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**The EIR-Programmes for Computing the Gross
Heat Output of Solar Collectors
(MURD and ETA)**

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Würenlingen, November 1980

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ABSTRACT

For the computation of the gross heat output of solar collectors by means of meteo data and characteristic collector parameters two programs were developed:

- MURD for the determination of the "mean usable radiation density".
- ETA for the calculation of the collector efficiency i.e. relative values of gross heat output.

In the first part of this report the main features of these programs are described and detailed instructions for the use of them are given. Results of some cases for the meteo-situation of Zurich airport are given in the second part. The appendix contains some additional remarks which are of interest to the user.

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INTRODUCTION

In order to enable the members of IEA-Solar Energy, Task III (thermal performance testing of solar collectors) to compute on a common basis the "All Day Performance of Collectors" for the meteo-situations of different countries, a program and know-how transfer EIR-IEA was decided. For this purpose, the original EIR programs NUENDI and ETAH developed by A. Duppenhaler and P. Kesselring (1) were improved and extended. According to the various conditions to be fulfilled, numerous new options were built in. The new versions MURD and ETA are now completed, a description of the main features as well as detailed user instructions are given in chapter 1. Results for the cases and parameter sets chosen at the Boras-Meeting (June 10-13, 1980) are shown in chapter 2.

After having received the EIR-programs as well as the meteo data of Kloten (Zurich airport) and the results for the parameter sets mentioned above, our partners in different countries can adapt the programs for their computer systems, check the results and then apply to their own meteo data sets. Thus an international evaluation of MURD-functions (mean usable radiation density) and gross heat outputs as well as a verification and validation of our method becomes possible.

1. THE PROGRAMS MURD AND ETA

The basic principles of the programs MURD and ETA are described in the "Atlanta-paper" of P. Kesselring (2). Whereas MURD computes values of the mean usable radiation density by means of the meteo-data (G_h, D_h, T_a) for a given period and fixed collector parameters (T_m, TA, GA, n, b) ETA serves for the determination of the "mean collector gain" i.e. relative values of gross heat output referring to the integrated global radiation power on a horizontal surface. The mean collector gain is a function of the optical efficiency η_0 and the heat loss coefficient a_1 which are characteristic for a given special collector (variable collector parameters).

1.1 The concept

The basic idea in treating the all day performance of collectors has been to order the incoming radiation energy according to the efficiency, with which it can be used by the collector. This leads to the choice of $(T_m - T_a) / I$ as the ordering parameter. However, a linear collector equation (in IEA-notation)

$$\eta = \eta_0 - a_1 \cdot T^* \quad (1)$$

$$\text{with } T^* = U_0 \cdot (T_m - T_a) / I$$

$$\text{and } U_0 = 10 \text{ W/m}^2\text{K}$$

is not sufficient to describe the collector efficiency accurately enough for practical purposes. At least, two effects have to be considered in addition, namely the influence of

- incident angle of radiation to collector surface
- variation of heat loss coefficient with T_m and T_a .

1.1.1 Basic relations

These leads to the following equation for the instantaneous heat output (heat flux) of the collector in a steady state:

$$\dot{q} = \eta_o \cdot I_e - a_1 \cdot k(T_m, T_a) \cdot U_o \cdot (T_m - T_a) \quad (2)$$

with the effective radiation I_e :

$$I_e = \iint a(\theta, \phi, \vec{n}_c) \cdot \vec{n}_c \cdot \vec{j}(\theta, \phi, t) \cdot \sin\theta d\theta d\phi \quad (3)$$

Here we have defined the following parameters:

$\vec{j}(\theta, \phi, t) \cdot \sin\theta d\theta d\phi$ radiation density per m² collector surface coming from the angular element
 $d\Omega = \sin\theta d\theta d\phi$

$a(\theta, \phi, \vec{n}_c)$ incident angle modifier as a function of the polar coordinates of incoming radiation \vec{j} and of the collector position given by the normal unit vector \vec{n}_c of the collector surface

$k(T_m, T_a)$ variation of the thermal loss coefficient a_1 as a function of mean collector and ambient temperature.

The following simple approximations were proposed and are used in our programmes:

$$a(\theta) = 1 - \tan^n(\theta/2) \text{ with } \cos\theta = \vec{n}_c \cdot \vec{j} / |\vec{j}| \quad (4)$$

$$k = 1 + b \cdot (T_m - T_a) \quad (5)$$

A whole class of collectors - e.g. single glass, selective or double glass, non selective flat plate collectors - may usually be characterized sufficiently well by a single pair of parameter values n and b in eq. (4) and (5).

Integrating eq. (2) over a time period t_o gives

$$q = \int_0^{t_o} \left\{ \eta_o - a_1 \frac{k(T_m, T_a) \cdot U_o \cdot (T_m - T_a)}{I_e} \right\} I_e dt \quad (6)$$

Here the main collector efficiency parameters η_o and a_1 are put in evidence, whereas the correction factors for incident angle and temperature variation ((4) and (5)) are included with the

meteo- and user orientated parameters in the expression

$$x = k(T_m, T_a) \cdot U_o \cdot (T_m - T_a) / I_e \quad (7)$$

Equation (6) suggests the choice of x as a more refined ordering parameter and hence the definition of the energy distribution function as

$$\frac{dE}{dx} = I_e \cdot \frac{dt}{dx} : \text{MURD-function} \quad (8)$$

The corresponding transformation of the integral (6) yields

$$q = \eta_o \cdot \int_0^{x_o} (1-x/x_o) \cdot \frac{dE}{dx} \cdot dx = \eta_o \cdot F(x_o) \quad (9)$$

with $x_o = \eta_o / a_1$.

Given the set of parameters \vec{n}_c (collector orientation), T_m (mean temperature of the produced hot water), n (incident angle modifier class) and b (heat loss class), we can compute the corresponding MURD-function dE/dx according to eq. (8) from the meteo-time functions for radiation and ambient temperature.

For any collector characterized by η_o and a_1 , and belonging to the (n,b) -class, the gross heat output over the period t_o may now simply be calculated according to (9), i.e. as if the linear collector efficiency equation

$$\eta = \eta_o - a_1 \cdot x \quad (10)$$

were valid. If meteo-data of a certain climatic region are available for a period of several years, monthly averages of dE/dx and tables of the integral $F(x_o)$ can thus easily be computed. The value of such a treatment, e.g. for selecting a collector with an optimal gross heat output/price relation for a given application, is evident.

1.1.2 Numerical relations used in MURD

1.1.2.1 The effective radiation I_e

Since the meteo data are given by a finite number of measurements and furthermore the incoming radiation consists of a direct part and a diffuse part, the integral term (3) has to be modified. As it is usually the case, only values for global and diffuse radiation on a horizontal surface are available from the meteo stations. In order to get the effective radiation on tilted planes (collector surfaces), we used the following relations which were verified by numerous measurements (3):

$$\begin{array}{l} \text{Global radiation on} \\ \text{a tilted plane} \end{array} \quad G_{\alpha} = D_o + g \cdot \cos \theta \quad (11)$$

$$\begin{array}{l} \text{Diffuse radiation on} \\ \text{a tilted plane} \end{array} \quad D_{\alpha} = D_o + d \cdot \cos \theta \quad (12)$$

$$\begin{array}{l} \text{Global radiation on} \\ \text{horiz. plane } (\alpha=0) \end{array} \quad G_h = D_{oo} + g \cdot \sin h_s \quad (13)$$

$$\begin{array}{l} \text{Diffuse radiation on} \\ \text{horiz. plane } (\alpha=0) \end{array} \quad D_h = D_{oo} + d \cdot \sin h_s \quad (14)$$

D_o and D_{oo} are the non-directional parts of the diffuse radiation and are treated as isotropic radiations. The directional part of the diffuse radiation i.e. the part coming from the vicinity of the sun is added to the direct radiation from the sun. The angle of incidence θ is measured between the normal to the collector surface and the direction to the sun. For a horizontal surface $\cos \theta = \sin h_s$, h_s being the elevation of the sun.

Theoretical considerations led to the assumptions

$$d = f_{\mu} \cdot \mu \cdot I_v \quad (15)$$

$$D_o = (a + b \cdot f_{\alpha}) \cdot D_{oo} \quad (16)$$

$$\text{with } \mu = D_h / G_h \quad (17)$$

$$f_{\alpha} = \frac{1}{2}(1 + \cos \alpha) \quad (18)$$

$$I_v = (G_h - D_h) / \sin h_s \quad (19)$$

In order to determine the coefficients a, b and f_{μ} numerous least-squares fits were carried out by means of radiation data for which $0.15 \leq \mu \leq 0.99$. The best fits were obtained with the values:

$$f_{\mu} = 1$$

$$b = 1-a = \mu$$

Thus the following relationships were found:

$$d = \mu \cdot (G_h - D_h) / \sin h_s \quad (20)$$

$$g = (1+\mu) \cdot (G_h - D_h) / \sin h_s \quad (21)$$

$$D_{oo} = \mu \cdot D_h \quad (22)$$

$$D_o = (1 - \frac{\mu}{2}(1 - \cos \alpha)) \cdot D_{oo} \quad (23)$$

and the global radiation on a tilted surface can now be calculated according to (11) by means of measured values for G_h and D_h using the equations (21), (22) and (23).

