E 330

adres Stieltjesweg 1
2628 CK Delft
postadres Postbus 155
telefoon (015) 56 93 00
telex 31614

7/00/79
Bibliotheek Hoofdkantoor TNO
's-Gravenhage

Paper presented at the CSTB-EEC symposium "Temperature without heating"
held from 16 - 18 May 1979 in Brussels.

Acceptable window sizes and required sunshading in buildings without mechanical cooling

P. Euser, Institute of Applied Physics TNO-TH, Delft

TNO
5250

Bibliotheek Hoofdkantoor TNO
's-Gravenhage

1. Introduction

In the design stage of a building the question often arises whether the considered façade construction and compositions will provide an acceptable indoor climate in summer if no mechanical cooling will be applied.
Since computer programmes are available for the calculation of indoor temperatures and heating and cooling demands in buildings, in principle, it has become possible to give a good prediction of the indoor climate. Especially recently developed programmes offer various possibilities and they give results which have proved to be reliable. Some programmes can take actual meteorological data into account which results in a fairly realistic simulation of the dynamic thermal behaviour of the building.
Although the use of these programmes increases, there appears to be a need for a more simple, gobal method which, particularly in the early stages of building design, enables the designer to form a quick judgement. In order to meet this need the Institute of Applied Physics TNO-TH (TPD), with financial support and technical assistance of Stichting Bouwresearch, carried out an investigation in this field. This paper will give an abstract of its results. It will be explained to the designer how to determine in a fairly simple way with the aid of graphs and formulae resulting from this investigation, the thermal effect of several important properties of the building, such as façade, orientation, mass, depth. In particular it will be possible to find out which quantities and dimensions - especially as to the façade and its fenestration and sunshading - will result in acceptable comfort conditions without the application of mechanical cooling. In the other case it will be proved necessary to apply summer conditioning with the aid of a complete climate conditioning installation.
Thus the results of this investigation could contribute to the judgement of some important aspects such as thermal comfort, costs and energy consumption, a judgement which will have to be dealt with in each new building project when factors such as size, function and location of the building have already been determined.

2. Outlines of the investigation

Three different types of rooms, with for office buildings and dwellings conventional sizes and wall constructions, were chosen. For these rooms the room-air temperatures during the months June, July and August of a year considered average as far as meteorological circumstances are concerned, were calculated. The following influences were varied: glazing (single, double, normal, absorbing, reflecting, emissivity lowering coating, gas filling), sunshading (inside, outside, in between in double window), glass area, façade orientation, whereas for some other factors, such as internal heat load and the amount of ventilation air, certain starting values were chosen and only varied in some cases. From the calculated room-air temperatures both the maximum values and the number of exceedings of the two introduced temperature levels viz. 26°C and 28°C were derived. Then the derived values were worked up into a number of graphs and formulae for practical use.

3. Technical and physical starting points; definitions

The sizes and wall constructions of the *three chosen room types* (indicated by VT = 1, 2 and 3) are shown in figure 1.

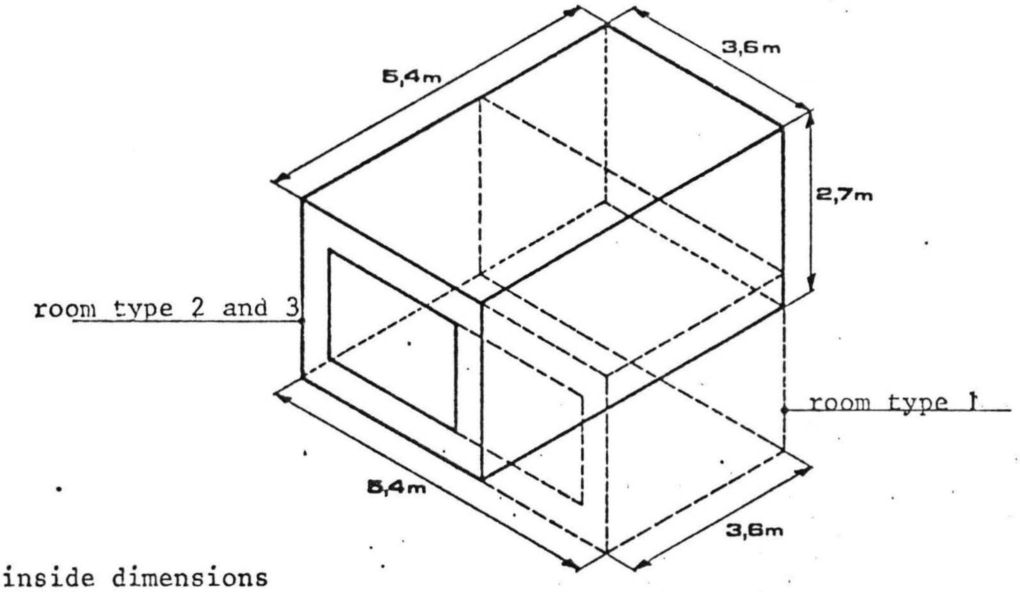
For the calculations the conditions in the adjacent rooms are supposed to be identical to the conditions in the actual room. The calculations had to be restricted to only these three, though accurately specified types of room. In order to make the final results also applicable to other types of room a *specific mass of the room SM* is introduced, defined by

$$SM = \frac{\Sigma\, f_w\, M_w}{A_{ext.w}} \qquad (1)$$

in which M_w is the mass of walls, floor and ceiling,

f_m is a weighing factor for the thermal dynamic effect of each wall,

$A_{ext.w}$ is the area (inside) of the exterior wall with glazing (glass area included).



inside dimensions

	room type 1	room type 2	room type 3
	ρd (kg/m²)	ρd (kg/m²)	ρd (kg/m²)
floor and ceiling	502 0,20 m concrete	500 0,20 m concrete	508 cavity ceiling 0,20 concrete
partition walls	260	260	40
corridor wall	40	260	40
non-transparent part of the exterior wall	- R=0,86	- R=0,86	- R=0,86 (m²K)/W
total area of exterior wall	14,6 m²	9,7 m²	9,7 m²
specific room mass SM	693 kg/m²	1521 kg/m²	588 kg/m²

Figure 1 - The main sizes of the chosen room types 1, 2 and 3, both with the mass of the walls per m² and the specific mass SM of the rooms

For the weighing factor f_w the following rough values, depending on construction and situation, can be used:

		f_w
homogeneous partition walls between identical rooms:		0.5
homogeneous corridor wall:	- when corridor conditions are identical	0.5
	- when corridor temperature is evidently lower than room temperature	1.0
floor:	- without insulating layer on floor side	0.5
	- with insulating layer on floor side	0.25
ceiling:	- without insulating layer on ceiling side	0.5
	- with insulating layer on ceiling side	0.25
outside wall		0.5

Pillars and other massive elements or objects are to be accounted for separately. When located entirely inside the room the f-value of these elements may assumed to be = 1. Also the 'remaining' corridor mass could be accounted for by adding a separate term or by taking f_w of the corridor wall > 1, although it is obvious that this should be dealt with with care.
Also it will be clear that the factor SM only gives a rough estimate of the dynamic behaviour of a room. The less a room differs from the here chosen room types, the more accurate the result will be in case of inter- or extrapolation. For practical reasons the value of SM should be easily determinable. It seems that the chosen description and use of SM comes up to this requirement.
The composition of the non-transparent part of the (one) *outside wall* was not varied at first. This part of the wall was supposed to be built up from insulation material with a negligible heat capacity and a heat resistance of (conventional at the time) 0.86 (m^2.K/W).
In some cases a higher heat resistance and/or heat capacity was used. Therefore, nominally, variable was only the area, depending on the variably chosen glass area.
For the basic calculations the glass area was varied in steps of 25, 50 and 75% of the total inside area of the outside wall. This factor is here called *glass percentage* referred to as PG. In the final results in some graphs the glass percentage is presented as a continuous variable, in other graphs as a discrete variable.

