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Economic Factors of Window Design and Related Aspects on Lighting

Fenêtres – aspects économiques et éclairage

Fenster – wirtschaftliche und beleuchtungstechnische Gesichtspunkte

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SUMMARY

The economic aspects on windows are related to the functions: get daylight into the building and let solar radiation contribute to heating the building. Overheating should however be prevented. An algorithm for the economical optimization of the window design is presented. The results of a manual calculation of the energy balance is shown. In the particular case the solar gain and losses through the windows balance each other. As to lighting a simple method for the estimation of indoor daylight is discussed.

RÉSUMÉ

Les considérations économiques sur l'élément «fenêtre» doivent tenir compte de deux aspects: le passage de la lumière naturelle à l'intérieur du bâtiment et le chauffage du bâtiment par radiation solaire. De trop grandes températures intérieures doivent cependant être limitées. Une formule est proposée permettant une optimisation du point de vue économique. Le résultat d'un calcul manuel du bilan énergétique est également présenté. Dans le cas particulier, les apports et les pertes d'énergie se compensent. En ce qui concerne l'éclairage, une méthode simple est proposée pour le calcul de la lumière naturelle à l'intérieur du bâtiment.

ZUSAMMENFASSUNG

Die wirtschaftlichen Aspekte des Bauelements «Fenster» sind von Lichtdurchlass und Wärmezufluss der Sonneneinstrahlung beeinflusst. Zu hohe Innentemperaturen sind zu vermeiden. Eine Formel für die wirtschaftliche Optimierung von Fenstern wird präsentiert. Das Ergebnis einer manuellen Berechnung der Wärmebilanz wird gezeigt. Im spezifischen Fall sind die Zuflüsse und Verluste etwa gleich gross. Hinsichtlich Beleuchtung wird eine einfache Methode zur Berechnung des Tageslichts im Innenraum erörtert.

1. INTRODUCTION

The window is one of the most complex and interesting components of a building. It is not only an "eye to the wind", as its etymology suggests, with aesthetic architectural qualities - it also has an impact on the economics of a building. The rise in energy costs and recent improvements in glass qualities, window design and lighting efficiency make it possible to find favourable solutions. These must then be seen in the context of the total building economics, i.e. from a system point of view. This study deals mostly with the parameters which should be considered and also makes tentative suggestions on the method to be followed.

How important is the window in the economic equation? In northern countries, solar gain through the windows can amount to one-third of annual heating requirements. The present study shows that heat losses through windows and solar gain can balance each other out during the heating season.

Another aspect is that the lighting costs of a building are of the same order of magnitude as the heating costs. Under less favourable conditions, as reported by Sterios et al. [11] from New Zealand, lighting costs are about three times as high as heating costs.

This clearly demonstrates that the window is a prime candidate for examination.

2. FUNCTIONS OF THE WINDOW

The window has many functions, but we shall confine ourselves here to the following:

- Admitting daylight into the building;
- Allowing solar radiation to contribute towards heating the building during the heating period;
- Limiting the penetration of solar radiation during the summer;
- Limiting thermal losses to the environment;
- Facilitating controlled natural ventilation;
- Protecting against noise from the environment.

Let us start with the two main aspects: the heating and the lighting of the building. They are interlinked, in that solar energy entering through the window and energy from lighting both have a heating effect. Furthermore, the more daylight enters through the window, the less lighting is needed.

3. THE ANNUAL ENERGY BALANCE

In seeking solutions, one should look for calculation methods that can easily be used by architects and that they will find meaningful. They should give answers to questions such as: "What happens if I increase fenestration with southern or western exposure, etc.?"

A method such as the one described by Öfverholm [9], based on cost geometry, could give a first indication, provided that the method is refined enough to give answers. The method sought must be transparent to the user, who must be able to understand how the various factors influence the end result. To illustrate this, we take the case of an office building described by Öfverholm [8]; the data have been slightly changed and recalculated in the light of climatic and economic conditions in Austria.

It is evident from the data presented below that energy plays a significant role and that the solar gain is considerable. Both statements indicate the desirability of increasing the size of windows. This would, however, make it necessary to guard against overheating through the sun during the summer. Thus, the costs for protection against the sun must be considered. The method used for the calculation is described by Källblad et al. [5]. It is based on the energy balance:

$$W_H = W_{Tr} + W_V - W_{Pe} - W_{Li} - W_{Sun} \quad (1)$$

where:

- W_H = energy required for heating;
- W_{Tr} = transmission losses through the walls, windows, floor, roof, etc.;
- W_V = ventilation losses;
- W_{Pe} = occupancy heat (from persons);
- W_{Li} = losses from lighting;
- W_{Sun} = gain from solar radiation through the windows.

The calculation is carried out separately for each month. The outdoor temperature is taken as the average temperature during a month. Thus, a constant requirement for heat for each month can be used in calculations if the gain from solar radiation is dealt with separately.

The energy balance for a year is calculated from the monthly data in MWh.

