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Roy S. Heiersted, Anker F. Nielsen

WINDOWS

Recent research and experiences by Norwegian Building Research Institute, Trondheim Division

Oslo/Trondheim 1985

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CONCLUDING REMARKS

After some discussion in the Scandinavian group of experts handling this matter, the test cycle in the laboratory was set to 12 hours -30°C and 12 hours +60°C on the outside of the window over a period of 45 days. The inside temperature throughout the whole period should be +23°C.

After the 45 days, a window shall fulfill the requirement to air and rain penetration.

This test method has now been in use in Sweden and Norway for approximately two years, and the experience is quite clear.
It separates the good windows from the less good ones, and gives good reasons to expect a lifetime not less than 30 years for windows standing the durability test.

WINDOWS
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PREFACE

At the Norwegian Building Research Institute we have been working with window research and development for many years and have made it one of our main fields of interest.

Different types of specialized testing equipment have been developed, built and bought for this purpose. Tests and studies are made both of the complete product and of all the components used for manufacturing the window: Glass, sealants, surface treatment, weather stripping, fittings, aluminium-, plastic- and wooden frames and sashes etc. They include durability, weather resistance, energy consumption, general physical and mechnical properties etc.

Tests and studies for new development are made in, among other things:

Driving rain apparaturs
Wind pressure apparaturs
Apparatus for simulated, accelerated ageing
Spesial equipment for testing durability of plastic windows
Ageing of sealed glazing units apparatus
Guarded hot-box for studies of energy transmission

The papers in this publication are examples from recent work at the Trondheim division of the institute. It is our hope that this volume will bring the reader an understanding of the importance of this field of development, and at the same time some useful practical knowledge about windows as they are produced and used today.

The papers were originally presented on a congress in Gothenburg, arranged by the Swedish Council for Building Research in 1984.

Oslo/Trondheim, March 1985

Jarle R. Herje
Head of Trondheim Division

1. IMPROVING CONDENSATION RESISTANCE ON INNER PANE OF SEALED UNITS BY INCREASING THE GLAZING REBATE

Measurements on wooden windows with double and triple sealed glazing units.

Roy Scott Heiersted

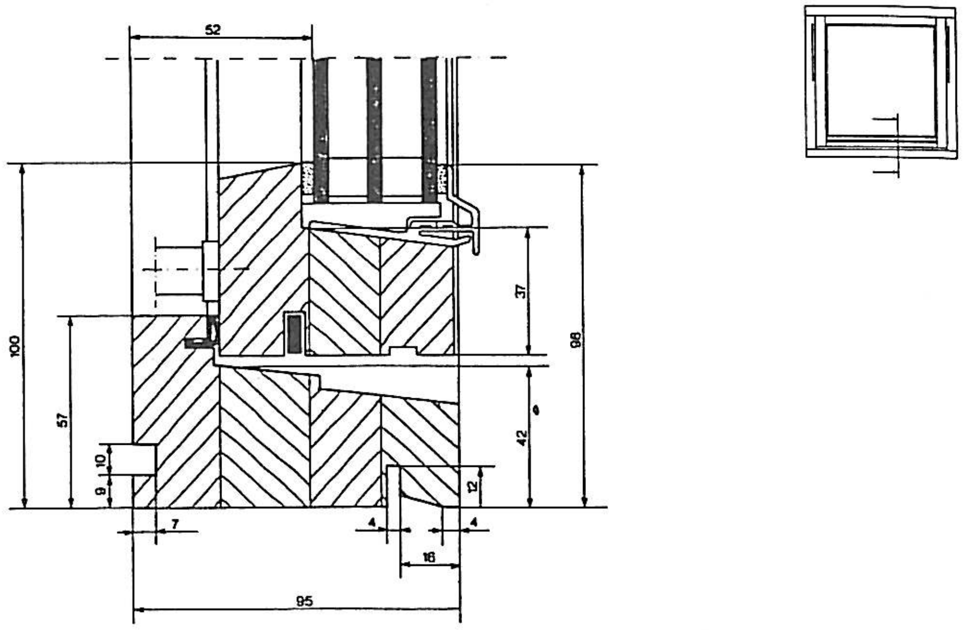

Fig. 1. The bottom frame and sash of the test window shown with a triple sealed glazing unit and the ventilated bottom rebate. The two windows in the test are identical except for the double and triple glazing units.

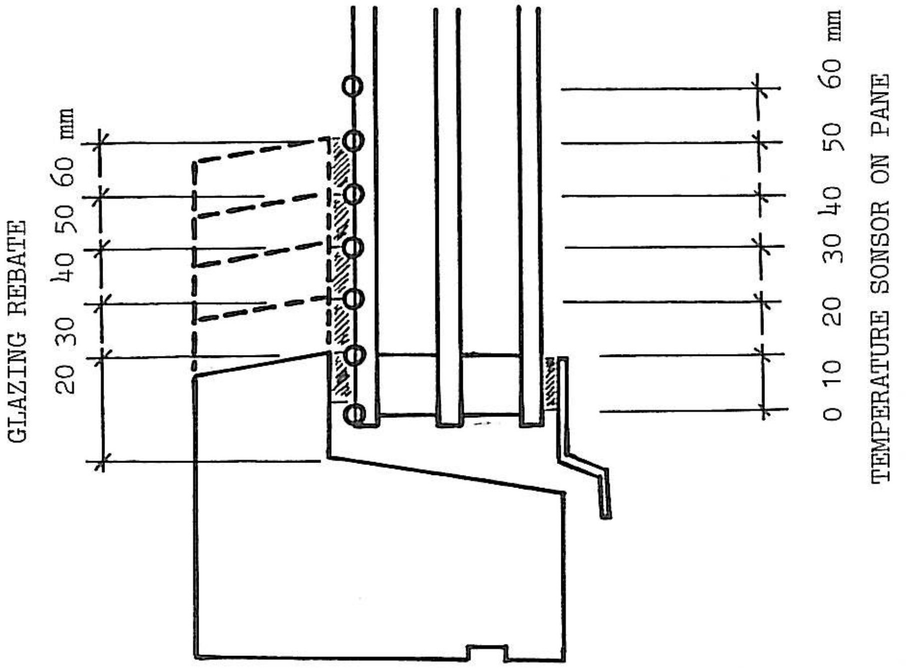

Fig. 2. Thermocouples in position at each 10 mm from the bottom cut edge of the inner glass pane. They are gradually covered by the next added rubber gasket and 10 mm wooden bead.

WATER CONDENSATION CAUSES ADDITIONAL MAINTENANCE OF WOODEN WINDOWS

The accumulation of water and ice along the edge of the inner pane of sealed glazing units are considered a severe problem during periods of heavy frost. The condensation of water starts growing from the corners of the pane and along the bottom sash, gradually shaping isothermal patterns all around the edge. If the water is not frequently dried off, it will finally run down onto the sash, and penetrate joints, gradually deteriorating wooden windows.

Both the cold-bridge in the metal spacer and the drained glazing rebate causes the condensation problem. Todays drained and ventilated rebate and the dry glazing using foamed rubber gaskets, are designed to prevent wooden windows from rot due to driving rain. Now an additional emphasis is needed in design to eliminate the interior maintenance problem.

THE WOODEN WINDOW USED IN THE TEST

The wooden window is a typical Scandinavian design. This one opens outwards. It is glazed from the outside, using an aluminium glazing bead at tilts across the drained bottom rebate. The dry glazing only uses foamed rubber gaskets, no putty. The standard height of the glazing rebate is 20 mm. The glazing unit is sized to about 10-12 mm overlap with the rebate.

TEST PROCEDURE

The condensation problem is most severe along the bottom sash. The thermal measurements are therefore consentrated in the lower area of the window. Very thin thermocouples are positioned at the vertical centerline at each 10 mm from the cut edge, and glued to the glass along the isotherms.

The tests are performed in a guarded hot box. The environmental conditions are 20^{o}C in the metering chamber and -10.0^{o}C in the cold chamber. The surface thermal resistances correspond to the building code requirement of 0.12 inside and 0.05 m^{2}K/W outside.

Temperatures are recorded in steady state condition. Measured temperatures are normalized to 20.0^{o}C and -10^{o}C air temperatures to allow the highest degree of reference between each test.

Five tests, to maximum rebate hight of 60 mm are performed on each window.

Table 1.

Double sealed glazing unit.

Measured temperatures at the inner pane with different glazing rebate. Test condition 20°C indoor and -10°C outdoor.

Position of the thermocouple from the cut edge of the inner pane	Hight of glazing rebate in the wooden sash				
	20 mm	30 mm	40 mm	50 mm	60 mm
150 mm	10.3°C	10.2°C	10.1°C	10.3°C	10.3°C
60 mm	9.1	8.7	8.1	7.3	6.1
50 mm	8.3	7.7	6.8	5.6	4.2
40 mm	7.9	7.0	5.7	4.3	
30 mm	6.1	5.0	3.4		
20 mm	3.8	2.5			
10 mm	- 0.3	Standard rebate			
0 mm	(- 1.0)	(-2.1)	(- 2.8)	(- 3.1)	(- 3.5)

Table 2.

Triple sealed glazing unit.

Measured temperatures at the inner pane with different glazing rebate. Test condition 20°C indoor and -10°C outdoor.

Position of the thermocouple from the cut edge of the inner pane	Hight of glazing rebate in the wooden sash				
	20 mm	30 mm	40 mm	50 mm	60 mm
150 mm	13.4°C	13.4°C	13.4°C	13.5°C	13.3°C
60 mm	11.8	11.4	10.9	10.0	8.9
50 mm	11.0	10.3	9.5	8.3	7.0
40 mm	10.1	9.1	7.9	6.4	
30 mm	8.4	7.1	5.7		
20 mm	6.1	4.4			
10 mm	2.2	Standard rebate			
0 mm	(0.7)	(- 0.4)	(- 0.9)	(- 1.3)	(- 1.5)

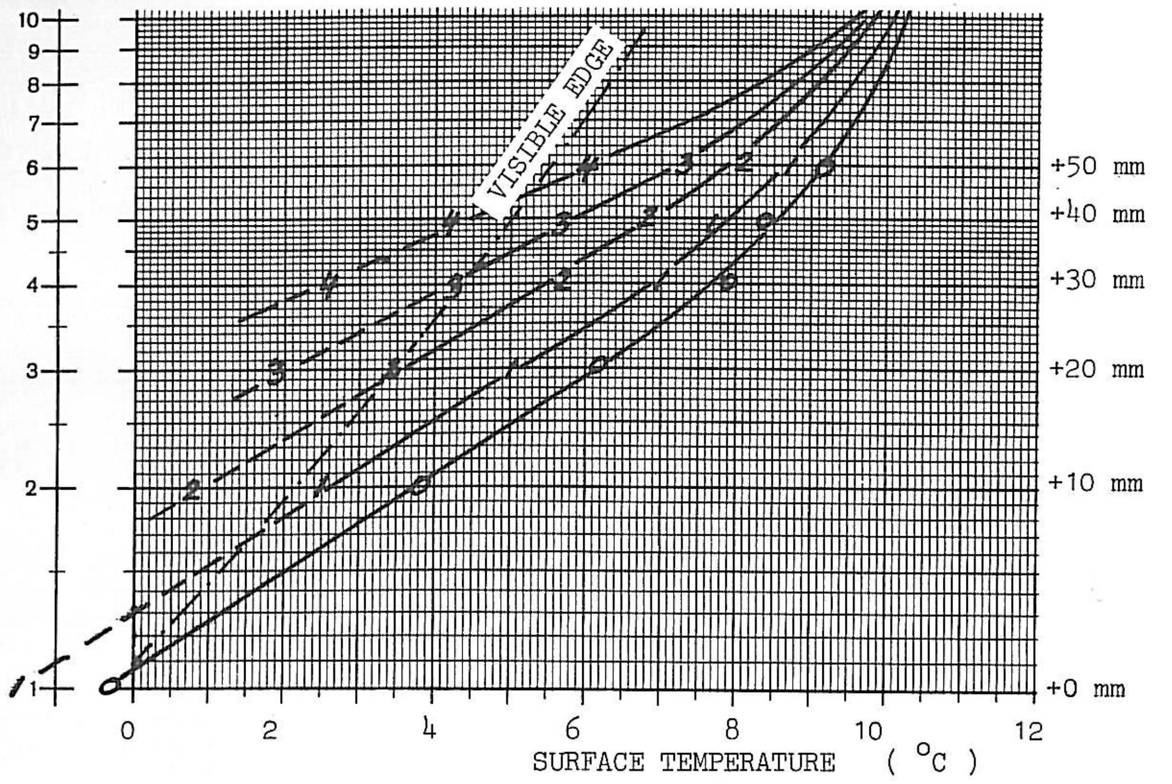

Fig. 3. Double sealed glazing unit.
The temperature at the visible edge of the inner pane increases with the glazing rebate.

