The BKL-Method

A simplified method to predict energy consumption in buildings

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Bo Adamson

Swedish Council for

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INTRODUCTION

Today several computer programs, based on detailed models of buildings, are available for calculation of heat consumption. Nevertheless, there is still a need for simplified methods, for example to be used as design tools in the early lay-out of a building when main frame computers are not accessible or when complex programs are too expensive to use.

The method described herein was developed to be used as a hand calculation method but the development of personal computers gives the possibility to use the method as a very quick design tool. The method cannot replace complex computer programs and should be seen as an improved degree-day method. In a low-energy house, where the heat losses are reduced by a high level of insulation etc., the free heat becomes an important part of energy used for space heating. Thus, calculation of solar gain is the most complex part of the method.

A simplified method to take solar gain into account when predicting the energy consumption in a building was used by Elmarsson in her diploma work, in 1977. The method was improved and a version was presented by Källblad & Adamson, 1978 Further studies and comparisons between the method and detailed computer calculations gave the method presented first at the CIB-symposium in Copenhagen (Källblad-Adamson, 1979).

This document presents the method, which in this version is called the BKL-method.

In chapter 1 the basics of the method are presented while chapter 2 gives a more practical view of the use of the method together with an illustrative example. The method requires climatic data in a specific form and the way to calculate these data is discussed in chapter 3. To determine the solar gain through windows, precalculated factors are used and the background for these is given in chapter 4. Chapter 5 gives some comparisons between results from this method and detailed computer simulations.

Finally it should be noticed that the method is developed for normal Swedish climate and problems may arise using the method for warmer climates.

THE CALCULATION METHOD

In order to utilize free heat from occupants, household, appliances, hot water and direct solar gain the heating system must be thermostatically controlled. The heating load will then be just what is necessary to maintain the desired indoor temperature; or equal to zero if the free heat is sufficient. Excess free heat has to be reduced through increased ventilation through windows. The "BKL-method" assumes that heating loads are thermostatically controlled on the indoor temperature.

1.1 Daily energy balance

If there is no free heat in a building the heat losses for a 24-hour period will be

$$P_f = \begin{cases} 24(F_{TR}+F_V)(T_i-T_{od}), & \text{if } T_i>T_{od} \\ \text{otherwise } 0 \end{cases}$$

where

P_f =required energy for heating during a 24-hour period

F_{TR} =transmission losses through walls, windows, floor, roof, etc. (W/^{o}C)

F_V =ventilation losses (W/^{o}C)

T_i =desired indoor temperature (^{o}C)

T_{od} =mean daily outdoor temperature (^{o}C)

Heat gain from occupants, appliances, solar radiation etc. can be utilized to compensate for heat losses during this 24-hour period. If the available free heat is insufficient, heat from the heating system is required. The relationship can be illustrated as in Figure 1.1. In one case the available energy ($P_{sol}+P_{bo}$) is more than sufficient to cover losses; in the second case extra heating (P_{till}) is required.

The accessible "occupancy heat" (P_{bo}) consists of heat from people, electrical appliances, water heaters etc. It can be reduced by such things as heating of cold water as it pas-

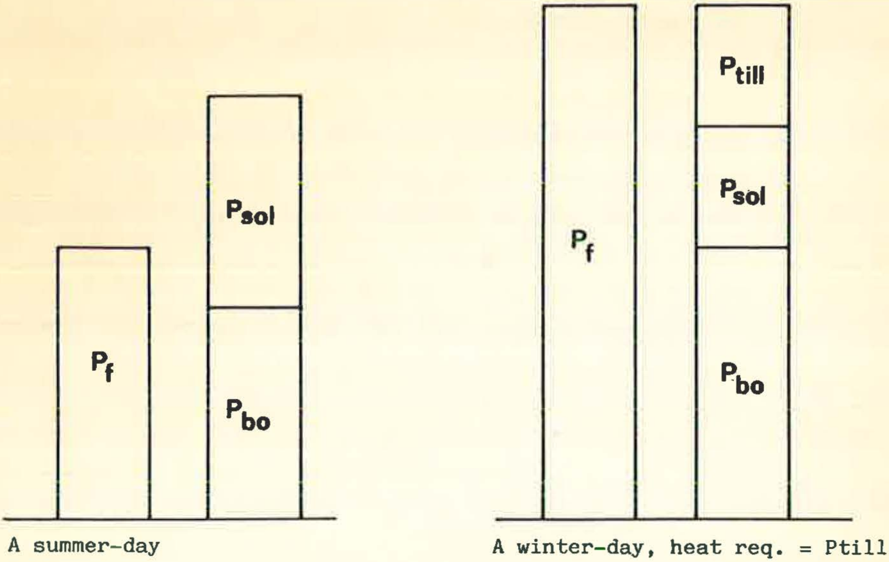


Figure 1.1 Energy balance for one day of 24 hours.

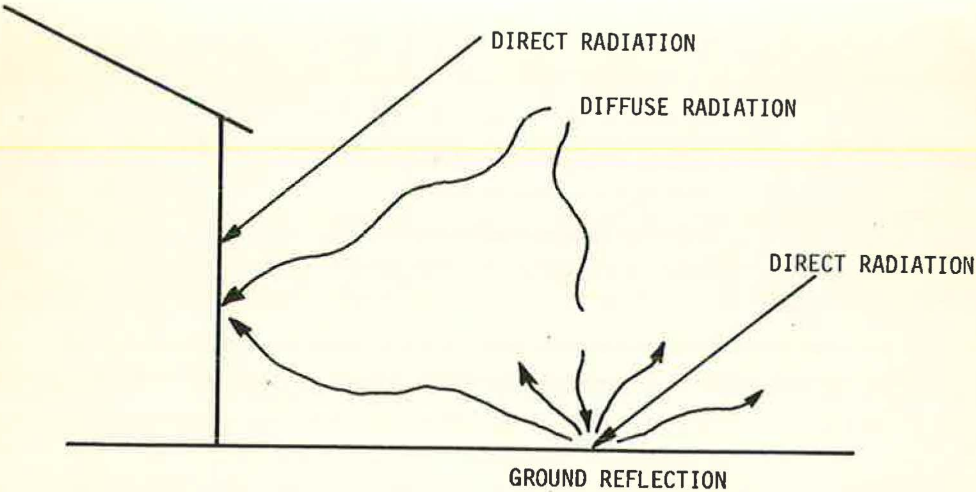


Figure 1.2 Solar and sky radiation on a facade.

ses through the building. Normally, occupancy heat can be assumed to be the same from day to day and can be determined through experience.

In order to calculate solar gain (P_{sol}) with acceptable accuracy it must be divided into direct solar radiation and diffuse sky radiation. Figure 1,2 shows, schematically, how the various radiation components strike an unshaded facade. A part of this radiation will be transmitted into the building through glass - depending on screening and the type of glass used.

The solar and sky radiation for each day can be divided into their respective direct and diffuse parts:

I_{dH} - diffuse sky radiation on a horizontal surface (Wh/m^2,day)

I_{rH} - direct solar radiation on a horizontal surface (Wh/m^2,day)

In order to simplify the calculations, the ratios between the above values and radiation through different glazing combinations under various screening conditions have been calculated. This was done with the help of computer programs that take into consideration sun path, ground reflection, reflections between window panes, etc.

With ratio α_d (for diffuse radiation) and α_r (for direct radiation)the solar heat gain can be determined for a window area of A m^2:

$$P_{sol} = \varphi A(\alpha_d I_{dH} + \alpha_r I_{rH}) \quad \text{Wh/day}$$

φ is the estimated reduction factor for solar radiation due to use of curtains, blinds and use of glazing types other than those considered in the α-values.

The α_d and α_r values vary with the slope of the window, type of glazing and screening. Furthermore, α_r is dependent on the orientation of the window and the time of year. Constant α_r-values can be assumed for each month. Section 4 gives a detailed description of how α-values are determined.

Finally, the heating load (Wh/day) is calculated:

$$P_{till} = \begin{cases} P_f - (P_{bo} + P_{sol}) & \text{if } P_f > P_{bo} + P_{sol} \\ 0, \text{ otherwise} \end{cases}$$

1.2 Monthly energy balance

Primarily, the monthly heating load is comprised of the heating requirements of various days. Daily calculations are however, exceedingly comprehensive and can be avoided by representing a given month's climate in a suitable way.

Solar and sky radiation on a horizontal surface can be represented graphically by a solar duration curve. If, for a given month, the day with the most total radiation is placed as day 1, the day with the next highest rate as day 2 etc. and the day with the least total radiation last; the total radiation for Stockholm in April, 1971 can be illustrated as in Figure 1.3. This diagram can be approximated by a rectilinear figure of the same area. Figure 1.4 shows some variations of this method which can be obtained from different monthly climate data. Values of only two or three days are necessary to be able to describe the total radiation for each day of an entire month. Section 3 gives a detailed description of how available climate data is treated.

Since the earlier mentioned α-values can be considered constant during the month, the given equation can be used to determine radiation for the two or three days which represent the total radiation diagram. (The first day and days d_1 and d_2 in Figure 1.3 and Figure 1.4). A diagram for a given month's radiation can then be attained as in the example shown in Figure 1.5. If this diagram is supplemented by occupancy heat, which is considered constant during one month, the diagram will be as shown in Figure 1.6.

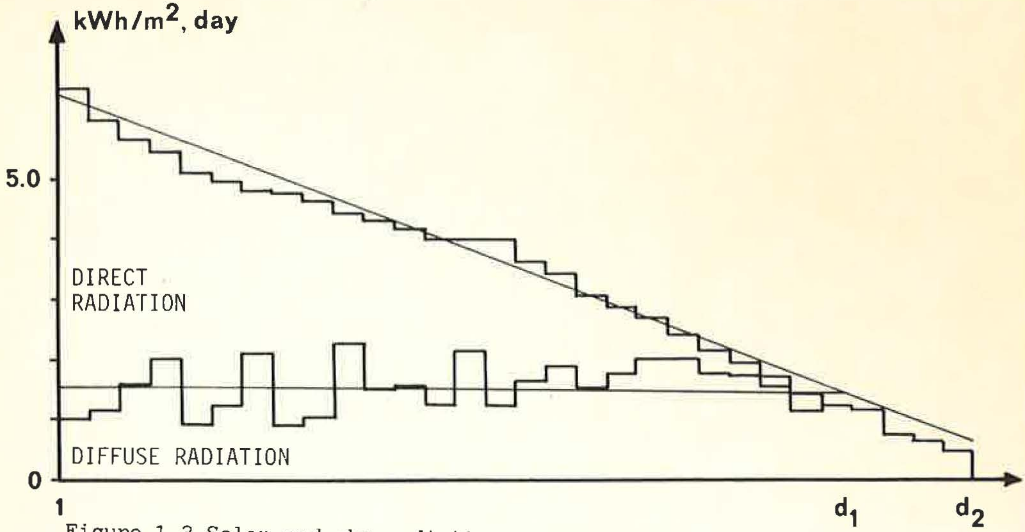


Figure 1.3 Solar and sky radiation on a horizontal surface, Stockholm, Sweden, April 1971.

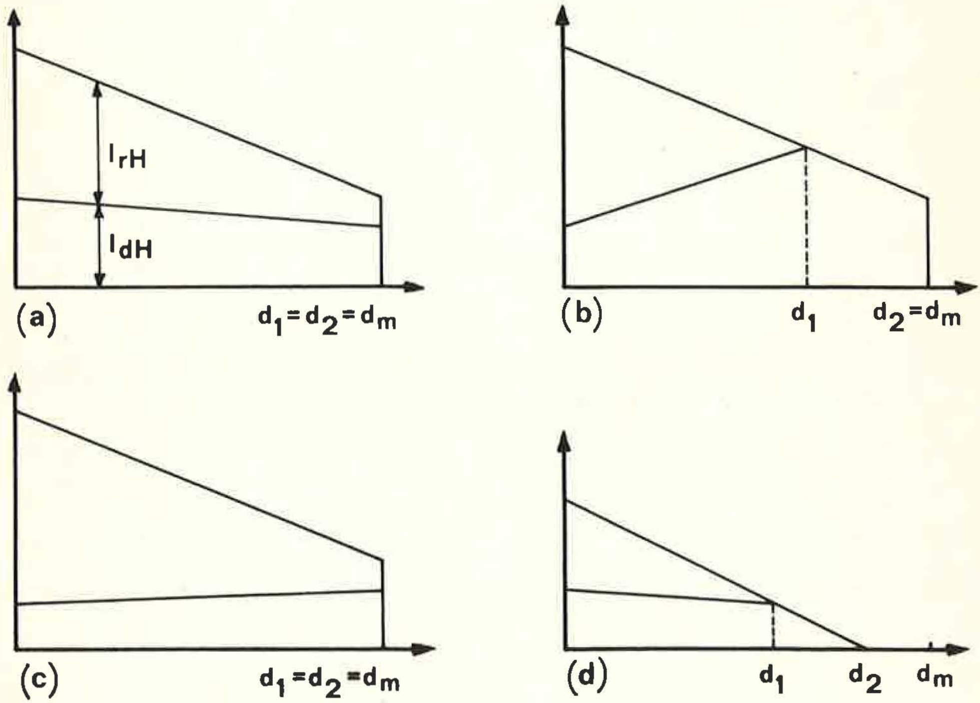


Figure 1.4 Some different types of distribution for solar and sky radiation during a month with dm days.