Inserting eq. (11) into (3), we get the term for the effective radiation which is to be used in MURD:

$$I_e = a(\theta) \cdot g \cdot \cos \theta + a_{diff} \cdot D_o \quad (24)$$

The incident angle modifier for direct radiation which is defined as

$$a(\theta) = \eta(\theta) / \eta_o$$

i.e. the optical efficiency ratio for sloping and perpendicular incidence is given by (4). For an isotropically distributed diffuse radiation a mean value over all directions is to be used. In the case of a horizontal surface ($\alpha=0$) a_{diff} thus becomes

$$a_{diff,o} = 2 \cdot \int_0^{\pi/2} a(\theta) \cos \theta \sin \theta d\theta \quad (25)$$

For tilted surfaces a correction has to be applied because a part of the sky cannot be "seen":

$$a_{\text{diff}} = \frac{\int_0^{\pi/2} a(\theta) \cos\theta \sin\theta d\theta - \int_{\pi/2-\alpha}^{\pi/2} \frac{\psi}{\pi} a(\theta) \cos\theta \sin\theta d\theta}{\int_0^{\pi/2} \cos\theta \sin\theta d\theta - \int_{\pi/2-\alpha}^{\pi/2} \frac{\psi}{\pi} \cos\theta \sin\theta d\theta} \quad (26)$$

where ψ is given by

$$\cos\psi = \cot\theta \cdot \cot\alpha$$

Using eq. (4), (25) and (26), we found by numerical analysis the following expressions:

$$a_{\text{diff}} = a_{\text{diff},0} \cdot (1 + c_{\alpha} \cdot \alpha \cdot (2.467 - \alpha^2)) \quad (27)$$

$$a_{\text{diff},0} = 0.51535 + 0.16668 \cdot n \cdot (1 - 0.10217 \cdot n) \quad (28)$$

with $c_{\alpha} = 0.05667 - 0.01517 \cdot n \cdot (1 - 0.08660 \cdot n)$

and α in radians.

Remark: If in addition to G_h and D_h the value of G_{α} is also known (by an additional direct measurement), the accuracy of (24) can be increased by replacing (23) by

$$D_o = G_{\alpha} - g \cdot \cos\theta \quad (29)$$

Finally, it should be noted that the formula (4) represents a good approximation for the incident angle modifier for flat-plate collectors i.e. plane cover windows. The exponent n was determined by means of least-squares fits with measured values of $n(\theta)/n_o$ for various collector types; the following averages were found:

cover type	n
single window	3.29
double window	2.49

Table 1:
Incident angle
modifier classes

For bent cover windows formula (4) is not valid.

1.1.2.2 The ordering parameter x

According to its definition (7) the variable x contains the variation of thermal losses with mean collector temperature and ambient temperature in form of the factor

$$k(T_m, T_a) = 1 + b \cdot (T_m - T_a) \quad (5)$$

It should be pointed out that this is a rather rough approximation. As we could show by various investigations, a much more accurate expression is given by

$$k(T_m, T_a, v_w) = 1 + 6 \cdot \frac{\epsilon \sigma}{a_1 U_o} \cdot f_b \cdot T_a^2 \cdot (T_m - T_a) + c \cdot v_w \quad (30)$$

where the dependence of the heat losses upon the velocity of wind (v_w) is also included. ϵ is the effective emittance of the absorber surface and σ the Stefan-Boltzmann constant. Mean values of the coefficients f_b and c are given in table 2. From (30) it follows that b in (5) is not a constant, but varies with the ambient temperature. In order to fulfill the IEA convention, we have used mean values of b (\bar{b}) for $T_a = 288$ K and put $c = 0$ for the computations of the examples given in chapter 2.

cover type	absorber type	f_b	\bar{b}	c
single window	selective	0.853	0.0010	0.033
single window	non selective	0.853	0.0036	0.033
double window	selective	0.602	0.0010	0.017
double window	non selective	0.602	0.0038	0.017

Table 2: Heat loss classes

1.1.2.3 The energy distribution function dE/dx

For each period considered (days or months of a year), the function $dE/dx(x)$ is computed from $x = 0.03$ to $x = 3.0$ in steps of $\Delta x = 0.03$ i.e. a table of 100 values is produced. If there are negative values of x , which is the case when $T_m < T_a$, 200 values are computed from $\xi = 0.03$ to $\xi = 6.0$, where $\xi = x - 3.0$. The transformation $x \rightarrow \xi$ simplifies the integration in (9) (cf. 1.1.2.1).

Remark: In our program the original EIR-definition of x is used. Therefore, all x -values are divided by 10 compared to the x -values according to (7). However, this is of no influence on the further computations in ETA. The output of ETA as well as the graphs of dE/dx are corrected for IEA-notation.

In computing $dE/dx(x)$, it has to be taken into account, that during one day, a fixed x -value may appear several times. Thus the numerical expression for (8) has to be written

$$\frac{\Delta E}{\Delta x}(x) \approx \frac{1}{\Delta x} \cdot \sum_{j=1}^n I_{e,j} \cdot \Delta t_j \quad (31)$$

The determination of $\Delta E/\Delta x(x)$ is done in several steps:

- Calculation of x_1 and $I_{e,1}$ for each measuring point ($t_1, T_{a,1}, G_{h,1}, D_{h,1}$) according to (7) and (24).
- Determination of the time functions $x(t)$ and $I_e(t)$. These functions are defined stepwise in the following manner

$$x(t)_1 = a_1 \cdot t^2 + b_1 \cdot t + c_1 \quad (32)$$

$$I_e(t)_1 = A_1 \cdot t^2 + B_1 \cdot t + C_1 \quad (33)$$

The coefficients a_1, b_1, c_1 , are determined by means of the three points of support

$$t_i - \Delta t/2, (x_{i-1} + x_i)/2$$

$$t_i, x_i$$

$$t_i + \Delta t/2, (x_i + x_{i+1})/2$$

and the coefficients A_i, B_i, C_i by

$$t_i - \Delta t/2, (I_{e,i-1} + I_{e,i})/2$$

$$t_i, I_{e,i}$$

$$t_i + \Delta t/2, (I_{e,i} + I_{e,i+1})/2$$

- Definition of the x -interval: Beginning with $x = 0$ ($\xi = 0$) the next x -values are given by $x = \Delta x, x = 2 \cdot \Delta x$, and so on up to $x = 3.0$ ($\xi = 6.0$). The limits of each interval are defined as x and $x + \Delta x$, so that $\Delta E / \Delta x$ is determined for $x_m = x + \Delta x / 2$.

- Determination of the intersections with the curve given by (32):

$$x(t) = x \quad \text{with the solutions } t_j \quad (j=1,n)$$

$$x(t) = x + \Delta x \quad \text{with the solutions } t_j^* \quad (j=1,n)$$

If there is no intersection, then $\Delta E / \Delta x = 0$.

- Determination of the $I_{e,j}$ -values by means of (33):

$$I_{e,j} = I_e(t_{j,m}) \quad \text{with } t_{j,m} = (t_j + t_j^*)/2$$

- Determination of $\Delta E / \Delta x$ according to (31):

$$\frac{\Delta E}{\Delta x} (x_m) = \frac{1}{\Delta x} \sum_{j=1}^n I_{e,j} \cdot \Delta t_j$$

$$\text{with } \Delta t_j = |t_j^* - t_j|$$

1.1.3 Numerical relations used in ETA

The program ETA computes values of the function $F(x_0)$ defined in (9) for several values of $x_0 = \eta_0/a_1$. If the minimum value x_{\min} of x , which occurs during the period under investigation, is greater than 0, the following equation holds

$$\int_{x_{\min}}^{x_0} \left(1 - \frac{x}{x_0}\right) \cdot \frac{dE}{dx} \cdot dx = \int_0^{x_0} \left(1 - \frac{x}{x_0}\right) \cdot \frac{dE}{dx} \cdot dx \quad (34)$$

In the case of negative values of x_{\min} , the range of integration has to be extended according to

$$\int_{x_{\min}}^{x_0} \left(1 - \frac{x}{x_0}\right) \cdot \frac{dE}{dx} \cdot dx = \int_0^{\xi_0} \left(1 - \frac{\xi + x_{\min}}{\xi_0 + x_{\min}}\right) \cdot \frac{dE}{d\xi} \cdot d\xi \quad (35)$$

with $\xi = x - x_{\min}$ and $\xi_0 = x_0 - x_{\min}$.

