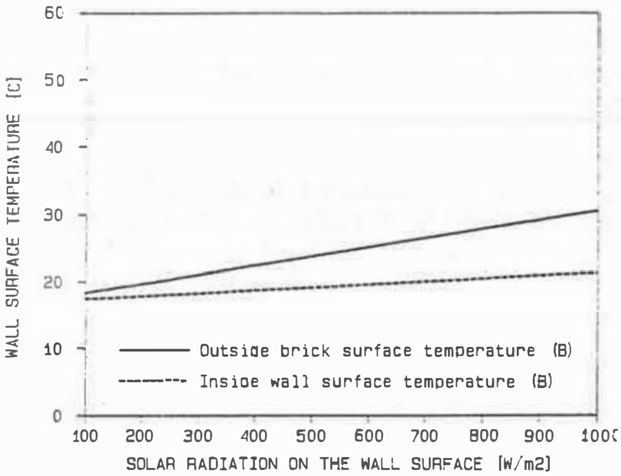

Fig. 3 South wall surface temperature: position B

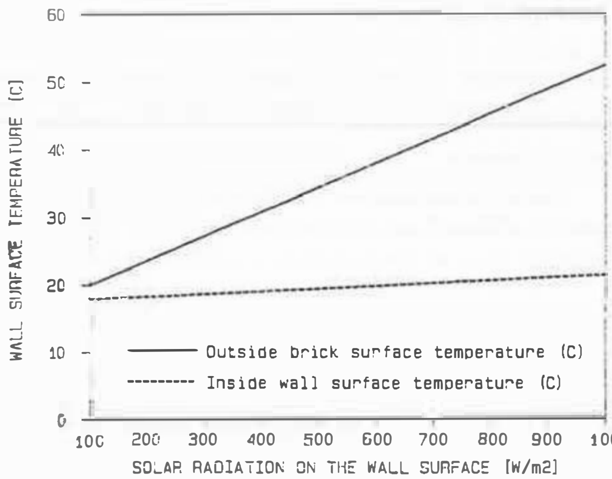

Fig. 4 South wall surface temperature: position C

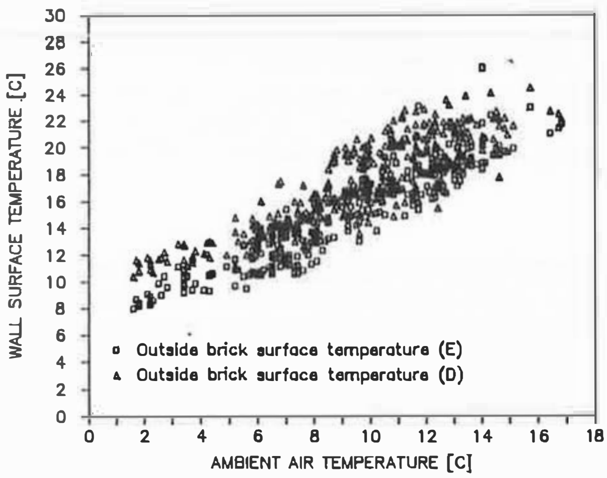

Fig. 5 West wall outside surface temperature: original data

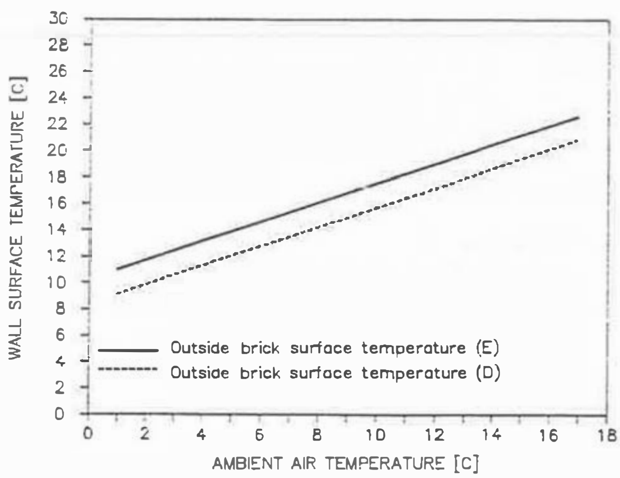

Fig. 6 West wall inside surface temperature: least square fit

ANALYSIS

The measured data was organised along the lines of the bin data method. The main parameters were subsequently analysed statistically and correlated in pairs. Solar radiation which is the main cause of surface temperature was then plotted against both outside and inside wall surface temperature. The data scatter is considerable because wind cooling effects are not included and the transient heating effects due to the duration of direct beam radiation are not fully accounted for in this analysis. Nevertheless the correlation between solar radiation and surface temperature is clearly established by curve fitting based on least square errors.

The assumption of the existence of a linear correlation between radiation and surface temperatures is justified in the narrow temperature range and limited maximum radiation experienced during the tests. It was noticed that at higher radiation values the errors increase which implies that the non-linearity is more pronounced above 900 W/m^2,^{o}C but radiation above these levels is quite infrequent.

South wall surface temperatures show benefits of the transparency of the insulation. Inside and outside wall surface temperatures in location C and B (covered by transparent insulation) show strong dependence on solar radiation. These outside brick surface temperatures are always higher than the inside surface temperatures and both increase with the increase in solar radiation. The outside brick surface temperature can almost reach 60 ^{o}C in location C (the most exposed to solar radiation) and it can go up to 38 ^{o}C in location B (less exposed to solar radiation). The outside brick surface temperature of 60 ^{o}C in location C does not damage the fabric and does not cause overheating inside.

The outside brick surface temperature in location A (not covered by transparent insulation) is always less that the inside wall surface temperature and it reaches the level of the inside surface temperature only at a solar radiation level of about 1000 W/m^2.

The comparison between outside brick surface temperatures in locations C and A or locations C and B show obvious benefits from transparent insulation on an irradiated wall. The inside surface temperatures in all locations show no overheating for solar radiation up to 1000 W/m^2.

Outside brick surface temperatures on the west wall are less exposed to solar radiation and therefore they are analysed as functions of the ambient air temperature. The outside brick surface temperatures in locations E and D are always higher than the ambient air temperature and always well above freezing. They are increasing functions of the ambient air temperature and in the domain of lower ambient air temperatures resulting from diffuse radiation only, the graphs show how the transparent insulation acts as an insulation only.

The limited range of temperature fluctuation on the inside wall surface was the result of energy balance reached by solar heating through tranparent insulation and natural cooling through uninsulated areas of the walls.

CONCLUSION

No overheating behind transparent insulation was experienced on either walls during the two years of testing while the ambient temperature and solar radiation reached their usual high values during the summer.

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Constructional and architectural aspects of facades using transparent insulation materials

B. C. Alexa **, A. Kerschberger *, A. Lohr **, B. Weidlich *

*** Büro fuer energiegerechtes Bauen, Oldenburger Strasse 68 , D-5000 Köln 60, FRG*
**Weidlich Ingenieurgesellschaft mbH, Giesebrechtstrasse 10, D-1000 Berlin 12, FRG*

ABSTRACT

As part of the system-study "Transparent Insulation", new areas for the application and integration of transparent insulation materials (TIM) are investigated, both for old and new buildings.

Depending on the selected material and passive solar system, a number of different facade-constructions arise, each of them creating a distinctive architectural form. Forms must be found which offer technical/constructional solutions for these new materials and at the same time provide for their aesthetic integration into the building. These criteria must be met to satisfy designers, architects, engineers and users.

Examples of glazed facades are shown to illustrate their constructional and formal implications.

INTRODUCTION

Part of a system study on transparent insulation undertaken by the authors deals with the architectural consequences of TIM technology and its effect on the appearance of facades.

Larger buildings, such as multi-family houses using a higher amount of glazed walls, can be related most easily to the familiar office-building with the all-glass facade. (Fig. 1 and 2). Because of this the level of acceptance of TIM technology will be higher in these cases than in single-family housing with its traditional facades.