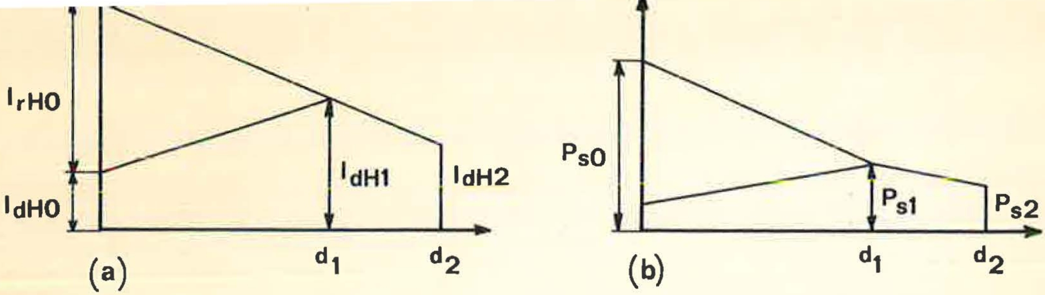


Figure 1.5 Distribution during a month for solar heat gain through a window (b) due to the radiation according to (a).

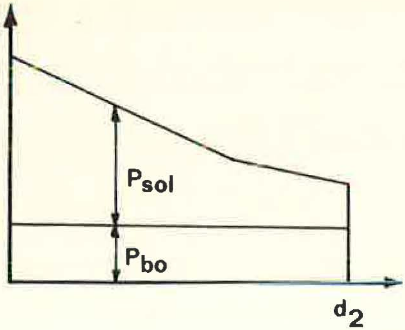


Figure 1.6 Total availible "free heat" during a month.

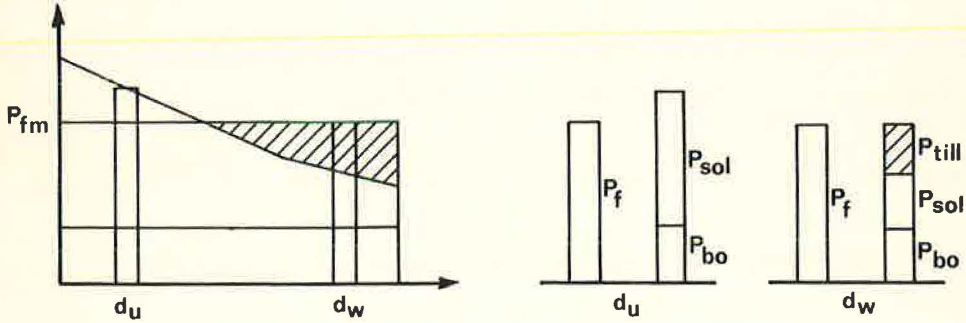


Figure 1.7 The montly heat requiremant with examples of one day without (du) and one day with (dw) heat requirement.

If the heat losses for each day of the month are assumed to be equal and are calculated with the mean monthly outdoor temperature, they can be represented by a horizontal line (P_{fm}) in the diagram with total available heat. This is shown in Figure 1.7 where the available heat is sufficient to heat the building during part of the month. Extra heating is required on certain days and the amount of energy is represented by the hatched area.

The purpose of this section is to serve as a teaching aid or as a guide for engineers and architects. It can also serve as a supplement to the method described in section 1.

2.1 The building's heat loss due to transmission

The method of calculation does not take into account the building's heat capacity. Transmission losses are:

$$F_{TR} = \sum_i U_i A_i \ (W/^oC)$$

where

U_i = the building component's U-value $(W/m^2, ^oC)$
A_i = the building component's area (m^2)

In the above equation all of the building's exterior areas must be included (exterior walls, windows, doors, floor, roof etc.).

How the U-values for the individual cases are to be calculated is omitted here. It should, however, be noted that U-values for windows should be so-called "darkness U-values". Some "equivalent U-values" including solar radiation should not be used since solar and sky radiation are treated separately in this method.

Where moveable insulation is employed, for example, insulating shutters, the mean daily values might possibly be used. This method has not been tested for detailed calculations in such cases, so caution is advised.

2.2 The building's heat loss due to ventilation

Ventilation is usually comprised of several components which is illustrated in a simplified way in Figure 2.1. These components which among other things depend on wind, temperatures and living habits, are of course, very difficult to predict.

In all cases, the total volume of inlet air v_t (m^3/h) has to be heated to the desired room temperature. If v_t is known, ventilation losses can be calculated using

$$F_v = 0.33\ v_t \quad (W/^{o}C)$$

where 0.33 is the air's heat content per m^3 and ^{o}C.

Since we are in this case only discussing heating, humidity is not discussed. Since the method assumes constant ventilation the daily mean value for ventilation is used.

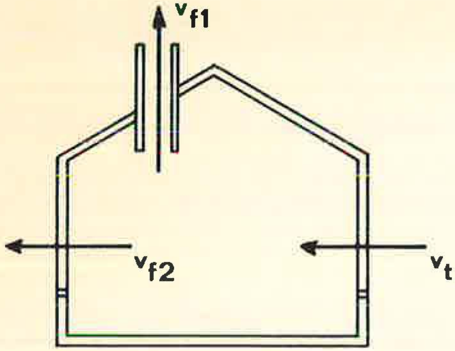
Heat exchanger

If there is a heat exchanger between exhaust and inlet ducts, the ventilation volumes are determined basically in the same manner as the regular exhaust/inlet system, but in order to take the heat exchanger into account, the controlled air flow is reduced by the same ratio as the degree of temperature efficiency for the heat exchanger.

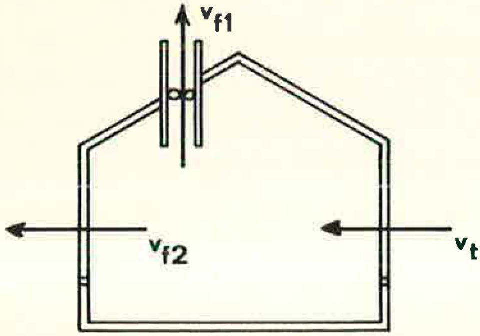
When evaluating energy savings due to heat exchangers the following, often by-passed phenomena should be considered:

- Not all the air passes through the heat exchanger, infiltration and airing practices contribute to ventilation entirely outside the system. Furthermore poorly sealed or uninsulated ducts reduce the system's efficiency.

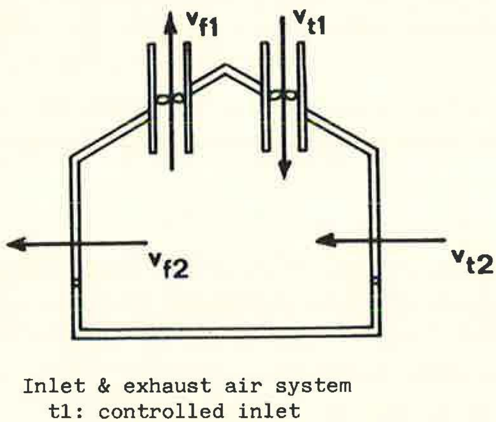
- Reduction of ventilation losses by using heat exchangers doesn't necessary imply energy



Natural ventilation
t : inlet through windows & cracks
f1: outlet through ducts
f2: outlet through windows & cracks



Exhaust air system
t : inlet through windows & cracks
f1: controlled exhaust air
f2: outlet through windows & cracks



Inlet & exhaust air system
t1: controlled inlet
t2: inlet through windows & cracks
f1: controlled exhust air
f2: outlet through windows & cracks

Figure 2.1 Air flows through a building with different HVAC-systems.

savings. If for example, available internal heat generation and passive solar gain cover losses then heat exchangers are redundant. This is why heat exchangers of this type should be included in heat loss calculation and not counted as an energy supplement.

2.3 Internal Heat Generation

Occupants

Since heat from occupants constitutes a part of the total energy load for a house, it should be quantified in some way. This is, of course, difficult since a family's living habits vary so greatly The only possibility is to make a good guess and we have used the following estimate for available heat from occupants:

1200 Wh/day/person

and assumed that 2 people live in a one-bedroom apartment, 3 in a two-bedroom and 4 in a three-bedroom apartment or larger.

Heat from electrical appliances

All of the electricity consumed by appliances such as refrigerators, lamps or T.V.s is converted to heat energy, mainly convective heat and part of it can be utilized for heating up the building.

As in the case of persons, it is difficult to estimate the actual heat contribution from these sources. We have used the following estimate for calculation purposes:

single family houses	8000 Wh/day
apartments	7000 Wh/day

These values can be used as an approximate average for the whole year. If more accurate calculations are to be done, consumption should be considered greater in the winter than the summer. The figures chosen here are no more valid than any other good guess!

Heat from/to the water system

Many measurements and estimates pertaining to annual energy consumption for water heating have been carried out. Until recently, the average figures for houses and apartments in Sweden were about 5000 kWh and 4000 kWh, respectively. Recent studies have shown that hot water consumption in new houses has been considerably reduced. A reasonable figure today should be about 4000 kWh for a single-family house. Apartments can be assumed to consume about 3000 kWh if they have separate laundry facilities that aren't included in the total energy load.

Part of this energy can be available for heating in such ways as through cooling off in the bathtub. If the hot water boiler is placed within the heated space which normally is the case in single family houses, the losses from the boiler will also be available for heating. How much of a contribution such factors make is determined on a very loose basis. An additional factor, which makes estimates even more complicated, is that the cold water is heated up during its way through the building. The heat for this is taken from the building.

A recent study, Lindskoug 1983, shows that the waste water temperature is approximately 20-25 ^{o}C higher than the temperature of the cold water, supplied to the building. Using average values of the total water volume and the hot water volume used in the actual single family houses it can be shown that 150-250 W is used for heating up the cold water. It is advisable to assume that the total effect of heat losses to cold water and heat gain from the hot water boiler is a heat loss of 150 W e.g. 3600 Wh/day in a single family house. For apartment buildings no measurements at all are available and the heat losses to cold water and the useful heat gain from the hot water boiler are unknown. In order not to forget them a guess can be 3600 kWh/day per apartment. For calculation purpose these losses should be taken into account by reducing the heat gain from occupants, electrical appliances etc.

Other

Besides the above mentioned sources of "extra" heat, there are fans and pumps etc. that can be considered. All the excess energy from a totally enclosed fan in an inlet duct can be counted as heating while the corresponding amount of energy in an exhaust duct fan is lost.

Solar Heat Gain

Available solar heat is calculated according to the method described in section 1. α_d and α_r are found in tables as in section 4. The calculations should be carried out in the following order.

All the windows are arranged so that each category (j) includes glass surfaces that have construction (type of glazing, number of panes etc.), orientation, slope and shading in common. For example, all the windows of an unshaded facade can be considered in the same group. For each window category (j) the following can then be determined:

A_j - which pertains to the glazed surfaces only, excluding frames!

α_{dj} - transmission and shading factor with respect to diffuse radiation in the given orientation, slope and shading conditions.

α_{rj} - as above, but for direct solar radiation for months m=1-12.

When the α-values for all the glazed surfaces have been determined, the sum will be as follows:

$$\alpha_{dtot}=\sum_j \alpha_{dj}A_j$$

$$\alpha_{rtot,m}=\sum_j \alpha_{rj,m}A_j$$

For the sunniest day of each month the available solar heat is calculated by:

$$P_{s0}=\varphi(\alpha_{dtot}I_{dH0}+\alpha_{rtot,m}I_{rH0})\ \text{Wh/day}$$

where I_{dH0} and I_{rH0} are solar radiation on a horizontal surface during the sunniest day of that month. φ is an estimate of how much solar heat is reduced because of curtains etc. or because of another type of glass being used than the one that the α-values apply for.

For day d_1 (see Figure 2.2) the available solar heat is calculated by:

$$P_{s1}=\varphi(\alpha_{dtot}I_{dH1}+\alpha_{rtot,m}I_{rH1})\ \text{Wh/day}$$

where φ, α_{dtot} and $\alpha_{rtot,m}$ are as above, and I_{dH1} and I_{rH1} are found in section 3.

Data for one more day, d_2, is needed at times to be able to completely specify the monthly solar and indirect radiation, see Figure 2.2.

The available solar radiation for that day can be calculated by:

$$P_{s2} = \varphi\alpha_{dtot}I_{dH2}$$

where φ and α_{dtot} are as above, and I_{dH1} as in section 3. In these cases where this day is not necessary for specifying solar radiation, $d_2=d_1$ and $I_{dH2}=0$ have been used in appendix C to attain generally valid equations.