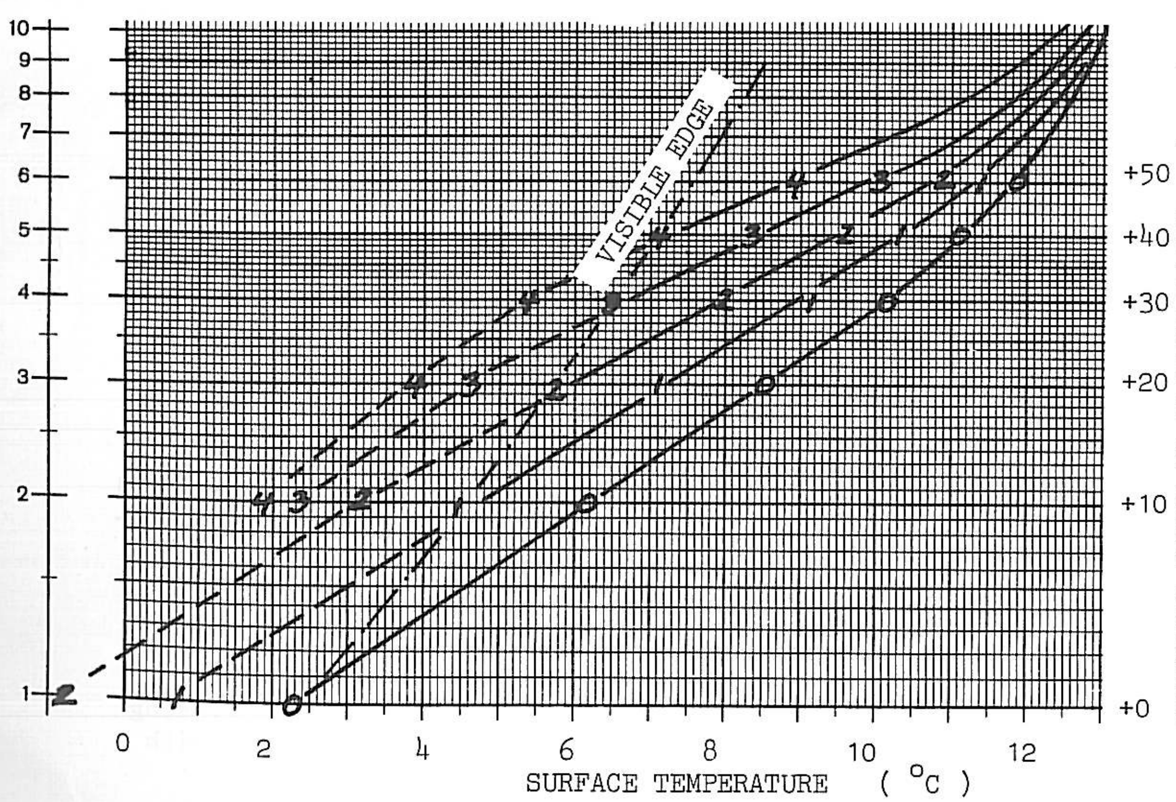

Fig. 4. Triple sealed glazing unit.
The temperatures on the inner glass are measured each 10 mm from the out edge, indicating very steep gradients in 60 mm edge zone.

MEASURED TEMPERATURES WITH INCREASING GLAZING REBATE

The test results in table 1 and 2 show how an increased rebate to 30 mm, from the standard 20 mm improves the glass temperature by 2.8 K on the double and 2.2 K on the triple unit. (The 20 mm rebate exposes the thermocouple 10 mm from the cut edge as the visual edge of the pane.) Further a 20 mm increase to a 40 mm glazing rebate gives 3.7 K and 3.5 K improvements respectively at an ambient wind condition of -10°C. By this additional 20 mm glazing rebate the temperature difference between the visual edge of the inner pane and the room, is reduced by as much as 20%. This may be just enough to avoid condensation in most climatic situations.

The graphical presentation of the measurements in fig. 3 and 4 indicate a major improvement at the glass temperature by the first 10-20 mm added hight to a standard glazing rebate.

The graphs also show a decrease in glass temperature by higher rebate. This is caused by the internal insulation of the glass by the rebate and full-hight rubber gasket. If an ordinary gasket was placed only at the top of the rebate, an even stronger cooling of the glass could be expected. All together the lowered glass temperature from the higher rebate, reduces the potensial temperature improvement to approximately half. The full potensial is the temperature gradient of the inner glass at the standard rebate.

The measured results contain the real interaction between a complex geometry and an exterior forced convection with its ventilation of the glass rebate. Together with the interior natural convection with its air pockets caused by geometry, this problem can hardly be solved by computation only.

CONCLUSION

The improved condensation resistance on sealed units by a higher glazing rebate is a general solution to all types of window designs. At the same time any changes of the exterior ventilated glazing rebate and the dry glazing method must be avoided. Even when such solutions do show good thermal improvements.

The test shows a 20% reduction of temperature difference to the room by an additional 20 mm rebate. The same for both double and triple glazing. However, the double glazing has the highest condensation risk. To give a double sealed unit the same edge temperature as a triple, windows for double glazing need an additional 10 mm hight to the glazing rebate.

This is of importance to users of the new LE (low emissivity) coated glazing. Their U-value equals an ordinary triple glazing unit. At the same time they (normally) are double glazing with the same cold-bridge in the spacer as ordinary double units. Consequently with the same initial condensation risk, but with steeper temperature gradients around the edge of the glazing.

2. LIGHT TRANSMITTANCE AND COLOUR TONING AND -RENDERING IN COATED GLAZING

Measurements on 25 coated glazing systems

Kristin Breder
Roy Scott Heiersted

INTRODUCTION

During the past few years several new products with coatings have entered the insulating glass marked. These products may be grouped in four different groups as done by the Norwegian Building Research Institute (NBI) in no. A 571.954 (1982) from the series of Building detailsheets.

The group are

0 Units with ordinary glass

1 Solar control units

2 Light and heat control units

3 Low emissivity units

The products have been grouped like this because of their different light and energy properties.

In 1982 NBI did an investigation of a series of different coated products for the Norwegian Consumers Counsil. Both U-values and optical properties of the units were measured, (Heiersted, 1982). This paper will describe the optical properties as measured, and also as judged visually regarding colour toning of transmitted and reflected light. This project has later been added on to by measurements of new products on the marked. Some of these results are also included in this paper.

MEASUREMENTS

Some of the basical figures from the measurements are given in Table 1. If nothing else is stated the products measured were sealed glazing units with the specified product as one glass, and ordinary 4 mm floatglass as the other, and 12 mm air/ gas space. The gas content was in some cases also checked, but that is considered as unimportant for this part of the project.

Series 1.

Included in the first series were units numbered from 1 to 13 in Table 1. First the light transmission in the visible range was measured. The figures are given in the table as percent of total incoming light, and also as percent of the transmission in an ordinary double insulating glas unit. As can be seen from the table the amount of visible light transmitted through some of the units is considerably reduced. This is of course especially true for the units belonging to group 1, solar control units, such as no. 7 and 9. But as shown in figure 1. the transmitted light spectra is considerably different, which make the units tone both the colour of the transmitted and reflected light differently.

This is an effect that should be taken into account when such units are used. Two different approaches to describe this colour of the light was attempted. Table 1a give the CIE coordinates for the transmitted light. This is a standardized way to describe colour, and the next column in the table gives the names of the corresponding colour. This method however, does not give a very clear visual idea of the colour, because the colour saturation might be different. Therefore for this series a visual inspection was done. This was done in front of a light box with white light with colour temperature of 5500 K. Transmitted light was viewed by placing the units in front of the box, keeping the rest of the room dark. The reflected light was observed with the units at about 60^{o} angle to the box and with the dark room as a background. As description of the colours was used a comparision to the colours as given by the Rank Strand electric "Cinemoid" Reference book for colour filter for theatre lighting. The observed colours are very close to the reference, but the saturation of the filter-colours are higher than those of the glass units. As seen from the colour names the visual observation is for more nuanced than the colours given by the CIE system. The descriptions of the reflected light is done in a similar way. For the colour of the transmitted light it is clear that the same type of coating basically give the same colour toning. As example can be seen that the gold coated units are in the green-rose area. However the metal coatings often have an interference layer as adhesion promoter and for protection. Depending on the thickness and type of the interference layer both the transmitted and reflected ligtht can get several different colours. This is especially done on units in group 1 and 2, and the different reflected colours are used for arcitectual purposes. Results are given in table 1b.

Series 2.

This is the measurements given in the table as no.14-25. The CIE coordinates and colour is given in table 1a. When compared to series 1, these also give a light change to the yellow part of the visible spectrum. A visual observation was not done on this series, but a general idea can be seen from comparing the CIE coordinates for the two series.

However, an additional measurement was done on this series. That is the colour rendering index R_a. This tells something about how the light source, in this case seen as daylight through the windows, will change the "true" colours which are observed in a room. (CIE no.13.2.1974). The colour rendering index R_i is found for 8 different colours and the R_a is calculated as a mean value for these. German Industrial Standard DIN 5035 give a fur step grading of light sources with $R_a \geq 85$ as best class, and also give certain rules for electing light sources for different purposes. This is not done for daylight through windows, but it might be possible to view this on the same scale. For certain operations as quality control, and so on, it is recommended that the $R_a > 90$.

DISCUSSION

This investigation shows that the coating of glass to give better solar control properties and to give better U-values has given additional effects. The solar control units, group 1, and the light and heat control units, group 2, give a lot of possibilities to make units with desired colour reflexes. When this is combined with spandrels with the same colour reflex, new and interesting arcitectual possibilites have come up.

To a certain limit the coating technology has given possibilities to give good sun control effects, and a protection against overheating during the summer.

But all these products give a certain colouring of the transmitted light, and in some cases this might not be a desirable effect.

The Low Emissivity units, group 3, are basically designed to give as good energy properties as possible, at the same time as the light transmission is unaffected. Some of these units have light transmission curves that are close to those of ordinary float glass units, but they still do colour the light slightly.

"Light quality" is a subjective word, and peoples opinion are decided a lot by habit and tradition. But in Scandinavia, where great parts of the year offer very little daylight, most people find it desireable to have windows with high light transmittance and little colour toning in the visible light range. This is especially true for residential buildings.