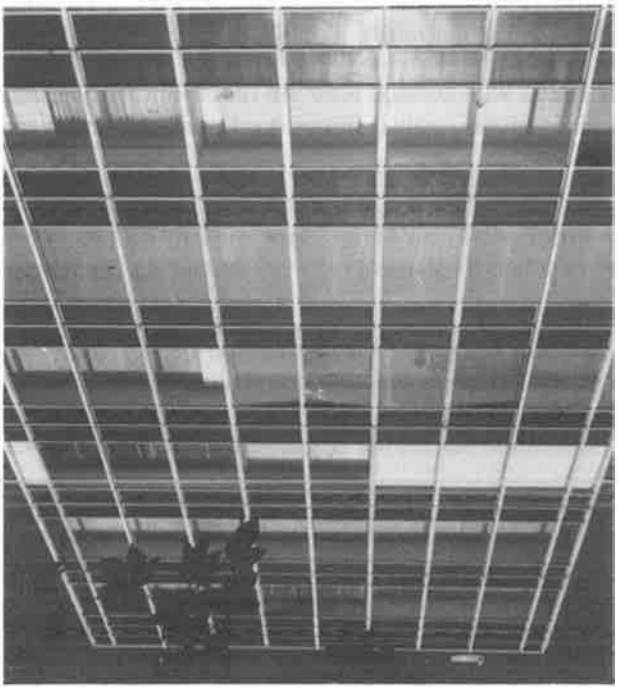


Fig. 1 Facade of an office building in Cologne, FRG

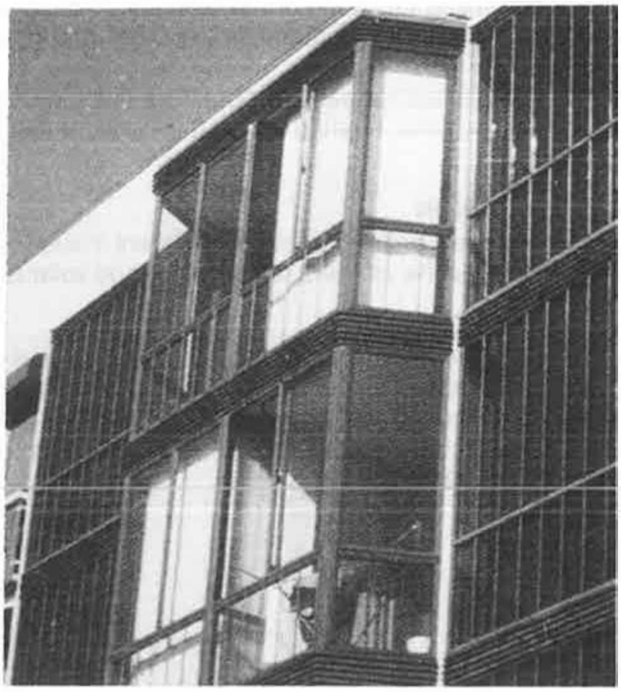


Fig. 2 Solar dwellings in Marostica, Italy (1)

SOLAR WALLS AS HISTORICAL FORE-RUNNERS: A CATALOGUE OF EXAMPLES

The knowledge of examples of solar walls built during recent years provides the designer with a catalogue of various solutions for his own work. Design problems which are analogous to that of TIM technology have been solved in numerous applications, mostly in new dwellings but also in larger buildings (Fig. 3). Among clients and users they were not known very well and therefore were not really accepted. Their first appearances were similar to what we know from recent examples of facades using transparent insulation material (Fig. 4). What can be learned from these cases ?

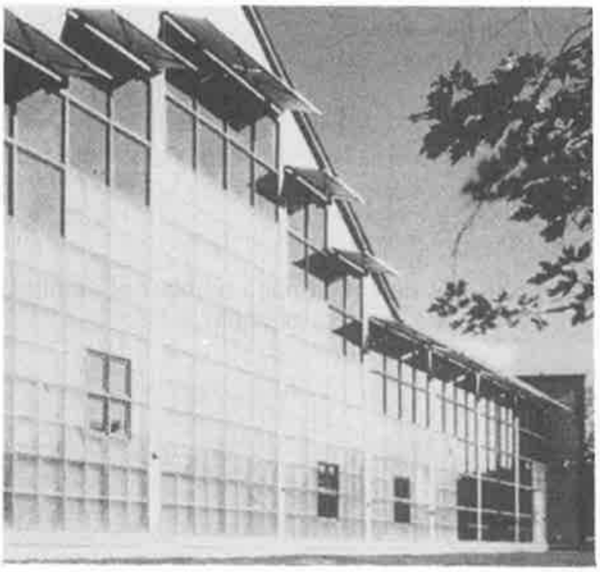


Fig. 3 Trombe wall of a school near Philadelphia, USA

Fig. 4 House in Zaberfeld, FRG, using TIM

A special aesthetic problem is the application of TIM within the existing building stock. The appearance of old buildings will change dramatically. For a certain transitional period designers may use known images for TIM-facades such as the image of traditional Japanese architecture (Fig. 5 and 6).

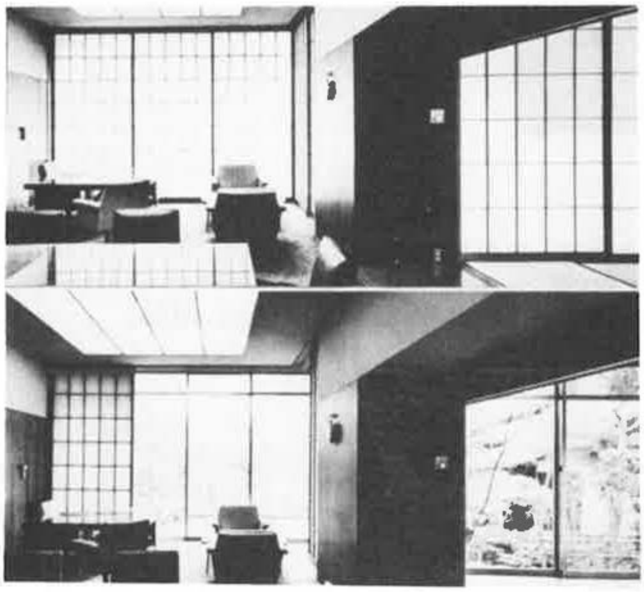


Fig. 5 Kitamura Residence in Kyoto, Japan

Fig. 6 Wellesly Science Center in Massachusetts, USA

PLAYGROUND

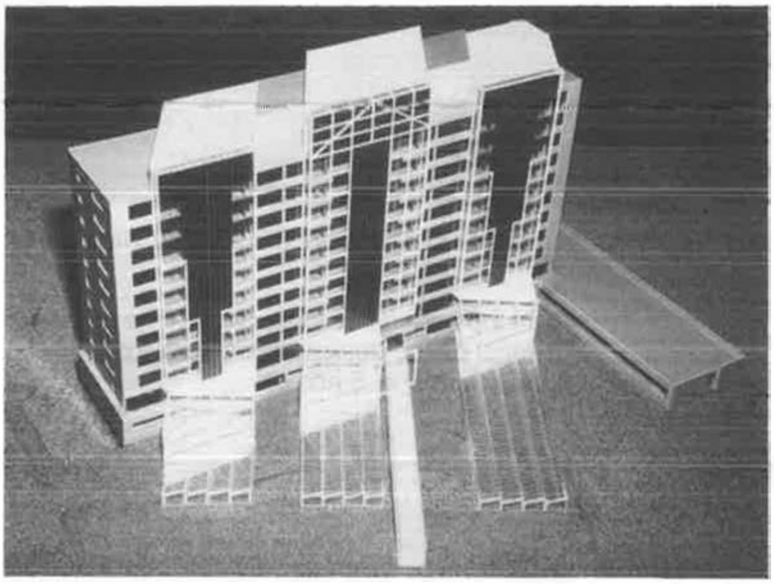
Different levels within the transparent insulation system can be influenced by the designer: this may include:

- the structure in front of the system (such as protection bars)
- the structure and design of shading devices (outside/inside)
- the surface structure of the transparent cover
- the width, depth and profile of the frames
- different forms of mounting (screws, metal sheets)
- the material and texture of the frames
- the arrangement of mullions within the transparent component
- the spacial order of the transparent insulation material

the colour of all components of the transparent insulation system including:

- the shading device
- the frame / mullions
- the transparent cover (may be tinted, printed over)
- the transparent insulation material (in whole or in part)
- glue (like stripes or dots)
- the absorber
- coloured foil inserted between TIM layers

If the designers master these vast amount of possiblities with this new material a number of architecturally appealing TIM buildings will be seen in the future. Will they look like this last example ?