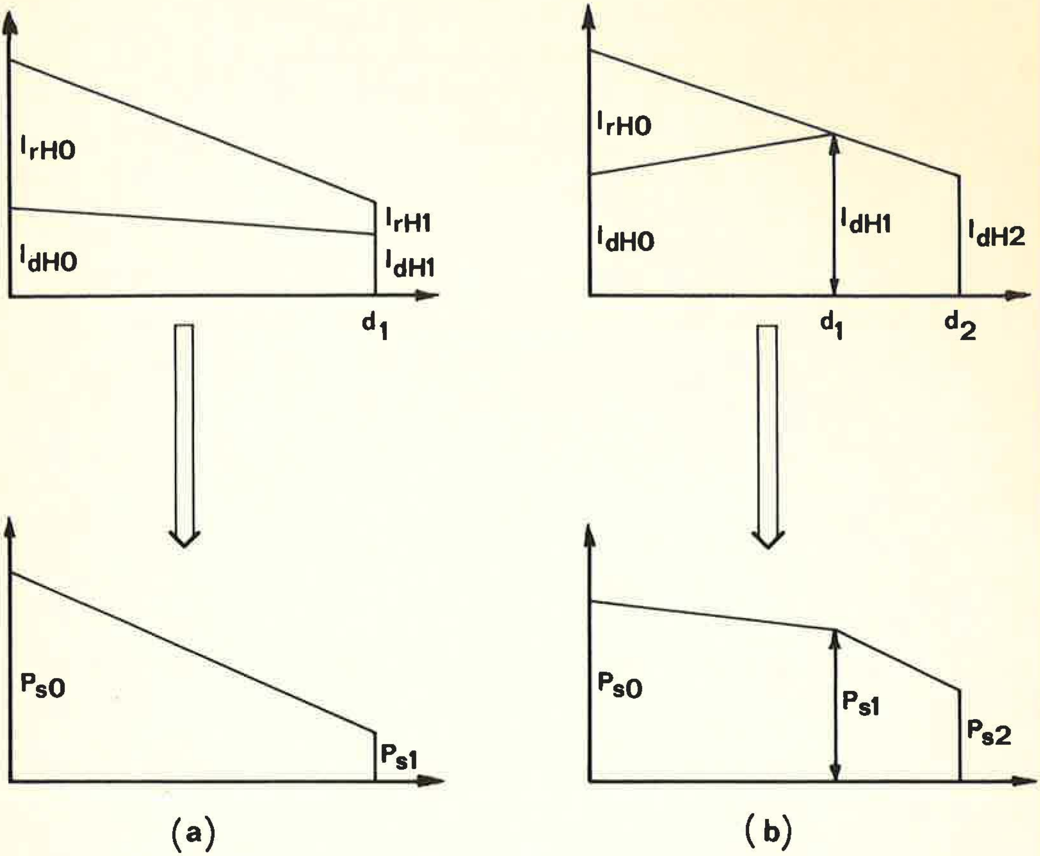


Figure 2.2 Determination of Solar Heat Gain.

Depending on the distribution of solar radiation during the month and screening etc. that effects α-values, the distribution of totally available solar heat varies a great deal. $P_{s0}>P_{s1}$ is usually valid but the opposite is possible. In some cases, even $P_{s0}\leq P_{s2}$, applies. Nevertheless, P_{s1} is always greater than P_{s2}. Figure 2.3 shows a few examples of some possible distributions of available solar heat.

To be able to use a standardized calculation for arriving at heating requirements, it is advisable to give the duration diagrams a more general form. This is shown in Figure 2.4. The necessary steps to attain the general form in different cases are shown below. In most cases $P_{s0}\geq P_{s1}$, so that no changes in the form are necessary.

If $P_{s0}=P_{s1}$:

$A=P_{s0}$, $B=P_{s1}$ and $C=P_{s2}$

$$d_b=d_1$$

If $P_{s1}>P_{s0}>P_{s2}$:

$A=P_{s1}$, $B=P_{s0}$ and $C=P_{s2}$

$$d_b=\frac{d_1(P_{s0}-P_{s2})+d_2(P_{s1}-P_{s0})}{P_{s1}-P_{s2}}$$

If $P_{s0}=P_{s2}$:

$A=P_{s1}$, $B=P_{s2}$ and $C=P_{s0}$

$$d_b=d_2-\frac{d_1(P_{s2}-P_{s0})}{P_{s1}-P_{s0}}$$

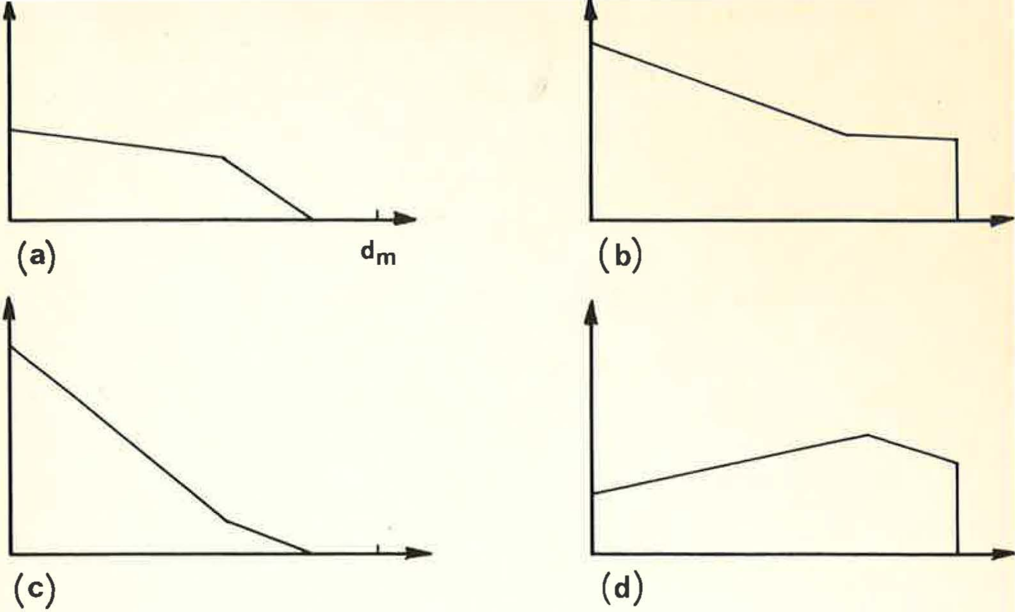
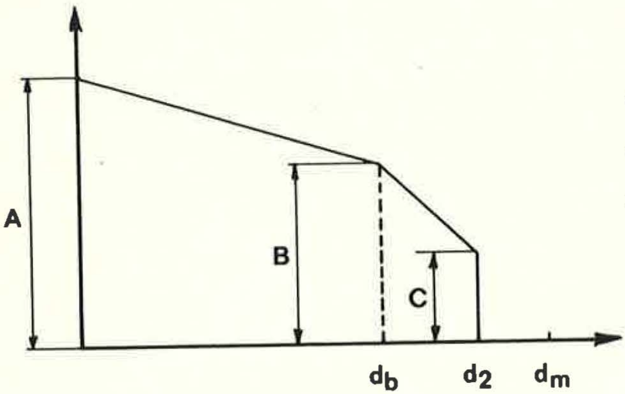


Figure 2.3 Some variations of distribution of solar heat gain through windows during a month with dm days..



$A \geq B \geq C \geq 0$

$db \geq d2 \geq dm$

If $db = d2$, then $C=0$

Figure 2.4 General format of distribution of solar heat gain.

The total available solar energy for one month can be calculated as follows:

$$W_{sol} = \frac{A+B}{2} d_b + \frac{B+C}{2}(d_2-d_b) \text{ Wh/month}$$

2.5 Heating requirements

First the average of the energy losses during one month (P_{fm}) is calculated

$$P_{fm} = \begin{cases} 24(F_{TR}+F_v)(T_i-T_{om}) \text{ Wh/day, if } T_i>T_{om} \\ 0, \text{ otherwise} \end{cases}$$

F_{TR} and F_v are losses due to transmission and ventilation as described in sections 2.1 and 2.2. T_i is the desired indoor temperature and T_{om} is the mean monthly outdoor temperature.

The average heat loss is then weighed against available internal heat generation and solar gain to determine the required heating load. The first step is to see if internal heat generation (P_{bo}) is sufficient to compensate heat losses. P_{bo} is assumed constant during the entire month and the remaining heating load is calculated as follows:

$$P_{rest} = \begin{cases} P_{fm}-P_{bo} \text{ if } P_{fm}>P_{bo} \\ 0, \text{ otherwise} \end{cases}$$

In some cases, the heating load can be partially if not completely covered by solar gain. How much of the available solar energy can be utilized depends on its distribution over the various days. A few examples of this are shown in Figure 2.5 where P_{rest} (heating load) is represented as well. d_m is the total number of days in the month.

Those days on which $P_{sol}>P_{rest}$ require no extra heat-

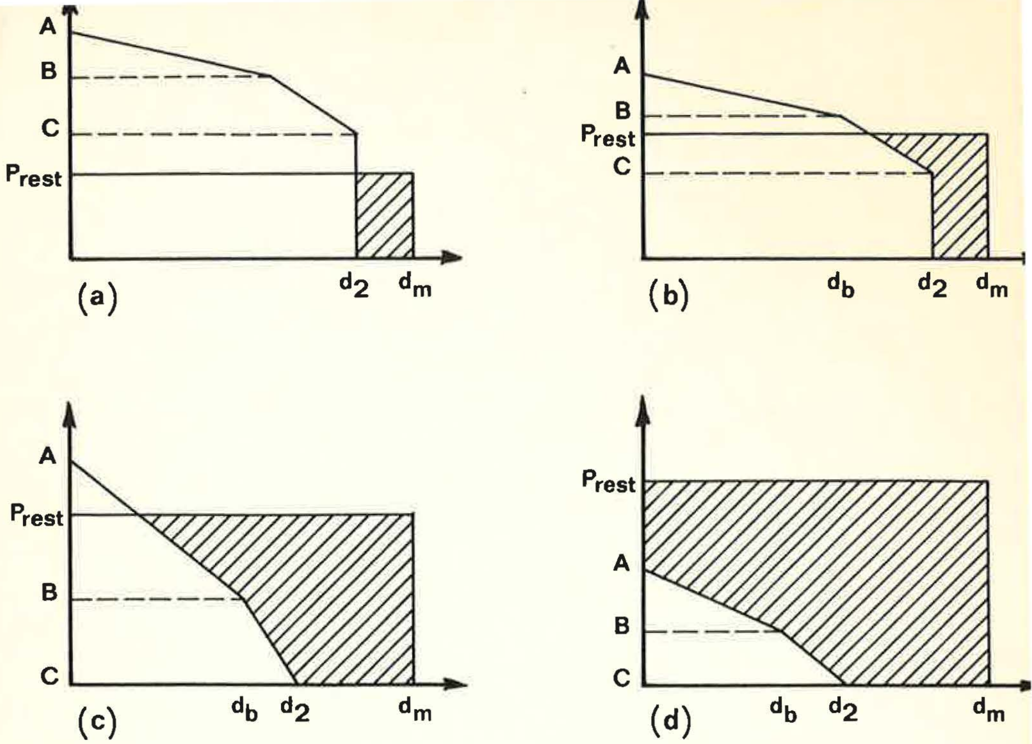


Figure 2.5 Principal formats for predicting monthly heat requirement.

ing whereas the other days require a heating load of:

$$P_{till} = P_{rest} - P_{sol} \quad \text{Wh/day}$$

The total heating load (W_{till}) for a given month is the sum of P_{till} for all the days of the month. This sum is directly proportional to the hatched area in Figure 2.5. Instead of adding up all the days of the month, this area can be calculated in the following way:

If $P_{rest}<C$

$$W_{till}=P_{rest}(d_m-d_2) \quad \text{Wh/month}$$

Figure 2.5a shows an example where $d_2<d_m$. Where $d_2=d_m$, $W_{till}=0$

If $C<P_{rest}<B$

$$W_{till}=P_{rest}(d_m-d_2)+\frac{(P_{rest}-C)^2}{2(B-C)}(d_2-d_b) \quad \text{Wh/month}$$

Figure 2.5b shows an example of this case where $d_2>d_b$. In certain cases, $d_2=d_b$ so the last part of the equation will be 0.

If $B>P_{rest}<A$:

$$W_{till}=P_{rest}*d_m-W_{sol}+\frac{(A-P_{rest})^2 d_2}{2(A-B)} \quad \text{Wh/month}$$

with

$$W_{sol}=\frac{A+B}{2}d_b+\frac{B+C}{2}(d_2-d_b)$$

See Figure 2.5c.

If $A<P_{rest}$:

$$W_{till}=P_{rest}\ d_m-W_{sol} \quad \text{Wh/month}$$

with

W_{sol} as above. In this case, all available solar energy is utilized, see Figure 2.5d.

2.6 Calculation examples

The example shown here is a single-family house with no basement and total losses due to transmission and ventilation of 125 W/^{o}C and an indoor temperature of 20 ^{o}C. The climatic data used is for Malmö, 1971 as shown in section 3.