For this reason, $dE/d\xi$ tables are produced by MURD from $\xi = 0$ ($x = -3.0$) to $\xi = 6.0$ ($x = 3.0$) in the case of negative x -values i.e. when $T_m - T_a < 0$ for any measuring point.

If, for low T_m , some x -values are less than -3.0 , a correction has to be applied due to the tail of the $dE/d\xi$ function in this range. $F(x_0)$ is then given by

$$F(x_0) = \frac{1}{x_0} \int_0^{\xi_0} (\xi - \xi_0) \cdot E'(\xi) d\xi + \sum_{i=1}^3 \frac{c_i}{i} \cdot \xi_{\min}^i \quad (36)$$

with $\xi_0 = x_0 - x_z$, $\xi_{\min} = x_{\min} - x_z$, $x_z = -3.0$

and $c_1 = -\xi_0 \cdot E'(0)/x_0$

$$c_2 = (1 - \xi_0 / (100 + x_2)) \cdot E'(0) / x_0$$

$$c_3 = (1 / (100 + x_2)) \cdot E'(0) / x_0$$

$$E'(\xi) \equiv dE/d\xi(\xi)$$

The integrals in (34), (35) and (36) are computed by means of Simpson's formula and the $E'(x)$ resp. $E'(\xi)$ values provided by MURD.

In addition to the tables of $F(x_0)$ for different values of T_m (mean collector fluid temperature) ETA calculates averages of the wind velocity and the integrated global radiation power on a m^2 of horizontal surface and collector (tilted) surface.

1.2 User's guide

1.2.1 Input of MURD

The control parameters of the program, the local parameters of the measuring station of the meteo data, the collector parameters and the specifications of the periods have to be read by punched cards. As can be seen from the listing (MURD36-46) there are seven

PROGRAM CONTROL PARAMETERS (1st card/format: MURD 15):

- KMAX gives the number of periods for which the MURD-function is wanted (for our examples given in chapter 2: KMAX = 4)
- KPRINT(1) decides whether the specifications of the collector parameters are printed (=1) or not (=0) (examples: 1)
- KPRINT(2) has the same function for the printing of the dE/dx -values of a period (examples: 1)

- KPRINT(3) decides on the printing of the dE/dx -values of each day of a period (examples: 0)
- KPRINT(4) decides on the printing of $x(t)$, $I_e(t)$ and $\sum_j \Delta t_j(x)$ of each day of a period (examples: 0)
- KPRINT(5) decides whether the dE/dx -values are written on permanent file (=1) or not (=0) (examples: 1)
- IND this index has to be put = 0 if the timing of the meteo data is given in zonal time (clock) and = 1 for real local time (examples: 0). The exact definition of time is needed for the SUBROUTINE WINKEL which serves for the calculation of the position of the sun.

All the control parameters are punched on the first card. The format is given by MURD 15. The second and the third card (MURD 50-51) contain the

LOCAL PARAMETERS (2nd and 3rd card/format: MURD 16-17):

- PHI = ϕ latitude of the meteo-station in degrees
(Zurich airport: 47.45)
- FLAM = λ longitude of the meteo-station in degrees
(Zurich airport: - 8.57)
- FLAZ = λ_2 longitude of the time-zone in degrees
(Zurich airport: - 15.0, in the case of "summer-time": - 30.0)
- TITLE denotation of the station in alphanumeric symbols (Zurich airport: ZURICH AIRPORT)
- ZANF time of the first measurement of meteo data in the morning in hours (Zurich airport: 6.00)

- ZEND time of the last measurement of meteo data in the evening in hours (Zurich airport: 19.00)
- DELT time interval between two succeeding measurements in minutes (Zurich airport: 60.0)
- IA first year for which meteo data are stored on the magnetic tape (Zurich airport: 63, instead of 1963!)
- IE last year for which meteo data are stored on the magnetic tape (Zurich airport: 72).

On the fourth card (MURD 60) the fixed collector parameters are given:

COLLECTOR PARAMETERS (4th card/format: MURD 18):

- TK = T_m mean collector fluid temperature in degrees Celsius (for our examples: 30.0, 50.0 and 70.0)

 Remark: How to get results for fixed inlet temperatures (T_i) see appendix I.
- ALPH = α collector tilt angle in degrees (horizontal: 0.0, vertical: 90.0, for our examples: 30.0 and 60.0)
- GAM = γ collector orientation in degrees (south facing: 0.0, west facing: 90.0, east facing: - 90.0)
- NKOL = n incident angle modifier according to table 1 (examples: 2.5 and 3.3)
- BK = b heat loss class according to table 2 (examples: 0.0040)
- CK = c heat loss class (wind velocity) according to table 2 (examples: 0.0)

The next cards (MURD 74) define the periods to be investigated (number of cards = KMAX):

DEFINITION OF PERIOD (card 5 - card (KMAX+4)/format:MURD 15):

- JAA number of the first year (examples: 66)
- JAE number of the last year (examples: 70)
- NA number of the first day of the period
- NE number of the last day of the period

Table 3 gives the numbers of the monthly periods of the year, in our examples the values for March (3), June (6), September (9)

Month	NA	NE	Month	NA	NE
1	1	31	7	183	213
2	32	60	8	214	244
3	61	91	9	245	274
4	92	121	10	275	305
5	122	152	11	306	335
6	153	182	12	336	366

Table 3: Monthly Periods

and December (12) were used.

In the beginning of the main program, the local meteo data are read from magnetic tape (MURD 123-124). Of course, the form of the READ order has to be changed, if the storage of the meteo data is arranged otherwise. In our case, only integers are used:

- JAI number of the year (two-figure)
- NI number of the day of the year (1 - 366)
- ITE(J) ambient temperatures in degrees Celsius

- IWI(J) wind velocities in knots (1 knot = 0.5144 m/sec),
the conversion from knots in m/sec is done by
the program)
- IGE(J) global radiation power on a horizontal plane in
kcal/h·m² (1 kcal/h·m² = 1.163 W/m², this conversion
is also done by the program)
- IDI(J) diffuse radiation power on a horizontal plane
in kcal/h·m²
- IGP(J) global radiation power on the collector surface
(α , γ) in kcal/h·m²; these values are not known
for the meteo station at Zurich airport, they
are computed in the already described manner
(1.1.2.1: $IGP = G_0$ in (11)).

Remarks:

- The data file of each year contains 366 days. If the year is
no leap-year, then the data of the 60th day are replaced by the
following values:

$$ITE(J) = IWI(J) = 99 \qquad (37)$$

$$IGE(J) = IDI(J) = 9999$$

and these values are leapt over.

- Only complete data sets should be used i.e. the data of each
day of a period should be available completely from sunrise
to sunset. If during one year, the data of some days are
missing, these data should be stored according to (37), they
are then replaced by averages of the corresponding values of
the preceding days.
- If, for test purposes, only the data of a few days are used
to compute $dE/dx(x)$ and $F(x_0)$ and no other data are available,
the statement MURD 115 has to be replaced by "DO 20 N = NA,NE"

It is then $IA = IE = JAA = JAE$ and for a single day in addition $NA = NE$.

1.2.2 Output of MURD

The output of MURD consists of tables for the MURD-functions of the different periods, the parameters used for the computations are also given. The values in the tables are given in Wh per x-interval for the whole period (1 Wh = $3.6 \cdot 10^3$ Joule, 10^6 Wh = 3.6 GJ). KP indicates the total number of positive x-values, KN the number of negative x-values and KZ the number of cases for which $x = 0$. All other symbols are explained in 1.2.1.

1.2.3 Input of ETA

Tables of $F(x_0)$ for up to three different meteo stations may be produced by ETA. The denotation (names) of the stations are read by means of alphanumeric symbols on a punched card (ETA 27). The needed input parameters are taken from the second data card (ETA 28):

INPUT PARAMETERS (2nd card/format: ETA 17):

- NTL number of x_0 -values = number of columns per table
- TLO initial (lowest) value of x_0
- DTL steps of x_0 (DTL = Δx_0)
- MO number of periods = number of tables per station
- LM total number of lines to be printed for each period = number of T_m -values times number of stations

- LMA number of lines to be printed for each period
 and the first station = number of T_m -values
 for the first station
- LMB LMA + number of T_m -values for the second station.

In our examples given in chapter 2, the following values were used: NTL = 10, TLO = 0.75, DTL = 0.25 (the maximum value of x_o thus being 3.00), MO = 4 (March, June, September, December), LM = LMA = LMB = 3 (only one station, three T_m -values: 30, 50, 70° C).

1.2.4 Output of ETA

The heading of the printed output consists of the name of the meteo station, the date of the years, the meteo data of which were used, the values of the parameters α , γ , n_{kol} , b_k , c_k as well as the denotation for the type of collector concerned.

The columns of the tables are headed by the x_o -values which are the same for each period.