Another factor which, as the glass area, strongly determines the solar heat gain and consequently the indoor temperature, is the *solar entrance factor* ZTA of the sunshading system (always to be considered consisting of glazing + sunshading material, if any). The factor ZTA (in Dutch: zontoetredingsfactor absoluut) is defined by (see also figure 2):

$$ZTA = \frac{\text{solar energy entering the room through the sunshading system}}{\text{the incident solar energy outside the sunshading system}} \qquad (2)$$

condition: indoor temperature = outdoor temperature.

As to the transfer of (solar) heat in the sunshading system, the solar entrance process has not been completely described by the ZTA-factor. So, as to the increase of the room air temperature it is of importance to know which part of the entering heat comes from convection heat and which part from radiation heat, whereas for the course of the indoor air temperature during the entire 24 hours' day the heat resistance (or the U-value) of the system is of importance.

In order to express the first mentioned effect the convection factor CF has been introduced, defined by:

$$CF = \frac{\text{solar energy entering through the sunshading system by convection}}{\text{total amount of solar energy entering through the sunshading system}} \qquad (3)$$

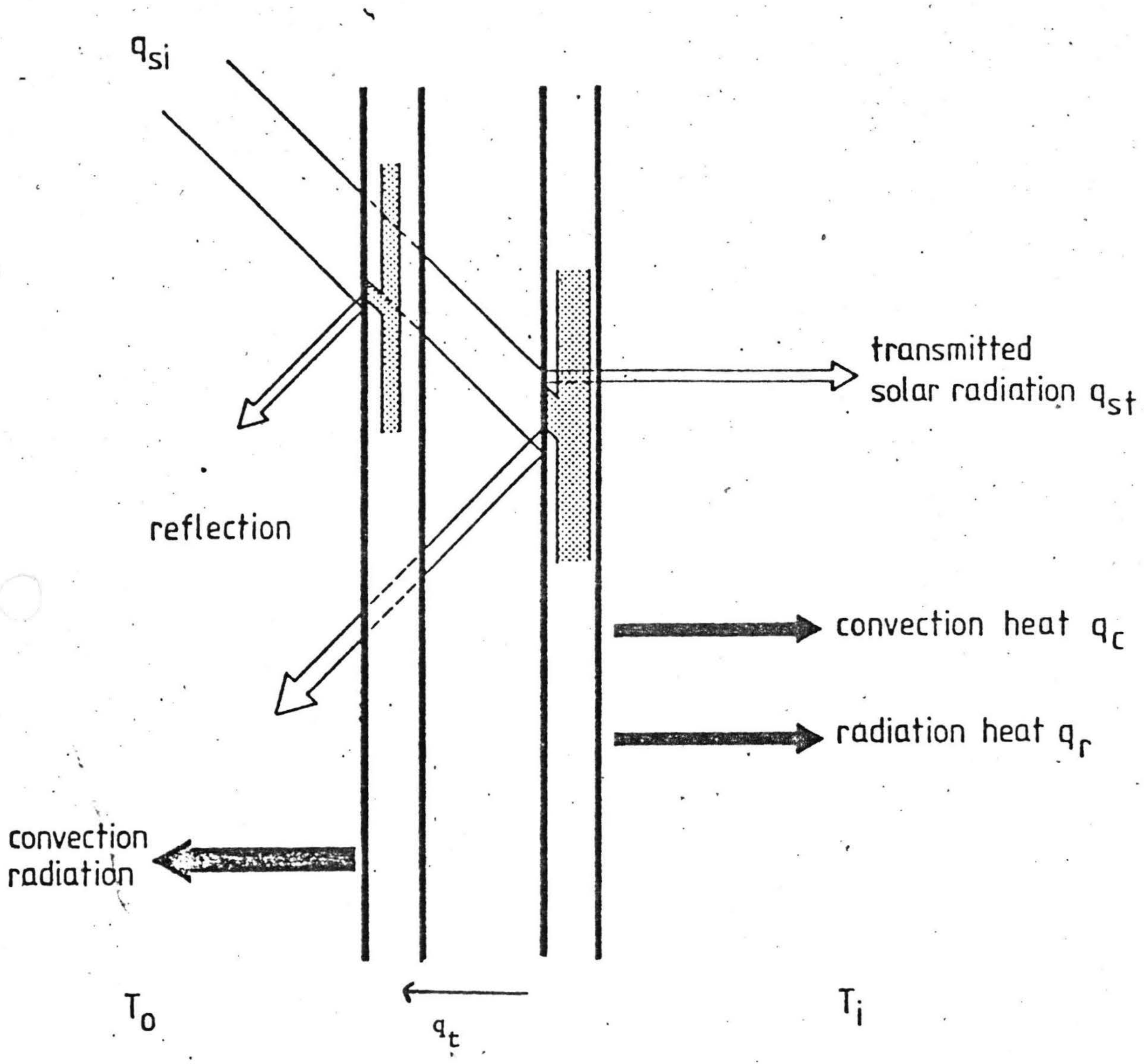
whereas the U-value is defined by:

$$U = \frac{\text{heat flow from inside to outside per area unity}}{\text{difference between inside and outside temperature without solar radiation}} \qquad (4)$$

With respect to the CF-factor, in the final results, only a distinction has been made between systems with a high CF-value (systems with indoor sunshading) and systems with a low CF-value (systems without indoor sunshading).

With the aid of these three quantities, viz. ZTA, CF and U the sunshading qualities of a sunshading system can be determined accurately enough.

The sunshading systems (indicated by ZS) presented in calculations and final results, have been divided into four main categories:



sun shading factor $$ZTA = \frac{q_{st} + q_c + q_r}{q_{si}} \quad , \quad T_i = T_o$$

convection factor $$CF = \frac{q_c}{q_{st} + q_c + q_r} \quad , \quad T_i = T_o$$

U-value $$U = \frac{q_t}{A(T_i - T_o)} \quad , \quad q_{si} = 0$$

Figure 2 - The reflection, absorption and transmission of solar radiation, the convection and radiation heat flows at the out- and inside surfaces, both with the expressions for ZTA, CF and U-value in case of two-pane sunshading system.

ZS = 1	single glass, uncoloured or coloured, possibly with outside sunshading; normal emission factors	without indoor sunshading	(1A)
		with indoor sunshading	(1B)
ZS = 2	double glass, uncoloured or coloured or reflecting, possibly with outside sunshading; normal emission factors	without indoor sunshading	(2A)
		with indoor sunshading	(2B)
ZS = 3	double glass, sunreflecting, provided with a coating having a low emission factor	without indoor sunshading or curtain	(3A)
		with indoor sunshading or curtain	(3B)
ZS = 4	double glass with gas filling; coating with low emission factor, possibly provided with outside sunshading	without indoor sunshading	(4A)
		with indoor sunshading	(4B)

In the investigation some varieties of systems with double glazing and sunshading in between the two window panes were considered separately because of their specific composition, in particular when the cavity between the two panes is ventilated. However, provided it is well interpreted, this sunshading system can be defined and dealt with through ZTA, CF and U-values sufficiently within the scope of the four above-mentioned categories.

It remains to be mentioned, that for the computer programme with which the room air temperatures were calculated, the sunshading systems were not simulated by means of ZTA, CF and U, but by means of so called heat transfer network models which extensively describe reflection, absorption, and transmission of the sun radiation on the one hand, and on the other hand heat transfer to both the indoor side and the outdoor side of a system (figure 3).

Also with these network models for each 'sunshading situation' the quantities ZTA, CF (when indoor temperature = outdoor temperature) and U (without solar radiation) have been calculated; thereupon these quantities only served to make the results practically manageable. It happens to be that of several sunshading systems the ZTA, CF and U are fairly well known. Figure 4 gives a review. For more extensive data [1] and [2] are referred to.