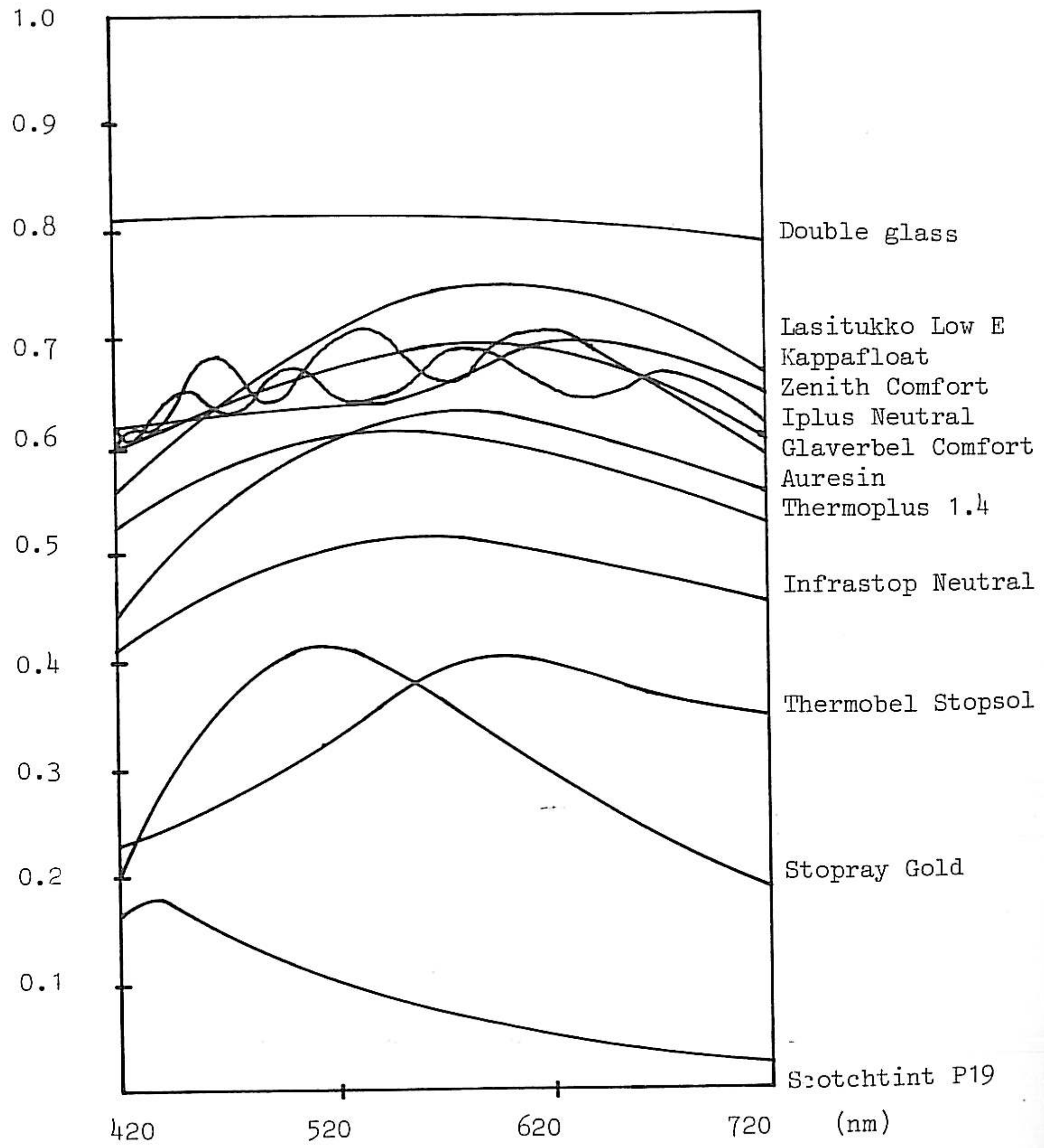

Fig. 1. Transmitted light spectra for some commercial available products.

TABLE 1a. Measured optical properties.

No. PRODUCT	% light transm	Relative trans. to double unit	Max. light trans (%)	Wave length at max tr. (nm)	CIE coordinates for trans. light		CIE colour	R_a index
					x	y		
1 Thermoplus 1.6	69	0.84	65	560	0.329	0.357	Yellow	
2 Thermoplus 1.4	61	0.74	60	550	0.330	0.362	"	
3 Auresin 66/44	66	0.80	64	600	0.355	0.393	"	
4 Inf.Neutral 51/39	54	0.66	50	590	0.337	0.365	"	
5 Therm. Comfort	67	0.82	68	600	0.328	0.352	"	
6 Stopay Gold 40/27	41	0.50	42	600	0.324	0.375	Green yellow	
7 Therm.Clear Stopsol	38	0.46	40	620	0.342	0.364	Yellow	
8 Climaplus GLS 1.4	60	0.73	60	560	0.333	0.364	"	
9 Scotchtint 19	14	0.17	18	420	0.284	0.312	Blue	
10 Kappafloat	66	0.80	66	620	0.337	0.347	Yellow orange	
11 Kappafloat, triple	58	0.71	60	620	0.336	0.349	" "	
12 Double unit	82	1.00	82	520	0.317	0.340	Green	
13 Triple unit	72	0.88	74	520	0.317	0.342	"	
14 6 mm floatglass + 4 mm Kappafloat	58	0.71	61	610	0.342	0.339	Yellow orange	96
15 6 mm Spectrafloat + 4 mm Kappafloat	32	0.39	41	720	0.368	0.359	Yellow	96
16 6 mm laminated glass + 4 mm Kappafloat	58	0.71	62	620	0.346	0.341	Yellow Orange	92
17 6 mm Suncool Azur			29	580	0.350	0.358	Yellow	81
18 6 mm Suncool Bronze			11	570	0.357	0.374	Yellow green	64
19 6 mm Suncool Silver			20	560	0.337	0.347	Green yellow	82
20 6 mm Suncool Azur + 4 mm Kappafloat			22	610	0.366	0.363	Yellow	94
21 6 mm Suncool Bronze + 4 mm Kappafloat			83	600	0.372	0.377	Yellow	67
22 6 mm Suncool Silver + 4 mm Kappafloat			15	600	0.354	0.353	Yellow	92
23 Comfort Glaverbel			70	550	0.340	0.346	"	87
24 Iplus Neutral			89	580	0.339	0.344	Yellow green	91
25 Lasitukko LE	62	0.76	76	600	0.342	0.354	Yellow	77

TABLE 1b. Visually observed properties.

No.	PRODUCT	CIE colour	Visual colour observation transmission	Visual colour observation reflection
1	Thermoplus 1.6	Yellow	Pale green + pale rose	Straw tint
2	Thermoplus 1.4	"	" "	" "
3	Auresin 66/44	"	Pale yellow	Pale lavender
4	Inf.Neutral 51/39	"	Pale green + pale rose	Pale gold + steel blue
5	Therm. Comfort	"	Straw tint + steel tint	Pale rose + pale grey
6	Stopay Gold 40/27	Green yellow	Straw tint + ariel blue	Gold tint + pale green
7	Therm.Clear Stopsol	Yellow	Chocolate tint	Pale grey
8	Climaplus GLS 1.4	"	Pale green + pale rose	Straw tint
9	Scotchtint 19	Blue	Steel tint	Pale grey
10	Kappafloat	Yellow Orange	Chocolate tint + pale rose	Ariel blue + pale grey
11	Kappafloat, triple	"	"	"
12	Double unit	Green	Pale grey	Steel tint + pale grey
13	Triple unit	"	"	"

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3. TRENDS IN PRODUCT DEVELOPMENT OF COATED GLAZING

Kristin Breder
Roy Scott Heiersted

INTRODUCITON.

Coated glazing for building purposes has been known for quite a few years. In one of the first known examples it was used for arcitectual purpose, but it was discovered that the coated glass also offered a considerable solar shading effect. In many cases, especially in commercial buildings this is a desireable effect, and different metal coatings was developed for solar control purposes. In addition these products were used as special arcitectual effects.
Then it was seen that some of the coatings, such as the gold coatings, lowered the U-value for the sealed units. As energysaving became a more important factor in the bulding design, this effect has shown to be one ot the most interesting. Work was done on coatings which lowered the U-value and at the same time had high transmittance for visible sunlight. This research work has led to the Low Emissivity Coatings (LE coatings) which are on the market today.

PRODUCTS AVAILABLE TODAY.

Much of the recent interest also in commercial available units have been concentrated on the LE-types. These products actually have Low Emissivity, but also a fairly high absorbance. Figure 1 shows the radiation properties for a solar control unit and a LE-unit.

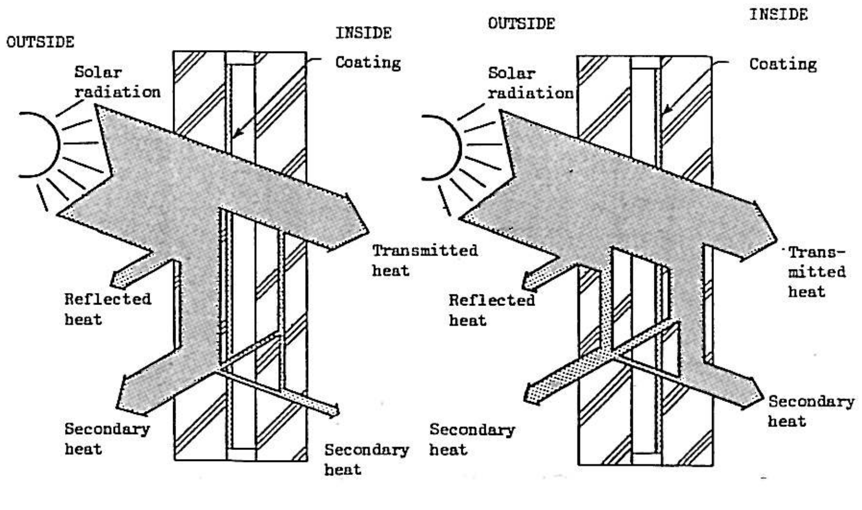

Figure 1. Solar control unit, coating on outer glass. Low Emissivity coating on inner glass.

As it is seen from the exaple the product actually benfit from the fact that the amount of absrobed energy in the coating is rather high. The solar heat gain is improved because some of the absorbed heat is transmitted into the room as secondary heat. Also the unit will feel more confortable because the temperature on the inner glass is increased. For solar control units the absorbance in the coated layer is used opposite direction. The coating is on the inside of the outer glass, and the secondaryheat is transmitted to the outside.

The ideal coating with respect ot energysaving properties is the one which combines low U-vlaue with high solarfactor. The solar factor is a measure of the total solar energy trasmitted to the room, measured relatively to a normal double unit.
An example of the solar radiation properties for three different units are shown in table 1.

Table 1. Example of the distribution of the solar radiation. Incoming radiation is 100%.

	"Auresin"	"Zenith"	Ordinary unit
Reflected, R_s	30%	15%	10%
Absorbed, A_s	35%	40%	20%
Transmitted T_s	35%	45%	70%
Absorbed,			
- outer glass A_1	25%	10%	10%
- inner glass A_2	10%	30%	10%
Secondary heat,			
- out SER	25%	15%	13%
- in SET	10%	25%	7%
Total solar heat to inside, TET*)	45%	70%	77%

*) TET (Total Energy Transmission) = T_s + SET

The U-value may be additionally lowered by filling the units with low conducting gas, this will not change the solar factor.

POSSIBLE COATINGS.

A coating with high solar factor and low U-value will be a coating with high transmittance in the visible area and low transmittance in the infrared area. This is shown as the dotted line in figure 2. The solid line represents measurements on a Indium Tin Oxide film.

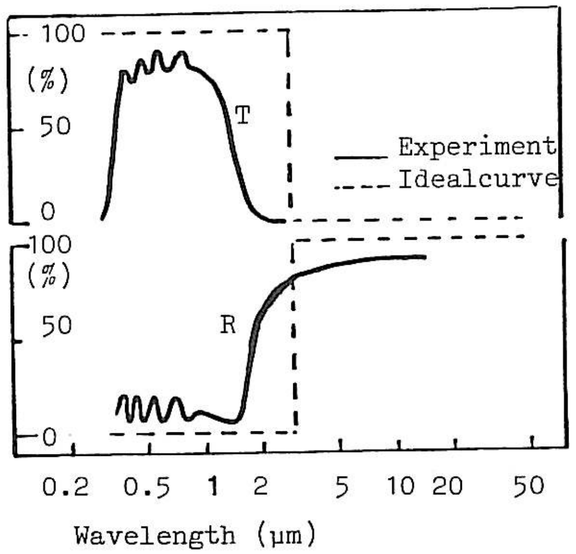

Fig. 2. Spectral transmittance and reflectance for a LE-coating (solid line). Dotted line represents ideal curve.