The energy balance without solar gain is calculated first. The results of this calculation are shown in the table below (in kWh). For example, the calculation for March is as follows

$$P_{fm}=24*125(20-0.52)/1000=58.44 \text{ kWh/day}$$

Internal heat generation was assumed constant for each month and based on 4 persons at 1200 Wh/day each, and the heat from electrical appliances was assumed to be 8000 Wh/day. This figure could be adjusted to a slightly higher value during the winter and lower during the summer.

	d_m	T_{um}	Daily value (kWh/day)			Monthly value (kWh/month)		
			P_{fm}	P_{bo}	P_{rest}	W_{fm}	W_{bo}	W_{rest}
JAN	31	0.34	58.98	12.80	46.18	1828	397	1432
FEB	28	1.82	54.54	"	41.74	1527	358	1169
MAR	31	0.52	58.44	"	45.64	1812	397	1415
APR	30	6.12	41.64	"	28.84	1249	384	865
MAY	31	12.21	23.37	"	10.57	724	397	328
JUN	30	14.67	15.99	"	3.19	480	384	96
JUL	31	17.78	6.66	"	0	206	397	0
AUG	31	17.19	8.43	"	0	261	397	0
SEP	30	12.31	23.07	"	10.27	692	384	308
OCT	31	9.82	30.54	"	17.74	947	397	550
NOV	30	5.00	45.00	"	32.20	1350	384	966
DEC	31	4.88	45.36	"	32.56	1406	397	1009
			Annual total kWh/year			12482	4673	8183

In the next step, P_{rest} is determined, whereupon the monthly values can be calculated. These values are not needed to calculate the heating load but can be of interest when studying the total energy balance. They are easily arrived at by multiplying the daily values by the number of days in the month and can then be added up to annual totals. The next step is to calculate the available solar gain for those months where $P_{rest}>0$. This is also shown in a table. Triple glazed windows are assumed in the following four groups:

1. 12 m^2 facing south with a roof overhang that can be treated as a horizontal shade.

2. 2 m^2 facing south, unshaded

3. 4 m^2 facing east, unshaded

4. 2 m^2 facing north, unshaded

The solar gain is assumed to be reduced by 25% due to use of curtains and blinds. The α-values are obtained as described in section 4 and α_{dtot} and α_{rtot} are determined as described in section 2.4. Note that α_{dtot} is not affected by orientation but is dependent on shading, while α_{rtot} is dependent on both factors.

Glazed surfaces (m^2)

A_1=12.0 A_2=2.0 A_3=4.0 A_4=2.0

Reduction factor for curtains etc.

φ=0.75

α-factor for diffuse radiation

α_{d1}=0.259 α_{d2}=0.396 α_{d3}=0.396 α_{d4}=0.396

α_{dtot}=12*0.259+2*0.396+4*0.396+2*0.396=6.28

	α-factors for direct radiation					Solar gain (kWh/day)		
	α_{r1}	α_{r2}	α_{r3}	α_{r4}	α_{rtot}	P_{s0}	P_{s1}	P_{s2}
JAN	3.352	3.778	0.644	0.079	50.51	18.56	1.36	0
FEB	1.705	2.126	0.599	0.079	27.27	31.89	2.99	0
MAR	0.779	1.181	0.552	0.079	14.08	35.33	6.43	1.39
APR	0.287	0.630	0.500	0.083	6.87	38.37	8.56	4.41
MAY	0.120	0.390	0.455	0.119	4.28	30.49	12.92	0
JUN	0.083	0-301	0.438	0.156	3.66	27.66	12.45	7.88
JUL	0.092	0.330	0.444	0.142	3.82	26.93	15.32	14.43
AUG	0.184	0.493	0.471	0.096	5.27	28.59	13.12	0
SEP	0.492	0.872	0.515	0.079	9.87	38.98	8.03	2.33
OCT	1.205	1.621	0.577	0.079	20.17	41.43	4.19	0.12
NOV	2.573	2.998	0.620	0.079	39.51	28.18	2.04	0
DEC	4.046	4.472	0.640	0.079	60.21	18.87	0.93	0

For example, in the month of September:

α_{rtot}=12*0.492+2*0.872+4*0.515+2*0.079=9.87

P_{s0}, P_{s1} and P_{s2} can be calculated as described in section 2.4 with the help of the solar radiation tables for

Malmö in section 3.

$$P_{s0}=0.75(6.28*1.159+9.87*4.530)=38.98 \text{ kWh/day}$$

$$P_{s1}=0.75(6.28*1.707+9.87*0.0) = 8.03 \text{ kWh/day}$$

$$P_{s2}=0.75*6.28*0.495 = 2.33 \text{ kWh/day}$$

The last table of calculations includes W_{till} as described in section 2.6. The first step is to transfer P_{rest} and the solar radiation data to the table. Since $P_{s0}>P_{s1}$ for all the months the solar duration diagram is not affected.

$A<P_{rest}$, for January, hence:

$$W_{sol}=0.5(18.56+1.36)*20+0.5(1.36+0.0)(30-20)=206 \text{ kWh/month}$$

and

$$W_{till}=46.18*31-W_{sol}=1226 \text{ kWh/month}$$

The same calculation applies for February, November and December.

For March, April, September and October, $B<P_{rest}<A$ and the heating load for those months is determined as in the following example for April:

$$W_{sol}=0.5(38.37+8.56)*26+0.5(8.56+4.41)(30-26)=636\text{kWh/month}$$

and

$$W_{till}=28.84*30-W_{sol}+\frac{(38.37-28.84)^2}{2(38.37-8.56)}*26=269 \text{ kWh/month}$$

	P_{rest}	A	B	C	d_b	d_2	d_m	W_{sol}	W_{till}
	kWh/day	kWh/day	kWh/day	kWh/day				kWh/m	kWh/m
JAN	46.18	18.56	1.36	0	20	30	31	206	1226
FEB	41.74	31.89	2.99	0	19	27	28	343	825
MAR	45.64	53.33	6.43	1.39	22	31	31	494	920
APR	28.84	38.37	8.56	4.41	26	30	30	636	269
MAY	10.57	30.49	12.92	0	31	31	31	673	0
JUN	3.19	27.66	12.45	7.88	26	30	30	562	0
JUL	0	26.93	15.32	14.43	30	31	31	649	0
AUG	0	28.59	13.12	0	31	31	31	646	0
SEP	10.27	38.98	8.03	2.33	23	30	30	577	37
OCT	17.74	41.43	4.19	0.12	23	31	31	542	181
NOV	32.20	28.18	2.04	0	18	26	3	280	686
DEC	32.56	18.87	0-93	0	19	26	31	191	818
			Annual total (kWh/year)					5799	4962

The available solar gain covers heating requirements in May and June, even on the cloudiest days so the heating loads can be added up to give annual totals.

W_{sol} for each month is not necessary but can be of interest when studying the toal energy balance.

The following table shows the final total energy balance for heating the house (note that household electricity and heating of water is not included in the table).

	Heat losses	Available internal heat generation and solar gain		Utilized internal heat genertion and solar gain		Heating load
	W_{fm}	W_{bo}	W_{sol}	W_{bou}	W_{solu}	W_{till}
	kWh/ month	kWh/ month	kWh/ month	kWh/ month	kWh/ month	kWh/ month
JAN	1828	397	206	397	206	1226
FEB	1527	358	343	358	343	825
MAR	1812	397	494	397	494	920
APR	1249	384	636	384	596	269
MAY	724	397	673	397	328	0
JUN	480	384	562	384	96	0
JUL	206	397	649	206	0	0
AUG	261	397	646	261	0	0
SEP	692	384	577	384	271	37
OCT	947	397	542	397	369	181
NOV	1340	384	200	344	280	686
DEC	1406	397	191	397	191	818
SUM	12482	4673	5799	4346	3174	4962

3 CLIMATIC DATA

As described in chapter 1, the method needs monthly climatic data in a specific form. It is obvious how to get the average outdoor air temperature, while the solar radiation data require some explanations. Appendix A gives a list of a FORTRAN-program, BKLCLI, to carry out the following calculations for each month.

3.1 Required basic data

As the method primarily is based on daily average of temperatures and daily sum of solar radiation, the necessary input data are:

I_{GL} Daily sum of global radiation on horizontal surface

I_{dH} Daily sum of diffuse radiation on horizontal surface

T_{out} Daily average of outdoor air temperature

When reading these values, the program accumulates T_{out} to get the monthly average of the outdoor temperature and sets the daily sum of direct radiation on horizontal surface as $I_{RH}=I_{GL}-I_{dH}$.

3.2 Sorting and linear regression

The next step is to sort the days after decreasing global radiation which, in the program, is carried out by a simple "bubble"-sort.

If linear regression is applied on the two sets of sorted data, we get two lines determined by their values for d=0 and their slopes:

I_{GL0} Global radiation for d=0

G_{slope} The slope of the regression line for global radiation

I_{RH0} As above but for direct radiation

R_{slope} - " -

The global radiation for the last day of the month (d_m) is then determined by

$$I_{GL2}=I_{GL0}+G_{slope}d_m$$

If this value is positive or zero, as shown in Figure 3.1(a), we set the last day with radiation $d_2=d_m$. Otherwise, the regression line is adjusted to get d_2 as the nearest integer whereafter I_{GL0} is adjusted to keep the monthly sum of global radiation. In this case we get $I_{GL2}=0.0$ as shown in Figure 3.1(b). These adjustments are mainly done for pedagogical reasons to avoid negative solar radiation and split days. The next step is to determine the last day with direct radiation (d_1) and the global (I_{GL1}) and direct radiation (I_{RH1}) for that day. First d_2 is used to determine if that day has any direct radiation

$$I_{RH1}=I_{RH0}+R_{slope}d_2$$

If this value is positive or zero we set $d_1=d_2$, otherwise we adjust d_2 to the nearest integer and I_{RH0} to keep the monthly sum of direct radiation. In this case we get $I_{RH1}=0.0$.

Finally we determine I_{dH0}, I_{dH1} and I_{dH2} as differences between global and direct radition for d=0, d_1 and d_2.

3.3 Examples of climatic data

Within IEA-Solar Heating and Cooling - Task 8 - Passive and Hybrid Solar Low Energy Buildings, hourly climatic data from Copenhagen in Denmark and Denver, Colorado in U.S. have been given. Adding these data into daily values and then using the program in Appendix A gives Tables 3.1 and 3.2. Table 3.3 gives the climate data for Malmö, Sweden, used in section 2.

As can be seen from the second table, $d_1=d_2=d_m$ for all months in Denver whereas in Copenhagen we have some winter days without any direct radiation and a few without any solar radiation at all due to the linearized representation.

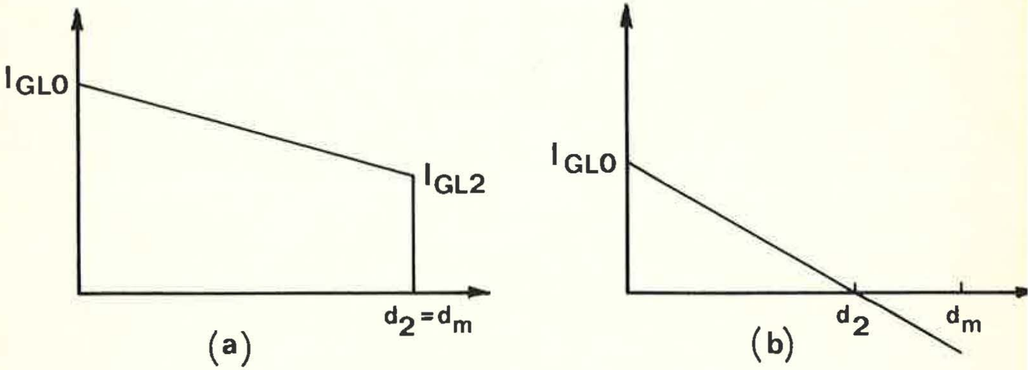


Figure 3.1 Two types of regression lines for monthly global radiation.

Table 3.1 Climate data for Copenhagen.

Data from IEA-Solar Heating and Cooling. Latitude 56 N.

	IdHO	IRHO	IdH1	IRH1	IdH2	d1	d2	dm	Tout
JAN	.424	.415	.308	.000	.000	19	30	31	-.60
FEB	.965	1.695	.532	.000	.000	20	25	28	-1.09
MAR	1.779	2.137	1.044	.000	.000	22	30	31	2.61
APR	1.698	5.083	2.082	.000	1.142	25	30	30	6.60
MAY	2.484	5.633	2.317	.000	1.917	29	31	31	10.64
JUN	2.251	7.053	2.974	.097	2.974	30	30	30	15.65
JUL	2.668	5.606	2.500	.000	2.101	29	31	31	16.44
AUG	1.975	4.588	1.984	.154	1.984	31	31	31	16.65
SEP	1.741	2.478	1.213	.115	1.213	30	30	30	13.69
OCT	1.078	1.706	.752	.000	.045	23	31	31	9.17
NOV	.585	.689	.343	.000	.005	22	30	30	5.00
DEC	.323	.470	.185	.000	.000	23	30	31	1.65

Table 3.2 Climate data for Denver.

Data from IEA-Solar Heating and Cooling. Latitude 39 N.