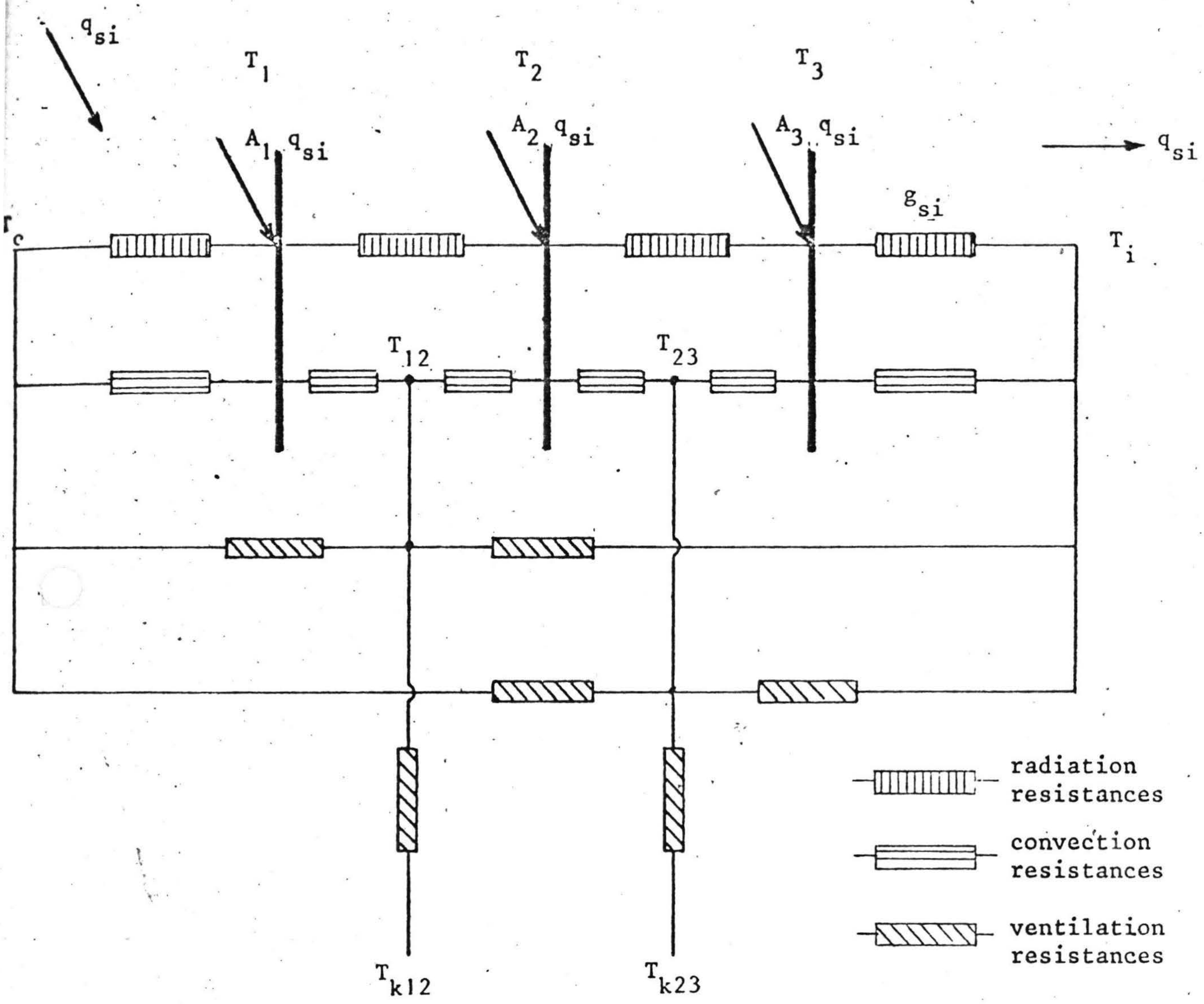


Figure 3 - Network model applied for (a) the calculation of ZTA, CF and U-value, (b) the simulation of sunshading systems in the computer programme for the room temperature calculations

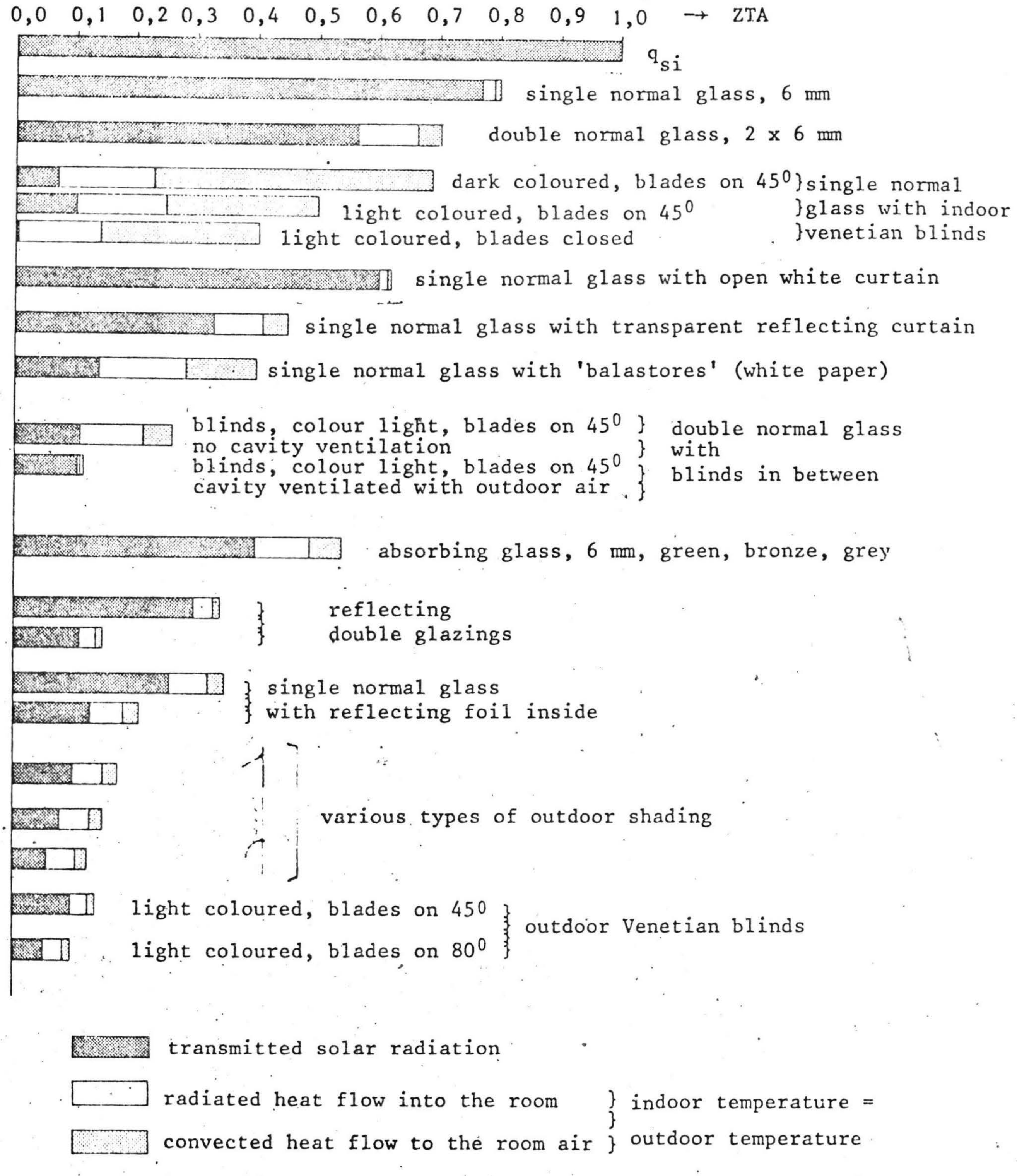


Figure 4 - The solar entrance factor ZTA for various glass types and sunshading systems

On ground of the above-mentioned considerations in all cases calculations have been carried out for a ventilation with air having a temperature equal to that of the outside air and a flow corresponding to three air changes per hour during office hours (N = 3) and half an air change out of office hours (N = 0.5), all this for a period of three months at a stretch. In some calculations lower and higher ventilation rates during office hours (N = 1 resp. 5) were performed (out of office hours the situation remained N = 0.5).