The first line of each table shows

- the number of the month (period)
- the monthly (periodic) mean value of

$$\int_0^{t_o} G_h dt = \Delta t \cdot \sum_1 G_{h,i} \quad (38)$$

the integrated global radiation power on a m^2 of horizontal surface in kWh

- the monthly (periodic) mean value of

$$\int_0^{t_o} G_{\alpha,\gamma} dt = \Delta t \cdot \sum_1 G_{\alpha,\gamma,i} \quad (39)$$

the integrated global radiation power on a m^2 of collector surface in kWh (tilt angle α , orientation γ)

- the monthly (periodic) mean value of the velocity of wind in m/sec.

The first column of each table gives the values of T_m , the mean collector fluid temperature.

In the following columns relative values of $F(x_o)$, the so-called "mean collector gains" are given in percent (%). The mean collector gain is defined as follows:

$$\bar{\eta}_h = F(x_o) / \int_0^{t_o} G_h dt \quad (40)$$

so that the gross heat output of a collector is determined by

$$q = \eta_o \cdot \bar{\eta}_h \cdot \int_0^{t_o} G_h dt \quad (41)$$

Note that the gross heat output q is completely determined by eight collector parameters

$$\eta_o, a_1, n, b, c, \alpha, \gamma, T_m.$$

1.2.5 Concentrating, east-west tracking collectors

The programmes MURD and ETA also allow the computation of the MURD-functions and the mean collector gains of concentrating, east-west tracking collectors without cover window. For this purpose, no modifications of the programmes are necessary. Only the input value of the incident angle modifier has to be changed: Instead of the values quoted in table 1, the value of a_{diff} ($< 1!$) has to be used. As we were able to prove, a good approximation for this type of collector is given by

$$a_{diff} = 1/c_o \quad (42)$$

c_o being the concentration factor.

Unfortunately, no good values for b and c and even for a_1 (heat loss coefficients) are known up to the present. Here, the influence of the wind velocity on the heat losses is greater than that with flat-plate covered collectors.

In addition, the range of x_0 is extended to $x_{0,max} = 4.0$ ($\xi_{0,max} = 8.0$) because of the higher stagnation temperatures which can be obtained by concentrating collectors.