To achieve these properties there are certain physical properties the coating must posess. (Lampert 1981). The coating must be conductive to be reflective in the infrared area. To ensure transmittance in the visible area the energy band gap in the molecules must be sufficiently large, and there must be a limited number of exited levels within this gap. The infrared reflection is increased by increased thickness, but then the visible transmittance is reduced. Further the infrared reflectivity is improved by high moblity of the electrons.

Once these requirements are stated, the physicists have systematically investigated caotings that theoretically may seem to have the desired properties. The work has been consentrated on single layer films of semiconducting material, on metal films, and on metal with interference coatings and protective coatings. An overview of some of the more promising ones are given in table 2.

Table 2. Possible coatings for LE-purposes.

Semiconducting materials Single layer	Metal coatings with protective layer	Multilayer film
In_2O_s : Sn	Au/Bi_2O_3	$TiO_2/Ag/TiO_2$
SnO_2 : Sb	Au_2O	$Bi_2O_3/Au/Bi_2O_3$
SnO_2 : F	Cu_2O	ZnS/Ag/ZnS
Cd_2SnO_4 : In	$Al_2\ O_3$	ZnS/Cu/ZnS
Cd_2SnO_4 : Al	Ag/Bi_2O_3	
SnO_2	Sb_2O_3	
	Al_2O_3	
	TiO_2	
	SnO_2	
	Cu/Bi_2O_3	
	SiO_2	
	SnO_2	

Once the ideal coating is found, it must be possible to produce on a lager scale. Therefore a lot of research is done on coating technology, and several methods are available. This will however not be covered further in this paper.

NEW POSSIBLITIES

Still there are several possibilities in the coating technology that have not been investigated. A lot of interesting materials have been suggested and some interesting work have been done. Materials that might have very good LE-properties are TiN, ZrN, HfN, LaB_6, $AuAl_2$ (Granqvist 82). Other possibilities, as shown by swedish researchers, might be to use new types of multilayer coatings. Promising research has been done on Indium Tin Oxide (ITO) coatings with an outer layer of MgF_2.

This combiantion has shown to give very high solar transmission, even higher than for the uncoated glass. At the same time the infrared reflection is only slightly decreased. (Hamberg et al 1982). Another approach to increase the solar transmittance is to use a conducting micromesh with a grid spacing of a few microns. Then the solar radiaton can be transmitted and thermal radiation reflected.
Still another interesting technology is optically switching materials (Granqvist 82). Electrochromic coatings have an absorption which can be changed reversible by the application of a voltage with positive or negative polarity. Some materials of this type is already in use for other purposes.

Photochromic coatings have a reversible irradiation induced absorption, and thermocromic materials display a reversible temperaturedependent change of the optical properties.

Research on the glass itself might also prove to ble useful. A more transparent glass, and thus a unit with high solar factor might be possible to achieve by changing the composition,for instance to get an ironfree glass. Such units with an opitmal gas micture will perform very good as energysaving glazing.

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4. ENERGY CONSUMPTION IN BUILDING WITH SUNSPACE

Anker F. Nielsen

Introduction

There has been a rising interest in buildings with glazed rooms - sunspaces - for protection against the outdoor climate. The conclusions in this paper are drawn from Scandinavian climate with very little or no sunradiation in the winter. Calculations for single-family houses (Nielsen 1981) with a sunspace have shown that the energy savings are small, and it is very expensive to heat the sunspace all the year. In this paper we will look on large buildings with sunspaces. In Trondheim we have two buildings of this type. First the university center at Dragvoll and the second a new hotel (Royal Garden) at the river. The calculations of energy cunsumption are done on a block of flats, but other building types could also use sunspaces as office-buildings and hotels.

Block of flats

The energy consumption and the temperatures are calculated for a block with 3 floors and 15 flats. The building is 50 m long, 12 m wide and 9 m high. The gables are oriented against south and north. The thermal insulation is in accordance with the Norwegian building code - U-values of roofs 0.2 of walls 0.25 and of windows 2.1 W/m^{2}C. The triple glazing comes to 20 % of the floor area of the building. The windows are placed evenly in all facades. The indoor temperature in the flats is 21^{o}C, and the heat gain from human beings and electrical applicances are 15 kWh/day in each flat. The air change is 0.5 times pr. hour. Two of these blocks are placed parallel with 12 meters distance. The room between the blocks is provided with gables and roof of single or double glass. The area of the sunspace is 600 m^2. The air change in the sunspace is 1 time pr. hour. It is taken into account that the solar heat gain through the windows facing the sunspace is reduced. Because of the glazing in the sunspace and the shadow from the other block. During the period of planning and design it is important to know the expected energy consumption for different lay-outs of the buildings. This could be done with a large complex computer program, but would be very expensive. For this purpose it is better to use a simplified method as EFB 1 and only use the complex program in a later phase. We are using a version of the EFB 1 program (Nielsen 1984) with modifications for calculations on multi-room buildings. This gives fast calculations of the energy consumption and the mean temperature in the sunspace.

Blocks with and without sunspace

In all the calculations is used climate from Trondheim in Norway. The first calculations are done on a single block without sunspace for two cases:

1.	Full sun on all facades	171 MWh/year
2.	Shadow on east or westfacade	183 MWh/year

In the next calculation the sunspace between the two blocks is taken into account. With single glazing the energy saving is 7 % of the second case. Double glazing would save 2 % more.

Ventilation system

The calculated savings from the use of sunspace are small, but it is possible to get more savings from a change of the ventilation system. If the ventilation air of the blocks could be taken from the sunspace and the exhaust air blown out in the sunspace the savings would be 25 %. A part of these savings could be used to change the construction of the facades facing the sunspace to a mean U-value of 2.1 W/m^2. This value is used in all later calculations. The energy consumption would then be 180 MWh/year for single glazing and 164 MWh/year for double glazing. In reality it would be difficult to get that low energy consumption, as part of the ventilation has to go outside the sunspace. That is the case for exhaust from kitchens and toilets.

Temperatures in the sunspace

The mean temperature is calculated each month by the computer program. Days with sun will have temperatures above the mean and days without sun temperature below the mean. The number of hours with each temperature could only be calculated with a complex computer program. The sunspace temperature with single glazing is shown in figure 1 together with the outdoor temperature. The temperature is 5-6^{o}C higher than the outdoor temperature in the winter. With double glazing the temperature would be 2^{o}C higher than single glazing.

In the figure is shown how much of the heating of the sunspace comes from the sun. In the winter the sun has nearly no effect - it is heat loss from the blocks that is important. In the summer the sun is more important.

The low temperature of the sunspace in the winter will give problems with ice and snow on the glazing. In summer there will be problems with overheating in some periods.

Heating of the sunspace

In this case we calculate with a more realistic ventilation system. Ventilation air to the flats is taken from the outside and heated in the block. The exhaust air from the flats is used to heat the sunspace. This gives a higher energy consumption than the earlier system.

The system could not heat the sunspace very much so we calculate the extra heating in the sunspace to get a sertain minimum temperature. If we heat the sunspace the energy consumption in the blocks will go down. In figure 2 is the yearly total energy consumption of the two blocks and the sunspace depending on the temperature in the sunspace. With single glazing the energy consumption is rising for temperatures above +5^{o}C. With double glazing the rising starts at +10^{o}C and with triple glazing at +15^{o}C. This shows that if we select the right glazing it is possible to heat the sunspace with the same energy as the blocks would have without sunspace.

Conclusions

The calculations show that use of sunspaces between large buildings will give energy savings even in Scandinavian climate. But it is very important to use the best ventilation system and to utilize the heat losses from the buildings. In our climate both the winter and the summer conditions have to be taken into account in the design (Nielsen 1983).

The economy of sunspaces is interesting as the price could be lower than ordinary buildings with the same volume. If the sunspace is used as walking and livingarea then the area in the adjoining building could be reduced. It is also possible to use simple constructions as the outdoor climate does not touch the facade against the sunspace. It is expected that more buildings with sunspaces will be built in the future.

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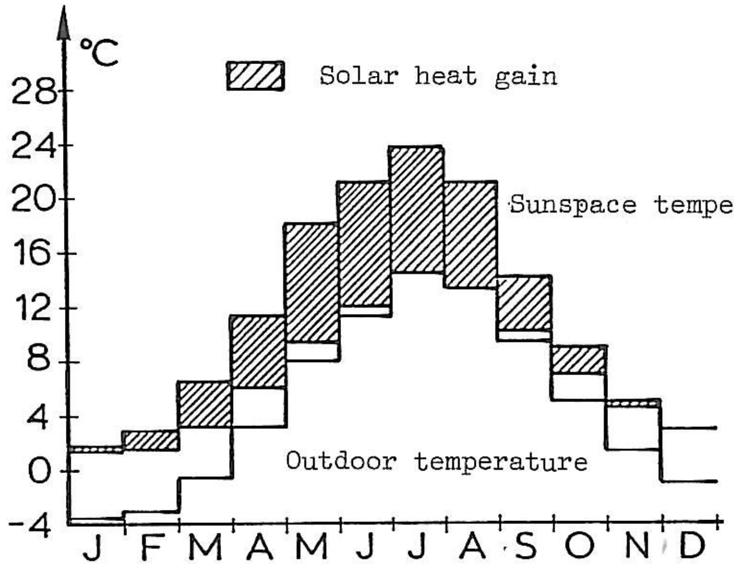

Figure 1. Mean temperatures for sunspace in Trondheim, Norway.

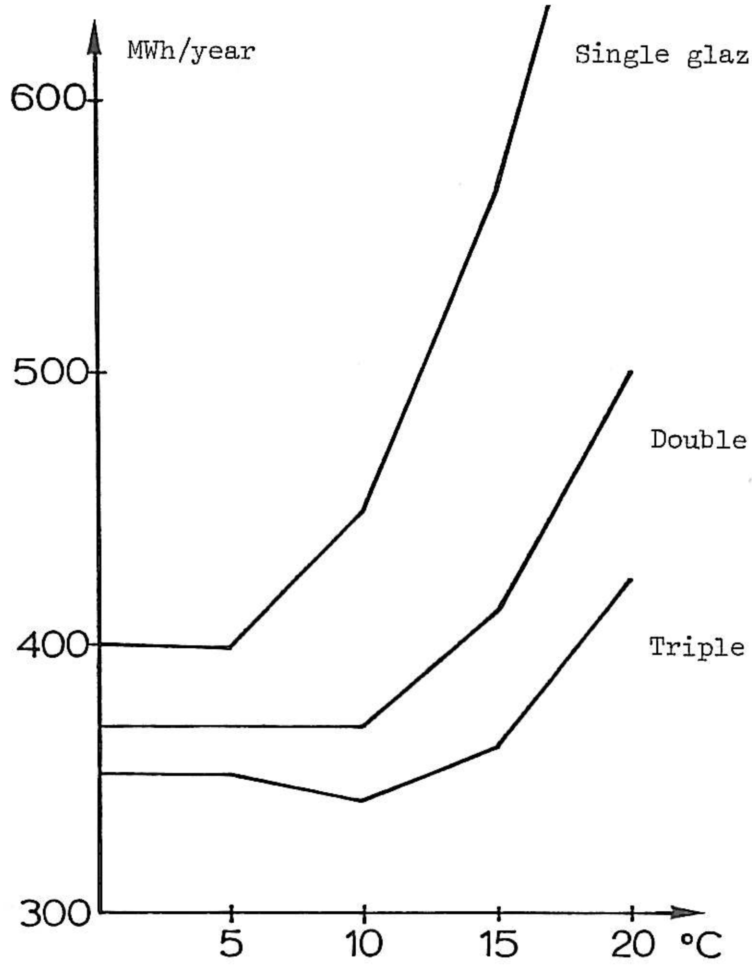

Figure 2. Energy consumption for the 2 blocks and the sunspace with variable minimum temperature in the sunspace.