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Application of transparent thermal insulation to existing houses

Disfiguring the facade – or improving its thermal and aesthetic qualities

K. Brandstetter

Lehrstuhl 1 für Baukonstruktion und Entwerfen, Prof. P. Sulzer
Universität Stuttgart, FRG

ABSTRACT

Preliminary studies have been undertaken how to apply transparent thermal insu= lation (TTI) to existing houses within the meaning of architecture. The trial demonstrated, that TTI-components ought to be adaptable in dimensions aswell as in appearance. As sunshades may cause unfortunate alterations of a house's face and as they usually demand extra-costs, the question rose, whether shadeless TTI-systems with a lower solar efficiency wouldn't meet better real needs.

BACKGROUND

TTI had been graphicly applied by Munding I1I to facades of existing houses. Her results have been found to be unsatisfactory from a view-point of architecture (Fig.). It was obvious, that the imperfections were related to the use of large-sized TTI-components and to the facades' partial covering.

PROCEDURE

Anticipating a considered wider investigation, small-scaled TTI-components have been drafted and graphicly applied partly to the same facades, which Munding had used (Fig.) and partly to those of other existing houses (Fig.), which seemed to be typical to a certain Southern-German housing-stock. In addition, inquiries have been undertook with seven house-owners, who showed interest in improving their houses' thermal quality.

RESULTS

General aspects

Conditions are different whether TTI is applied to a building under design or to an existing building:

- a building under design is fairly free in dimens ons and in appearance. TTI-components applied to it, therefore may be rigid in dimensions and in visual quality.

- an existing building is bound in dimensions and in appearance neither allow= ing nor standing much alterations normally. TTI-components therefore ought to be adaptable in dimensions and in visual quality.

As adaptable TTI-components are free to be used with buildings under design too, their development should have priority.

Dimensional adaptibility

Dimensions of existing buildings have deviations even when originally planed in equal sizes. Furthermore, especially dimensions of existing houses are mostly irregular by origin. Hence, the TTI-components must equalize devergencies by adaptation. Thereby, it is important, that the more interesting methods of equa= lization work the best the smaller the components' sizes are. However, the higher rate of (normally-) opaque reveals and joints produced on this way must be seen.

Adaptability in appearance

Especially (small-) houses are not only defined geometrically but also by the perceived appearance within their surroundings. Thereby, the following items must be seen:

- windows are the sole elements with a shiny, reflecting surface defining a house's character predominantly. All other surfaces are lustreless.

- exterior wall-surfaces are either grained, when plastered or patterned, when lined, claded or covered in another way. Thereby, vertical patterns are found more often than horizontal-ones.

- discontinuances in exterior wall-surfaces are simply arranged. Either the upper storey(-s) will differ from ground-storey all around or one facade will differ entirely from the others. Partial coverings surrounded by other surfaces in one facade are rather unknown.

- to sunshade exterior walls unless by trees or creepers was unusual in former times. However, espaliers and balconies did it in some areas apart from their real purposes.

TTI-components therefore should be lustreless in order not to compete with the expressive importance of windows. They should allow the creation of patterns, which harmonize with a house's typical style, and they should be supplemented by opaque versions with a fairly identical look in order to prevent visually discontinuances in one facade as mentioned before.

Sunshades sometimes may be formed like espaliers (Fig.) or established by built-on balconies. In some cases venetians will help, when forming a horizontal pattern. However, sunshades cause the main problems from a view-point of keep= ing a house's face at least essentially.

INQUIRIES

Though being interested, all seven inquired house-owners were rather reserved to energy-saving-rates. Apparently, they have had bad experience in past. Five of seven just compared prices of performance and the rest pointed out, that the extra-costs should pay within some five years the latest. Six owners preferred solutions, which could be done by do-it-yourself-execution. However, in two of those cases the preference might have been influenced just by sympathy to the distinct solution.

CONCLUSIONS

TTI's application must not uglify existing houses. It is possible to keep a house's distinct appearance - at least essentially - by use of small-sized com= ponents, which alsowill have the better chance in practice because of their better fit. Though physicists by right tend to improve TTI's solar efficiency by using latest technical devices, it is obvious, that in practice simple solutions are requested. It raises the question, whether it wouldn't be more reasonable to improve thickness of the thermal-insulating-course even by loosing a bit of solar efficiency in favour to save both: sunshadings and costs. In fact, a sort of TTI-plaster would be ideal.

In summing-up, it can be stated, that applying TTI to existing houses is lastly but a matter of balance between solar efficiency, esthetical demands, perfor= mance and price.

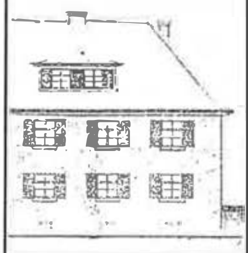
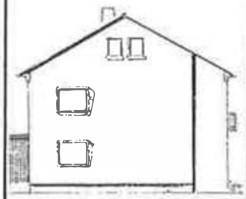
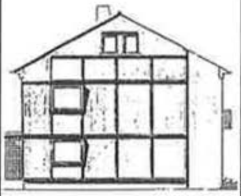
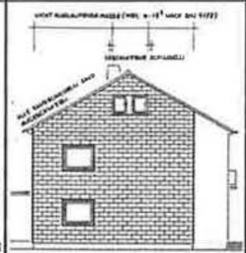
Facade of a house from	status quo	Trial of TTI-application by Munding	the author	a student
the early thirties				
the early fifties				
the early sixties				

Fig.: Diagram showing in an extract some uf the used test-facades in status quo and with TTI-applications from different persons.

I1I Munding, M., "Anwendung der transparenten Wärmedämmung im Altbau unter Be= rücksichtigung architektonischer und energetischer Gesichtspunkte", diploma thesis presented at Stuttgart-University, Dept. of Civil Engineering;pub= lished by Fraunhofer-Institut für Bauphysik (IBP), Stuttgart.

Case studies on the practical applicability of transparent thermal insulation to different types of residential estates in Stuttgart

K. Bertsch, M. Beck

Fraunhofer Institute of Building Physics Department of Heat/Climate
(Dir. Prof. Dr.-Ing. habil. K. Gertis)
Nobelstrasse 12, D-7000 Stuttgart 80, FRG

ABSTRACT

There are several approaches conceivable to assess the potential for applying transparent thermal insulation systems to the stock of existing buildings. In the present study it has been attempted to give an outline of this potential by examining different types of settlement structures comprising a large number of similar and typical constructions with regard to their suitability for retrofitting. Possible applications are discussed for specified examples, namely for settlements and suburban districts which have been established in the urban area of Stuttgart since the turn of the century. It was found that particularly suburban districts that were developed in the post world war II era provide a large potential of applications which is however partially subject to certain restrictions.

INTRODUCTION

Since the present study concentrates solely on examining existing buildings with regard to their suitability for being retrofitted with transparent thermal insulating systems, it does not provide solutions involving changes in the building's structure or design. Accordingly, economical and energetic analyses for specific applications have not been considered, although these aspects should of course be borne in mind, too. The study is based on applications of prefabricated facade units. As all of the transparent insulating materials known to date need some sort of weather protection, it is obvious to employ well-established structural principles tried and tested in glass front or metal facade construction, and arranging an integrated shading device does not pose an additional problem, either.

From an architect's point of view, there are no fundamental hinderances to applying transparent thermal insulation materials to new buildings, since these insulating systems can be integrated in the building concept as creative design elements of their own right. Due to stagnation in the building sector, the number of new buildings to be completed is reclining. Hence, a much larger field of application is opened up by renovating and retrofitting existing buildings. In fact, this field of application still holds a lot of interesting and promising opportunities. When applying relatively large prefabricated components to an old building, interferences with its architectural features have to be anticipated, because the additional installation of transparent elements is liable to change the characteristic look of a building or even to adversely affect the optical impression of adjacent structures or entire neighbourhood units.

Case studies

As the volume of this application potential cannot simply be estimated on the basis of individual buildings or classification criteria such as e.g. single-family house, row-house (terraced house), low-rise building or high-rise block it was decided to select settlement structures instead. On account of their great variety and their large number of buildings with common characteristics these structures appear to provide a much more reliable basis.

Eisenbahnerdörfle

In the 19th century, block structures were the prevailing type of urban development concept. The present quarter was built from 1890 to 1930. The street fronts of the oldest houses are adorned with rich red brick ornaments. Hence, transparent thermal insulations of any type would sifnificantly change the characteristic look of the street; aspects of preservation of monuments would even forbid any application at all. The buildings that were raised after 1910 are simpler in design; here, the visual impression will not necessarily have to change in case transparent insulation is applied to the continuous strip windows or strip parapets. Finally, houses dating from the last building period in the 1920s do not have any complementary ornamentation. They are rendered simply and the regular intervals between the windows would even permit to mount prefabricated units.