1.3 Program listings

On the following pages, the listings of the programmes MURD and ETA are represented.


```

PROGRAM MURO (INPUT,OUTPUT,TAPE1,TAPE2)                                MURO 1
C
C NEW VERSION OF THE EIS-PROGRAM FOR THE DETERMINATION OF THE MEAN    MURO 2
C USABLE RADIATION DENSITY FUNCTION D(U)OVER) FOR GIVEN RETU-DATA    MURO 3
C AND COLLECTION PARAMETERS, WRITTEN BY J.F. WIDDEL                      MURO 4
C                                                                           MURO 5
C NAME NMOU                                                                MURO 6
C DIMENSION ZEIT(13),STAI(3),NAI(3),IT(1200),IG(1200),IO(1200)      MURO 7
C DIMENSION I(1200),IP(1200),SUT(1200),RPP(1200),TITL(13)           MURO 8
C COMMON IFE(1200),IGF(1200),I(1200),I(1200),ICP(1200),OEF(1200),  MURO 10
C Z(1200),X(1200),S(1200),SY(1200),PHI(142),GL,IMB,INT,          MURO 11
C TR,ALP,GT,GA,HR,CA                                                MURO 12
C DATA DR,PARF,PARC/0.009,100,1347                                  MURO 13
C
C 100 FORMAT (7I4)                                                       MURO 14
C 101 FORMAT (F6.4,F12.4,F6.1,F4.3AC)                                    MURO 15
C 102 FORMAT (F6.4,F12.4,F6.1,F4.3)                                     MURO 16
C 110 FORMAT (F5.1,F2F4.2,F3F4.1)                                     MURO 17
C 100 FORMAT (12H)OUTPUT MURO 17,3AB)                                MURO 18
C 101 FORMAT(//SUN,HRP //,15,214,HRZ //,15,15X,HRM //,15,15X,HRZERD//,  MURO 20
C 1F6.3//)                                                            MURO 21
C 1001 FORMAT (//////1X//FAN31//,14, //,14,5X,ODAYS//,15, //,15, 9X, MURO 22
C 10TR //,FA,1, // (CEL) ALFA //,FO,1, // (DEG) GAMMA //,FO,1, // (MURO 23
C 20C //,SUN,HRMOL //,FO,2, //,HR //,17, // (1/REL) CR //,FO,3, MURO 24
C 3 // (SEC/7) //)                                                    MURO 25
C 1004 FORMAT (//,1X, //PEAN USABLE RADIATION DENSITY FOR THE WHOLE PERIOD, MURO 26
C 101UR, //RI FROM //,FA,3, // TO //,FA,3, //10A, // (AI = X - XZERD //) MURO 27
C 1003 FORMAT (10F13.5)                                               MURO 28
C 1004 FORMAT (//,1X, //USABLE RADIATION DENSITY UP TO THE //,15, //, DAYS, MURO 29
C 1104, //RI FROM //,FA,3, // TO //,FA,3, //16X, // (XI = X - XZERD //) MURO 30
C 1005 FORMAT (//,1X, //LOCAL TIME (HRS) //,10F7.1)                 MURO 31
C 1006 FORMAT (1X, //I (W/P2) //,10F7.1)                             MURO 32
C 1007 FORMAT (1X, //R (REL RZ/d) //,10F7.1)                          MURO 33
C 1008 FORMAT (1X, //HRS (HRS) //,7F14F7.2)                           MURO 34
C                                                                           MURO 35
C PROGRAM CONTROL PARAMETERS                                           MURO 36
C                                                                           MURO 37
C HEAD 500, //,HR, //PRINT, //IND                                     MURO 38
C                                                                           MURO 39
C NREP NUMBER OF PROGRAM ITERATIONS / PERIODS                          MURO 40
C PRINT(1) # 0 PRINT SPECIFICATIONS OF PERIOD AND COLLECTION PARAM. MURO 41
C PRINT(2) # 0 PRINT DE/UR-VALUES OF ONE PERIOD                       MURO 42
C PRINT(3) # 0 PRINT DE/UR-VALUES OF EACH DAY                          MURO 43
C PRINT(4) # 0 PRINT DE/UR-VALUES (11) HRS OF EACH DAY                MURO 44
C PRINT(5) # 0 WRITE DE/UR-VALUES OF ONE PERIOD ON PUNCH (TAPE1) MURO 45
C IND # 0 SEE SUBROUTINE BINDEL                                        MURO 46
C                                                                           MURO 47
C LOCAL PARAMETERS                                                    MURO 48
C                                                                           MURO 49
C PCAU 501, //,FI, //FLA1, //FLA2, //TITL                             MURO 50
C PLAU 502, //,ZAMP, //ZEND, //DELTA, //IAE                             MURO 51
C DL = FLA1 - FLA2                                                    MURO 52
C ULT = DELTA/50.                                                      MURO 53
C NINT = IFIX((ZEND-ZAMP)/DELTA/50. //) //1                          MURO 54
C INT = NINT // 5 INT = INT //1                                        MURO 55
C IF (INT.GT.200) STOP INT.GT.200 //                                  MURO 56
C                                                                           MURO 57
C COLLECTOR PARAMETERS                                                MURO 58
C                                                                           MURO 59
C KLAN 510, //,ALP, //GA, //RMDL, //,CR                               MURO 60

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      TM = TR + 0.01
      ALPA = ALPH * S   GAMMA = GAM
      UD = ATAF11.1/NS.
      ALPH = ALPH*RD   S   GAM = GAM*BC
      PRINT 93, TITLE
C
C      LOOP OF PERIODS
C
      DO 999 K = 1, NMAX
      PL = 0
C
C      DEFINITION OF PERIOD
C
      READ 900, JAA, JAE, HAA, HE
      IF (JAA.LT.1) STOP, JAA TOO SMALL
      IF (JAE.GT.1) STOP, JAE TOO LARGE
      IF (PRINT1) 0.01 GO TO 9001
      PRINT 1001, JAA, JAE, HAA, HE, TR, ALPA, GAMMA, NHOL, BR, CR
9001 CONTINUE
C
C      INITIALIZATION
C
      IF (NHOL.LT.1) MAX = MAXC
      IF (NHOL.GT.1) MAX = MAXF
      XIM = MAX*DA
      NHULL = 0.0
900  PERIOD 2
      PL = PL+1
      IF (AL.0.0) GO TO 910
      IF (PH.0.0) AND (NT.0.0) GOTO 910
      PAR = 2*MAX
      XIM = 2*XIM
      NHULL = -XIM/2.
910  KP = NZ * KH = 0
      XMIN = XIM
      XUM = 0.
      SIF1 = SICINF = 0.0
      DO 30 J = 1, INT
30  ZEST(J) = ZANF + DELT*(J-2)
      DO 35 L = 1, NMAX
35  DEK(L) = 0.0
      S15 = S16 = 0.0
      I=15 = 0
      DO 36 J = 2, INT
      IT1(J) = 0
      I=1(J) = 0
      IP1(J) = 0
      IG1(J) = 0
36  IS1(J) = 0
      P = 0
C
C      MAIN PROGRAM
C
      DO 10 JA = 1, JAE
      DO 20 N = 1, NMAX
C
C      INPUT OF LOCAL METEO DATA (TAPE 2)
C
C      IF THE GLOBAL RADIATION IN THE COLLECTOR PLANE IS KNOWN
C      0411 CARDS 125 AND 126 AND REPLACE CARD 124 BY
      MURD 61
      MURD 62
      MURD 63
      MURD 64
      MURD 65
      MURD 66
      MURD 67
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      MURD 119
      MURD 120
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C      1*(I01(J),J=2,INT),(IG(J),J=2,INT)          PURD 121
C
      READ (2) JAI,NI,(ITE(J),J=2,INT),IM(IJ),J=2,INT),(IGL(J),J=2,INT) PURD 122
      2*(I01(J),J=2,INT)                              PURD 123
      DO 37 J=2,INT                                    PURD 124
      37 IG(J) = -999999                                PURD 125
      IF (JAI.LT.JAA) GO TO 20                         PURD 126
      IF (NI.LT.NA.NE.NE) GO TO 20                    PURD 127
C
C      DATA CONTROL                                  PURD 128
C
C      IGES = I0IS = 0                                PURD 129
      DO 29 J = 2,INT                                  PURD 130
      IGES = IGES+IGE(J)                                PURD 131
      29 I0IS = I0IS+I0I(J)                             PURD 132
      IF (IGES.LT.9999.AND.I0IS.LT.9999) GO TO 27    PURD 133
      IF (NI.NE.99) GO TO 29                          PURD 134
      IF (JAI.AND.3).NE.0) GO TO 20                  PURD 135
      29 DO 26 J = 2,INT                                PURD 136
      ITE(J) = I(IJ)                                  PURD 137
      I0(J) = IM(IJ)                                  PURD 138
      I0P(J) = IP(IJ)                                 PURD 139
      IGL(J) = IG(IJ)                                 PURD 140
      26 I0I(J) = I0I(J)                               PURD 141
      27 P = 4+1                                       PURD 142
      DO 28 J = 2,INT                                  PURD 143
      I(IJ) = (I(IJ)+(M-1)+ITE(J))/M                 PURD 144
      I0(J) = (I0I(J)+(M-1)+I0I(J))/M                PURD 145
      IP(J) = (IP(IJ)+(M-1)+IP(IJ))/M                PURD 146
      IG(J) = (IG(IJ)+(M-1)+IG(IJ))/M                PURD 147
      28 I0I(J) = (I0I(J)+(M-1)+I0I(J))/M            PURD 148
C
C      CALL XISIT                                     PURD 149
C
      DO 406 J=2,INT                                   PURD 150
      IF (X(J).GT.7.) KP=KP+1                          PURD 151
      IF (X(J).LT.7.) KN=KN+1                          PURD 152
      IF (X(J).EQ.0.) KZ = KZ+1                        PURD 153
      IF (X(J).LT.XMIN) XMIN = X(J)                   PURD 154
      406 CONTINUE                                     PURD 155
      IF (XMIN.EQ.0.) GO TO 20                          PURD 156
      S1 = X(1)-X(2)                                    PURD 157
      IF (S1.GT.0.) X(1) = -10.0                       PURD 158
      IF (S1.LE.0.) X(1) = 10.0                        PURD 159
      S16 = X(INT) - X(INT-1)                          PURD 160
      IF (S16.LT.0.) X(INT) = -10.0                   PURD 161
      IF (S16.GE.0.) X(INT) = 10.0                    PURD 162
C
C      CALCULATION OF DE/OX (X) = SENSITIVITY/OXI    PURD 163
C
      DO 40 J = 2,INT                                  PURD 164
      SIG = SIG + DELT*FLOAT(IG(IJ))*1.163            PURD 165
      I0IS = I0IS+I0I(J)                              PURD 166
      SIS = SIS + DELT*SYE(J)                         PURD 167
      40 F(J) = 0.0                                     PURD 168
      Z(ITAI) = Z(IT(J-1)) + 0.5*DEL7               PURD 169
      Z(ITAI2) = Z(IT(J))                            PURD 170
      Z(ITAI3) = Z(IT(J+1)) - 0.5*DEL7               PURD 171
      XAC(1) = (X(J-1)+X(J))/2. - XNULL              PURD 172
      XAC(2) = F(J) - XNULL                           PURD 173

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XAC(3) = (X(2+1)+X(1))/2. = XNULL
SIAC(1) = (S(1J-1)+S(1J))/2.
SIA(2) = S(1J)
SIA(3) = (S(1J+1)+S(1J))/2.
EPS = 0.2
U = ABS(XAC(1)-XAC(2))
V = ABS(SIA(2)-SIA(3))
IF ((0.2*U).GT.V*UP*(0.2*V).GT.U) EPS = 0.3
CALL PARADIC (ZEITR,XA,A1,B1,C1,DUM,DUM,EPS)
EPS = 0.2
U = ABS(SIA(1)-SIA(2))
V = ABS(SIA(2)-SIA(3))
IF ((0.2*U).GT.V*UP*(0.2*V).GT.U) EPS = 0.3
CALL PARADIC (ZEITR,SIA,A2,B2,C2,DUM,DUM,EPS)
C
C IF X(T) = CONSTANT / A1 = B1 = 0
C
IF (A1.NE.0.O.OR.B1.NE.0.O) GO TO 50
L = 1/(X(1)/DA) + 1
IF (L.GT.MAX(OR,L,LT,1)) GO TO 40
DIL = D*LT
SIL = A2*ZEIT(1J)+ZEIT(1J)+B2*ZEIT(1J)+C2
DEXIL) = D*EXIL)+SIL/DIL/DA
DOT(1J) = DOT(1J)+DTL
GO TO 40
C
C IF X(T) IS A LINEAR FUNCTION / A1 = 0
C
50 IF (A1.NE.0.O) GO TO 55
DO 65 L = 1,MAX
XL = DX*FLCATE(L-1)
ZU = ZEIT(1J)-0.5*DELT
ZL = ZL(1J)+0.5*DELT
Z(1J) = (XL-C1)/A1
IF (ZL(1J).L.(ZU,OR,ZEIT(1J).GT.ZO) GO TO 65
SIL = (XL-C1)/A1
SIL = A2*SIL+SIL+B2*SIL+C2
LTC = ABS(DX/P1)
DEXIL) = D*EXIL)+SIL/DIL/DA
DOT(1J) = DOT(1J)+DTL
65 CONTINUE
GO TO 40
C
C IF X(T) IS A PARABOLIC FUNCTION / A1 ≠ 0, B1 ≠ 0
C
55 DO 66 L = 1,MAX
FL = DX*FLCATE(L-1)
NUMZ = B1*OR)-4.*A1*(C1-FL)
W = B1*B1-4.*A1*(C1-FL-DX)
ZU = ZEIT(1J)-0.5*DELT
ZL = ZL(1J)+0.5*DELT
IF (NUMZ.LT.0.O.AND.W.LT.0.O) GO TO 60
C
C IF X(T) SHOWS A MAXIMUM OR A MINIMUM WITHIN THE INTERVAL DX
C
IF (NUMZ.GE.0.O.OR.W.LT.0.O) GO TO 100
W = SQR(W)
Z(1J) = (-B1+W)/(2.*A1)
Z(1J) = (-B1-W)/(2.*A1)
GO TO 100

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100 IF (MURZ.GE.O.O.AND.M.GE.L.O) GO TO 105
MURZ = SQRT(MURZ)
ZEIT1 = (-B1+MURZ)/(Z.OA1)
ZEIT2 = (-B1-MURZ)/(Z.OA1)
101 Z1 = ZEIT1
Z2 = ZEIT2
IF (ZEIT1.LT.ZEIT2) GO TO 102
Z1 = ZEIT2
Z2 = ZEIT1
102 IF ((Z1.LT.ZU.OO.Z1.GT.ZO).AND.(Z2.LT.ZU.OO.Z2.GT.ZO)) GO TO 60
IF (Z1.GE.ZU.AND.Z2.LE.ZU) GO TO 103
IF (Z1.GE.ZU) GO TO 104
DTL = Z2-ZU
SIL = A2+Z2+Z2+42+Z2+C2
DEK(L) = DEK(L)+SIL*DTL/DX
SOT(J) = SOT(J)+DTL
GO TO 60
104 DTL = ZU-Z1
SIL = A2+Z1+Z1+42+Z1+C2
DEK(L) = DEK(L)+SIL*DTL/DX
SOT(J) = SOT(J)+DTL
GO TO 60
103 DTL = Z2-Z1
ZM = (Z2+Z1)/2
SIL = A2+ZM+ZM+42+ZM+C2
DEK(L) = DEK(L)+SIL*DTL/DX
SOT(J) = SOT(J)+DTL
GO TO 60
C
C IF NOT INTERSECTS THE INTERVAL OR
C
105 MURZ = SQRT(MURZ)
ZEIT1 = (-B1+MURZ)/(Z.OA1)
ZEIT2 = (-B1-MURZ)/(Z.OA1)
Z1 = ZEIT1
Z2 = ZEIT2
IF (ZEIT1.LT.ZEIT2) GO TO 106
Z1 = ZEIT2
Z2 = ZEIT1
106 M = SQRT(M)
ZEITV1 = (-B1+M)/(Z.OA1)
ZEITV2 = (-B1-M)/(Z.OA1)
ZV1 = ZEITV1
ZV2 = ZEITV2
IF (ZEITV1.LT.ZEITV2) GO TO 70
ZV1 = ZEITV2
ZV2 = ZEITV1
70 IF ((Z1.LT.ZU.OO.Z1.GT.ZO).AND.(ZV1.LT.ZU.OO.ZV1.GT.ZO)) GO TO 60
DTL = ABS(ZV1-Z1)
IF (Z1.GT.ZU) DTL = ZU-ZV1
IF (ZV1.GT.ZU) DTL = ZU-Z1
IF (Z1.LT.ZU) DTL = ZV1-ZU
IF (ZV1.LT.ZU) DTL = Z1-ZU
SIL = A2+Z1+Z1+42+Z1+C2
DEK(L) = DEK(L)+SIL*DTL/DX
SOT(J) = SOT(J)+DTL
60 IF ((Z2.LT.ZU.OO.Z2.GT.ZO).AND.(ZV2.LT.ZU.OO.ZV2.GT.ZO)) GO TO 60
DTL = ABS(ZV2-Z2)
IF (Z2.GT.ZU) DTL = ZU-ZV2
IF (ZV2.GT.ZU) DTL = ZU-Z2
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IF (Z2.LT.ZU) DTL = ZV2-ZU          MUND 301
IF (ZV2.LT.ZU) DTL = Z2-ZU          MUND 302
SIL = A2+Z2+Z2+Z2+Z2+C2            MUND 303
DEX(L) = DEX(L)+SIL*DTL/DX         MUND 304
SDT(J) = SDT(J)+DTL                MUND 305
60 CONTINUE                          MUND 306
IF (SDT(J).NE.0.)GO TO 40           MUND 307
XL = A1+Z.LITE(J)*2+01*ZLITE(J)+C1 MUND 308
L = IFIX(XL/DX) + 1                 MUND 309
IF (L.GT.MAX)DP.L.LY.1) GO TO 40  MUND 310
SDT(J) = DELT                       MUND 311
DEX(L) = DEX(L) + SIL*DLT/DX        MUND 312
41 CONTINUE                          MUND 313
C                                     MUND 314
C   OUTPUT SPECIFICATION             MUND 315
C                                     MUND 316
IF (NPRINT(1).EQ.0) GO TO 9003     MUND 317
PRINT 1004,N,DX,XIN                 MUND 318
PRINT 1005,(DEX(L),L=1,MAX)         MUND 319
9003 CONTINUE                        MUND 320
IF (NPRINT(4).EQ.0) GO TO 9004     MUND 321
PRINT 1004,N,DX,XIN                 MUND 322
PRINT 1005,(DEX(L),L=1,MAX)         MUND 323
PRINT 1005,ZEIT                      MUND 324
PRINT 1006,S1                          MUND 325
PRINT 1007,S2                          MUND 326
PRINT 1008,(SDT(J),J=2,INT)         MUND 327
9004 CONTINUE                        MUND 328
20 CONTINUE                          MUND 329
10 CONTINUE                          MUND 330
IF (N.L.EQ.1) GOTO 900             MUND 331
C                                     MUND 332
IF (NPRINT(2).EQ.0) GO TO 9002     MUND 333
PRINT 901,KP,M2,KN,XNULL            MUND 334
PRINT 1002,DX,XIN                   MUND 335
PRINT 1003,(DEX(L),L=1,MAX)         MUND 336
9002 CONTINUE                        MUND 337
IF (NPRINT(5).EQ.0) GO TO 9005     MUND 338
C                                     MUND 339
C   DATA ON PERMANENT FILE (TAPE 1) MUND 340
C                                     MUND 341
WRITE (1) JAA,JAE,NB,NE,IN,ALPA,JAMA,MKOL,DR,CK,MAX,OK,XNULL,XIN,MUND 342
PRINT,S15,SIG,INIC,(DEX(I),I=1,MAX) MUND 343
9005 CONTINUE                        MUND 344
999 CONTINUE                          MUND 345
STOP                                  MUND 346
END                                    MUND 347