5. LONG TIME PRACTICAL EXPERIENCE WITH SEALED GLAZING UNITS IN SEVERE NORWEGIAN CLIMATE

Tore Gjelsvik, technical physicist MNIF, MNFS

INTRODUCTION

Sealed glazing units are manufactured with dry air or gas between the panes and a gas- and vapour-tight seal along the edges. The practical service life of such units is obviously dependent upon the efficiency of the edge seal. A high water vapour diffusion rate or a rapid breakdown of the edge seal will reduce the practical service life of the units considerably.

Much work has been carried out over the years to make it possible to forecast the expected service life of sealed glazing units. The traditional way is by accelerated aging tests in the laboratory. The value of such tests has been disputed. Anyhow, they usually constitute the most important part of the basis for a rapid evaluation of new types of unit.

The alternative to laboratory testing is to collect information from units on natural exposure. To follow up units in the field is, however, a time-consuming job. A more rapid and effective way is by making systematical field studies on units of different age.

NBI FIELD STUDIES 1963, 1973 AND 1983.

The most comprehensive field study carried out by the Norwegian Building Research Institute is the one known as the West Coast Field Study 1963. This study covered a total of 2040 seald glazing units, divided on ten different brand names and installation years from 1951 to 1963. The units were then up to 12 years old when inspected in 1963. The study covered visual inspection as well as measurement of dew point. Detailed results are found in the report (1).

Later on, the same units have been inspected again in 1973 and 1983. In 1963, a total of 2040 units was included. In 1983, the number of counting units had been reduced to 1769. The difference is coming from a couple of buildings wrecked down and removed, several cases of remodeling and change of windows, as well as units broken by accidents. Only units that could be followed through from 1963 to 1983 have been taken as counting. These were from 20 to 32 years old at the final inspection.

RESULTS

The units studied covered a total of ten types or brands. Included was one type of all-glass unit with fused edge seal in Group I, two types of unit with direct glass-to-metal seal in Group II and seven types with glued edge seal in Group III. Details are found in Table 1. The distribution of the counting units is shown in Table 2.

The types of damage recorded in 1973 and 1983 were the same as in 1963. Included were observations of visible condensation and scumming at the time of inspection, measured dew point above (or at) the critical limit, visible cracks in the glass as a result of condensation, visible cracks in the metal seal as well as deflection of the metal seal. Cracks in the glass, cracks in the metal seal and deflection of metal seal were, however, only

Table 1. Classification of the products studied.

Group	Type of seal	Brand name
I	All-glass	Gado
II	Glass-to-metal	Schalker Thermopane
III	Glued	Aluco Aterphone Cudo Duoterm Multipane Polyglass Polyverbel

Table 2. Distribution of units on different types and year of installation

Type of unit	Year of installation												Total
	1951	-52	-53	-54	-55	-56	-57	-58	-59	-60	-61	62/3	
Gado								2					2
Schalker				56	35	22		43	47	23	61	58	345
Thermopane	2	4	3	25	16	35	107	87	46	100	100	65	590
Aluco												9	9
Aterphone									9			1	10
Cudo									40	126	53	45	264
Duoterm										3	13		16
Multipane										18	1	5	24
Polyglass					1		9	8	44	34	13	28	137
Polyverbel						6	163	78	59	38	28		372

recorded in connection with visible condensation or dew points above the critical limit. For practical reasons, it was found conveniant to distinguish between only two types of damage when the material was treated in detail:

1. Visible condensation and scumming.
2. Dew point above the critical limit.

In addition, recordings on replacement of units were sorted out. On this basis, damage frequencies have been calculated for all combinations of type of unit and year of installation. The results will appear from Table 3. In each counting square in the table, three figures are given. The one at the top is for 1963, the central figure for 1973 and the one at the bottom for 1983.

Table 3. Damage frequencies, %.

Type of unit	Year of installation												Average all years
	1951	-52	-53	-54	-55	-56	-57	-58	-59	-60	-61	62/3	
Gado								50 100 100					50 100 100
Schalker				2 5 30	0 0 17	5 46 46		0 0 14	0 9 13	0 26 43	7 39 75	2 14 26	2 16 33
Thermopane	0 0 0	0 0 25	0 33 67	8 12 24	0 25 63	0 3 32	3 16 36	1 14 53	2 11 35	1 3 12	1 5 19	0 25 55	2 11 34
Aluco												0 100 100	0 100 100
Aterphone									30 60 60			0 100 100	27 64 64
Cudo									10 50 90	3 33 97	0 30 74	0 0 60	3 30 85
Duoterm										0 0 100	0 46 92		0 38 94
Multipane										100 100 100	0 100 100	60 80 100	88 96 100
Polyglass					50 100 100		10 90 100	64 93 100	2 22 87	0 18 68	0 0 31	0 7 21	8 29 67
Polyverbel						56 67 100	61 81 99	18 48 58	2 17 39	0 36 76	0 7 11		33 53 73

A closer study of Table 3 reveals that the results are very diversified. Some of the brands seem to have had edge seals with such a poor durability that there is nothing left after a period from 10 to 20 years of natural exposure. Others have served much better, and the best results are obviously found for the glass-to-metal seal units Schalker and Thermopane as well as the 1961/63 production of the glued types Polyglass and Polyverbel. The latter results are closely related to wellknown changes in the products.

Also for Schalker and Thermopane, the production from some of the years seems to be much better than from some of the others. In general, the results may look discouraging. It should be noted, however, that about two third of the Schalker and Thermopane units were still in good condition after a service period from 20 to 32 years.

The measured dew points have been treated statistically. The limited space available does not make it possible to present all data here, but a few selected results can be given. Figure 1 shows the median dew point values for the Thermopane units, as measured in 1963, 1973 and 1983 respectively. All units with a dew point at or above the critical limit of -5°C are here for simplicity marked with a dew point of -5°C. There is, as can be expected, a move towards inferior dew point with increasing age. For the years 1953, 1955, 1958 and 1962/63, the average unit had in 1983 reached the critical limit. This corresponds very well with the figures in Table 1. The average remaining service life for the rest of the units can be predicted from the data given.

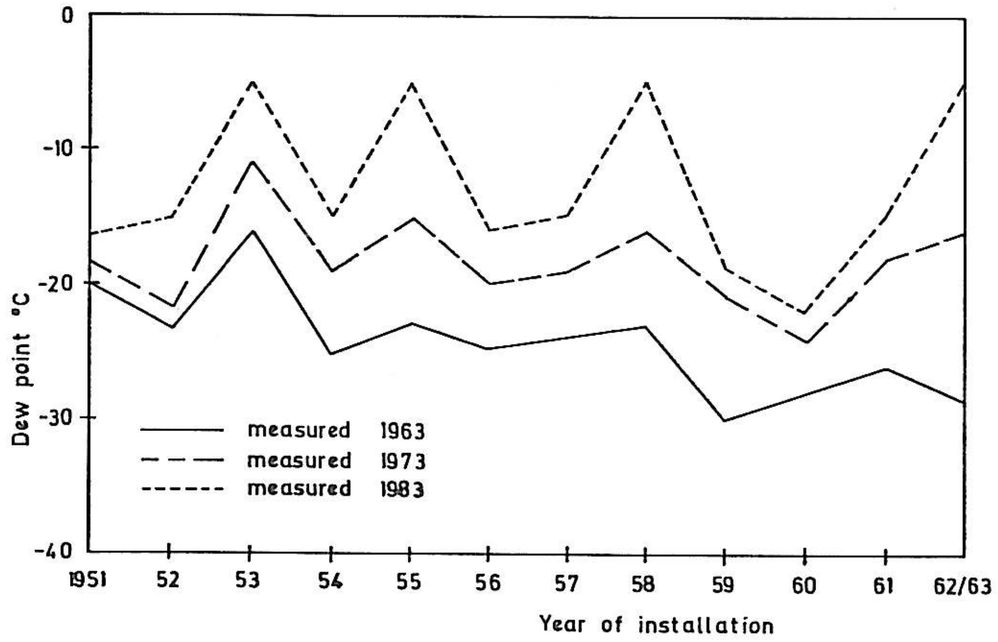

Fig. 1. Median dew points for the Thermopane units.

Another selected set of results is given in Table 4, showing the damage frequencies as a function of the type of window. More data will be given in the final report.

It should be emphasized that the results presented here are valid only for the types of sealed glazing units produced in the years from 1951 to 1963, installed in the windows from that period of time with the installation technique and materials used in the same period.

Table 4. Distribution of recorded damage on different kinds of window, all types of units included.

Kind of window	Number of units checked	Damage frequencies		
		1963	1973	1983
Fixed windows	1027	10	30	55
Horizontally pivoted windows	515	11	30	54
Sidehung windows	121	7	20	55
Top- and bottom-hung windows	79	19	48	83
Doors	27	11	33	56
Total	1769	11	31	56

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6. INFLUENCE OF COATED GLAZING ON EQUIVALENT U-VALUES FOR WINDOWS

Anker F. Nielsen

INTRODUCTION

The most well known simplified method for calculation of energy consumption is the degree-day method. The degree-day is the integrated value of the temperature differens between indoor and outside climate during the heating season. By multiplying the degree-days with the specific heat loss of the building, the energy consumption is found. But it does not take into account the effect of the heat gain from internal sources and insulation. This is treated by not using the indoor temperature as the base of the degree-day, but an lower temperature. This method is acceptable for internal gains, that is nearly constant each month trough the year. For solar heat gain it is not so easy, as the amount of sun is changing from month to month. In old houses without thermal insulation the fault is not very large, but for new hightly insulated houses the results could be quite misleading.

THE ENERGY BALANCE OF THE WINDOW

The window has two effects on the energy balance - first it is a part of the thermal loss of the building and second it is giving solar heat gain.

Heat loss

The heat loss is described in the U-value of the window, as it can be calculated or measured from the materials used. The U-value inclueds both the value of the frame and the glazing. As the glazing is the part of the building with the lowest U-value, a lot of work has been done by using more panes, selective coatings on the panes and gas-fillings in the cavity.

Solar heat gain

The solar heat gain is described as the amount of energy coming into the building through the glazing. The energy includes both direct radiation and secondary heat from absorption in the glasses. The solar heat gain is dependent on the number of panes and the selective coatings on the panes.

Utilization of the solar heat gain

From the previous information it is possible to calculate both the heat loss and the solar heat gain. From the difference we get the energy balance. But that is not correct because we can not be sure that the solar heat gain can be utilized in the building. It depends on the heat loss of the rest of the building, the total area of glazing, the climate and the internal heat gain.

THE EQUIVALENT U-VALUE

The energy balance of the window is found from the heat loss and the utilized solar heat gain. The equivalent U-value is defined as:

$$U_e = U - (Q_S \cdot a) / (24 \cdot DD) \text{ W/m}^2\text{K}$$

where U is the ordinary U-value

Q_S is the solar heat gain

a is the utilization factor

DD is the degree-days.

This equation shows that the equivalent U-value is not only dependent on the material properties of the window, but also of the building (utilization factor) and the climate (solar heat gain and degree-days). The equivalent U-value will describe a window type, but the value is not useful, if we do not know under which conditions it is calculated.