Despite relatively large internal court yards, the solar radiation incident on the exterior walls is considerably reduced in winter. The south side of the yard will have 0 - 4 hours of sun daily and the street front up to 3 hours since the area is too densely built. On account of their design, the rear sides of the old buildings are not suited for an application of insulation units; for these particular requirements, novel insulation systems such as small format units or transparent plaster materials should be developed.

Stuttgart Rot

After the first world war, the concept of linear building (row units) came to the fore in urban development. This type of building concept was intended to provide equal quality for all residential buildings, namely equal orientation, equal conditions for daylighting and insolation. In order to ensure that all flats would get their share of sunlight every day, buildings were mainly oriented towards east and west, i.e. the building axis had a north/south orientation. The tendency towards linear building was still kept for some time after the second world war. In the wake of World War II, housing shortage and buildings destroyed by war called for immediate action. The quarter of Rot was designed for 20 000 to 25 000 inhabitants and was built from 1949 to 1959. This estate comprises varied types of buildings with two to five storeys. Conditions for insolation are favourable and accordingly for transparent thermal insulation as well. The building materials that were used for enclosing walls, such as rubble concrete, bricks and cavity bricks for instance are suited for economical applications. The level of insulation has to be raised, anyway. The great number of equal buildings permits cost-controlling normal factory production. Moreover, the buildings' architecural design could be further improved by means of transparent insulation.

Freiberg I

Compared to Rot, the quarter of Freiberg is distinguished by its type of construction. Here, floor plans are generally more differenciated, buildings are more cubic and balconies are inserted into the massing in front of the living rooms. Rot had still been built in a traditional way, but from the sixties onwards prefabricated construction methods using large components were gaining more and more ground. External building parts were provided with a thermal insulation layer inserted between the outer concrete leaf and the structural inner leaf. Due to concrete corrosion some buildings already require renovation. This type of sandwich construction particularly encourages transparent thermal insulations as there is no need for solar protection. The outer concrete leaf heats up with incident sunlight and prevents heat from flowing to the outside. Accordingly, the central insulation layer prevents the inner leaf from overheating. The architectural impression created by the large concrete units can be saved and the building surfaces can be adapted to a more recent design by selecting lightly coloured obscure glazing. Unfortunately, the location of the buildings on a slight northern slope has a slightly adverse effect on the incidence of sunlight.

Freiberg II

This example of another town quarter which was planned around the same time as Freiberg I, shows a new tendency. As it was feared that an ever increasing demand for housing would destroy more and more of the open country, a new concept was created. Instead of arranging flats horizontally, they were now arranged vertically above each other in high-rise buildings. Between these high-rise buildings that are situated in a staggered arrangement in order to ensure good insolation conditions there are spatious green areas. Certainly it was considered that a concentration of so many flats might have a negative psychological influence on the inhabitants. For this reason, the flats were staggered against each other to create individual spaces sheltered from neighbours. In terms of building physics this meant a very unfavourable enlargement of the external surfaces, the staggered arrangement actually has the effect of a cooling rib. Since these buildings were also constructed with prefabricated sandwich units, transparent thermal insulation layers can compensate for these adverse effects and contribute considerably to saving energy.

SUMMARY

As is clearly demonstrated by this study, there is an immense potential for the application of transparent insulations, particularly in post-WWII housing estates. On the other hand, there are also housing estates or special types of buildings where the building style and the absence of sun restrict the use of such elements. Besides, there are some constructions where the utilization of transparent elements is excluded from the start on grounds of preservation of historical monuments.

The examples considered in this paper are not restricted to Stuttgart; they can be transferred to other European countries with similar conditions and historical developments.

Market potential of transparent insulation for housing in the UK

P.L.M. Hurd, A. Pollock, L.F. Jesch

Energy Engineering (Birmingham) Ltd.
192 Franklin Road, Birmingham B30 2HE, UK

ABSTRACT

The market for transparent insulation technology for housing in the UK is discussed on the basis of trends in housing provision. About 7 million houses in the UK do not have cavity walls and could potentially benefit from the technology. In new-built housing, public sector housing provision has decreased dramatically so it is the private sector who must be convinced. Given the trend to segment the housing market, it would seem that the newly retired are the fastest growing and most appropriate customers for new houses using transparent insulation technology.

INTRODUCTION

At the first Workshop for Transparent Insulation in Freiburg, F.R.G. in 1986, A. Goetzberger and M. Rommel (1) have outlined the principle of the heating of buildings by the application of external transparent insulation on massive house wall. They have reported on a four-year test period of a single family house in Freiburg, suggesting that the potential energy saving in comparison to a conventional house is in the range of 80%. Trials in Birmingham in the UK reported elsewhere in this meeting support these findings.

This paper complements the examination of technical feasibility by looking at the potential opportunities and problems in the marketing of transparent insulation for use in housing in the United Kingdom.

Five major sectors of buildings where applications are possible may be identified: commercial, industrial, public, agricultural and residential (housing) .

Our approach is to overview current trends and to identify growth areas in the UK within each sector. Many factors must then be taken into account to determine the appropriateness of transparent insulation to particular markets. Each sector demands separate detailed analysis, but for the purposes of this paper No. 5, housing, will be examined in detail. Within the housing sector, the potential applications for transparent insulation falls within two areas:

1. Retrofitting of older buildings without cavity wall insulation
2. New houses

RETROFITTING

In the UK, over 85% of the housing stock which pre-dates the end of the First World War was built without cavity wall insulation (2). Between then and 1939 just less than half the houses built were without cavity walls. By the mid- 80's this figure is down to 3.1% mostly accounted for by timber frame dwellings. Figure 1 illustrates this shift in building practice. However it is still the case that approximately one third of houses in the UK are without cavity walls: a total of 7,250,000 buildings which could benefit from the increased comfort and energy savings which external transparent insulation could provide.

It is probable that the tapping of this market will depend on the development of appropriate standard panels. In some cases the aesthetics will be an important issue. In others an effective solution to the problems experienced with cold and damp may outweigh the feeling about appearances. In most cases however the central issue will be the capital funding of the retrofit.

NEW-BUILT HOUSING

As shown in Fig. 2, the housing stock in the United Kingdom totalled more than 22 million dwelllings in 1984, more than one and a half times the figure of a little more than 14 million in 1951 (3). Within the last decade political changes have caused a large fall in public provision of housing. This has resulted in a net decrease in the annual number of houses built, illustrated (4) in Figure 3, and the impetus for growth has swung dramatically to the private sector. The last ten years have also seen a considerable rise in personal income and in disposable income (5). Building cost rises (3) are illustrated in Figure 5.

Judging from current trends it would seem that if transparent insulation technology is to gain a foothold in the housing market in the UK, then it is the builders, developers and consumers who must be convinced of its benefits.

MARKET TARGETING IN THE HOUSE-BUILDING BUSINESS

It is now common practice for builders to target their developments at particular sections of the market. Homes are built specificaly for groups such as the "first-time-buyers" or the "second-time-around buyer". The differences are reflected in the amenities and price of the houses. It would seem that the value of transparent insulation in increased comfort, reduced energy costs and increased autonomy would be best appreciated by 'second-time' house-owners. They will have first-hand experience of the costs of energy and the