4. Caloulation method

For the calculation of the average indoor air temperature of the rooms under conditions as discussed in par. 3, a computer programme is used which was developed by TPD. The basic programme has been described in [3]. With this computer programme room temperatures and heating and cooling demands in rooms can be calculated for a limited series of days with identical solar heat loads and outside temperatures. Later a modification of this programme was made [4], applying thermal response factors, enabling the calculation of long periods without causing high computing costs. Such calculations are e.g. performed to calculate the temperature exceeding rates, as performed within the scope of this investigation, or to get to know the heating and cooling demands for a whole year as input data for the calculation of yearly energy consumptions for climate conditioning installations. For these yearly calculations weather data obtained from computer tapes from the Royal Dutch Meteorological Institute in De Bilt, were fed into the computer model in the form of hourly values, for each desired period of the years 1961-1975. This last mentioned programme for yearly calculations was used for this investigation.

Within the scope of this paper a more extensive description of the applied computer programme and the further employed calculation method cannot be given. For this purpose [3], [4] and [5] can be referred to. Figure 5 shows a block scheme.

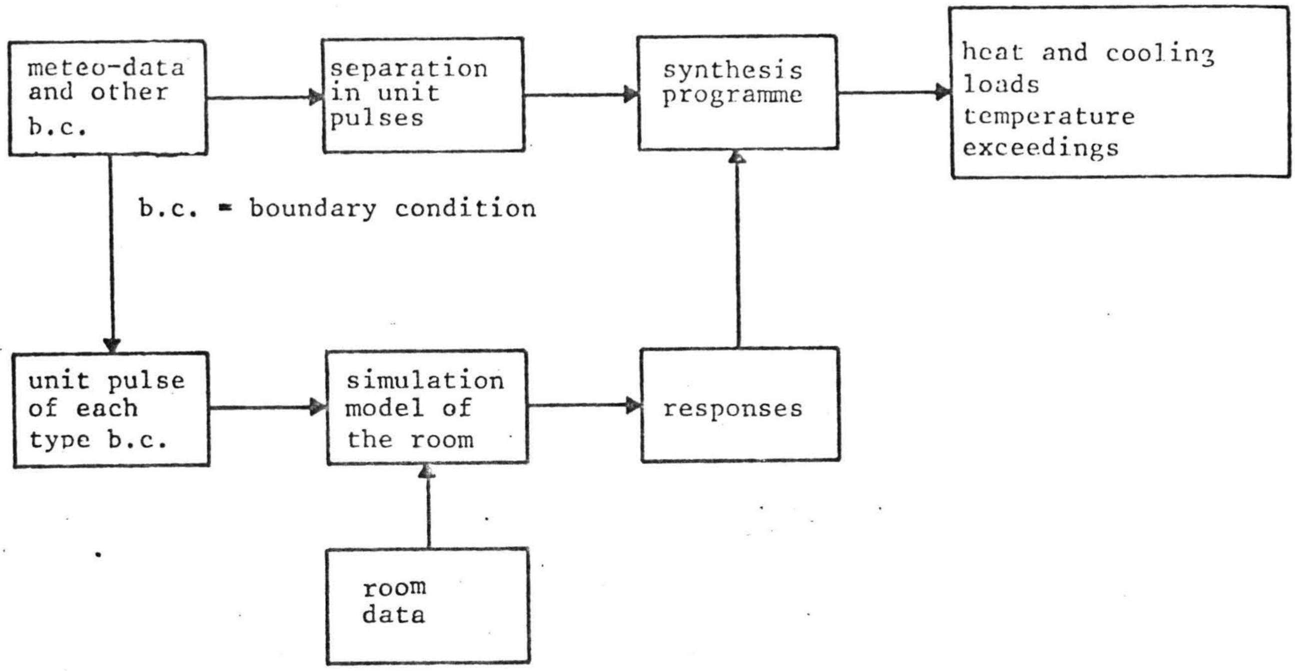


Figure 5 - Scheme of the calculation of the temperature exceedings as applied in the computer programma used for this investigation

5. Comfort criteria and introduced calculation quantities

When calculating maximum cooling loads in indoor climate control technics the indoor temperature is often assumed to be fixed between 22^0 and 24^0C. Should the designed outside conditions have been put rather extreme, then, provided the internal heat loads do not increase, none at all or only few temperature exceedings are to be expected.

If, however, when designing, it has to be considered first whether the indoor climate of the building can also be controlled without mechanical cooling, either by choice of building properties and/or through an effective control of the mechanical ventilation, additional data on possibly acceptable higher temperature levels are needed.

In order to indicate acceptable temperatures, higher than the customary 22^0 to 24^0C under controlled conditions, data from recent literature can be applied, viz. [7] and [8]. From [7] we derived the graph in figure 6, in which for two situations - which have different air movement - the comfort limits have been referred to as 'upper limit' and 'lower limit', both corresponding with a percentage of dissatisfied people of 15%. Further data of these situations are the following:

- metabolism $M = 90$ W per m^2 body area (normal office work)
- clo-value of the clothing $I_{cl} = 0.60$ clo (summer clothes)
- exposure time: 4 hours
- air velocity $v = 0.25$ m/s respectively 1 m/s (in the immediate surroundings of the person.

Situations with air velocities in the room of 0.1 till 0.2 m/s mostly only occur in closed rooms with normal temperature differences. However, higher air velocities can occur when windows and/or doors are opened, through which discomfort can be diminished when the indoor temperatures are increasing.

The graph in figure 6 shows that with an air velocity of 1 m/s the indoor temperature is allowed to be 2 to 3 K higher than with an air velocity of 0.25 m/s, all other conditions being equal. Since on the other hand the possibility of draft increases with higher air velocities, the marges will be restricted of course.

Special attention should be given to recent investigations on the reaction of persons to temperatures increasing in the course of the day. From the in [8] described research on test-persons, performing ordinary office work during one day in a room in which the air (= radiant) temperature was increased with 0.6°C/h from 23° to 27.8°C, the temperature leading to more than 20% of discontented appeared to be 27.8°C, with a relative humidity (R.H.) diverging from about 85 to 65%, and 27.2°C with a R.H. diverging from about 45 to 35%. The air movement was relatively small and constant: the air velocities were about 0.1 m/s, the clo-value 0.5.

On ground of the above-mentioned considerations and taking into account the relatively high R.H.-values which, in summer, occur in non-conditioned rooms (because the air humidity outdoors may be high as well), two temperature levels were introduced as starting points when handling the basic results into the final results, viz. the earlier mentioned levels 26° and 28°C.

It has to be put emphatically, however, that the introduced temperature levels of 26° and 28°C, are clearly meant to be limited values for the two different situations (respectively slight and strong air movement) since a) the 'upper limit' from figure 6 already means 15% of discontented, b) this percentage can be higher as a result of yearly divergencies (although it may be lower too).