THE NORWEGIAN BUILDING CODE

In the Norwegian building code from 1981 and Norwegian Standard NS 3031 equivalent U-values have been inclued for calculation of energy consumption and criteria for the amount of glazing that is allowed in a building. The equivalent U-values have only been stated for ordinary clear glass panes as shown in table 1.

These values are not correct in real buildings, and it do not include the new glazings with coated panes and gasfillings. These glazings can be described by two parameters - the U-value (U) and the relative solar factor (S). The last is defined as the solar heat gain for the glazing divided by the solar heat gain for ordinary double pane. Measurements of these two parameters are found in Heiersted and Nielsen 1983. The Norwegian Building Research Institute has made formulas, that can be used for all types of glazing. The table 2 gives the values that have been made to fit with the building code on the ordinary double and triple pane.

CALCULATIONS OF THE EQUIVALENT U-VALUE

From calculations of energy consumption in buildings with the EFB 1-method (Nielsen 1984) it is possible to calculate the real equivalent U-value. This has been done for a single family house placed in Oslo 59°56 (figure 1) and in Tromsø 69°39 (figure 2). The calculations have been done for different window area, orientation and solar factors. The first m^2 of window area will always give the lowest equivalent U-value. That is because the solar heat is small and the utilization factor is high. When the window area increases, the equivalent U-value will always be higher. That is explained from the utilization factor that will decrease when the solar heat gain increases and the heat loss do not increase in the same tempo. The variations from the climate is great specially for southfacing windows. The values do not fit very good with the equivalent U-values in the Norwegian building code - specially not for ordinary window areas between 15 and 25 m^2.

DESIGN METHODS FOR WINDOWS

The use of the equivalent U-value as a method to select windows for a low energy consumtion in a building is not very good. The equivalent U-value depends on a lot of parameters:

- U-values of the window
- solar factor of the window
- transmission and ventilation losses of the building
- window area and orientation
- internal heat gain in the building
- solar climate of the location
- temperature climate of the location
- the calculation period (month/winter/year)

This shows that it would be very confusing for the architect and engineer to use the equivalent U-value. We have found, that the use of a design chart will make it much easier for the consultants. This is described in the papers (Nielsen and Heiersted 1983) and (Heiersted 1984). In reality these design charts are another way of giving an equivalent U-value, but it is easier to use and decribe. It is important to get away from the ordinary building codes that only state the ordinary U-value and do not take the solar heat gain into account. But the ordinary equivalent U-value is not to be recommended.

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Window	Orientation	Equivalent U-value
Double pane $U=3.0\ W/m^2K$	south west/east north	0.0 0.8 2.3
Triple pane $U=2.1\ W/m^2K$	south west/east north	- 0.6 0.4 1.5

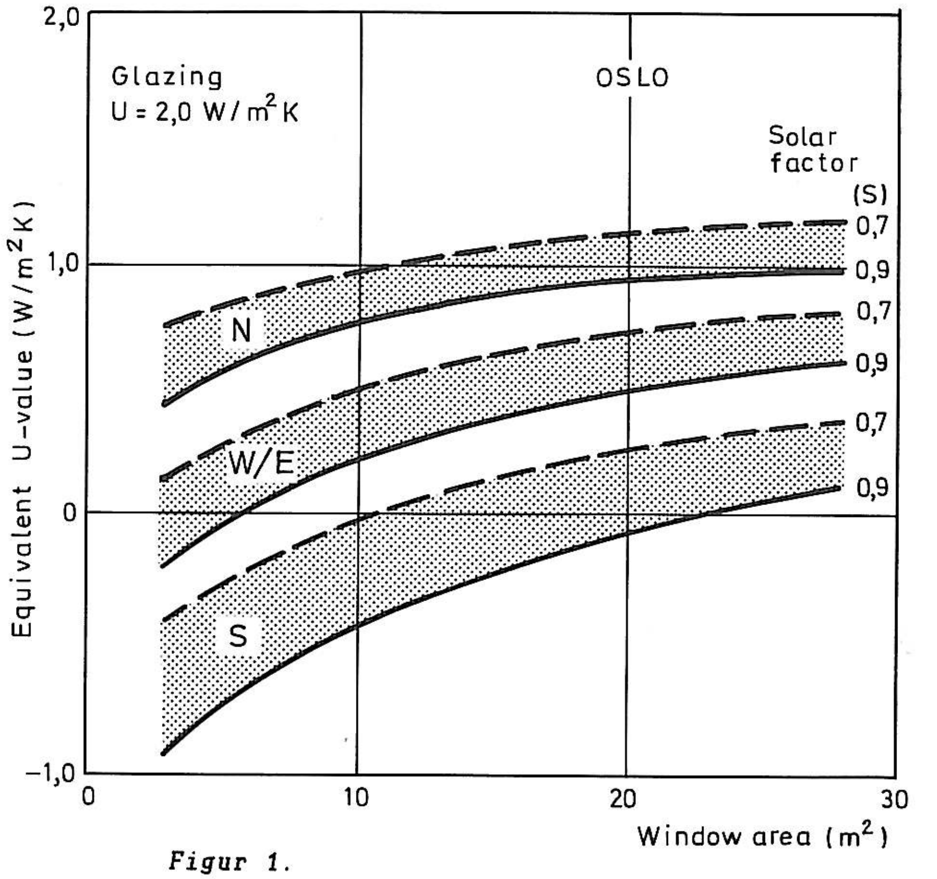
Table 1.

Equivalent U-values from NS 3031

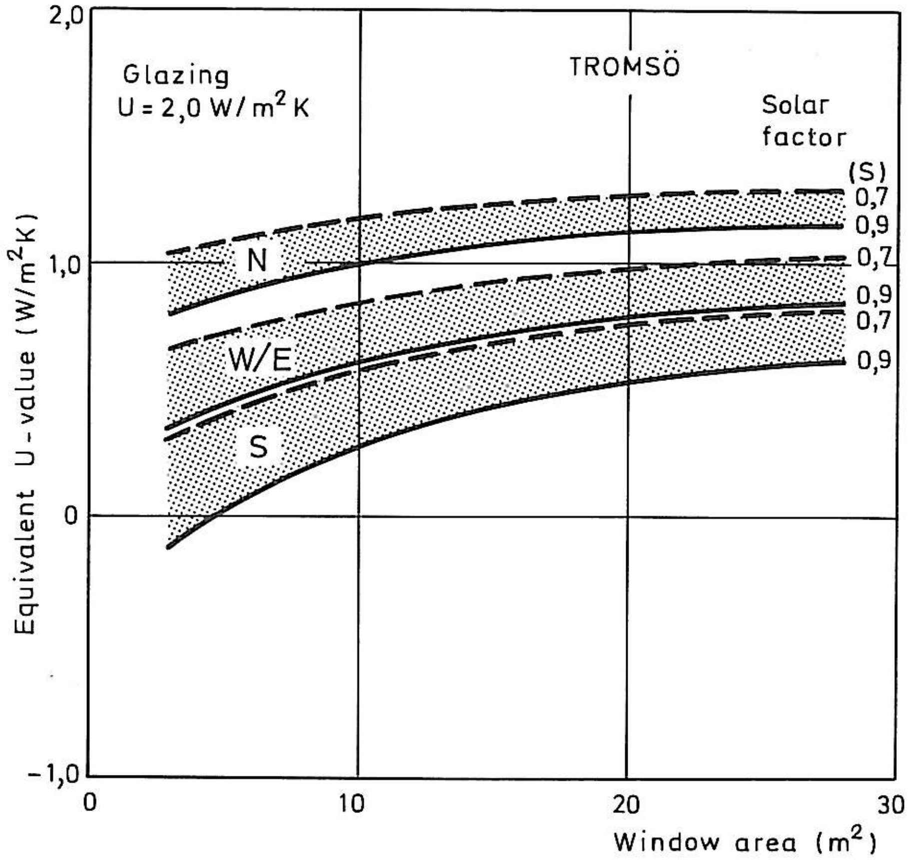
Orientation	Equivalent U-value
south	$U_e = 0.7U - 1.2S - 1.0$
west/east	$U_e = 0.5U - 0.7S$
north	$U_e = 0.9U - 1.1S + 0.6$

Table 2.

Formulas for coated glazing, supplement to NS 3031. U is ordinary U-value. S is solar factor.



Figur 1.
Equivalent U-value for single family house with ordinary triple panes in Oslo



Figur 2.
Equivalent U-value for single family house with ordinary triple panes in Tromsø

7. EFB 1. ENERGY CONSUMPTION CALCULATION METHOD

Anker F. Nielsen

INTRODUCTION

In the planning and design phase it is important to calculate the energy consumption for the building, if a low energy consumption is wanted. As an example - what happens if we change the window area or the type of glazing? We could take an complex computer program that is using hourly values an a lot of input data. In most cases it would be timeconsuming and expensive. We could instead take the simplified method known as degree-day-method. It is fast and easy to use, but the results is not reliable for highly insulated buildings and coated glazings. The best method will be to use a simplified method, that is based on results from a complex computer program and verified against it later. The EFB 1 is a method of this type developed at the Thermal Insulation Laboratory in Denmark (Nielsen 1979). IEA (International Energy Agency) has made a evaluation of methods for calculations of energy savings in residential buildings (Källblad 1983). One of the methods is EFB 1, that has been found to have hight or medium confidence in energy saving results.

PRINCIPLE

In EFB 1 the calculations are done month by month from three quantities:

- The transmission and ventilation heat loss of the building.
- The internal heat gain from persons, electric appliances and hot water.
- The solar heat gain from insolation through the windows.

From these three montly values we calculate two limits for the energy consumption Q_{min} and Q_{max}. The real consumption will be between these limits. The actual value is dependent of the heat accumulation in the building.

Transmission and ventilation loss (Q_{TV})

For every month we caluclate the transmission loss from the building design, areas and U-values. The ventilation is calculated from the volume, fresh air shift, specific heat of air and temperature differens. As indoor temperature is used the mean value f.inst. 21°C. As outdoor temperature the monthly mean temperature.

Internal heat gains (Q_I)

The internal gains from persons and electric appliances is calculated based on evaluation of the use of the building. The value can change from month to month.

Solar heat gains (Q_S)

Based on size and type of the windows the insolation through the windows can be calculated. The insolation of 1 m^2 double pane is calculated and tabled for different directions of the window. The solar gain is calculated as insolation times area times relative solar factor. The last value is defined as the amount of energy going through a certain window divided by the energy going through a normal double pane. Values of the solar factor is found in Heiersted and Nielsen 1983.

Limit values for the energy consumption.

The minimum energy consumption is calculated considering that heat gain from sun, electric appliances and persons for one month can be utilized 100% to cover transmission loss and ventilation loss. A house with such high heat capacity is practically impossible to build. If the heat gain is bigger than the consumption it will cause a useless heat surplus.

$$Q_{MID} = f \cdot Q_{TV}$$

$$f = 1 - 0.4027 \cdot \sqrt{\frac{Q_S}{Q_{TV}}} + 0.08388 \; \frac{Q_S}{Q_{TV}}$$

Note: If A is less than 15% of Q_{TV} then Q_S, can be utilized 100%.

Besides heat gain from insolation we have also heat gain from persons and electric appliances. For residential houses it would be most reasonable to assume that the heat supply Q_I is independent of Q_S. In other words the energy consumption can be reduced once more using the same formula:

$$Q_{MAX} = f \cdot Q_{MID} \qquad (4)$$

where f is formula with inserted values Q_I instead of Q_S and Q_{MID} instead of Q_{TV}.

By calculating $Q_{MAX} + Q_S + Q_I - Q_{TV}$ the useless heat surplus can be calculated.

Heat accumulation.