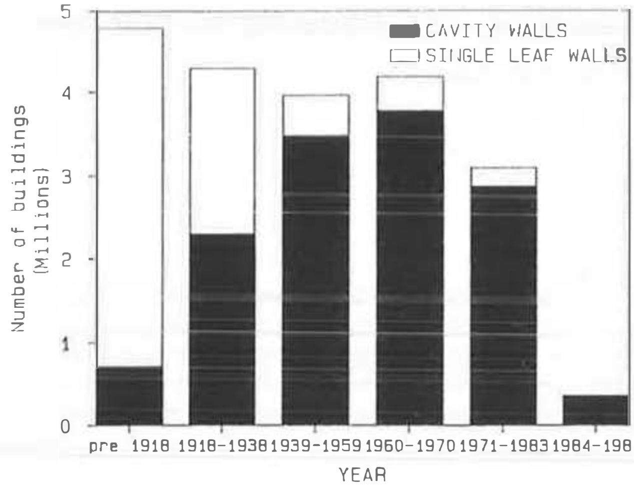


Fig. 1 Cavity walls in houses in the UK

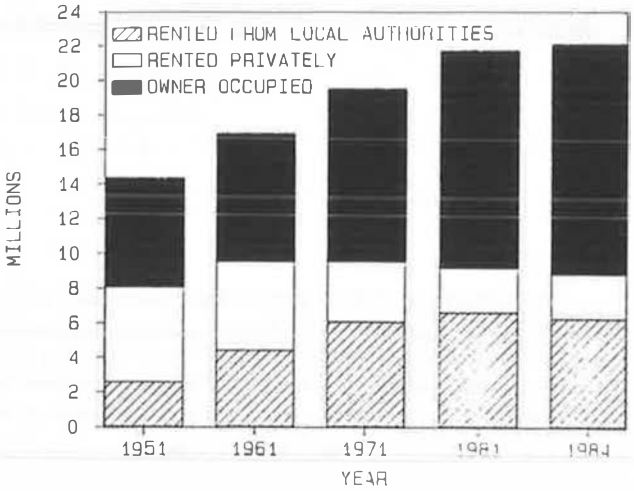


Fig. 2 The housing stock in the UK: 1951 – 1984

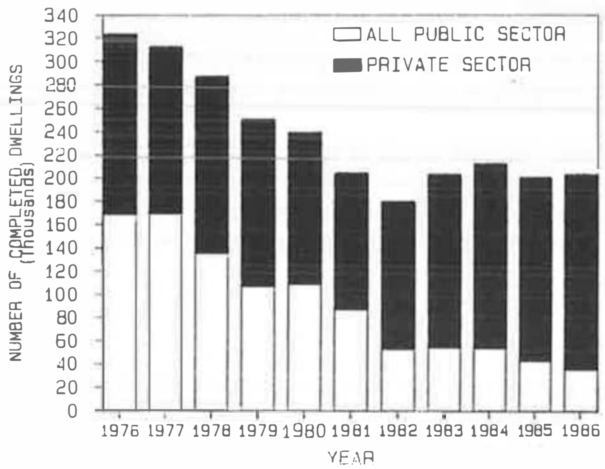


Fig. 3 Annual housing provision in the UK: 1976 – 1986

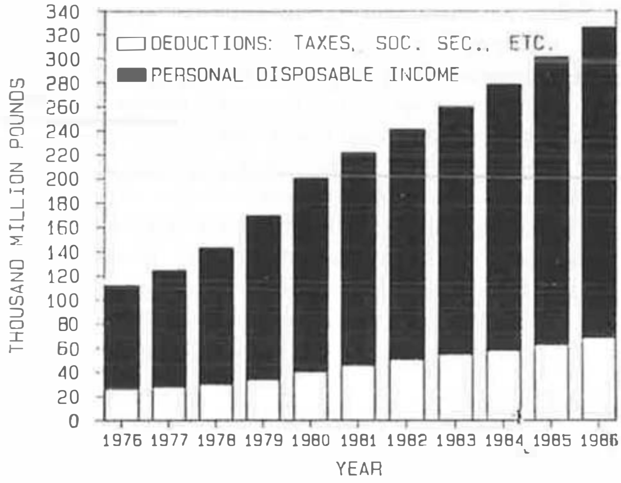


Fig. 4 Personal disposable income in the UK: 1976 – 1986

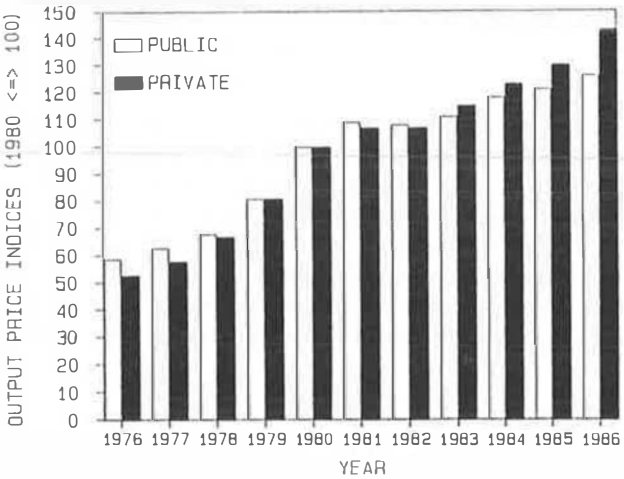


Fig. 5 Construction cost and price indices in the UK 1976 – 1986

At age	Male	Female
0	71.3	77.4
65	13.2	17.3
70	10.3	13.7
75	7.9	10.5
80	6.0	7.8
85	4.7	5.8

Fig. 6 Life expectancy in the UK: 1981 – 83

value of comfort - and are most likely to be able to meet the initial extra capital outlay. There is however a market sector which may be even more attracted to the use of transparent insulation technology in their new homes: the rapidly growing group of the newly retired.

HOUSING FOR THE ELDERLY

The most significant new market for housing is the increasing number of elderly in our society. Until very recently 'housing for the elderly' signified an old peoples home: usually a publicly funded facility for old people who were no longer capable of living independently. Today a whole new industry is growing up around provision for the needs of the increasing number of relatively well- off people at the age of retirement and afterwards. The 1950's and 60's saw the birth of the teenager: today's media have almost finished with the yuppie "young, upwarldy-mobile professionals", and are now proclaiming the birth of the "glam": "Greying, leisured, affluent, married". Life expectancy in the 1980's is illustrated in Figure 6.

In fact 1500 people in Britain reach their 65th birthday every day. More than half a million will do so this year. Of those who are 65 today, men will live on average another 14 years, and women another 18 years.

Within this decade, the implications of these figures for the building industry have changed enormously. The existence of sheltered housing, usually for rent, is now established. In a report prepared by the University of Surrey in 1986 for The Housing Research Foundation (4), it was estimated that 300,000 sheltered housing units were in existence by the end of 1985, and that the annual increase for this type of accommodation was 20 – 24,000. It is however the growth in privately owned, purpose-built retirement homes which is most striking. Before 1983 fewer than 2,500 such units were built, while by 1985 this number had increased to 31,000. Buyers of these homes are looking for both accommodation which is appropriate to their needs, and which is a sound investment of their money.

Many of these people will be living in houses which are too large for them now that their children have grown up. Such people are in increasing numbers realising the capital from their large family-sized homes and are selling out. They use part of the proceeds of the sale in purchasing a new home and invest the rest to provide an income to supplement their pension or savings. These elderly capital-rich house-purchasers are willing to invest in capital intensive technologies so long as that this will result in comfortable conditions and later economies in maintenance and heating costs. "Prices are high, but so are standards" is the comment of a national newspaper in relation to this area. (6)

If ten percent of people buy a new house on their 65th birthday and 10% of that 10% clad their new house with transparent insulation, this would result in a sale of 5000 passive solar energy projects per year.

It must be borne in mind that that this market will be a cautious one: consumers making the final large investment of their lives will want proof of a sound and well-developed technology. However, a new wave of quality-consciousness, spear-headed by the requirements of the relatively affluent elderly, is now afoot. At the Centre for Applied Gerontology at the University of Birmingham a strong programme is underway to influence product-design and marketing decsions in favour of the elderly.With the widespread adoption of a motto, not only this market, but also the entire home-building industry may be opened up.

Using the logo of an owl as a seal of product approval, the staff insist:

"Design for the old and you include the young –
Design for the young and you exclude the old"

This motto will certainly be one to see us into the next decade when today's fledgling transparent insulation technology – and its market – will learn to fly !

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A low energy air heated solar house with transparent insulation

L.F. Jesch

Energy Engineering (Birmingham) Ltd.
192 Franklin Rd., Birmingham B30 2HE, UK

ABSTRACT

The design of a single family, low energy, air heated solar house with transparent insulation has been completed. To be built in Birmingham, UK it has 91 m^2 floor space in a split level arrangement. In the Midlands climate the house requires no auxiliary heating but it needs cooling during a portion of the summer. The cooling is achieved by variable air change rate ventilation The method of stepwise parametric optimisation was used for the preliminary design using the f-load computer simulation program. The detailed design, based on the Transparent Insulation Computer Aided Design TICAD program is now being implemented.

DESIGN

Based on long term average climatic data the monthly net solar gain for the year was determined. This was augmented by internal incidental gains from cooking, electrical equipment and people. The total heat gain from all sources was balanced against heat loss through the envelope of the house and against heat loss due to infiltration.