	IdHO	IRHO	IdH1	IRH1	IdH2	d1	d2	dm	Tout
JAN	.335	3.510	.690	.727	.690	31	31	31	-1.68
FEB	.602	4.848	1.138	.226	1.138	28	28	28	-.60
MAR	.988	6.057	1.670	1.433	1.670	31	31	31	3.56
APR	1.212	7.711	2.345	.777	2.345	30	30	30	9.31
MAY	1.279	8.420	2.995	1.217	2.995	31	31	31	14.04
JUN	1.394	8.667	2.668	2.063	2.668	30	30	30	18.16
JUL	1.277	7.936	2.265	3.183	2.265	31	31	31	22.69
AUG	1.032	7.514	2.294	1.869	2.294	31	31	31	21.16
SEP	.879	6.586	1.606	2.134	1.606	30	30	30	16.85
OCT	.626	5.160	1.046	1.611	1.046	31	31	31	9.49
NOV	.172	3.741	1.001	.642	1.001	30	30	30	3.49
DEC	.241	2.900	.746	.809	.746	31	31	31	-.71

Table 3.3 Climate data for Malmö,Sweden.

Data for 1971 from SMHI. Latitude 56 N.

	IdHO	IRHO	IdH1	IRH1	IdH2	d1	d2	dm	Tout
JAN	.426	.437	.288	.000	.000	20	30	31	.34
FEB	.758	1.385	.635	.000	.000	19	27	28	1.82
MAR	1.142	2.837	1.365	.000	.295	22	31	31	.52
APR	1.202	6.348	1.819	.000	.937	26	30	30	6.12
MAY	.928	8.143	2.578	.244	.000	31	31	31	12.21
JUN	1.571	7.380	2.644	.000	1.674	26	30	30	14.67
JUL	.765	8.136	3.254	.000	3.066	30	31	31	17.78
AUG	.917	6.141	2.295	.586	.000	31	31	31	17.19
SEP	1.159	4.530	1.707	.000	.495	23	30	30	12.31
OCT	.926	2.451	.890	.000	.025	23	31	31	9.82
NOV	.547	.864	.434	.000	.000	18	26	30	5.00
DEC	.353	.381	.198	.000	.000	19	26	31	4.88

4 SOLAR GAIN FACTORS

The method requires precalculated solar gain factors which can be calculated with the FORTRAN-program, BKLALF, listed in Appendix A. The program uses the theories described in this section.

4.1 Diffuse radiation

If the diffuse sky radiation on a horizontal surface is i_{dH} (W/m^2) the diffuse radiation striking on a window surface is

$$i_{ds}=F_{ss}i_{dH}+r_g F_{gs}i_{dH} \quad (W/m^2)$$

where

F_{ss} = view factor between the sky and the surface
F_{gs} = view factor between the ground and the sky
r_g = ground reflectivity

This incident radiation is partly transmitted through the window, partly absorbed in the panes of the window and partly reflected out. Some of the absorbed energy will go into the room and some to the outdoor air. Totally we get following energy transfered into the room:

$$i_{dtot}=T_d i_{ds}+\sum_n \frac{m_n}{m_{tot}} A_{dn}i_{ds}$$

where

T_d = diffuse transmission factor for the window
A_{dn}= diffuse absorption factor for the n:th pane
m_n = heat resistance between the n:th pane and the outdoor air
m_{tot}=heat resistance for the window

Substition of the above equations gives

$$i_{dtot}=(F_{ss}r_gF_{gs})(T_d+\sum_n \frac{m_n}{m_{tot}} A_{dn})i_{dH}$$

To get the daily sum of the total transmitted diffuse radiation we have to integrate the last equation over the day, but since all coefficients in the equation are constants, we directly get the solar gain factor for diffuse radiation

$$\alpha_d = i_{dtot}/i_{dH}$$

The program in Appendix A uses the SHADOW-routine to calculate the view factors. This routine is based on TRNSYS's TYPE34 - routine. The ground reflectivity is set to 0.25 and a heat resistance of 0.06 on the outside, 0.17 between panes and 0.11 m^2K/W on the inside of the window is used.

The TDIFF-routine gives the transmission and absorption factors for the window. The values given in the DATA-statements of that routine are calculated with use of Fresnel's laws and taking two polarisation directions and all inter reflections into account, see Källblad, 1973.

4.2 Direct radiation

Direct radiation with a normal intensity of i_{Rn} W/m^2 gives $i_{Rn}\sin(h)$ on a horizontal surface where h is the solar altitude. This gives a daily sum of direct radiation on a horizontal surface

$$I_{RH} = \int_{24h} i_{Rn}(t)\sin(h(t))dt$$

which in the program is approximated by a sum of the values for each half hour of true solar time. The normal intensity $i_{Rn}(t)$ is calculated as for clear days in Sweden according to Brown, G and Isfält, E (1974).

If the incident angle on a window is θ, we have a total radiation onto the window caused by the direct radiation

$$i_{Rs} = i_{Rs1} + i_{Rs2}$$

where

$$i_{Rs1} = \begin{cases} i_{Rn}\cos\theta, \text{ if } \cos\theta > 0 \\ 0 \text{ elsewhere} \end{cases}$$

$$i_{Rs2} = r_g \, F_{gs} \, i_{Rn}\sin(h)$$

The ground reflectivity and the view factor are the same as above and, as the reflection is assumed as diffuse, i_{Rs2} is diffuse radiation going into the room in the same way as described in section 4.1. The direct part, i_{Rs1}, is going into the room in a similar way but now with absorption and transmission factors for direct radiation which are dependent on the incident angle. We get a total solar heat gain due to direct radiation as

$$i_{Rtot} = i_{Rt1} + i_{Rt2}$$

where

$$i_{Rt1} = \left(T_R(0) + \sum_n \frac{m_n}{m_{tot}} A_{Rn}(0)\right) i_{Rs1}$$

$$i_{Rt2} = \left(T_d + \sum_n \frac{m_n}{m_{tot}} A_{dn}\right) i_{Rs2}$$

The solar angles and thus the intensity, the incident angle, the absorption and transmission factors vary during the day and during the year, the solar gain factors cannot be calculated direct as for the diffuse radiation. For the 15th of each month, the daily sum of solar heat gain I_{Rtot} is obtained by integration of i_{Rtot} over the day. In the program this is approximated by a sum of the values for each half hour. The program uses the SOLAR-routine to calculate the solar declination according to Spencer, 1971, the sun rise and the sunset time for each month. Through the entry point SUN, the necessary time dependent solar angles and direct normal radiation is obtained. The SHADOW-routine, through its entry-point SHDWR, gives the cosine for the incident angle and the shading factor for this solar angles and the TDIFF-routine's entry-point TDIR performs an interpolation to serve with absorption and transmission factors for the actual incident angle.

After the integrations of daily sum of direct radiation on a horizontal surface I_{RH} and the daily sum of solar heat gain I_{Rtot} we get the solar gain factor as

$$\alpha_r = I_{Rtot}/I_{RH}$$

The listed program carries out the above calculation for 12 months and 16 different directions for each case specified by the input and produce tables as below.

Table 4.1 Example of output from the program BKLALF in Appendix A.

ALFA-VALUES FOR THE BKL-METHOD, LATITUDE: 56 0 NORTH.
Solar gain factors for unshaded, vertical windows

			DIRECT RADIATION, DIFFERENT FACADE ORIENTATION							
CASE	DIFF. RAD.		NORTH	NNE NNW	NE NW	ENE WNW	EAST WEST	ESE WSW	SE SW	SSE SSW	SOUTH
		JAN	.088	.088	.088	.193	.735	1.711	2.916	3.944	4.314
		FEB	.088	.088	.110	.295	.677	1.176	1.712	2.189	2.403
		MAR	.088	.095	.180	.371	.619	.874	1.099	1.266	1.334
		APR	.093	.140	.259	.412	.560	.673	.733	.732	.713
		MAY	.135	.190	.304	.420	.508	.550	.533	.475	.444
2-pane	.440	JUN	.179	.227	.332	.429	.490	.498	.448	.377	.345
		JUL	.162	.213	.322	.426	.496	.516	.477	.409	.377
		AUG	.109	.163	.280	.412	.527	.601	.620	.586	.559
		SEP	.088	.111	.213	.384	.578	.755	.891	.969	.985
		OKT	.088	.088	.138	.336	.650	1.015	1.377	1.683	1.829
		NOV	.088	.088	.090	.228	.702	1.447	2.324	3.103	3.401
		DEC	.088	.088	.088	.161	.744	1.936	3.464	4.714	5.147
		JAN	.079	.079	.079	.165	.650	1.531	2.623	3.563	3.900
		FEB	.079	.079	.096	.260	.605	1.056	1.540	1.973	2.171
		MAR	.079	.084	.159	.332	.556	.786	.990	1.140	1.200
		APR	.083	.124	.231	.370	.503	.605	.659	.657	.639
		MAY	.119	.169	.273	.377	.457	.494	.479	.424	.396
3-pane	.396	JUN	.158	.202	.298	.386	.440	.448	.401	.335	.305
		JUL	.143	.190	.289	.383	.447	.464	.428	.365	.335
		AUG	.096	.145	.250	.370	.474	.541	.558	.525	.500
		SEP	.079	.098	.190	.344	.519	.679	.802	.872	.885
		OKT	.079	.080	.121	.298	.582	.912	1.239	1.516	1.650
		NOV	.079	.079	.081	.198	.624	1.297	2.091	2.801	3.075
		DEC	.079	.079	.079	.137	.654	1.731	3.116	4.260	4.653
		JAN	.073	.073	.073	.147	.587	1.392	2.388	3.249	3.555
		FEB	.073	.073	.087	.235	.550	.961	1.402	1.798	1.981
		MAR	.073	.077	.144	.301	.506	.715	.901	1.039	1.094
		APR	.076	.112	.211	.336	.458	.551	.601	.599	.582
		MAY	.108	.154	.248	.344	.416	.451	.437	.386	.360
4-pane	.363	JUN	.144	.184	.271	.352	.401	.409	.366	.305	.277
		JUL	.130	.173	.263	.349	.407	.424	.390	.332	.304
		AUG	.087	.132	.228	.337	.432	.493	.509	.479	.455
		SEP	.073	.089	.172	.313	.473	.619	.731	.795	.807
		OKT	.073	.073	.109	.271	.530	.830	1.128	1.381	1.506
		NOV	.073	.073	.074	.177	.566	1.180	1.903	2.553	2.804
		DEC	.073	.073	.073	.121	.589	1.573	2.837	3.886	4.240

5 VALIDATIONS OF THE METHOD

The BKL-method has been compared with detailed computer calculation carried out with the JULOTTA-program (Källblad and Higgs, 1981). Some comparisons with other programs have also been carried out within the International Energy Agency (IEA).

In the first comparison a two-storey terrace house with a total of 147 m^2 floor area has been studied. The thermal characteristics of the building are given in Table 5.1 and climatic data from the period September 1945 - August 1946 in Stockholm, Sweden, are used in the calculations.

Table 5.1 Common thermal characteristics of the building studied in Table 5.2 - 5.4.

Building part	Area m^2	U-value $W/m^2, °C$
Roof	73.4	Var.
Floor	73.4	0.162
Windows, 2-panes	Var.	3.0
Windows, 3-panes	Var.	2.0
Windows, 4-panes	Var.	1.5
North facing windows	4.5	Var.
Outer walls and south windows	69.1	Var.

Space volume: 353 m^2
Concrete slabs (In table 5.3 this is valid for the high cap.)
The heat input is controlled by room thermostats which do not allow the room air temperature to exceed 20°C.

The results from the BKL-method are compared with the computer calculations in Table 5.2 and the agreement between the methods are good. Table 5.3 gives some ideas about the variations one can obtain. The table shows the monthly heat re-- quirement for three cases with exactly the same transmission and ventilation losses, they differ only by different heat capacity. As the BKL-method neglects the heat capacity, differences in the same order as shown in Table 5.3 must be accepted.

Table 5.2 Comparison between the BKL-method and computer calculatins with the JULOTTA-program.

Case No.	South window area (m^2)	Number of panes in all windows	Venti- lation (m^3/h)	U-value of walls & roof ($W/m^2,°C$)	Annual heat requirement BKL (kWh)	JULOTTA (kWh)	BKL/JULOTTA
1	6.7	2	176	0.279	12030	11740	1.02
2	"	"	395	0.098	17420	17670	0.99
3	"	"	"	0.279	20140	19710	1.02
4	"	3	71	0.098	4970	5050	0.98
5	"	"	176	"	8570	8810	0.97
6	"	"	"	0.279	11130	10880	1.02
7 *)	"	"	"	"	7200	7100	1.01
8	"	4	71	0.098	4610	4670	0.99
9	"	"	"	0.279	7040	6720	1.05
10	"	"	176	"	10810	10500	1.03
11	10.5	2	176	"	11720	11770	1.00
12	"	3	"	"	10580	10610	1.00
13	"	4	"	"	10150	10120	1.00
14	20.9	3	71	"	6890	6940	0.99
15	"	"	176	"	9960	10330	0.96
16	"	"	282	"	13260	13920	0.95

*) Internal heat gain 15.9 kWh/day, elsewere 0.