From the previous section a maximum and a minimum energy consumption is calculated. Between these two limits more exact and dynmaic calculations will be found. From experience the following can be stated; if we place Q_{MIN} as 0% and Q_{MAX} as 100% the value would depend on the construction material

40 - 50% mostly bricks and concrete
50 - 60% mostly leightweight concrete
60 - 80% mostly fibrous plaster

DATA FOR CALCULATIONS

It is important to know which data is necessary to make calculations of the energy consumption with EFB 1. The data are divided in three groups - climate data, building data and user data. The first part can not be changed. The second part can be changed in the planning and design phase. The third part gives the users influence.

Climate data.

The outdoor temperature is the mean for each month. The insolation through an 1 m^2 double pane should be calculated in kWh/month wiht windows facing north, south, east and west. These data are necessary for each location with a different climate.

Building data.

These must be calculated from the drawings and descriptions of the building. The most important is areas, U-values, fresh air shift, heat recovery and indoor temperature. For windows we need to know more because these have both heat loss and heat gain . The heat loss is calculated from U-value of the glass, U-value of the frame and the area of glass and frame. The heat gain is calculated from the glass area, the relative solar factor,the direction of the window and eventually an outdoor shading. The selction of the glazing is important as both the U-value and the solar factor could be changed. Values of these parametres is found in Heiersted and Nielsen 1983.

User data.

If we make comparisons of calculated and measured energy consumption a wide range of result could be expected. That is because of the inhabitants use the building in their own way. They can change certain data as indoor temperature, ventilation rate, indoor shading of windows and the heat gain from persons, hot water and electric appliances.

But these parameters can be taken into account in the calculation and give a better agreement between calculated and measured energy consumptions.

EXAMPLES

The EFB 1 method has been used to calculate the effect of different window sizes and different glass types. An example of the calculation will be given at the poster session. It is made as an handcalculation method but also programmed on Texas Instruments TI-59, Hewlett Pachard CV-41 and as an FORTRAN version. EFB 1 is used in Denmark and Norway, but we have tried it on other climates as descreibes in Nielsen and Heiersted 1983.

Selection of glazing.

The method has been used for calculations of energy consumption on houses with different glazings. For a singel family house in Oslo with 15% windows the energy consumption is found to be 15.5 MWh/year. The glazing has a U-value of 3 W/m^{2}K and a solar factor of 1.0. This is equivalent with normal double pane. Similar calculations has been made with other types of glzings. The resuts are best described with a relative energy consumption scale on the Y-axis, where 100% is the value for clear double pane. On the x-axis is the k-value of the glazing. In the chart is lines for different solar factors. This chart will change for different building types and glazing areas. Architects and engineers can use this chart for easy prediction of energy consumption for different types of glazings.

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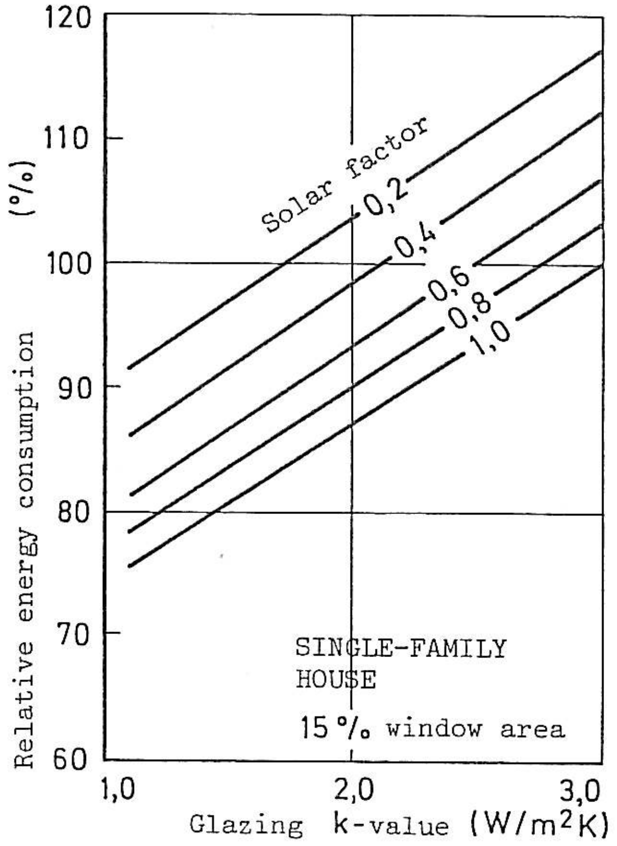

Design chart for selection of glazing in single-family houses in Scandinavian climate. The values are based on EFB 1 calculations.

8. ENERGY SAVING POTENTIAL WITH DIFFERENT GLAZING IN RESIDENTIAL HOUSES

Generalized design charts and equations allow simultaneous comparison with solar and thermal properties of different glazing products.

Roy Scott Heiersted

THERMAL AND SOLAR PROPERTIES OF GLAZING

Todays coated products have an improved thermal insulation compared with ordinary double and triple clear glass units. However, this achievement is reached by sacrificing a significant portion of the direct solar transmittance. The energy saving potensial of todays coated glazing is not significantly improved from ordinary triple units (Heiersted 1983).

Clear glass panes only have a slight influence on the annual solar heat gain. But with coated glazing the solar property of the window changes within a wide range. It seems necessary to introduce two design parameters for glazing properties in residential application, both the thermal transmittance (U-value) and the solar heat gain (Solar factor).

Thermal transmittance (U-value)

It is the U-value of the glazing itself which is to be used as variable in the design charts and equations. Make sure the U-values of comparing glazing products refer to the same test method or the same calculation model.

The most significant improvement of U-valus of glazing lies in the coating technology on glass. The limit to the low emissivity property is the visible effects as daylight transmittance and colour toning and -rendering (Breder 1984).

Solar heat gain (S-factor)

The total solar heat gain through a particular glazing is given relative to a double glazing of 4 mm clear glass panes.
This ratio is named the Solar factor, and not a shading coefficient to emphasis that a high solar heat gain is considered a favourable property in residential use in colder climates.

Because the coated glazing significantly reduces the direct solar transmittance, todays products of low emissivity glazing actually benefit from the fact that the coating absorbs just as much as it reflects. The absorption in the inner glass helps improving the solar heat gain quite similar to three layers of clear glass (Heiersted 1983).

CALCULATING THE ENERGY DEMAND OF HOUSES

Differences in the solar property of glazing may lead to higher energy demand even if the thermal insulation of the glazing is improved. It is important to point out this delicate balance of the solar and thermal properties. To check the significance of each product, calculations of energy consumption are made in four different houses.

During the computer calculations with the EFB-1 method, all parameters of the house except the solar and thermal properties of glazing are kept constant (Nielsen 1984).

Table 1

U-value and Solar factor

Thermal and solar transmittance and the relative solar factor of glazing products (examples)

Glazing unit	U-value (W/m^2K)	Solar transmittance Direct + Secondary= Total	Solar factor
Ordinary glass,			
Double, 12 mm air	3.0	70 % + 7 % = 77 %	1.00
Triple, 2x12 mm air	2.1	61 % + 10 % = 71 %	0.92
Solar control coating,			
Gold + argon	1.7	36 % + 10 % = 46 %	0.60
Gold + argon	1.6	22 % + 6 % = 28 %	0.36
LE-coated, double,			
Tinoxide + air	2.0	47 % + 24 % = 71 %	0.92
Silver + air	2.0	46 % + 13 % = 59 %	0.76
Silver + argon	1.8	46 % + 14 % = 60 %	0.78
LE-coated, triple,			
Silver + air	1.5	40 % + 15 % = 55 %	0.72

Table 2

Areal heat-loss ratio

Transmission and ventilation heat-losses for the glazed area and the total building envelope of the reference houses

House	Windows $x = U \cdot A_w$ (W/K)	Building envelope and Ventilation $y = \Sigma U \cdot A + Q_{vent}$ (W/K)	Areal heat-loss ratio $A = x/y$
DS15	54.0	144.0 + 44.1 = 188.1	0.287
DS25	90.0	177.0 + 44.1 = 221.1	0.407
TH15	49.5	99.1 + 47.6 = 146.7	0.337
TH25	82.5	129.3 + 47.6 = 176.9	0.466

Reference houses

The calculated houses are insulated according to the Norwegian Building Code, with U-values for walls and floor/ceiling about 0.25 - 0.30 W/m^2K. The ventilation rate is half on air change per hour, and the free heat from people and electricity is 6500 kWh/year.

The solar heat gain utilization in the reference houses correspond to a middle-to-light weight building structure. The four different houses (Nielsen 1983):

- Detached single-family house of 120 m^2 living area and 15 % window-to-floor area (DS15)
- Same single-family house with 25 % window area (DS25)
- Terraced house (town house) of 110 m^2 living area and 15 % window area (TH15)
- Same terraced house with 25 % window area (TH25)

Areal heat-loss ratio (A-ratio)

All the reference houses intially use a sealed double glazing unit of U = 3.0 W/m^2K and S = 1.00 (Solar factor) to simulate a 100 % energy demand. Table 2 shows the various heat-losses in the reference houses. The A-ratio (Areal heat-loss ratio) for the double glazing will in a following chapter bridge the individual buildings into one generalized model.

DESIGN CHARTS FOR RESIDENTIAL HOUSES

By introducing an ordinary double glazing as a reference, the relative energy demand caused by other glazing products become equal for most climates. Even the geographical orientation of the building is neglected by the relative scale. Meaning there is allways a 100 % energy demand with double glazing for any building, climate and orientation (Heiersted 1983).

This leads to design charts and equations which let architects and consultants easily handle both the thermal insulation and the solar heat gain properties of the glazing simultaneously.

Fig. 1 shows the design charts for the two detached single-family houses with 15 % and 25 % window-to-floor area. Fig. 2 shows the same diagrams for the terraced houses.

The relative energy demand for each house may be expressed as equations (Eq. 1):

- House DS15. Single-family, 15 % windows

  $E = 81.29 + 13.25 \cdot U - 21.04 \cdot S$ (%)
- House DS25. Single-family, 25 % windows

  $E = 70.49 + 19.23 \cdot U - 28.18 \cdot S$ (%)
- House TH15. Terraced, 15 % windows

  $E = 75.85 + 16.21 \cdot U - 24.48 \cdot S$ (%)
- House TH25. Terraced, 25 % windows

  $E = 63.44 + 22.71 \cdot U - 31.56 \cdot S$ (%)

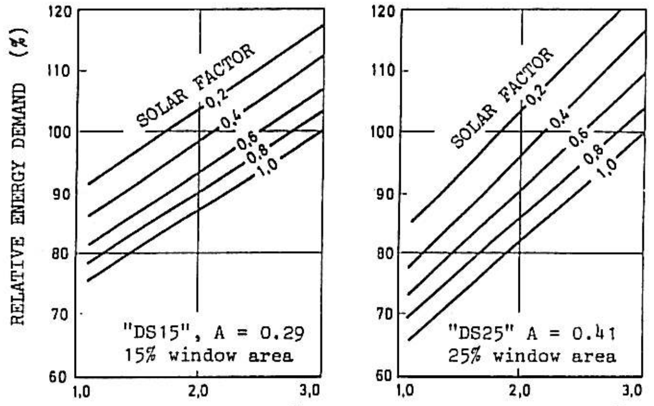

Fig. 1. Relative energy demand in detached single-family houses.

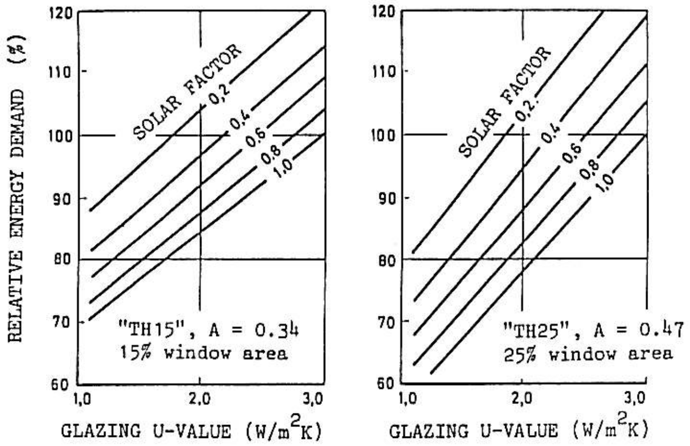

Fig. 2. Relative energy demand in terraced houses (town houses).