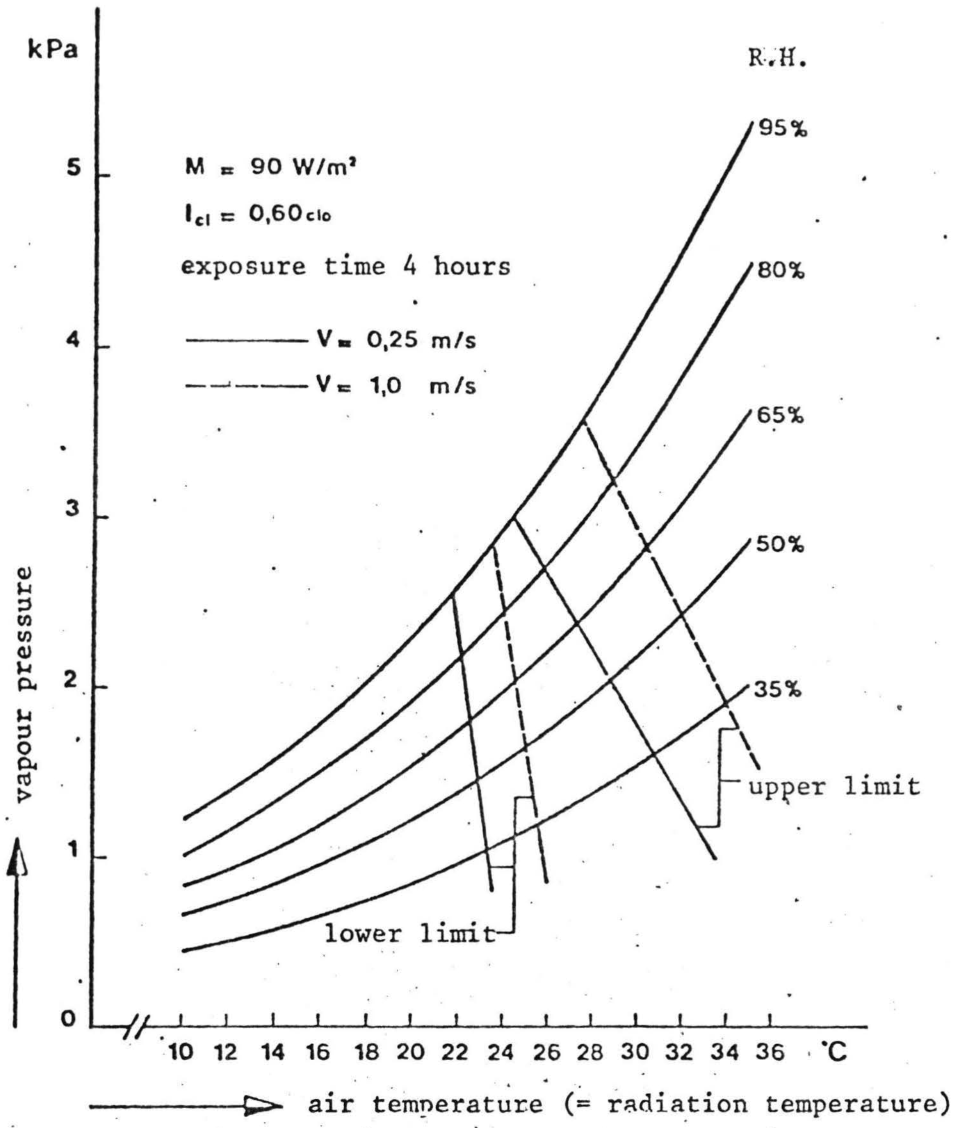


Figure 6 - The comfort limits depending on the air humidity and air velocity; further conditions as mentioned in the graph.

The following quantities, also appearing in the final results, have been calculated:

TMAX : the highest value of room air temperature occuring during the months June, July and August of the chosen average summer period.

M26 ($\bar{w}$, 3m) : the number of hours on which the room air temperature has exceeded the level of 26^{0}C in the three months mentioned, averagely per week ($\bar{w}$), respectively during this entire period totally (3m).

M28 ($\bar{w}$, 3m) : the number of hours on which the room air temperature, during the three months mentioned, has exceeded the level of 28^{0}C averagely per week ($\bar{w}$), respectively during this entire period totally (3m).

A week consists of 5 working days. The maximum number of exceeding hours for the three values mentioned with 9 office hours per day will therefore be 585.

The chosen average summer period was June, July and August 1964, as was derived from calculations carried out for some situations for the period 1961-1970 initially and for the period 1961-1975 later on. Caused by the yearly divergencies, the following derived standard deviations (+ and -) will be indicative of the mean marges:

TMAX : 2.0^0 to 2.5^{0}C

M26 : 5 to 10%

M28 : 3 to 5%

depending on the room situations.

6. Further data handling

The calculated exceeding rates M26 and M28 were plotted graphically as a function of the solar entrance factor ZTA, the remaining variables functioning as parameters: percentage of glass (PG), type of room, orientation, type of glazing and sunshading (ZS) and the other assumed conditions:

internal heat load 10 W/m^2 and ventilation rate N = 3.

From the relations M26 and M28, which as a function of ZTA, proved to have an almost linear course, by extrapolation the ZTA-values corresponding to M26 = 0 (i.e. TMAX 26,0^{0}C) resp. to M28 = 0 (i.e. TMAX 28.0^{0}C) were found.

Together with the for each situation calculated TMAX, this resulted in data which could form the relations TMAX = f(ZTA). From these relations, case for case, the ZTA-values for TMAX = 26^0C resp. TMAX = 28^0C and the corresponding PG-values were found, being combinations of ZTA- and PG-values meeting the fixed limits of TMAX = 26^0 and TMAX = 28^0C.
In this data handling first the graphs were made in which ZTA is a function of the specific room mass SM, with PG as a parameter. An example of these graphs is given in figure 7. Vertically SM has been plotted logarithmically, based on the SM-values of the three types of rooms. By means of the method of the smallest squares for each PG-value a straight line has been drawn through the three points, which for all cases proved to be a good approximation. Thus relations of the form:

$$ZTA = A \ln \frac{SM}{100} + B \qquad (5)$$

were found ($\frac{SM}{100}$ being a dimensionless variable).
With the aid of the equation (5) graphs were made in which PG is plotted as a function of ZTA, with SM as a parameter. An example of these graphs is given in figure 8. Through the indicated points, which each of them meet equation (5), then the hyperbolic approximations of the form

$$ZTA = \frac{C}{PG} + D \qquad (6)$$

were formed, again with the aid of the method of the smallest squares.
In publication [6] the relations (5) and (6) have been given graphically for various situations, distinguished by
- the acceptable temperatue level TMAX = 26^0 respectively TMAX = 28^0C
- the type of fenestration and sunshading (four categories ZS = 1 to 4).

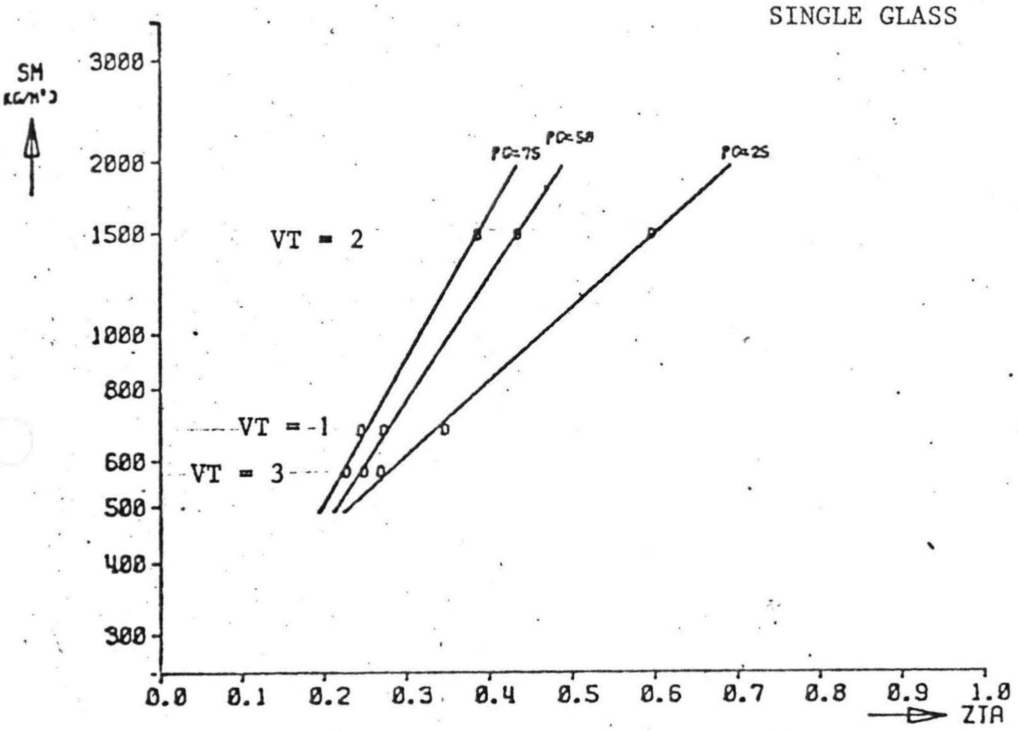
The results of the orientations south and west proved to differ only a little (calculated during office hours) and were therefore jointed in the working graphs. Moreover, it was found possible to introduce a multiplication factor for east with an average value of 1.45. With this factor, a ZTA-value, found for south and west averagely, can be multiplied to obtain equal conditions for the orientation east.
Naturally it is also possible to use equations (5) and (6) directly, e.g. by using pocket or table calculators. For this purpose an extra table is given in [6] stating the values A, B, C and D for several situations.