	Losses		Gains			
	Transmission	Ventilation	Lighting	Persons	Sun	Heating
January	104	121	17	15	26	168
---	-	-	-	-	-	-
April	49	52	13	15	51	21
October	51	54	17	17	49	22
---	-	-	-	-	-	-
December	95	114	19	16	23	151
Total for October to April	537	626	117	115	277	655

Table 1. Energy balance by month.

If we consider the windows according to their exposure, we obtain the following picture:

	South	West + East	North	Total
Losses in MWh	117	121	42	280
Gains in MWh	162	92	23	277
Net MWh	- 45	+ 29	+ 19	+ 3
Effective U-value W/°C m²	Negative	0.38	0.72	0

Table 2. Annual energy balance, considering only the windows.

This demonstrates the importance of a southern exposure of windows in the utilization of solar energy. It should be pointed out that the values given were calculated for an Austrian climate and for fenestration of only 20%. Fenestration was calculated as the glazed area divided by the total area of the external wall. The window design selected is a low-emission insulation glazing with an assumed U-value of 1.6 W/m², °C, an energy transmission coefficient of 67% and a light transmission coefficient of 79%, i.e. almost the best values obtainable today, see Balkow [1].

A remark could be made about window frames. Out of the 280 MWh mentioned in table 2, window frames account for about 70 MWh, i.e. approximately one-quarter of the total losses through the windows. There is, however, no solar gain through the frames, which underlines the need to reduce the area of the frames as far as possible. From the energy conservation point of view, the frames are often the weakest element of the building.

4. LIGHTING FACTORS

The energy obtained from lighting is often regarded as a utility that is obtained free of charge because the building has to be illuminated in any case. This reasoning is not correct, particularly when electricity costs are substantially higher than those, say, for gas or oil. In Austria, 3:1 ratios of electricity/gas unit costs might even be arrived at. If future trends are considered, an average of 4:1 might be arrived at over the life-cycle.

Let us apply the 3:1 cost ratio to the energy figures for one year:

- Energy for lighting over an entire year	170 MWh;
- Energy for heating during the heating season	655 MWh;
- Costs for lighting	3 • 170 = 510 monetary units;
- Costs for heating	1 • 655 = 655 monetary units.

This calculation shows that attention has to be paid to lighting costs. The energy required for lighting is normally calculated by assuming a W/m² figure for a specific space and by multiplying this figure by the expected yearly utilization in hours. To take the example of office space of 900 m²: this gives 900 m² • 15 W/m² • 1,500 h = 20,250 kWh. This is a crude calculation method based on the capacity to be installed for lighting. In calculating the number of hours of utilization, one can take various factors into consideration, such as:

- Normal utilization hours (office hours);
- Additional lighting time for cleaning and other operations;
- Average daily usable daylight hours during one month;
- The utilization of dimmers and/or switchable sections of lighting controlled by sensors;
- The utilization of task lighting;
- Behavioural influences on the utilization of lighting;
- Areas in which no daylight is available;
- Security;
- The cleaning of windows and light fittings.

All these factors have to be considered for a life-cycle of, say, 60 years.

The following approach may be taken in calculating the daylight which can be used: the average monthly solar radiation on an outdoor horizontal area is multiplied by a conversion factor to arrive at the illumination of a specific indoor horizontal area. For the conversion factor, the American Institute of Architects [12] has suggested as an alternative the "Daylight Factors Method". This gives a percentage (F) to be multiplied by the available exterior illumination. The method can be supplemented by the inclusion of glass characteristics and can be changed to read:

$$F = f\left(L_t \cdot \frac{W_1 \cdot H_1^2}{W_s \cdot H_s^2}\right) + f\ (R) \qquad (2)$$

where:

F = above-mentioned daylight factor in per cent;

f = relationship between F and L_t, W, H, R;

L_t = light transmission coefficient of window;

W = width of window;

H = height of window above reference plane.

The indices relate to the actual design (1) and a standard design (s) for comparison purposes;

R = a factor depending on the dimensions of the room and reflectance, primarily of the walls.

It would be advantageous if the calculations could be related to a standard room from the lighting point of view so that (R) would be the same for all alternatives. It is assumed that the distance from the window to the reference point in the room would always be the same. This simplified approach would have to be tested by detailed calculations or better still by measurement under real conditions. The second step in the calculations is to multiply F by the solar radiation on an outdoor area. It is suggested that values be selected for each month. A typical day would have to be found for each month and the calculations should be based on the variations in daylight during that day.

It would be advantageous to prepare a table such as the following, expressed in lux values for a typical room.

Time of day	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700
January										
February										

September	200	320	420	480	500	470	400	300	180	60
--------										
etc.										

Table 3. Daylight illumination in lux as a function of time of day.

The figures in table 3 should be considered as the true average lux values per hour on a typical day of the month. The differences from the desired lux value, say, 450 lux, would have to be made good by artificial lighting.