By using transparent insulation (1) and by varying the size and insulation characteristics of the building elements it was possible to achieve a "zero heating" requirement design solution at the expense of some cooling in the summer. The design met the original specifications of the building and required only standard material most of which is readily available locally.

Part of the roof has solar air collectors which are made with transparent insulation covers, the other part has transparent insulation for direct solar gain. The east, south and west facing walls are also fitted with transparent insulation and passive solar heating provides most of the heating load. Movable insulation is provided by shutters which reduce the night time U values and increase the privacy and security of the building.

Solar heated air from the roof collectors is passed through two parallel pebble bed heat stores positioned on either side of the stairs in the center of the house and each being two story high. This and the high density walls together with the concrete floor provide a very large effective thermal mass to guarantee that indoor temperature variations will be minimised.

The north end of the building is partly earth sheltered and is well insulated. The floor of the living room is floated on 100 mm polystyrene insulation. All windows are triple glazed and equipped with insulating shutters.

SIMULATION

The preliminary design used a simple strategy of stepwise parametric optimisation. The parametric runs covered different allowable relative humidity levels and different day and night room temperatures during both the heating and cooling seasons. Minimum operating cost was the objective to reach.

By varying the ventilation rates (more in the summer) infiltration could control the comfort in the house. In practice most people would open windows and use natural or forced ventalation (2) particularly when the outside temperature was below the desired room temperature. Thus using the ambient temperature for cooling reduces (3) the number of cooling degree-days.

The quasi optimal design resulted in zero annual total heating requirement and 983 kWh annual total cooling requirement, which was considered small for Birmingham conditions if a slight rise in summer indoor temperature is accepted for a short period of time. The variable rate air cooling is designed to match the cooling load requirement. The building has low natural infiltration.

The cost of building the solar heated house was analysed and found to be competitive with conventional houses which use gas or oil fired central heating systems. The fan forced air cooling is extremly economical and cost effective.

BUILDING DESCRIPTION

The house is at 52.4 degrees northern latitude, the yearly average ambient air temperature is 10.2 ^oC and the annual total horizontal solar radiation is 960 kWh/m^2. The building as shown on Fig. 1. is rectangular and facing due south. The living room (L) has a glazed south wall, behind it are the dining room (D) and kitchen (K) facing east and west respectively. As the building stands on a sloping ground part of the north end of the ground floor is earth protected.

The bedrooms (B) and the bathroom are on the upper floor on the north side of the building in a split level arrangement, not on top of the living room. The stairs are between the dining room and the kitchen lead-

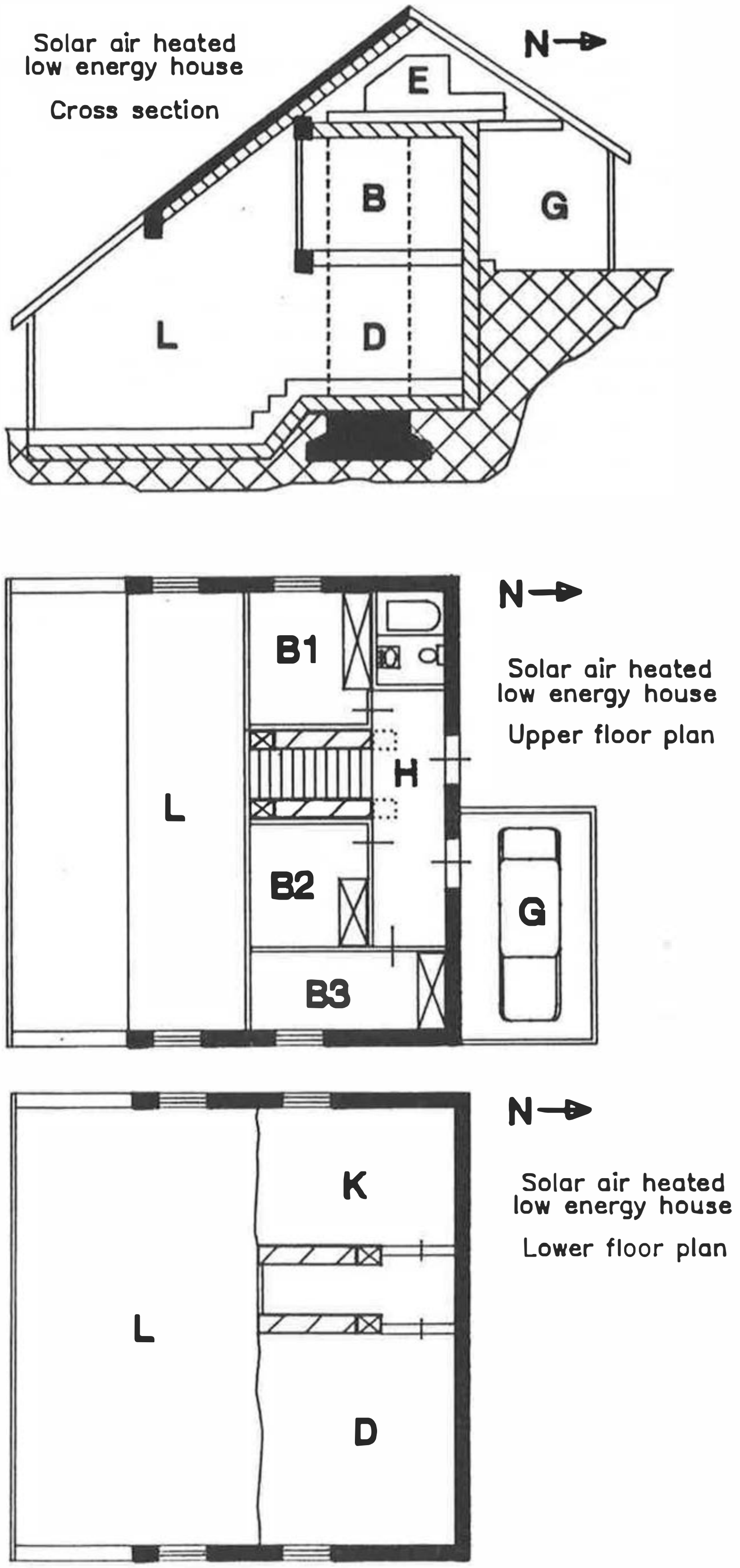

Fig.1 Cross section and floor plans of the building.

Legend: B bedrooms, D dining room, E energy equipment, G garage,
H hall, K kitchen, L living room, N north.

ing from the living room to the upper level between two structures which separate them from adjacent spaces. These structures contain the pebble bed heat store.

The south facing sloping roof has solar air collectors near the apex and a glazed lower portion which joins the large window walls. Part of the design process concentrated on finding the right balance of areas and positions between glass and non transparent walls and roof. The more glass is used the less heating is needed but at the expense of summer cooling.

NATURAL LIGHTING

Using transparent insulation enabled the control of heat passage in and out of the house and improved the design by combining heat and light inside the house. The lower, southern end of the living room has much glass on three sides and transparent insulation below the glass on the roof. To avoid glare movable and adjustable shutters and louvers are used for shading, but during daytime the room will be airy and light and those in it will feel that they are in a much larger space then in reality they are.

TRANSPARENT INSULATION

The lower part of the roof, the air collectors, all east, south and west facing exposed walls have transparent insulation on the outside, supported by metal frame or wooden frame and covered by glass. Only windows and the large patio door are not covered with transparent insulation.

CONCLUSION

The limits of infiltration control strategy are recognised especially when the ambient temperature is close to room temperature or the ambient relative humidity is high. Large air flow rates can increase air velocities beyond comfortable (4) levels. In such cases it is common to use an enthalpy controller which operates the ventilation system when the enthalpy of the outside air is low enough to meet the requirements of both the latent and sensible cooling loads.

A house can be heated totally by solar energy and by normal incidental gains in a northern climate if transparent insulation is used in a carefully designed manner. The total cost of the house is competitive with similar size buildings when low energy operating costs are taken into account.

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Retrofit of an old 8 family house by transparent wall insulation

E. Bollin

Fraunhofer-Institut für Solare Energiesysteme
Oltmannsstrasse 22, D-7800 Freiburg, FRG

ABSTRACT

Retrofitting of buildings erected 30–40 years ago in Germany has a high potential for transparent insulation. Suppositions for this application will be specified. The state of the art of the currently undertaken pilot plant SONNENÄCKERWEG FREIBURG will show simulation results, architectural sketches and prototyp facade design.