SLIGHT AIR MOVEMENT IN THE ROOMS (TMAX = 26.0^{0}C)

ORIENTATION: EAST

GLAZING AND SUNSHADING:

SINGLE GLASS



WITHOUT

INDOOR SUNSHADING

(1A)

Figure 7 - The maximum value of ZTA depending on the specific room mass SM and percentage of glass PG.

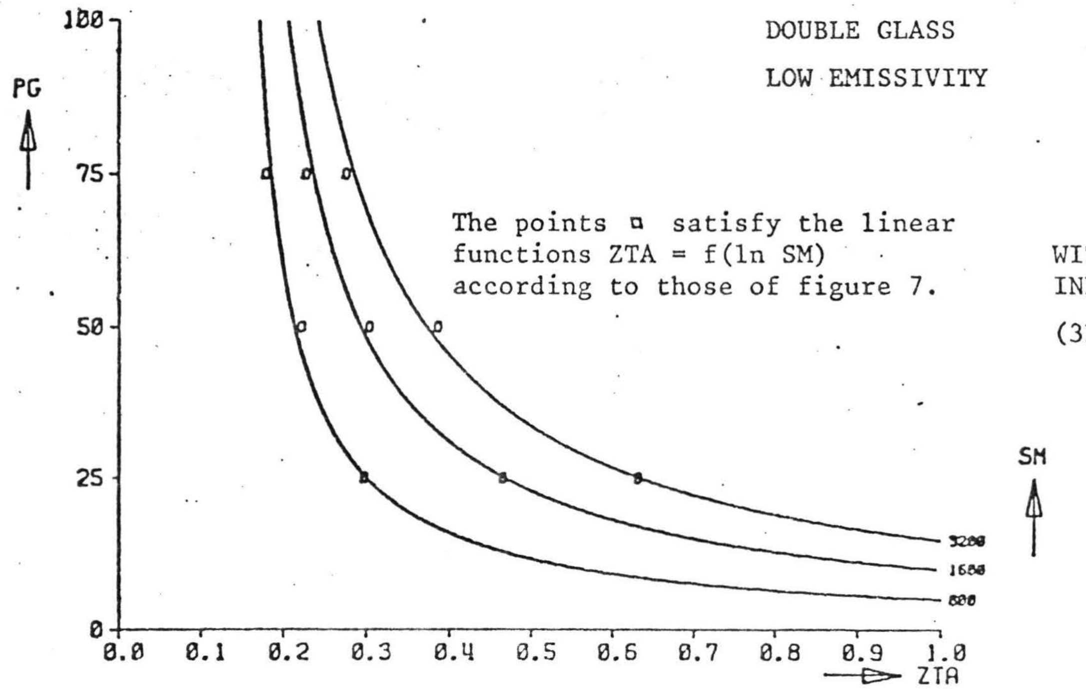
RELATIVE STRONG AIR MOVEMENT IN THE ROOMS (TMAX = 28.0^{0}C)

ORIENTATION: WEST

GLAZING AND SUNSHADING:

DOUBLE GLASS

LOW EMISSIVITY



WITH

INDOOR SUNSHADING

(3B)

Figure 8 - The maximum value of ZTA depending on the percentage of glass and the specific room mass SM.

Finally for a first approach the results have also been stated in a brief form (see the graphs in figures 9 and 10). In order to simplify matters in this case the specific room mass has not been given as a variable or a quantity, but instead the distinctions 'light' and 'heavy' have been introduced corresponding with SM = 640 kg/m^2 respectively 1540 kg/m^2. Moreover, the number of sunshading categories has been restricted from 8 to 4 viz. systems with single, respectively double glazing and systems with and without indoor sunshading.

Figures 9 and 10 probably also give a good illustration of the character of the results of the investigation. Depending on:

- the temperature limit: 26^{0}C for rooms with only slight air movement and 28^{0}C for rooms with a relatively strong air movement,
- presence of indoor sunshading (blinds, curtain, net curtains) or not,
- specific room mass,
- façade orientation,

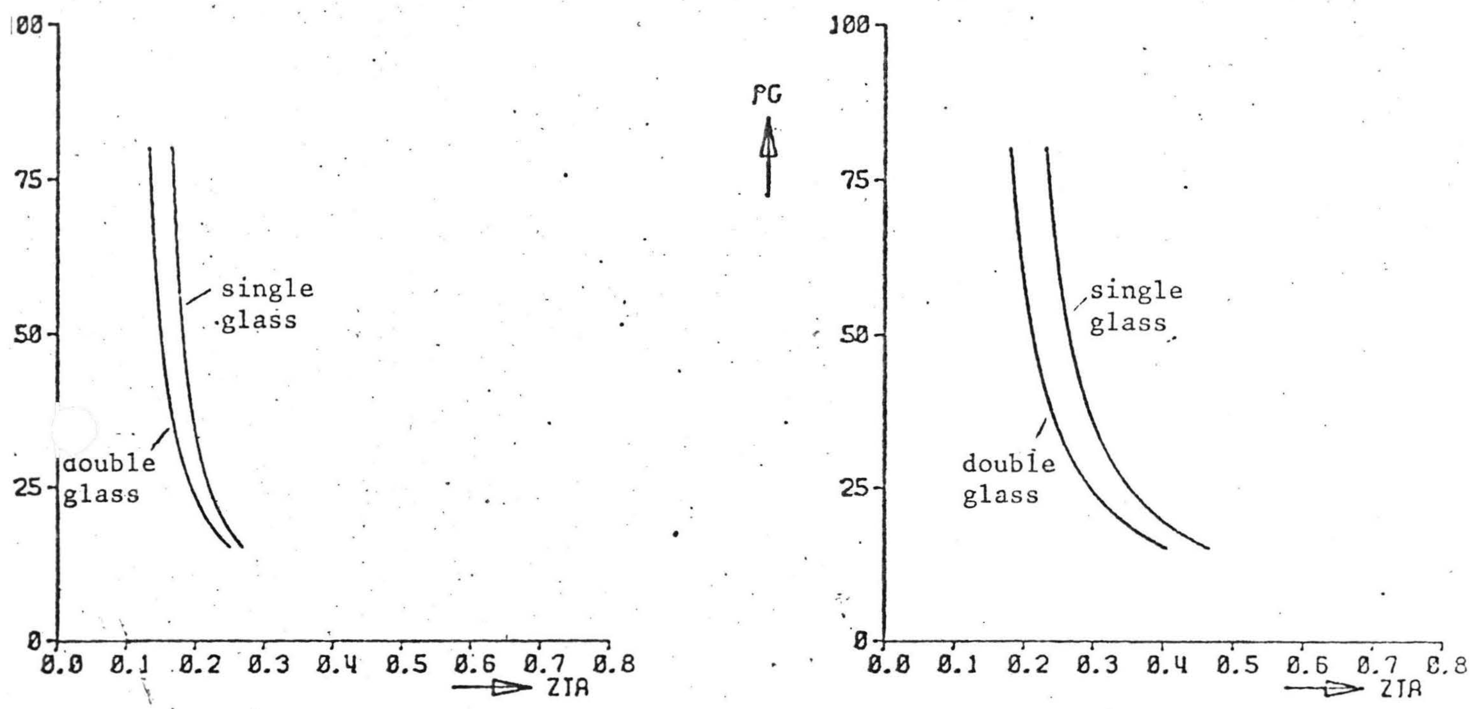
it can be read from the graphs which maximum ZTA-value or (on the other hand) which maximum glass area can be applied in order to obtain an indoor climate which is still acceptable during sunny warm summer periods.