```

```

SUBROUTINE PARABE(X,Y,A,B,C,X0,Y0,EPS)
C
C DETERMINATION OF THE INTERPOLATION FUNCTIONS FOR X(1) AND S(1)
C F(T) = A*T**2 + B*T + C
C
DIMENSION X(3),Y(3)
X1 = X(1)  S  Y1 = Y(1)
X2 = X(2)  S  Y2 = Y(2)
X3 = X(3)  S  Y3 = Y(3)
Z = (X3-Y2)+(X3-Y1)*(Y2-Y1)
IF( ABS(Z) - EPS) GO TO 10
10 CONTINUE
A = ((X2-X1)*(Y3-Y2)-(X3-X2)*(Y2-Y1))/Z
B = (Y3-Y1)/(Y3-Y1-A*(X1-X3))
C = Y2-X2*(A+B)
RETURN
20 A = 0.0
B = (Y3-Y1)/(X3-X1)
C = Y3-B*X3
RETURN
END

```

PARA	1
PARA	2
PARA	3
PARA	4
PARA	5
PARA	6
PARA	7
PARA	8
PARA	9
PARA	10
PARA	11
PARA	12
PARA	13
PARA	14
PARA	15
PARA	16
PARA	17
PARA	18
PARA	19
PARA	20
PARA	21

```

SUBROUTINE FISI1
C
C CALCULATION OF THE ORDERING PARAMETER NIT(I)
C THE INSOLATION ON COLLECTOR SURFACE SY(I) AND
C THE INCIDENT RADIATION ON THE ABSORBER SI(I)
C
C NRQL.GT.1 : EXPONENT OF INCIDENT ANGLE MODIFIER FOR FLAT-PLATE
C COLLECTORS WITH ONE OR TWO COVER WINDOWS
C
C NRQL.LT.1 : DIFFUSE RADIATION EFFICIENCY OF CONCENTRATING,
C EAST-WEST TRACKING COLLECTORS WITHOUT COVER WINDOW
C (NRQL = ADIF)
C
REAL NRQL
COMMON ITC(200),IGC(200),IUI(200),INI(200),IGP(200),DEX(200),
1 ZLIT(200),X(200),SII(200),SY(200),FI,FLAZ,DL,IND,INT,
4 TR,ALPH,MI,NRQL,GAM,OR,CX
C
IF(NRQL.GT.1) GOTO 5
ADIFU = NRQL * COM = 0.0 * GOTO 6
5 ADIFU = 0.51935*0.16666*NRQL*11.-0.10217*NRQL
COM = 0.656672-0.015187*NRQL*11.-0.02660*NRQL
6 ADIF = ADIFU*COM*ALPH**2.467-ALPH**2)
DO 10 J = 1,INT
CALL WINREL (ZLIT(J),MI,IND,FI,DL,FLAZ,MI,MI)
C = SIN(MI)*COS(ALPHI)*COS(HI)*SIN(ALPH)*COS(A-GAM)
IF (MI.LT.0.05.OR.C.LT.0.) C = 0.
L = SIN(ALPH)*SIN(HI)-COS(ALPH)*C*S(HI)*COS(A-GAM)
IF (ABS(L).GT.1.) D=1.0
D = SQRT(1.-D**2)
IF (MI.LT.0.05.OR.D.LT.0.) D=0.0
IF (IGC(J).EQ.0) GO TO 30
U = FLJAT(IGC(J))/FLOAT(IGC(J))
DIR = FLJAT(IGC(J))*1.-U*U)/SIN(HI)
IF (IGP(J).LT.0) GOTO 15
DIR = IGP(J) - DIR*COM * GO TO 16
15 V = 1.-COS(ALPHI))/2.
DIR = FLOAT(IGC(J))*U*1.-U*V)
16 SY(J) = (DIR*COM + DIR)*0.163
PHI = ACOS(C)
IF (NRQL.GT.1.) DIR = DIR*COM*PHI/PHI,NRQL)
IF (NRQL.LT.1.) DIR = DIR*COM
IF (C.LT.0.) DIR = 0.0
DIR = DIR*ADIF
SII(J) = (UI* + DIR)*0.163
IF (SII(J) > 30) SII(J) = 30
20 DIF = TR-FLOAT(ITC(J))
VM = 0.51644*FLOAT(IUI(J))
(J) = DIF*(1.+NRQL*DET*CK*VM)/SII(J)
IF (ABS(X(J)).GT.10.) GOTO 30
GO TO 10
30 VORZ = TR-FLOAT(ITE(J))
IF (VORZ.LT.0.) VORZ = 1.
VJAZ = VLRZ/ANS(VORZ)
X(J) = 10.*VORZ
SII(J) = 0.0
IF (IGC(J).EQ.0) SY(J)=0.0
10 CONTINUE
RETURN
END