Table 5.3 Monthly energy requierments for case 6 in table 5.2 with different heat capacity.

Month	Result from BKL-method	Results from JULOTTA Low cap.	Midium cap.	High cap.
1945-09	240	230	230	180
10	950	930	930	920
11	1550	1530	1520	1530
12	1960	1920	1920	1920
1946-01	1920	1890	1880	1890
02	1870	1840	1840	1840
03	1520	1500	1500	1500
04	730	700	700	680
05	350	410	410	400
06	10	30	30	10
07	0	0	0	0
08	30	30	30	10
Annual	11130	11010	10990	10880

In these comparisons, the solar gain factors have been calculated slightly different from the method shown in section 4, the actual solar radiation for each hour has been used. Table 5.4 on the other hand, shows a comparison where the solar gain factors have been calculated exactly as described in section 4 and the results are still in good agreement with the computer calculations.

Table 5.4 Comparison between the BKL-method and computer calculations with the JULOTTA-program

Case No.	South window area (m^2)	Number of panes in all windows	Ventilation (m^3/h)	U-value of walls & roof (W/m^2, °C)	Annual heat requirement BKL (kWh)	Annual heat requirement JULOTTA (kWh)	BKL/JULOTTA
17	20.9	3	176	0.283	8383	8301	1.01
18 *)	20.9	3	176	0.283	5374	5231	1.03
19	20.9	4	71	0.098	2910	2895	1.01
20 *)	20.9	4	71	0.098	1078	807	1.35
21 **)	20.9	3	176	0.283	9761	10548	1.08
22	10.5	3	176	0.283	17068	17009	1.00

*) Internal heat gain 15.9 kWh/day, elsewhere 0.

**) South facing windows shaded by an overhang of 1.1 meter on top of the 1.2 meter high window, elsewere no shading.

In one of the cases in Table 5.4 the south windows are shaded and the agreement is in this case not as good as for the other cases. This can indicate some problems to handle shadings with precalculated solar gain factors which in fact assume the same cloudiness during a whole day.

Case 20 in this table, however, indicate a more serious problem when dealing with extremely well insulated buildings with heat recovery on ventilation and relatively high internal and solar heat gain To overcome this problem, one might introduce some form of variable utilization factor for the free heat.

The comparisons within the IEA are fully reported by Källblad, 1983 and one of the results is shown in Figure 5.1. The Vetlanda house is a one-storey low-energy house without basement and situated in Vetlanda, Sweden. In this case, the south windows are shaded by an overhang and solar gain factors have been precalculated according to section 4 with use of daily sums of the measured radiation. In the figure, the DD-method is a simple Degree-Day estimation of the heat requirement and the other methods are of different complexities. The BKL-method seems to give acceptable results in this comparison as well .

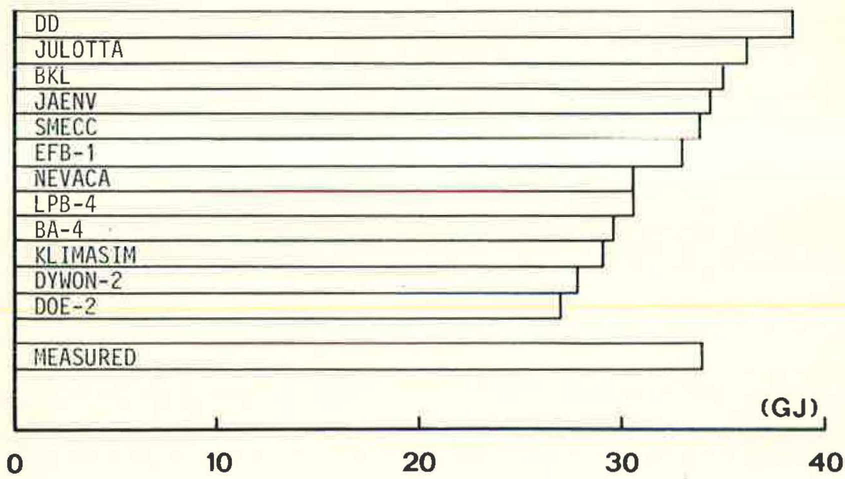


Figure 5.1 Five month heat requirement for the Vetlanda House.

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APPENDIX A

List of FORTRAN programs

1. BKLCLI to calculate condensed climate data for the BKL-method

2. BKLALF to calculate solar gain factors for the BKL-method

```
C********************************************************************* BKLCLI
C**                                                                        **
C**   PROGRAM:                                                             **
C**     BKL-METHOD-CLIMA.                                                  **
C**                                                                        **
C**   AUTHOR:                                                              **
C**     KURT KÄLLBLAD, 1983.                                               **
C**     Department of Building Science                                     **
C**     University of Lund                                                 **
C**     P.O.Box 725, S-220 07 LUND                                         **
C**     Sweden                                                             **
C**                                                                        **
C**   PURPOSE:                                                             **
C**    Calculation of condensed cimate data for the BKL-method.            **
C**    For further information, see the report on the method.              **
C**                                                                        **
C**   I/P    LOC         Name of location (max. 60 characters)             **
C**          LEAP        1 for a leap-year, else 0                          **
C**          T,Igl,IdH   Daily weather data (365 records)                   **
C**                      T   Daily average outdoor temperature              **
C**                      Igl Daily sum of global radiation                  **
C**                      IdH Daily sum of diffuse radiation on horiz.       **
C**                      (Temp. in grad C, radiation in kWh/m2,day)         **
C**                                                                        **
C**   O/P    Table of condensed climate data for the BKL-method.           **
C**                                                                        **
C**   LANGUAGE:                                                            **
C**     UNIVAC ASCII FORTRAN Level 9R1                                     **
C**     (Very few, if any, extentions from ANSI FORTRAN 77 is used.)       **
C**                                                                        **
C**   SUBPROGRAMS: None.                                                   **
C**                                                                        **
C****************************************************************************

      INTEGER D1,D2
      CHARACTER MONTH*3,LOC*60
      REAL IGL,IRH,IDH,IGLO,IRHO,IDHO,IRH1,IDH1,IGL2,IDH2
      DIMENSION IGL(31),IRH(31),IDH(31),NDM(12),MONTH(12)
      DATA NDM/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA MONTH/'JAN','FEB','MAR','APR','MAY','JUN',
     &           'JUL','AUG','SEP','OCT','NOV','DEC'/

C================================================================= HEADLINES
      READ(5,10) LOC
10    FORMAT(A60)
      WRITE(6,20) LOC
20    FORMAT('1     ',A60/6X,63('-')/
     &/15X,'IdHO   IRHO   IdH1   IRH1   IdH2    d1  d2  dm    Tout'
     &/15X,54('-'))
C==========================================================================
      READ(5,30) LEAP
30    FORMAT()
      IF(LEAP.EQ.1) NDM(2)=29
C==========================================================================
      DO 90 MO=1,12
C======================================= READ WEATHERDATA FOR ONE MONTH
        TAV=0.0
        DO 40 I=1,NDM(MO)
          READ(5,30) TOUT,IGL(I),IDH(I)
          IRH(I)=IGL(I)-IDH(I)
```

```
          TAV=TAV+TOUT
 40       CONTINUE
        TAV=TAV/NDM(MO)
C======================================================= SORTING
        DO 60 I=NDM(MO),2,-1
          DO 50 J=2,I
            IF (IGL(J).GT.IGL(J-1)) THEN
              X=IGL(J)
              IGL(J)=IGL(J-1)
              IGL(J-1)=X
              X=IRH(J)
              IRH(J)=IRH(J-1)
              IRH(J-1)=X
              L=1
            END IF
 50         CONTINUE
 60       CONTINUE
C============================================= LINEAR REGRESSION
        SUMX=0.0
        SUMGL=0.0
        SUMRH=0.0
        SUMX2=0.0
        SUMXGL=0.0
        SUMXRH=0.0

        DO 70 I=1,NDM(MO)
          X=REAL(I)-0.5
          SUMX=SUMX+X
          SUMGL=SUMGL+IGL(I)
          SUMRH=SUMRH+IRH(I)
          SUMX2=SUMX2+X*X
          SUMXGL=SUMXGL+X*IGL(I)
 70       SUMXRH=SUMXRH+X*IRH(I)

        DE=REAL(NDM(MO))*SUMX2-SUMX*SUMX
        GSLOOP=(REAL(NDM(MO))*SUMXGL-SUMGL*SUMX)/DE
        RSLOOP=(REAL(NDM(MO))*SUMXRH-SUMRH*SUMX)/DE
        IGLO=(SUMGL-GSLOOP*SUMX)/REAL(NDM(MO))
        IRHO=(SUMRH-RSLOOP*SUMX)/REAL(NDM(MO))
C======================================== LAST DAY WITH RADIATION
        IGL2=IGLO+GSLOOP*REAL(NDM(MO))
        IF (IGL2.GE.0.0) THEN
          D2=NDM(MO)
C------------------------------- CORRECTIONS FOR "NEG." RADIATION
        ELSE
          D2=NINT(2.0*SUMGL/IGLO)
          IGLO=2.0*SUMGL/REAL(D2)
          IGL2=0.0
        END IF
C================================= LAST DAY WITH DIRECT RADIATION
        IRH1=IRHO+RSLOOP*REAL(D2)
        IF (IRH1.GE.0.0) THEN
          D1=D2
C------------------------------- CORRECTIONS FOR "NEG." RADIATION
        ELSE
          D1=NINT(2.0*SUMRH/IRHO)
          IRHO=2.0*SUMRH/REAL(D1)
          IRH1=0.0
        END IF
C========================================== REMAINING COEFFICIENTS
```

```
            IDHO=IGLO-IRHO
            IDH1=IGLO+(IGL2-IGLO)*REAL(D1)/REAL(D2)-IRH1
            IDH2=IGL2-IRH1
C=================================================== PRINT MONTHLY VALUES
            WRITE(6,80) MONTH(MO),IDHO,IRHO,IDH1,IRH1,IDH2,D1,D2,NDM(MO),TAV
80          FORMAT(6X,A3,3X,5F7.3,I6,2I4,F8.2)
            IF (MO.LT.12 .AND. MOD(MO,3).EQ.O) WRITE(6,30)
90          CONTINUE
C===================================================== PRINT END OF TABLE
      WRITE(6,100)
100   FORMAT(6X,63('-'))

      END
```

```
C*************************************************************** BKLALF
C**                                                                  **
C**   PROGRAM:                                                       **
C**     BKL-METHOD-ALFA-VALUES.                                      **
C**                                                                  **
C**   AUTHOR:                                                        **
C**     KURT KÄLLBLAD, 1983.                                         **
C**     Department of Building Science                               **
C**     University of Lund                                           **
C**     P.O.Box 725, S-220 07 LUND, Sweden.                          **
C**                                                                  **
C**   PURPOSE:                                                       **
C**    Calculation of alfa-values for the BKL-method.                **
C**    For further information, see the report on the method.        **
C**                                                                  **
C**   I/P Common to all cases (2 cards):                             **
C**       1. HDL    Headline for output (max. of 72 characters)      **
C**       2. LATD   Degrees of Latitude of location                  **
C**          LATM   Minutes      ---     "   ---                     **
C**          NOCASE Number of cases which will follow                **
C**   I/P For each case (2 or 3 cards per case):                     **
C**       1. CASE   Case-identifier of max. 6 character              **
C**       2. NPAN   Number of panes                                  **
C**          TILT   Tilt angle (0 = vertical, 90 = hor.)             **
C**          WH     Window highth                                    **
C**          WW     Window width                                     **
C**          LS     = 0 if no shading, =1 if shading.                **
C**       If (LS = 1) :                                              **
C**       3. ((DIM(I,J),I=1,4),J=1,3)                                **
C**                 Dimension of overhang, left and right wing.      **
C**                 J=1: Overhang, J=2: Left wing, J=3: Right wing   **
C**                      I=1: Depth of owerhang/wing                 **
C**                      I=2: Distance from overhang/wing to window  **
C**                      I=3: Extention left of or above the window  **
C**                      I=4: Extention right of or below the window **
C**   NOTE: If the side wings are of dfferent sizes, the result is   **
C**   valid only for north, south and partly east-orientaded windows. **
C**   For partly west-orientated windows, the wings must shift places.**
C**                                                                  **
C**   LANGUAGE:                                                      **
C**     UNIVAC ASCII FORTRAN Level 9R1                               **
C**     (Very few, if any, extentions from ANSI FORTRAN 77 is used.) **
C**                                                                  **
C**   SUBPROGRAMS:                                                   **
C**     Subroutine TDIFF with Entry Point TDIR.                      **
C**     Subroutine SOLAR with Entry Point SUN.                       **
C**     Subroutine SHADOW with Entry Point SHDWR.                    **
C**                                                                  **
C**   NOTE: Current version does not handle shaded AND tilt windows, **
C**         only shaded OR tilt windows.                             **
C**                                                                  **
C*********************************************************************

      REAL IRN
      CHARACTER MONTH*3,CASE*6,HDL*72
      DIMENSION MONTH(12),ALFR(9),AB(4),RX(4),DIM(4,3)
      DATA RX,RXI,REFL,DTR/.06,.23,.40,.57,.11,.25,.017453292/
      DATA MONTH/'JAN','FEB','MAR','APR','MAY','JUN',
     &           'JUL','AUG','SEP','OKT','NOV','DEC'/