SPECIFIC ROOM MASS RELATIVE SMALL (SM = 640 kg/m²)

AIR MOVEMENT IN THE ROOMS:

SMALL (TMAX = 26.0°C) RELATIVE STRONG (TMAX = 28.0°C)

SYSTEMS WITHOUT INDOOR SUNSHADING



SYSTEMS WITH INDOOR SUNSHADING

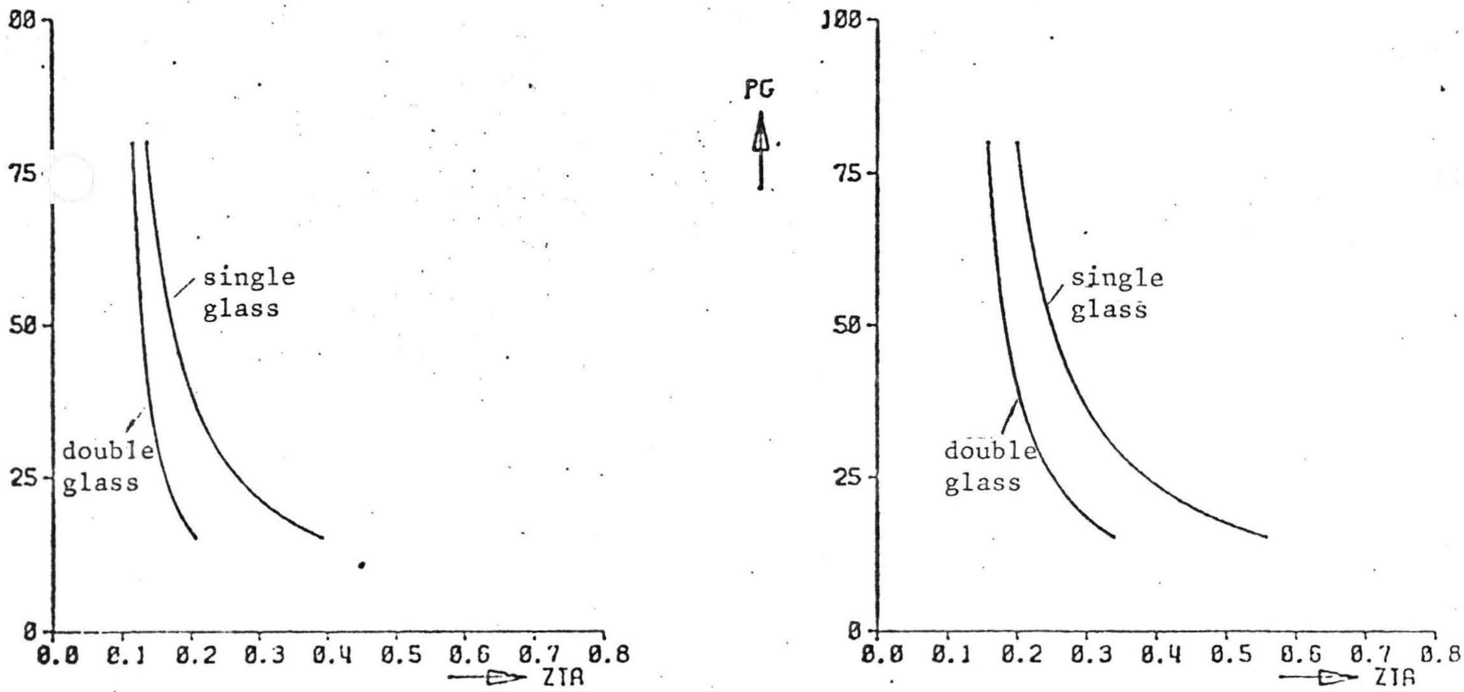


Figure 9 - The maximum ZTA (or PG) as a function of PG (resp. ZTA) for the circumstances as mentioned in the graphs.

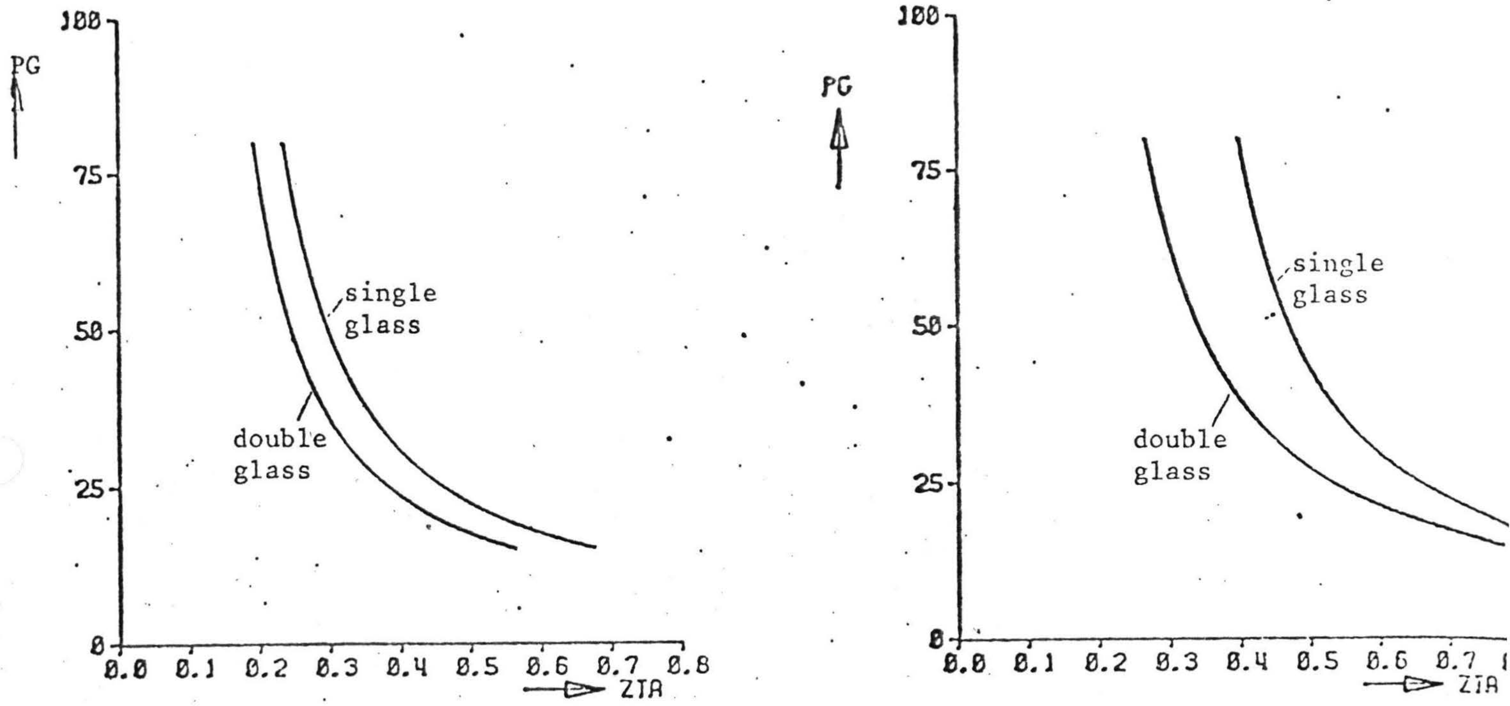
Orientation: south and west (normal office hours)
multiplication factor east: 1.4