Let us consider the figures for September. The need for lighting is then 450-200 lux at 0800 hours, and the total requirement for a typical day is 1,270 lux-hours, assuming that the lighting can be controlled in infinitesimal steps. The lowest figure is 1,270. The highest figure - 7 • 450 = 3,150 lux-hours - corresponds to the case in which all the artificial lighting has to be switched on when the daylight value falls below 450 lux. A realistic figure would be somewhere between the two extremes, assuming rational use of of artificial light, see Crisp [3].

5. OPTIMIZATION

Energy requirements for lighting and heating have to be considered together. It will be recalled from the above-mentioned data that the annual costs for lighting and heating were 510 and 655 monetary units, respectively. In that context, the cost per kWh for lighting is taken to be (α) times that for heating. This means that a weighting factor of (α) would be attached to savings in electricity for lighting and a factor of 1 to savings in thermal energy.

These ratios will be used for purposes of optimization. It is assumed that optimization is carried out by comparing alternatives which do not differ greatly. In other words, we change the conditions by increments, so that we do not miss the most favourable solution. This is important, as we are faced with discontinuity owing to changes in technical solutions. The relationship can be expressed as follows:

$$\frac{\Delta I + \Delta M + \Delta C}{(\Delta S_1 + \alpha \Delta S_2) \cdot \gamma} \leqq E_o \tag{3}$$

where:

ΔI = incremental investment required to realize the incremental energy savings;

ΔM = present value of incremental maintenance costs over the life-cycle;

ΔC = present value of incremental cleaning costs;

ΔS_1 = incremental thermal energy saving;

ΔS_2 = incremental electric energy saving;

γ = sum of conversion factors to present value for total energy savings over the life-cycle;

E_o = current energy price for thermal energy in the form of oil, gas, coal, etc.

COMMENTS

ΔI: When solar radiation is increased, e.g. by the installation of larger windows, the additional costs for the conservation of an acceptable indoor climate during the summer must not be forgotten. There are several ways of creating such a climate, e.g. by adding thermal inertia to the building. However, verification that acceptable conditions have been met is a complicated procedure. One may have to be content with rough rules of thumb, but these limit the validity of optimization.

ΔM: Maintenance costs over a life-cycle of 60 years are generally of the same order as the investment. The figures for the differences in maintenance costs for various materials such as wood, plastic or aluminium vary from country to country, as do local preferences for particular materials. In Sweden and Austria it seems to be considered that higher maintenance costs more than offset the lower investment for wooden as compared, e.g. to plastic designs. In that context it is essential to make comparisons between good designs and not between the best plastic design and a faulty wooden design.

ΔC: The solar gain and daylight indoors decrease when the windows are dirty. It has been stated by Marklund [6] that a loss of 25% might be incurred before the windows are considered as being abnormally dirty. It is interesting to mention the order of magnitude of cleaning operation costs. In the case of one building investigated, the window cleaning costs amounted to only 2% of the total cleaning costs. As a guideline, one might proceed on the basis of 0.15 hours per m² and year, corresponding to two window-cleaning operations a year. From these figures it is possible to judge whether it pays to clean the windows more often.

ΔS: It should be noted that ΔS_1 must be adjusted for average annual boiler efficiency.

The weighting (α) attached to ΔS_2 should be adjusted to the conditions in each country.

Equation (3) can be used to establish the most favourable designs for energy conservation. It should be stressed that the impact on the energy balance should always be taken into account in optimization calculations. This is sometimes overlooked in the search for the best lighting-control devices.

6. DAYLIGHT

New solutions for making better use of daylight are being presented. Evans [4] speaks of daylight in architecture - see also Merz [7] - and Ruck [10] speaks of beaming daylight into deep rooms. Clerestories, skylights and light shelves are design elements for increasing the daylight illumination of rooms.

7. CLIMATIC DATA

The lack of climatic data on solar radiation is often quoted as an obstacle to calculation. The Austrian Federal Ministry of Construction and Technology [2] has published solar radiation data for 700 locations. They refer to 48 different climatic patterns. The average daily global radiation in Wh/m² is presented for each month for 16 different points of the compass on a vertical surface and for two types of inclined surfaces. This facilitates the calculation of the energy balance and indoor daylight. The Austrian solution is well worth studying.

8. PROTECTION AGAINST SOLAR RADIATION

During the summer there is a risk of overheating. Measures have to be taken to limit the penetration of solar radiation into the building. There are several control devices: venetian blinds, roll shades, shutters, louvres, recessed glazing, overhang, etc. In addition there are new developments, such as variable transmission and electronically controlled fenestration systems. Although such solutions are not yet commercially available, it is interesting to note that they are technically possible.

9. OTHER ASPECTS

The impact of ventilation on the energy balance for one case is shown in table 1. However, this point cannot be elaborated within the framework of this study. Suffice it to say that rules for ventilation requirements have to be laid down so that meaningful energy balances can be calculated.

There is also the problem of acoustical control. In most cases, this can be achieved, if required, by increasing the distance between window panes.

10. CONCLUSIONS

In considering the economic aspects of window design, one must take into account the effect of solar radiation on both heating and daylight illumination. New glass qualities, more efficient artificial lighting and more extensive use of daylight provide new possibilities.

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