```

```
C=============================================== READ COMMON DATA
      READ(5,1) HDL
1     FORMAT(A72)
      READ(5,2) LATD,LATM,NOCASE
2     FORMAT()
      ALAT=DTR*(REAL(LATD)+REAL(LATM)/60.0)
C========================================================= HEADLINES
      WRITE(6,3) LATD,LATM,HDL
3     FORMAT('1      ALFA-VALUES FOR THE BKL-METHOD,'
     &,'  LATITUDE:',2I3,' NORTH.'/6X,A72//26X,'DIRECT RADIATION,'
     &,' DIFFERENT FACADE ORIENTATION'/13X,'DIFF.',15X
     &,'NNE    NE    ENE  EAST   ESE    SE    SSE '/6X,'CASE   RAD.'
     &,9X,'NORTH  NNW    NW   WNW  WEST   WSW    SW    SSW SOUTH')

      DO 120 NC=1,NOCASE
C========================================== READ DATA FOR ONE CASE
        READ(5,10) CASE
10      FORMAT(A6)
        READ(5,2) NPAN,TILT,WH,WW,L
        TILT=DTR*TILT
        LSH=0
        IF (L.GT.0) THEN
          READ(5,2) DIM
          DO 20 I=1,3
20          IF (DIM(1,I).GT.0.0) LSH=1
        END IF
C============================================ DIFFUSE COEFFICIENTS
        CALL SHADOW(WH,WW,TILT,LSH,DIM,FWS,FWG)
        CALL TDIFF(NPAN,PT,AB)
        ST=0.0
        DO 30 I=1,NPAN
30        ST=ST+RX(I)*AB(I)
        ST=ST/(RX(NPAN)+RXI)
        TDT=PT+ST
        ALFS=(FWS+REFL*FWG)*TDT
C============================================= DIRECT COEFFICIENTS
        WRITE(6,2)
        DO 110 MO=1,12
          SUMRH=0.0
          CALL SOLAR(ALAT,MO,SRT,SST)
          IT1=INT(2.0*SRT)
          IT2=INT(2.0*SST)
          IF (IT1.LE.0) IT1=1
          DO 40 N=1,9
40          ALFR(N)=0.0
C--------------------------------------------- TRUE SOLAR TIME LOOP
          DO 70 IT=IT1,IT2
            CALL SUN(0.5*REAL(IT),CW,CS,CZ,IRN)
            IF (CZ.GT.0.0) THEN
              SUMRH=SUMRH+IRN*CZ
              DO 60 NR=1,9
                ORIENT=DTR*22.5*REAL(NR-1)
                CALL SHDWR(CW,CS,CZ,ORIENT,CIF,FI)
                IF (CIF.GT.0.0 .AND. FI.GT.0.0) THEN
                  CALL TDIR(NPAN,CIF,PT,AB)
                  ST=0.0
                  DO 50 I=1,NPAN
50                  ST=ST+RX(I)*AB(I)
                  ST=ST/(RX(NPAN)+RXI)
                  ALFR(NR)=ALFR(NR)+IRN*CIF*FI*(PT+ST)
```

```
               END IF
 60            CONTINUE
             END IF
 70          CONTINUE
C--------------------------------------------------------------------------
            DO 80 NR=1,9
 80          ALFR(NR)=(ALFR(NR)+SUMRH*REFL*FWG*TDT)/SUMRH
            IF (MO.NE.6) THEN
             WRITE(6,90) MONTH(MO),(ALFR(I),I=1,9)
 90          FORMAT(19X,A3,F8.3,8F6.3)
            ELSE
             WRITE(6,100) CASE,ALFS,(ALFR(I),I=1,9)
 100         FORMAT(6X,A6,F5.3,'  JUN',F8.3,8F6.3)
            END IF
 110      CONTINUE
C===================================================== END OF ONE CASE
 120      CONTINUE
C======================================================== END OF TABLE
      END

C************************************************************** TDIFF

      SUBROUTINE TDIFF(N,T,A)
C***************************

      DIMENSION A(*),TSK(4),ASK(4,4),TDK(11,4),ADK(11,4,4)
      DATA TSK
     &/ .77978, .64427, .54763, .47333/
      DATA ASK
     &/ .08057, .00000, .00000, .00000
     &, .08835, .06507, .00000, .00000
     &, .09227, .07178, .05429, .00000
     &, .09438, .07537, .05965, .04619/
      DATA TDK
     &/ .00000, .23664, .45597, .61099, .71111
     &, .77289, .81014, .83222, .84505, .85224, .85604
     &, .00000, .11055, .28133, .44121, .56012
     &, .63590, .68068, .70672, .72209, .73138, .73712
     &, .00000, .05765, .18682, .33496, .45878
     &, .53903, .58363, .60767, .62163, .63079, .63750
     &, .00000, .03136, .12841, .26061, .38354
     &, .46490, .50687, .52689, .53795, .54602, .55314/
       DATA (((ADK(I,J,K),I=1,11),J=1,4),K=1,2)
     &/ .00000, .07780, .08312, .08377, .08276
     &, .08090, .07854, .07588, .07308, .07023, .06739
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000
     &, .00000, .10044, .10380, .09919, .09373
     &, .08899, .08496, .08137, .07804, .07487, .07184
     &, .00000, .03424, .04849, .05756, .06278
     &, .06494, .06507, .06401, .06229, .06024, .05803
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000/
       DATA (((ADK(I,J,K),I=1,11),J=1,4),K=3,4)
```

```
     &/ .00000, .10539, .11098, .10575, .09879
     &, .09301, .08857, .08487, .08149, .07827, .07515
     &, .00000, .04834, .06408, .07001, .07196
     &, .07190, .07073, .06894, .06680, .06450, .06213
     &, .00000, .01694, .03088, .04215, .04997
     &, .05397, .05514, .05472, .05351, .05193, .05019
     &, .00000, .00000, .00000, .00000, .00000
     &, .00000, .00000, .00000, .00000, .00000, .00000
     &, .00000, .10673, .11396, .10902, .10141
     &, .09515, .09069, .08718, .08395, .08078, .07763
     &, .00000, .05199, .07018, .07580, .07652
     &, .07557, .07405, .07217, .07000, .06764, .06520
     &, .00000, .02449, .04131, .05123, .05695
     &, .05948, .05984, .05898, .05751, .05577, .05391
     &, .00000, .00880, .02047, .03185, .04081
     &, .04577, .04740, .04720, .04621, .04493, .04355/

      T=TSK(N)
      DO 10 L=1,N
10      A(L)=ASK(L,N)
      RETURN

C***************************
      ENTRY TDIR(N,CIF,T,A)
C***************************

      IF (CIF.LE.0.0) THEN
        T=0.0
        DO 20 L=1,N
20        A(L)=0.0
      ELSE IF (CIF.LT.1.0) THEN
        X=10.0*CIF
        I=INT(X)
        T=TDK(I+1,N)+(X-REAL(I))*(TDK(I+2,N)-TDK(I+1,N))
        DO 30 L=1,N
30        A(L)=ADK(I+1,L,N)+(X-REAL(I))*(ADK(I+2,L,N)-ADK(I+1,L,N))
      ELSE
        T=TDK(11,N)
        DO 40 L=1,N
40        A(L)=ADK(11,L,N)
      END IF
      RETURN
      END

C*********************************************************************** SOLAR

      SUBROUTINE SOLAR(ALAT,MO,SRT,SST)
C*******************************

      REAL IRN
      DIMENSION A(2),B(4,2),NDM(12)
      DATA  EPS, A, B, NDM  / 1.E-8, 0.139, 0.109,
     & 5838.27, -26704.97, 70722.19, -72678.86,
     & 6714.56, -31165.97, 83437.14, -88563.88,
     & 0, 31, 59, 90, 120, 151, 181, 212, 243, 273, 304, 334/

C=============================================================== SUN DECLINATION
      PI=ATAN2(0.0,-1.0)
      V=2.0*PI*REAL(NDM(MO)+14)/365.0
      DEK = 0.006918 - 0.399912*COS(  V) + 0.070257*SIN(  V)
```

```
     &                  - 0.006758*COS(2*V) + 0.000907*SIN(2*V)
     &                  - 0.002697*COS(3*V) + 0.001480*SIN(3*V)
      CD=COS(DEK)
      SD=SIN(DEK)
      CL=COS(ALAT)
      SL=SIN(ALAT)
      CDCL=CD*CL
      SDSL=SD*SL
      IF (SDSL.GE.CDCL) THEN
C*      24 HOURS OF DAYLIGHT
        SRT=0.0
        SST=24.0
      ELSE IF (SDSL.LE.-CDCL) THEN
C*      24 HOURS OF NIGHT
        SRT=0.0
        SST=0.0
      ELSE
C*      DAY AND NIGHT
        X=ACOS(-SDSL/CDCL)
        SRT=12.0-X*12.0/PI
        SST=12.0+X*12.0/PI
      END IF
      RETURN
C*************************************
      ENTRY SUN(TST,CSW,CSS,CSZ,IRN)
C*************************************
C==================================== SOLAR ANGLES AT TRUE SOLAR TIME TST
      H=PI*(TST/12.0-1.0)
      CDH=CD*COS(H)
      CSW=CD*SIN(H)
      CSS=CDH*SL-SD*CL
      CSZ=CDH*CL+SD*SL
      IF(ABS(CSW).GT.1.0) CSW=SIGN(1.0,CSW)
      IF(ABS(CSS).GT.1.0) CSS=SIGN(1.0,CSS)
      IF(ABS(CSZ).GT.1.0) CSZ=SIGN(1.0,CSZ)
C========================================== DIRECT NORMAL SOLAR RADIATION
      IF (CSZ.LT.EPS) THEN
        IRN=0.0
      ELSE
        N=1
        IF(MO.LT.5.OR.MO.GT.9) N=2
        ALT=ASIN(CSZ)
        IF(ALT.GT.0.261799) IRN=1071.*EXP(-A(N)/CSZ)
        IF(ALT.LE.0.261799) IRN=B(1,N)*ALT
     &                             +B(2,N)*ALT**2
     &                             +B(3,N)*ALT**3
     &                             +B(4,N)*ALT**4
      END IF
      RETURN
      END
C******************************************************************* SHADOW
C**
C**      This routine is based on the TRNSYS's TYPE34-routine.
C**      All changes from that routine are marked as follow:
C**        C**X         This line is excluded (comment out).
C**        C**START NEW Start of new lines.
```

```
C**           C**END NEW   End of new lines.
C**
C**START NEW ===========================================================
      SUBROUTINE SHADOW(WH,WW,TILT,LSH,DIM,FWS,FWG)

      DIMENSION DIM(4,3),F12(2,3),FP(3),G(3),EL(3),ER(3)
      DATA RD, PI/ 0.017453292, 3.141592654/
C**END NEW =============================================================
C**X   SUBROUTINE TYPE34(TIME,XIN,OUT,T,DTDT,PAR,INFO)
C**X   DIMENSION PAR(15),OUT(10),INFO(10),F12(2,3),XIN(6)
C**X   DIMENSION FP(3),G(3),EL(3),ER(3)
C**X   DATA IUNIT/0/,RD/0.017453292/,PI/3.141592654/
       DATA STPNUM/10./
C**X   IF (INFO(7).GT.0) RETURN
C**X   IF (INFO(1).EQ.IUNIT) GO TO 1102
C**X   HT=PAR(1)
C**X   WT=PAR(2)
C**X   AREA=WT*HT
C**X   FP(1)=PAR(3)
C**X   G(1)=PAR(4)
C**X   EL(1)=PAR(5)
C**X   ER(1)=PAR(6)
C**X   FP(2)=PAR(7)
C**X   G(2)=PAR(8)
C**X   EL(2)=PAR(9)