RETROFITTING IN THE CITY OF FREIBURG

The pilot plant "Sonnenäckerweg" is situated in a residential quarter erected in the 50th as a low cost housing construction by the Siedlungsgesellschaft Freiburg. In this residential quarter the dominant construction is a two storey house for one or more families. 45% of the buildings which belong to the Siedlungsgesellschaft Freiburg are elder constructions and don't have a central heating system. Most of them are in the same state as the building of the Sonnenäckerweg. The average housing space of about 48m^2 is typical for Freiburg, which has more than 50% single households. The Sonnenäckerweg pilot plant should give an exmple how to retrofit those buildings with transparent insulation materials. The part of the building including the living and sleeping rooms is orientated to south-east (Figure 4).
The construction in detail:

outside walls:	30 cm brick (λ = 0,55 W/mk; ρ cp = 1200 kJ/m^{3}k)
ceiling:	concret
window:	single glass
insulation:	no
heating system:	single stove heating

The retrofit of the Sonnenäckerweg is part of the "Retrofit and Modernisation Programme" of the Siedlungsgesellschaft Freiburg, which has a 4 year budget of 80 Million DM for 1.837 dwellings.
This retrofit programme includes the following steps:
- double glass windows
- insulation of roof and cellar
- electric and sanitation installations
- retrofit of the roof, chimney and window shutters

The insulation of the outside walls is not included.
The specific cost of this retrofitting measures are about 450.- DM/m^2 . If insulation of the outside walls with opake material is included, the specific cost will increase up to 534,- DM/m^2.

FIVE SUPPOSITIONS FOR RETROFIT WITH TRANSPARENT MATERIAL

The following suppositions are necessary for the application of transparent insulation materials for retrofitting :

- For to have a good efficiency with this solar application the wall should have a high heat conductivity
- For to use the wall as a puffer for solar heating a high storage capacity is necessary.
- For to absorb a maximum of solar radiation we need a nearly detached building.
- For to get a benefit for the investment cost an existing single stove heating system is a necessary supposition.
- Transparent wall insulation should be a part of a total energy retrofit programm.

OBJECTS OF THE DEVELOPMENT OF TRANSPARENT WALL INSULATION FACADES FOR RETROFIT

In figure 1 the principle of the transparent wall insulation facade is shown. To fix the transparent insulation material we need a frame construction with low heat conductivity.The regulation of the heatflow in this element is done by a variable shutter system. An outside glassing protects the construction against the weather. At the Institut für Solare Energiesyteme of the Fraunhofer-Gesellschaft we have 5 year experience with roller blind installed between the two glaspanes of compound double glass windows (figure 2). With this construction the u-value of a conventional compound double window could be reduced from 2.6 to 1 W/m^2k with the blind closed.

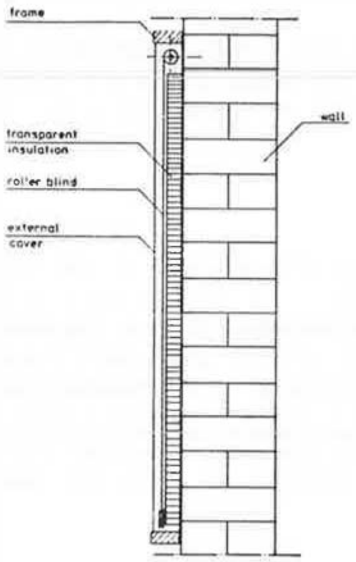


Figure 1: principle of the transparent wall insulation

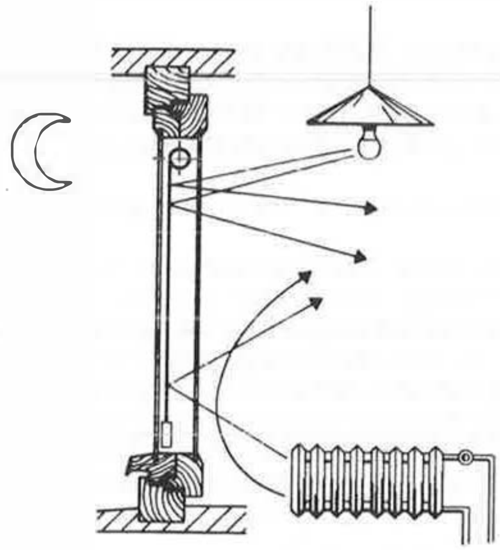


Figure 2: compound double glass window with integrated roller blind

With regard to an easy handling and low investment cost, we fixed the following objects of the development:

- a compact construction with a wood frame to which the insulation material and the roller blind could be attended.
- prefabricated moduls
- low installation expenditures at the site
- maintenance should be easy to handle
- appealing appearance
- high weather resistance
- open construction for water vapour diffusion.

With regard to these objects and with the know-how of the window construction we sketched a wood-metal construction. Figure 3 shows a vertical section of this modul. To adapt the modul to the predictions of the architecture the sizes of the frame could be modified. Maximum lenght and width are limited by the measures of the roller blind construction. For such a module a length of 2.5m and a width of 1.5m is typical.

SIMULATION RESULTS FOR THE SONNENÄCKERWEG 8 FAMILY HOUSE

With the help of the simulation programme "Suncode" the Institut für Bauphysik of the Fraunhofer-Gesellschaft did some simulation of the yearly heat consumption and maximum heat requirement for different insulation standards. Table 1 shows the results of this calculation, where as for point

2) to 5) a u-value of the roof of 0.3 W/m^2k and 0.55 W/m^2k for the cellar ceiling is predicted.

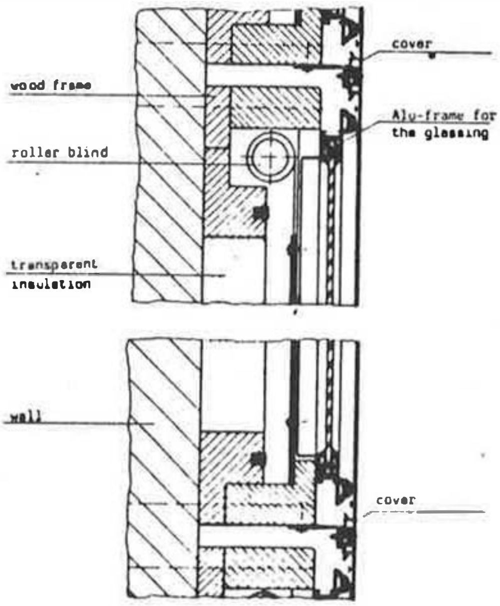


Figure 3: vertical section of the transparent facade module

Standards	yearly heat consumption (MWh)	maximum heat requirement (kW)
1) existing building construction	90 MWh	56 kW
2) opake insulation with 6 cm Styropor u - window = 2,6 W/m^2k	40 MWh	27 kW
3) opake insulation with 6 cm Styropor u - window/day = 1,0 W/m^2k u - window/night = 2,6 W/m^2k	30 MWh	27 kW
4) transparent wall insulation all around the building u - window/day = 1,0 W/m^2k u - window/night = 2,6 W/m^2k	16 MWh	24 kW
5) transparent wall insulation at the SE and SW facade, 10 cm Styropor at the NE and NW facade u - window/day = 1,0 W/m^2k u - window/night = 2,6 W/m^2k	17 MWh	25 kW

Table 1: Simulation results for the 8 family house at Sonnenäckerweg

Based on this results the following retrofit steps for the Sonnenäckerweg project are fixed:

- transparent insulation of the south-east and the sout-west facade with 10cm honeycomb material
- opake insulation of the north-east and north-west facade with 10cm PUR panels
- 10cm PUR panels covered with aluminium for the insulation of the cellar ceiling
- compound double glass windows with integrated roller blind

FACADE DESIGN

Architects participate in this project since the beginning. Figure 4 gives an impression how transparent insulated facades could embellish the appearence of this building.