MODELLING A MULTI-BUILDING EQUATION

The indivitual equations (Eq. 1) for the reference houses show a variable sensitivity to changes in the U-value and the S-factor. There is an obvious dependance of the window-to-floor ratio and the heat-losses in the windows and building envelope.

To allow a simpler mathematical regression, these equations may be rewritten:

$$E = 100 + B\cdot(3-U) + C\cdot(1-S) \qquad \text{(Eq. 2)}$$

By linear regression the coefficients (B) to the U-value and (C) to the S-factor are expressed as functions of the A-ratio, i.e. the areal heat-loss ratio of the windows versus the building envelope and ventilation (table 2). Data for the reference houses give:

$$B = 1.45 - 51.57\cdot A \ (n = 4,\ R^2 = 1.00)$$
$$C = 4.64 + 57.92\cdot A \ (n = 4,\ R^2 = 1.00) \qquad \text{(Eq. 3)}$$

The multi-building equation is modelled from the rewritten Eq. 2 and the substitution of Eq. 3. The relative energy demand for detached and terraced houses (Eq. 4):

$$E = (108.99 - 96.79\cdot A) + U\cdot(51.57\cdot A - 1.45) - S\cdot(57.92\cdot A + 4.64)$$

where, E(%), relative energy demand, compared with double glazing in the same building

U(W/m^{2}K), thermal transmittance

S(-), relative solar heat gain (solar factor)

A(-), areal heat-loss ratio

The limitations to the multi-building equation do only depend on the areal heat-loss ratio of the windows, as long as the floor area and the standard of insulation are fairly compareable to Scandinavian residential houses.

The areal heat-loss ratio may be interpeted:

A = 0.0 when there is 0 m^2 window area

A -> 0.7 for extreme large window area

Proposed limitation, $0.55 > A > 0.15$

CONCLUSION

The design charts for the relative energy demand and the multi-building equation are straight-forward tools in the prediction of energy saving potensial of different glazing products. The basic concept, however, is to compare alternative glazing in the same building.

This way of treating energy saving may be seen as just an other way of presenting the "energy U-value" or the more requently called Equivalent U-value of windows. The aim of the equivalent U-value is to combine the solar and thermal properties of glazing with the solar heat gain ultilization in buildings (Nielsen 1984).

And for the more experienced user, even different glazing in different buildings may be compared. But then we initially need an estimate on the energy demand expressed in (kWh) for any glazing in both of the buildings. By transforming these energy demands to the percentage scales, we will for instance be able to predict whether a 27 % window area with a special LE-triple gasfilled glazing is competitive with 20 % ordinary triple glazing.

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9. TEST METHOD FOR DURABILITY OF PVC-WINDOWS

Ing. Carsten Dreier

INTRODUCTION

There has been no durability tests on windows except for weather-o-meter tests on surface treatments. For wooden windows, such a test can establish the frequency of maintenance, but not tell how long a window will last without any special treatment.

For windows made out of so called maintenance-free materials, we needed a test method to evaluate the different types of raw material combinations resistant to climatic exposure.

PVC extrusions for window profiles were introduced in Middle Europe more than twenty years ago. The experience with these windows on natural exposure is of great value, but the material technology runs very fast, bringing new and perhaps better suitable materials for window constructions. Thanks to that, the gained experience in the material behaviour over the last twenty years is of less importance and can not be transferred directly to the new developed materials and constructions.

Therefore a test method for durability was needed to save time and get a quick answer to the questions involved.

TEMPERATURE CYCLING TEST

We know that the most important climatic factors affecting facade materials are wind, rain, sunshine and temperature, of which sunshine and temperature will affect the PVC in a special way. In the Scandinavian countries with long and hard winters, also rapid temperature changes are of importance to establish the lifetime of a PVC construction.

Thanks to that knowledge, the temperature had to be involved in a new test method, and based on earlier experience with all kinds of window testing, we started the work with the special method for white PVC construction.

In the first experimental series we introduced 4 different PVC extrusions in windows together with 2 types of wooden windows. After measuring rain and wind penetration, all windows were installed into a well insulated wall between two chambers. The temperature in the "hot" chamber was +23°C during the whole test. In the cold chamber, the temperature was kept on -30°C for 10 hours, and then changed to +65°C for 14 hours. The cycle was repeated for 30 days.

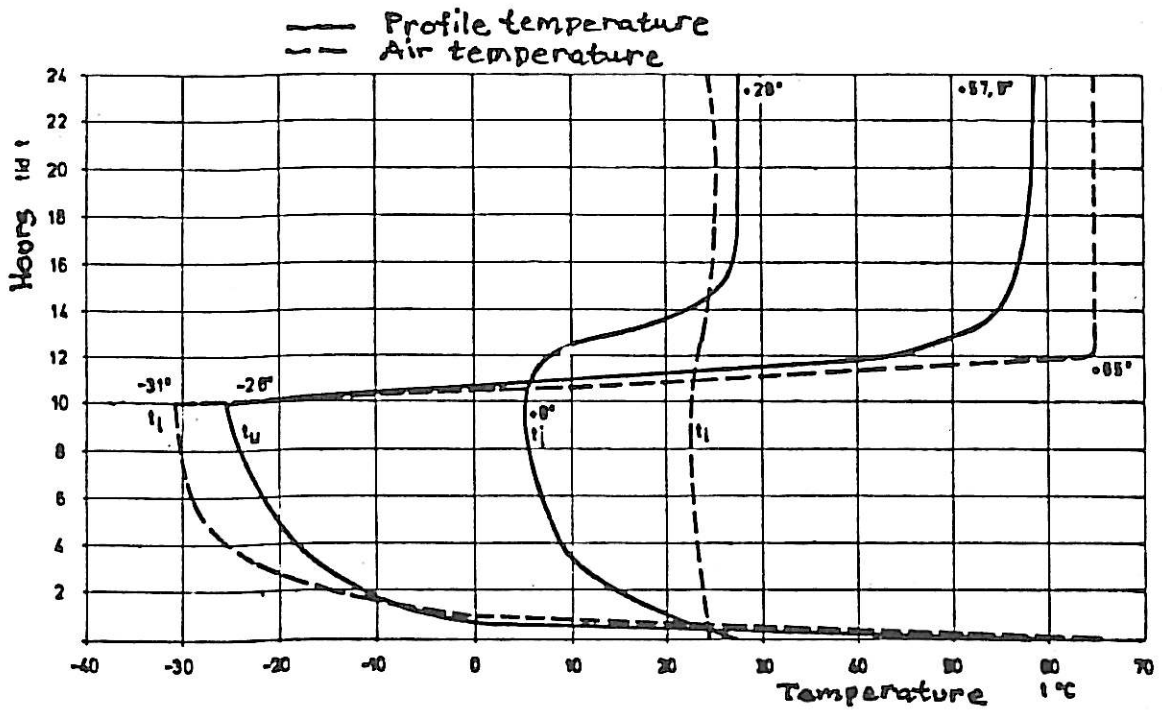

Figure 1

During this period all deformations of sashes and frames were measured, and the first test period ended with a new rain and wind penetration test.

The deformation which occurred on the PVC test windows had exactly the same characteristics which we have seen on windows in practice, while no deformation at all could be measured on the wooden windows.

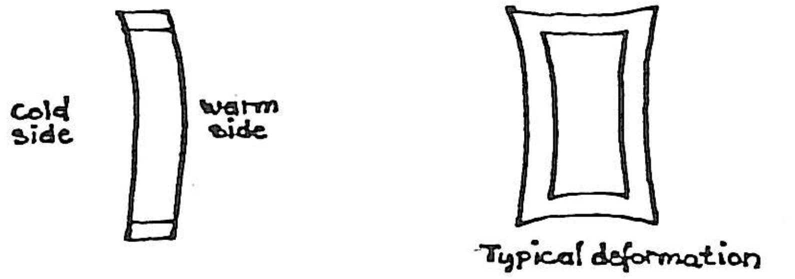

Figure 2

The repeated rain and wind penetration test showed clearly the increasing leakage thanks to the deformation, more or less on the different constructions. The measured deformation curve also showed that the deformation in the cold period of the test cycle did not quite return to the origin during the hot period, and we got what we call a permanent deformation on the windows.

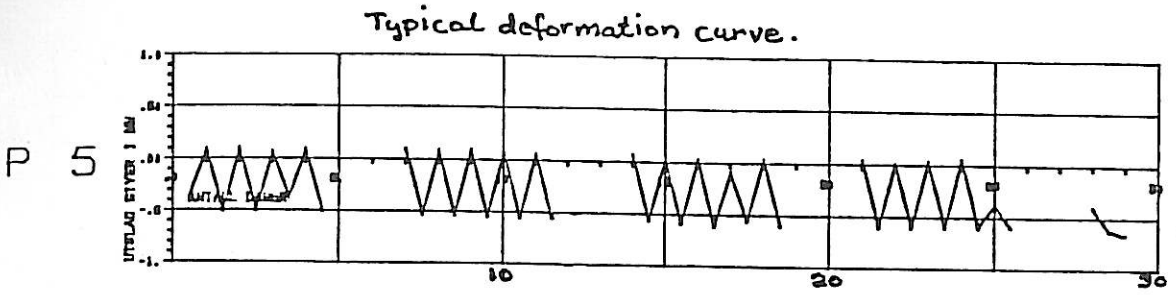

Figure 3

On PVC profiles reinforced by means of aluminium or steel channels, the movements were less than on not reinforced ones, and the constructive details of the different profile systems effected the movements and the deformation.

After a resting period of 3 months, where the deformation was naturally reduced, we started another 30-days cycle period with temperature variations. The same happened again with slowly increasing deformation, and also the air and water leakage increased.

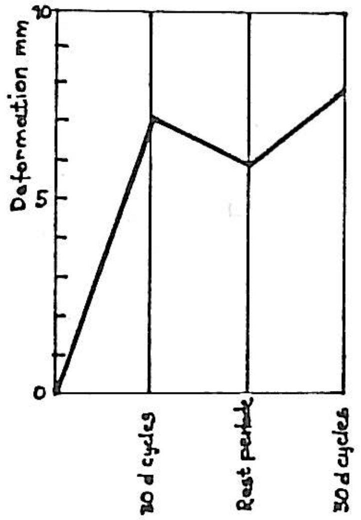

Figure 4

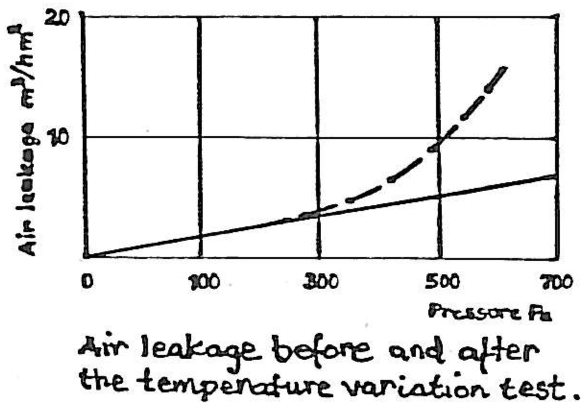

Figure 5

CORRELATION WITH PRACTICAL EXPERIENCE

We had now found a method for testing durability of PVC windows in the laboratory. But what about the number of cycles and the correlation with practical conditions?

Measurements on 15 years old windows installed in Germany gave us the answer. We measured exactly the same type of deformation which we had produced in the laboratory. And the dimensions of the deformation increased according to the age of the window.