C**X   ER(2)=PAR(10)
C**X   FP(3)=PAR(11)
C**X   G(3)=PAR(12)
C**X   EL(3)=PAR(13)
C**X   ER(3)=PAR(14)
C**X   WAZI=PAR(15)*RD
C..THIS COMPONENT CALCULATES THE AVERAGE SOLAR FLUX ON A
C..SHADED VERTICAL RECEIVER
C..ALPH    SOLAR AZIMUTH ANGLE (+VE WEST OF SOUTH - DEG.)
C..COSZ    COSINE OF SOLAR ZENITH ANGLE
C..FI      SHADE RATIO: SUNLIT RECEIVER AREA TO TOTAL RECEIVER AREA
C..HT      WINDOW HEIGHT
C..WT      WINDOW WIDTH
C..FP(1)   DEPTH OF OVERHANG
C..G(1)    DISTANCE FROM TOP OF WINDOW TO OVERHANG
C..EL(1)   DISTANCE OVERHANG EXTENDED BEYOND LEFT EDGE OF WINDOW
C..ER(1)   DISTANCE OVERHANG EXTENDED BEYOND RIGHT EDGE OF WINDOW
C..FP(2)   DEPTH OF LEFT FIN
C..EL(2)   DISTANCE LEFT FIN EXTENDS ABOVE TOP OF WINDOW
C..G(2)    DISTANCE FROM LEFT EDGE OF WINDOW TO LEFT FIN
C..ER(2)   DISTANCE FIN STOPS SHORT OF BOTTOM OF WINDOW
C..FP(3)   DEPTH OF RIGHT FIN
C..EL(3)   DISTANCE RIGHT FIN EXTENDS ABOVE TOP OF WINDOW
C..G(3)    DISTANCE FROM RIGHT EDGE OF WINDOW TO RIGHT FIN
C..ER(3)   DISTANCE RIGHT FIN STOPS SHORT OF BOTTOM OF WINDOW
C..WAZI    WINDOW AZIMUTH ANGLE (+VE WEST OF SOUTH - DEG.)
C..TILT    WINDOW TILT FROM VERTICAL (=0. - DEG.)
C**X 1102  IUNIT=INFO(1)
C**X   IF (INFO(7).GT.-1) GO TO 3000
C**X   CALL TYPECK(1,INFO,6,15,0)
C**START NEW ===========================================================
      HT=WH
      WT=WW
      AREA=WT*HT
      DO 999 I=1,3
```

```
          FP(I)=DIM(1,I)
          G(I)=DIM(2,I)
          EL(I)=DIM(3,I)
999       ER(I)=DIM(4,I)
        SINT=SIN(TILT)
        COST=COS(TILT)

        IF (LSH.EQ.0) THEN
          FWS=0.5*(1.0+SINT)
          FWG=0.5*(1.0-SINT)
        ELSE
C**END NEW ====================================================
C..CALCULATE THE RADIATION VIEW FACTORS
         XX=WT
         YY=HT
         DO 2100 I=1,3
            F12(1,I)=0.
            F12(2,I)=0.
            IF(FP(I).LT.0.001) GO TO 2050
            STEP1=XX/STPNUM
            STEP2=YY/STPNUM
            FPL=XX+EL(I)+ER(I)
            X=-STEP1/2.0
            DO 200 I1=1,10
               X=X+STEP1
               BB1=EL(I)+X
               BB2=FPL-BB1
               Y=-STEP2/2.0
               FD1=0.0
               FD2=0.
               DO 210 I2=1,10
                  Y=Y+STEP2
                  C=Y+G(I)
                  X1=FP(I)/BB1
                  X2=FP(I)/BB2
                  Y1=C/BB1
                  Y2=C/BB2
                  SUM1=X1*X1+Y1*Y1
                  SUM2=X2*X2+Y2*Y2
                  ARG1=SQRT(SUM1)
                  ARG2=SQRT(SUM2)
                  ARG11=1./ABS(Y1)
                  ARG12=1./ARG1
                  ARG21=1./ABS(Y2)
                  ARG22=1./ARG2
                  F1=ATAN(ARG11)-ABS(Y1)*ATAN(ARG12)/ARG1
                  F2=ATAN(ARG21)-ABS(Y2)*ATAN(ARG22)/ARG2
                  IF(BB1.LT.0.0) F1=-F1
                  IF(BB2.LT.0.0) F2=-F2
                  FD1=FD1+STEP2*F1/PI/2.0
                  FD2=FD2+STEP2*F2/PI/2.
  210             CONTINUE
               F12(1,I)=F12(1,I)+FD1*STEP1
               F12(2,I)=F12(2,I)+FD2*STEP1
  200          CONTINUE
            F12(1,I)=F12(1,I)/WT/HT
            F12(2,I)=F12(2,I)/WT/HT
 2050       CONTINUE
            IF(I.GT.1) GO TO 2100
            XX=HT
```

```
            YY=WT
 2100       CONTINUE
C**X   OUT(8)=F12(1,1)+F12(2,1)
C**X   OUT(9)=F12(1,2)+F12(2,2)
C**X   OUT(10)=F12(1,3)+F12(2,3)
       IF(F12(1,2).LT.0.) F12(1,2)=0.
       IF(F12(2,2).LT.0.) F12(2,2)=0.
       IF(F12(1,3).LT.0.) F12(1,3)=0.
       IF(F12(2,3).LT.0.) F12(2,3)=0.
C**X   OUT(6)=0.5-OUT(8)-F12(1,2)-F12(1,3)
C**X   OUT(7)=0.5-F12(2,2)-F12(2,3)
 3000  CONTINUE
C**START NEW ==================================================================
         FWS=0.5-F12(1,1)-F12(2,1)-F12(1,2)-F12(1,3)
         FWG=0.5-F12(2,2)-F12(2,3)
      END IF
      RETURN

C*********************************************
      ENTRY SHDWR(CSW,CSS,CSZ,ORIENT,CIF,FI)
C*********************************************

      CIF=CSZ*SINT-CSS*COST*COS(ORIENT)-CSW*COST*SIN(ORIENT)

      FI=1.0
      IF (CIF.LE.0.0001) THEN
        FI=0.0
      ELSE IF (LSH.EQ.1) THEN
        WAZI=(ORIENT-RD*180.0)
        ALPH=ATAN2(CSW,CSS)
        COSZ=CSZ
C**END NEW ====================================================================
C..CALCULATE FI - ALGORITHM BY TSENG-YAO SUN FOR ASHRAE
C**X   WAZI=PAR(15)*RD
C**X   ALPH=XIN(2)*RD
C**X   COSZ=COS(XIN(1)*RD)
C**X   FI=1.0
       ARSHA=0.0
       A=G(1)
       H=HT
       GAMMA=ALPH-WAZI
       COSG=COS(GAMMA)
       IF (COSZ.GT.0.999999) GO TO 100
       IF(COSG)100,100,104
  100  FI=0.0
       ARSHA=H*WT
       GO TO 2000
  104  CONTINUE
       SBETA=COSZ
       IF (SBETA)100,100,152
  152  SING=SIN(GAMMA)
       VERT=SBETA/SQRT(1.-SBETA*SBETA)/COSG
       HORIZ=ABS(SING)/COSG
       IF (GAMMA)155,157,154
C      .....SUN ON LEFT
  154  B=EL(1)
       GO TO 156
C      .....SUN ON RIGHT
  155  B=ER(1)
       GO TO 156
```

```
C      .....SUN ON CENTER
  157 T=FP(1)*VERT-A
      IF(T.GE.H) GO TO 100
      IF(T.LE.0.0) GO TO 2000
      ARSHA=T*WT
      FI=1.0-T/H
      GO TO 2000
  156 TCETA=VERT/HORIZ
      ARSHF=0.0
      ARSIF=0.0
      AREAO=0.0
      AREA1=0.0
      ARSH1=0.0
      K=1
      L=1
      T1=FP(1)*VERT
      FM1=FP(1)*HORIZ
      IF (FP(1))37,37,153
  153 T=T1
      FM=FM1
      AB=B*TCETA
      UG=(WT+B)*TCETA
      DE=(H+A)/TCETA
C     .....SHADING FROM HORIZONTAL OVERHANG - AREAO
      IF(T-A)37,37,2
    2 IF(AB-A)14,14,3
    3 IF(DE-B)12,12,4
    4 IF(FM-B)11,11,5
    5 IF(DE-(WT+B))8,8,6
    6 IF(FM-(WT+B))9,7,7
C     .....HORIZ 9
    7 AREAO=WT*(0.5*(AB+UG)-A)
      GO TO 37
    8 IF(T-(H+A))9,10,10
C     .....HORIZ 7
    9 AREAO=(T-A)*WT-(FM-B)*(FM-B)*TCETA*0.5
      L=2
      GO TO 37
C     .....HORIZ 8
   10 AREAO=H*WT-(DE-B)*(DE-B)*TCETA*0.5
      GO TO 37
C     .....HORIZ 3
   11 AREAO=WT*(T-A)
      L=2
      GO TO 37
   12 IF(T-(H+A))11,13,13
C     .....HORIZ 2
   13 AREAO=WT*H
      GO TO 68
   14 IF(UG-A)37,37,15
   15 IF(DE-(WT+B))18,18,16
   16 IF(FM-(WT+B))20,17,17
C     .....HORIZ 6
   17 AREAO=(UG-A)*(UG-A)/TCETA*0.5
      GO TO 37
   18 IF(T-(H+A))20,19,19
C     .....HORIZ 5
   19 AREAO=H*(WT-(A+0.5*H)/TCETA+B)
      GO TO 37
C     .....HORIZ 4
```

```
   20 AREAO=(T-A)*(WT+B-FM*(1.0+A/T)*0.5)
      L=2
C     .....SHADING FROM WINGWALL (AREA1)
   37 IF(GAMMA)66,68,74
   74 FPF=FP(2)
      AF=EL(2)
      BF=G(2)
      CX=-ER(2)
      GO TO 84
   66 FPF=FP(3)
      AF=EL(3)
      BF=G(3)
      CX=-ER(3)
   84 IF(FPF)68,68,67
   67 T=FPF*VERT
      FM=FPF*HORIZ
      AF1=AF
      IF(AREAO)73,73,88
C     .....TEST FOR OVERLAP OF FIN AND OVERHANG SHADOW
   88 AT=A+(BF-B)*TCETA
      IF(AT-AF)711,73,73
C     .....OVERLAP EXISTS...IF L=2 HORIZONTAL SHADOW EDGE IN WINDOW
  711 GO TO (621,712),L
  712 IF((FM-BF)-(FM1-B))621,622,622
  621 AF=AT
      L=1
      GO TO 73
  622 AREA1=WT*(T1-A)-AREAO
      AF=T1-A+AF1
      H=H+AF1-AF
   73 AB=BF*TCETA
      UG=(WT+BF)*TCETA
      DE=(H+AF)/TCETA
      DJ=CX/TCETA
      IF(FM-BF)69,69,38
   38 IF(AB-AF)39,50,50
   39 IF(UG-AF)48,48,40
   40 IF(T-AF)47,47,41
   41 IF(UG-(H+AF))44,44,42
   42 IF(T-(H+AF))91,80,80
C     .....FIN 9
   80 AREA1=H*((AF+H*0.5)/TCETA-BF)+AREA1
      GO TO 58
   44 IF(FM-(WT+BF))91,89,89
C     .....FIN 8
   89 AREA1=H*WT-(UG-AF)*(UG-AF)/TCETA*0.5+AREA1
      GO TO 58
C     .....FIN 7
   91 AREA1=(FM-BF)*H-(T-AF)*(T-AF)/TCETA*0.5+AREA1
      GO TO 63
   48 IF(FM-(WT+BF))47,47,49
C     .....FIN 3
   47 AREA1=H*(FM-BF)+AREA1
      GO TO 63
C     .....FIN 2
   49 AREA1=H*WT+AREA1
      GO TO 58
   50 IF(DE-BF)69,69,51
   51 IF(UG-(H+AF))55,55,52
   52 IF(T-(H+AF))93,94,94
```

```
C        .....FIN 6
   94    AREA1=(DE-BF)*(DE-BF)*TCETA*0.5+AREA1
         GO TO 58
C        .....FIN 4
   93    AREA1=(FM-BF)*(H+AF-(T+AB)*0.5)+AREA1
         GO TO 63
   55    IF(FM-(WT+BF))93,99,99
C        .....FIN 5
   99    AREA1=WT*(H-(BF+WT*0.5)*TCETA+AF)+AREA1
C        .....UNSHADED AREA UNDER SHORT FIN SHADOW (ARSH1)
   58    IF(DJ-BF)69,69,59
   59    IF(DJ-(WT+BF))61,61,60
C        .....SHORT 3
   60    ARSH1=-WT*(CX-(BF+WT/2.0)*TCETA)
         GO TO 69
C        .....SHORT 4
   61    ARSH1=-(CX-AB)**2/TCETA*0.5
         GO TO 69
   63    IF(DJ-BF)69,69,64
   64    IF(DJ-FM)61,61,65
C        .....SHORT 2
   65    ARSH1=-(FM-BF)*(CX-(T+AB)*0.5)
   69    GO TO (77,76),K
   76    ARSH1=-ARSH1
         AREA1=-AREA1
   77    ARSHF=ARSHF+ARSH1
         ARSIF=ARSIF+AREA1
C        .....TOTAL SHADED AREA (ARSHA)
   68    ARSHA=AREA0+ARSHF+ARSIF
         FI=1.-ARSHA/AREA
 2000    CONTINUE
C**X     GB=XIN(5)
C**X     GD=XIN(4)
C**X     GR=XIN(3)
C**X     RHO=XIN(6)
C**X     OUT(2)=GB*FI
C**X     OUT(3)=GD*OUT(6)
C**X     OUT(4)=RHO*GR*OUT(7)
C**X     OUT(1)=OUT(2)+OUT(3)+OUT(4)
C**X     OUT(5)=FI
C**START NEW ================================================
        END IF
C**END NEW ===================================================
         RETURN
         END
```