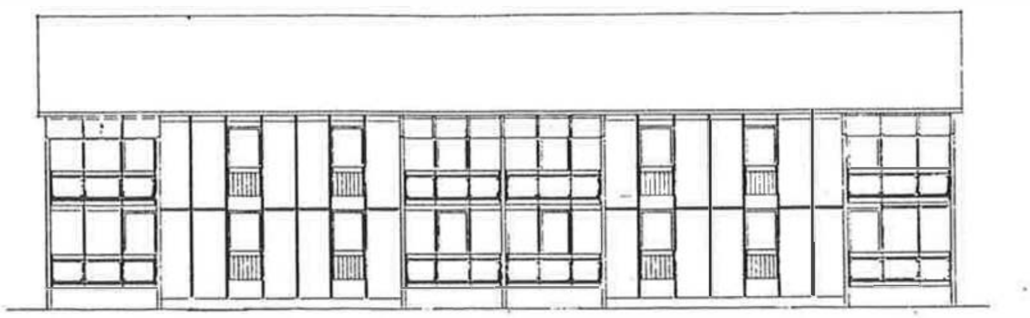


Figure 4: View of the south-east facade of the 8 family house at the Sonnenäckerweg, sketched by the architect R. Disch, Freiburg

Self-sufficient Solar House 2000

A. Goetzberger, W. Stahl

Fraunhofer-Institut für Solare Energiesysteme
Oltmannsstr. 22 D-7800 Freiburg FRG

ABSTRACT

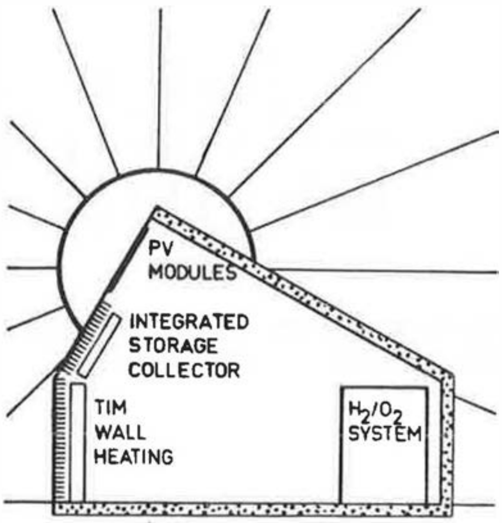
The concept of a building totally independent of any other energy source than solar radiation is presently being developed at our institute. Thermal conversion of solar energy by means of "Transparent Insulation Materials" provides energy for space heating and "Domestic Hot Water". Photovoltaic cells drive a closed loop Hydrogen/Oxygen System for high exergy energy demands. Pressurized gas-containers are used for compensating differences in solar supply and demand. For periods with very low solar input the H_2/O_2-System also serves as back up for heating purposes.

INTRODUCTION

Solar energy research and the application of already commercially available solar energy systems is extremely important for today and for our future. Exhaustible fossil fuels, exponentially increasing carbon-dioxid content of the earth's atmosphere, poisoning of environment and the risks of nuclear technologies strongly support solar energy as a long-term energy source.

The very high energy consumption of so-called industrialized countries is to almost 50 % due to Space Heating (SH) and Domestic Hot Water (DHW) in buildings. A family living in a typical residence in a European country consumes 30000 kWh per year. The solar input onto the residence area of 100 m^2 is 100000 kWh per year.

The aim of "Self-sufficient Solar House 2000" (SSSH 2000) is to show that it is possible to meet all the residential energy needs by solar radiation falling onto the surface of the house without any fossil back up and without electricity connection to the grid. The house will be designed following passive solar architectural rules.



SSSH 2000 - main solar components

TIM

Transparent Insulation Materials (TIM) are subject of various research activities in our institute. Theoretical and experimental investigations have led to a deeper understanding of the materials. First applications show fascinating results. Flat plate collectors reach the same efficiencies as vacuum tube collectors, box type solar cookers have stagnation temperatures of 200°C, solutions for seasonal storage are expected.

HEAT

More than five years ago first experiments with transparently insulated walls for SH purpose were carried out in Freiburg. These experiments have shown that the Trombe concept can be dramatically improved by TIM. Today TIM-wall heating-systems with u-values below 1 W/m^2K show positive heat balances, e.g. the wall is a heat source contributing to the overall SH demand. Heat flux regulation systems are needed for overheating protection. Concepts of using poor TIM without regulation are disadvantageous due to low heat input during heating season.

Work has started to design the TIM-wall heating-system for the SSSH 2000. Existing simulation programs (ESP, SIM-HAUS) are being changed for TIM applications; new programs are written. Contributions of wall heating to air exchange heat demand and system optimizations have to be investigated. Decisions between windows, wall heating and opaque insulation depending on orientation are possible with the computer simulation programs.

For DHW the Integrated Storage Collector (ISC) will probable be used. The ISC is superior than conventional systems due to operation without heat exchanger. This is possible because transparent insulation and high thermal mass prevent freezing. Solar fractions of 90 % are calculated for optimized systems.

The first simulations of the remaining total heat demand of the SSSH 2000 end up with values of 9 Wh per m^2 heated living area and heat degree days. Possibilities of distribution, regulation and recovering of heat are not yet included in this value. In using such systems we expect significant further decrease.

The heating system for the SSSH 2000 is based on more or less commercially available components. The almost negligible heat demand could be met by conventional energy sources. With these systems the SSSH 2000 already represents a very valuable demonstration of solar energy applications for decreasing dependences on fossil and nuclear sources of energy.

HYDROGEN/OXYGEN SYSTEM

Beside low temperature heat energy with high exergy content for cooking, lighting, communication and mechanic power is needed. Solar generated H_2 and O_2 are gases capable to meet these demands. H_2 and O_2 can be stored effectively with high energy density and this is necessary for self-sufficiency. Comparable battery systems are expected to be significantly more expensive than this gas system.

The H_2/O_2-System is developed as a closed system without any environmental influences. The electric power generated by a photovoltaic array is fed into an electrolyser. H_2 and O_2 are stored in separate gas-containers. Catalytic reactors are adjustable from low to high temperature heat demands and therefore suited best for cooking. A fuel cell can produce electricity. For short time storage and equalization of PV input a small lead-acid battery capacity is considered. With a DC/AC inverter and electronic controls a 220 V AC house grid will supply new energy saving electric devices. Because of the low remaining SH and DHW heat demand this demand can also be covered by the H_2/O_2-System.

CONCLUSIONS

TIM and H_2/O_2-System are the basis for building houses without connection to the electric grid and without fossil fuel consumption. With the "Self-sufficient Solar House 2000" it will be demonstrated that also in European climates solar radiation has the potential for substituting fossil and nuclear energy.

The project is a further step towards application of TIM, and is needed for experimental verification of the decrease of heat demand. It is also very valuable for demonstrating applications of solar energy systems and can therefore serve as a further step in solving the energy problem. After clarification of financial support the project is expected to start in 1988, and construction is expected to be finished in not more than 4 years.

ACKNOWLEDGEMENT

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CONCLUSION

Dr. L. F. Jesch

Energy Engineering (Birmingham) Ltd.
192 Franklin Road
Birmingham, B30 2HE, UK

The development of a convection suppressant material with high transmissivity is the starting point for a new technology with many potential applications. The 1988 Workshop – the second in the series – marked a significant point in the evolution of this technology.

Intensive basic research is the natural and necessary first step in establishing any new technology: materials development is the second. In 1986 the preoccupation of the transparent insulation community was to advance basic research and development and the papers presented indicated this clearly.

In the 1988 workshop new interests were added: we are now thinking of the systems and components which use those materials produced by R&D. We have also started to think about the future needs of design, so simulation papers were presented.

Particular attention was paid to the potential applications for transparent insulation in buildings. At a time when the benefits of passive solar architecture are becoming universally acknowledged and accepted, it would seem that transparent insulation will have a significant future role in this area. The designer of transparent insulation architectural components must consider their aesthetic integration into the building as well as their thermal performance and costs.

In 1988 then, we have identified a whole new set of problems related to applications. Discussion of the thermodynamic properties of transparent insulating materials remains important but increasingly we are ready to address the questions of customer acceptance of a future product. For the first time market research entered the discussion and economics was considered: a sure sign that soon we shall be able to bring the products to the market place and satisfy a need – if it still exists when we get there !

If we continue with basic research plus components and systems development while keeping an eye on the market and solutions to aesthetic problems, we are well on the way to providing heat, light and comfort to the customer, with energy savings thrown in for good measure.

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These Proceedings are published eight weeks after the workshop. This is possible because of the co-operation of the majority of authors who produced their camera ready copy on time and according to agreed specifications.

By publishing the proceedings after the presentations we preserve the character of the workshop which is an essentially immediate and informal interchange of information. The four i's. If we would produce the proceedings in advance the results reported in them would be several months old. Presently the science and technology of transparent insulation moves so fast that it is better to record the information at the time of the presentation. Perhaps in 2–3 years time we will be able to welcome all delegates with freshly printed Proceedings.

AUTHOR INDEX