SPECIFIC ROOM MASS RELATIVE LARGE (SM = 1520 kg/m^2)

AIR MOVEMENT IN THE ROOMS:

SMALL (TMAX = 26.0^{0}C) RELATIVE STRONG (TMAX = 28.0^{0}C)

SYSTEMS WITHOUT INDOOR SUNSHADING



SYSTEMS WITH INDOOR SUNSHADING

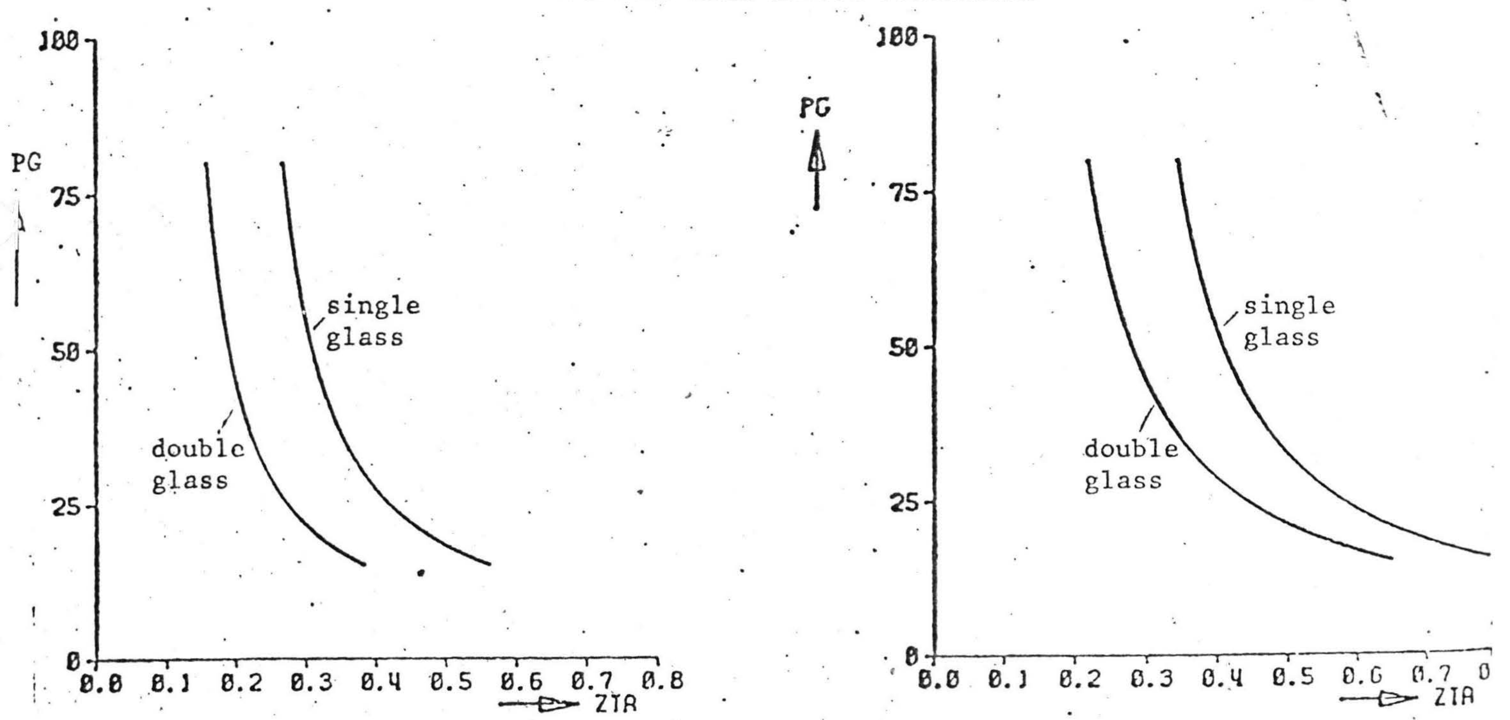


Figure 10 - The maximum value of ZTA (or PG) as a function of PG (resp. ZTA) for the circumstances as mentioned in the graphs.

Orientation: south and west (normal office hours)
multiplication factor east: 1.4

7. Differing circumstances

More extensive considerations on the influence of internal heat load and the influence of the quantity of ventilation air are given in [6]. Quantitative data are supplied in order to correct the maximum ZTA- and PG-values for situations in which the nominal values are not applicable for said quantities. For briefness' sake [6] must be referred to as far as this subject is concerned.
Should these additional data not be sufficient, e.g. because of situations differing too much, it is always possible to make use of the computer programme with which the calculations for this investigation were carried out. The use of this, or other similar programmes can also be recommended in more advanced stages of the building design, when the need for more accurate figures is larger and when more extensive data on building, equipment etc. are available.

8. Duration and amount of temperature exceedings

In the computer programme the temperature exceedings were added for the entire period (June, July, August), regardless succession, duration and amount ($T_x - T_{26/28}$). There are, however, possibilities to include these effects in the summons of the exceedings by coupling the room model to a human thermo-regulation model. At the same time room radiation temperatures, both with room air temperatures and room air velocities, may be supplied to such a model.
As to the chosen average summer period we note that in this respect a more general approach is possible by using a synthetic (statistical) meteorological year. Such a year could be composed for each climate if the relevant meteo-data are available [15].

Delft, 19 juli 1979
CS

Literature

[1] Zonwering bij gebouwen, Stichting Bouwresearch Publicatie nr. 42 (1974)

[2] Zontoetredingsgetallen, ISSO-publicatie nr. 2 (1976)

[3] S.W.T.M. Oegema, P. Euser, An accurate computing method for the analysis of the non-steady thermal behaviour of office buildings, First Symposium on the Use of Computers for Environmental Engineering related to Buildings, Washington, 1970.

[4] H.J. Nicolaas, K.Th. Knorr, P. Euser, A digital computer program for the calculation of yearly room energy demands and temperature exceeding rates using hourly weather data, Proceedings International Seminair Heat Transfer in Buildings (Dubrovnik, 1977).

[5] S.W.H. de Haan, P. Euser, Omrekening van zonnestraling op horizontale vlak naar ander vlak, TPD-rapport nr. 032-6, 1974.

[6] De invloed van zon-instraling op het binnenklimaat in gebouwen zonder mechanische koeling, Stichting Bouwresearch Publikatie (in preparation).

[7] A. Keijzer, B.D.R. Kluver, M. Woerlee, De grenzen voor de thermische belasting van de mens, aangegeven door de temperatuurindex uit de nieuwe klimaatparagraaf van het veiligheidsbesluit voor fabrieken en werkplaatsen 1938, thermofysiologisch geinterpreteerd, Publicatie NIPG-TNO (1973)

[8] Berglund, L.G. Gonzalez, R.R. Human, Response to Temperature Drifts, ASHREA Journal, august 1978, p. 38

[9] J. Lammers, Human factors, energy conservation and design practice, Dissertatie TH-Eindhoven (1978)

[10] R.G. Nevins, Energy conservation strategies and human comfort, ASHREA Journal, april 1975, p. 33

[11] N.O. Milbauk, A new approach to predicting the thermal environment in buildings at the early stage, BRE-report CP2/74

[12] G. Hauser, Bauliche Massnahmen zur Verminderung hoher Raumlufttemperaturen im Sommer, Bundesbaublatt H6 (1978)

[13] G. Hauser, H. Schulze, Das sommerliche Temperaturverhalten von Einfamilienhäusern, Gesundheits-Ingenieur 99 (1978), H. 8, pagina 230.

[14] H. Künzel, W. Frank, Die sommerlichen Temperaturverhältnisse in Wohngebäuden schwerer und leichter Bauart, G.J. Haustechnik, Bauphysik, Umwelttechnik 100 (1979) H. 3, pagina 85.

[15] A.G. de Jong, Statistisch simulatie-model van het buitenklimaat, Report ST147, Delft Technical University (1977).