```

```

FISI1 1
FISI1 2
FISI1 3
FISI1 4
FISI1 5
FISI1 6
FISI1 7
FISI1 8
FISI1 9
FISI1 10
FISI1 11
FISI1 12
FISI1 13
FISI1 14
FISI1 15
FISI1 16
FISI1 17
FISI1 18
FISI1 19
FISI1 20
FISI1 21
FISI1 22
FISI1 23
FISI1 24
FISI1 25
FISI1 26
FISI1 27
FISI1 28
FISI1 29
FISI1 30
FISI1 31
FISI1 32
FISI1 33
FISI1 34
FISI1 35
FISI1 36
FISI1 37
FISI1 38
FISI1 39
FISI1 40
FISI1 41
FISI1 42
FISI1 43
FISI1 44
FISI1 45
FISI1 46
FISI1 47
FISI1 48
FISI1 49
FISI1 50
FISI1 51
FISI1 52
FISI1 53
FISI1 54
FISI1 55
FISI1 56
FISI1 57
FISI1 58
FISI1 59
FISI1 60

```



```

C      FUNCTION APHI (PHI, NKOL)
C      CALCULATION OF INCIDENT ANGLE MODIFIER
C      REAL NKOL
C      PHI = ABS(PHI)
C      IF (PHI.EQ.0.) GO TO 10
C      PHI = PHI/2.
C      APHI = 1. - (SIN(PHI)/COS(PHI))**NKOL
C      RETURN
10  APHI = 1.
C      RETURN
C      END

```

APHI 1
 APHI 2
 APHI 3
 APHI 4
 APHI 5
 APHI 6
 APHI 7
 APHI 8
 APHI 9
 APHI 10
 APHI 11
 APHI 12
 APHI 13
 APHI 14

```

C      SUBROUTINE WINKL (ZEIT, INTAG, INDEK, P, DL, FLAZ, SH, SA)
C      CALCULATION OF ELEVATION AND AZIMUTH OF THE SUN
C      AS A FUNCTION OF TIME OF DAY
C      IF TIME IS GIVEN IN ZONAL TIME (CLOCK) * INDEK = 0
C      IF TIME IS GIVEN IN REAL LOCAL TIME * INDEK = 1
C
C      P1=3.14159265 * B0 = 2.*PI/365.2422
C      EPS = 0.40914 * ERZ = 0.016717
C      PHI = P1*PI/180.
C      FK = 01.*J-FLAZ/360.
C      LM = FLJAT(INTAG)-1.95*FLAZ/360.
C      PLM = (FLJAT(INTAG)-P1)*80.
C      XL = PLM + 2.*ERZ*SIN(P1*80)
C      DE = SIN(XL)*SIN(EPS) * DE = ASIN(DE)
C      AL = COS(XL)/COS(DE) * AL = ACOS(AL)
C      AL = SIGN(AL,PL)
C      IF (XL.GE.PI) AL = 2.*PI-AL
C      ZGL = (LM-AL)
C      ZKU = 12.*ZGL/PI - DL/15.
C      IF (INDEK.EQ.1) ZKO = 0.0
C      T = (ZEIT+ZK7-12.)*PI/12.
C      SH = SIN(PHI)*SIN(DE)+COS(PHI)*COS(DE)*COS(T)
C      SM = ASIN(SH)
C      SA = (SIN(PHI)*COS(DE)*COS(T)-COS(PHI)*SIN(DE))/COS(SM)
C      SA = ACOS(SA) * SA = SIGN(SA,T)
C      RETURN
C      END

```

WINK 1
 WINK 2
 WINK 3
 WINK 4
 WINK 5
 WINK 6
 WINK 7
 WINK 8
 WINK 9
 WINK 10
 WINK 11
 WINK 12
 WINK 13
 WINK 14
 WINK 15
 WINK 16
 WINK 17
 WINK 18
 WINK 19
 WINK 20
 WINK 21
 WINK 22
 WINK 23
 WINK 24
 WINK 25
 WINK 26
 WINK 27
 WINK 28
 WINK 29

FUNCTION SIMPSE(M,N0,N1,F)	SIM	1
IF(2*(M/2)-N) 5,10,5	SIM	2
5 N = M+1	SIM	3
10 M = (N1-N0)/M	SIM	4
SUM = (F(N0)+F(N1))/2.	SIM	5
N1 = M-1	SIM	6
10 15 I=1,N1,2	SIM	7
X11 = N0 + M*I	SIM	8
X12 = X11 + M	SIM	9
15 SUM = SUM + 2.*F(X11) + F(X12)	SIM	10
SIMPSE = 2.*M*SUM/3.0	SIM	11
RETURN	SIM	12
END	SIM	13

FUNCTION FUNCT1(X)	FUN	1
REAL X0	FUN	2
COMMON DEX(200),A0,X0,DX	FUN	3
L = IF(X/DX+0.5)	FUN	4
IF(L.EQ.0) GOTO 10	FUN	5
F = DEX(L)+(A0-X0*(X-X0))	FUN	6
IF (F.LT.0.0) GOTO 10	FUN	7
FUNCT1 = F	FUN	8
RETURN	FUN	9
10 FUNCT1 = 0.0	FUN	10
RETURN	FUN	11
END	FUN	12

2. RESULTS FOR THE METEO SITUATION OF ZURICH AIRPORT

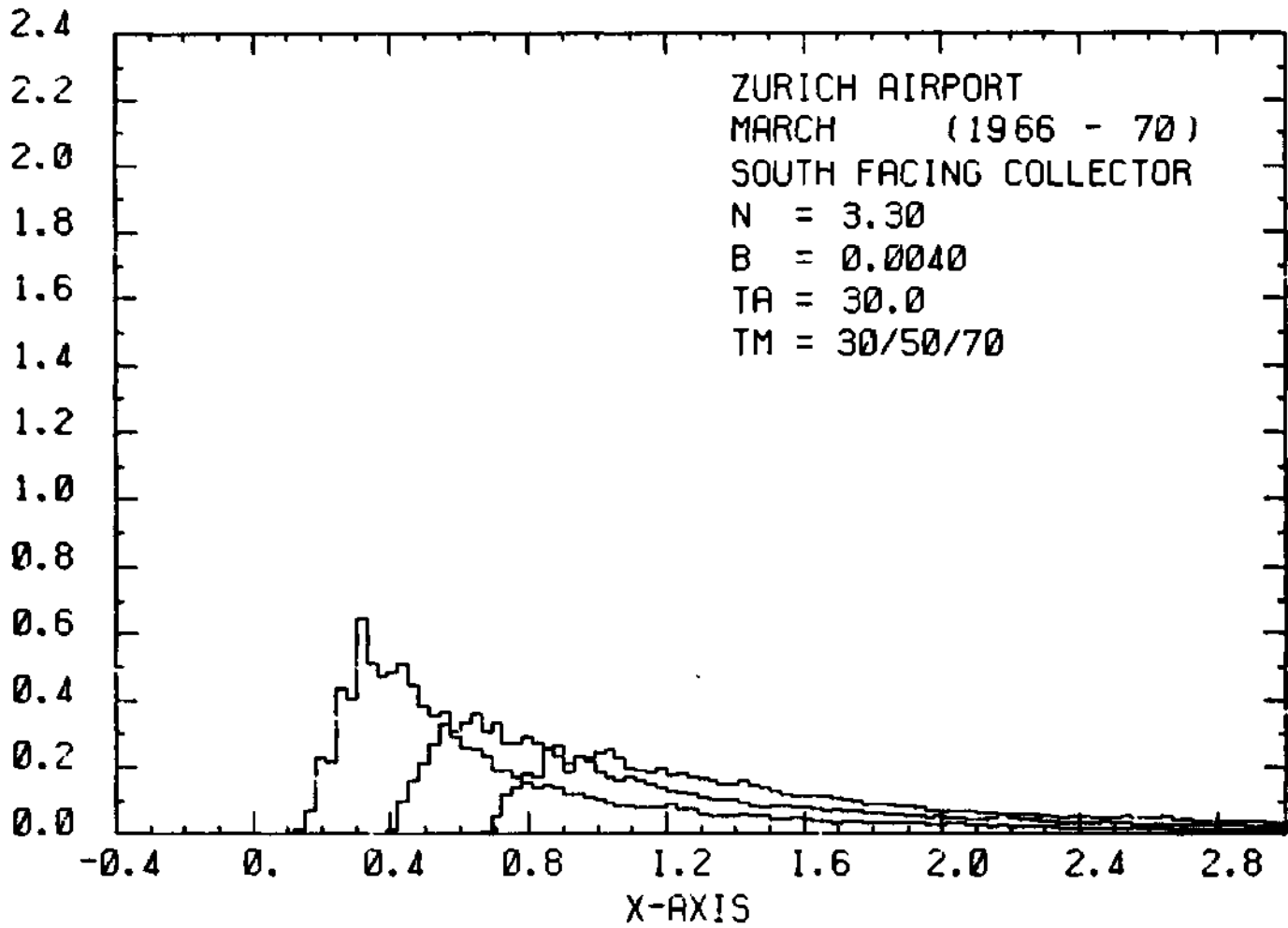
According to the decision at the preparatory May-meeting at EIR, we have computed the following cases for the meteo-situation of Zurich airport which is more or less significant of the Swiss Midlands:

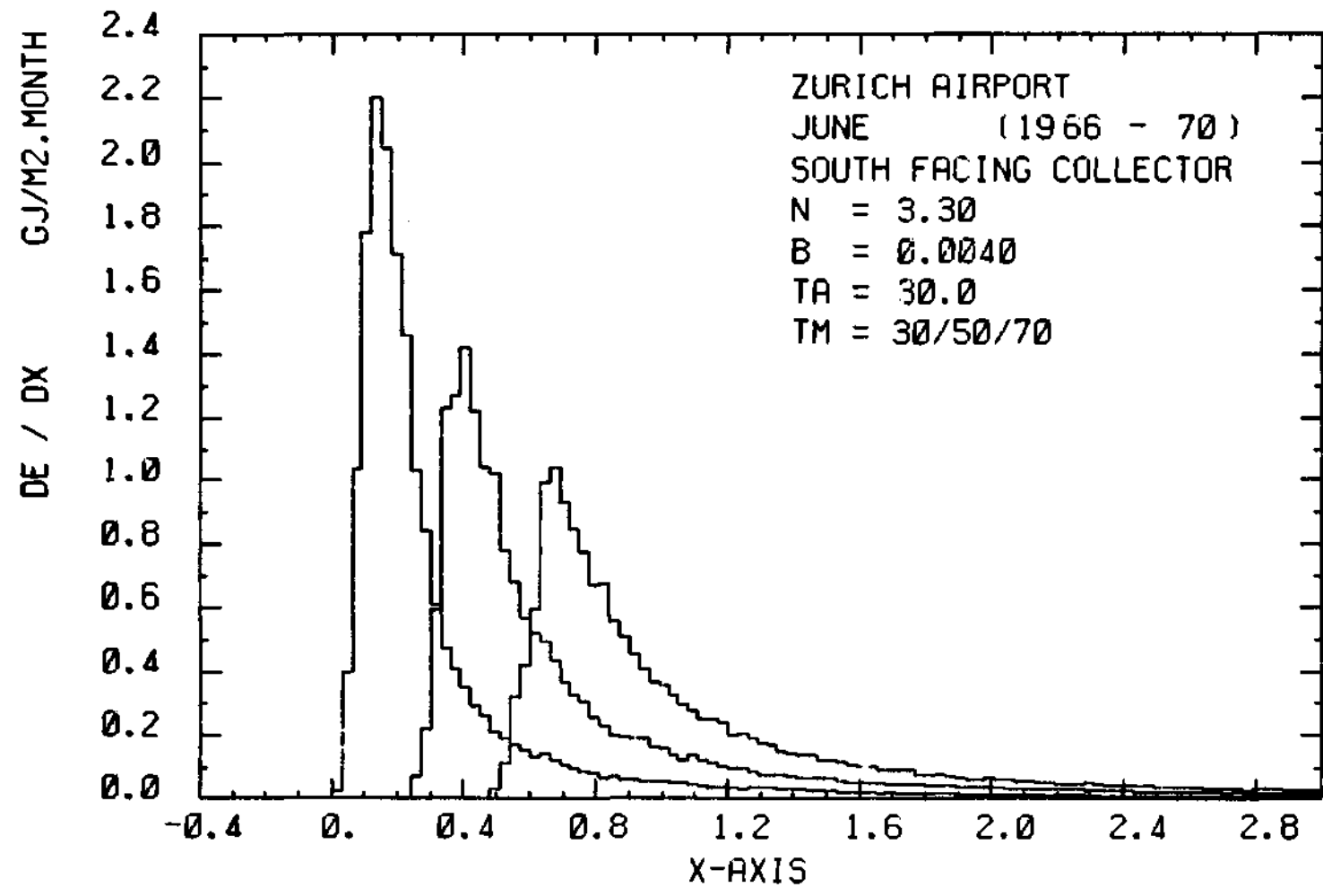
Collector orientation (γ):	South facing (0)
Collector class (n, b):	(3.3, 0.004 K ⁻¹) (2.5, 0.004 K ⁻¹)
Collector tilt angle TA (α):	30°, 60°
Monthly tables for month MO:	March, June, September, December
Values for constant collector temperature T _m :	30, 50, 70° C

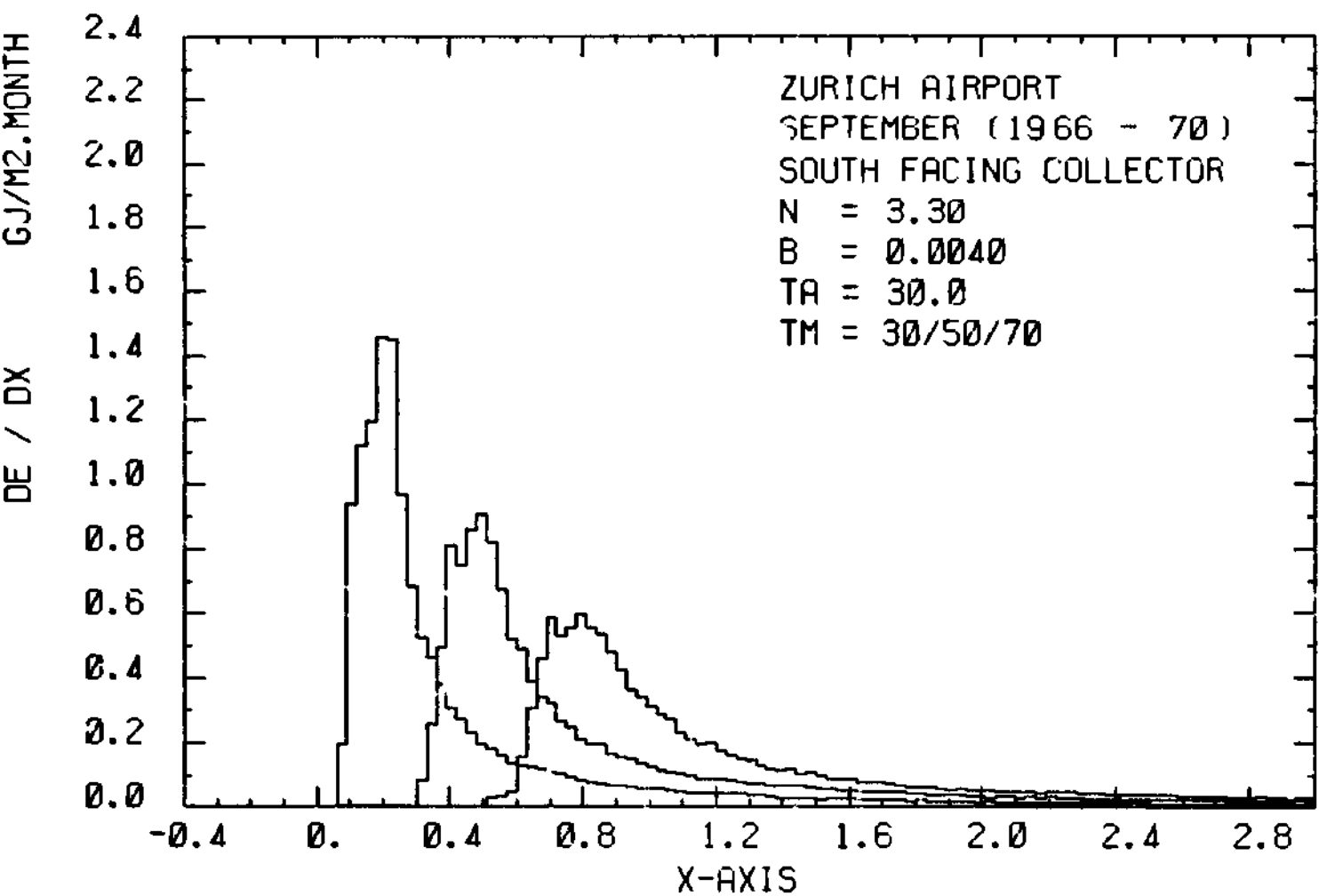
(How to get results for constant inlet temperatures T₁, see appendix I).

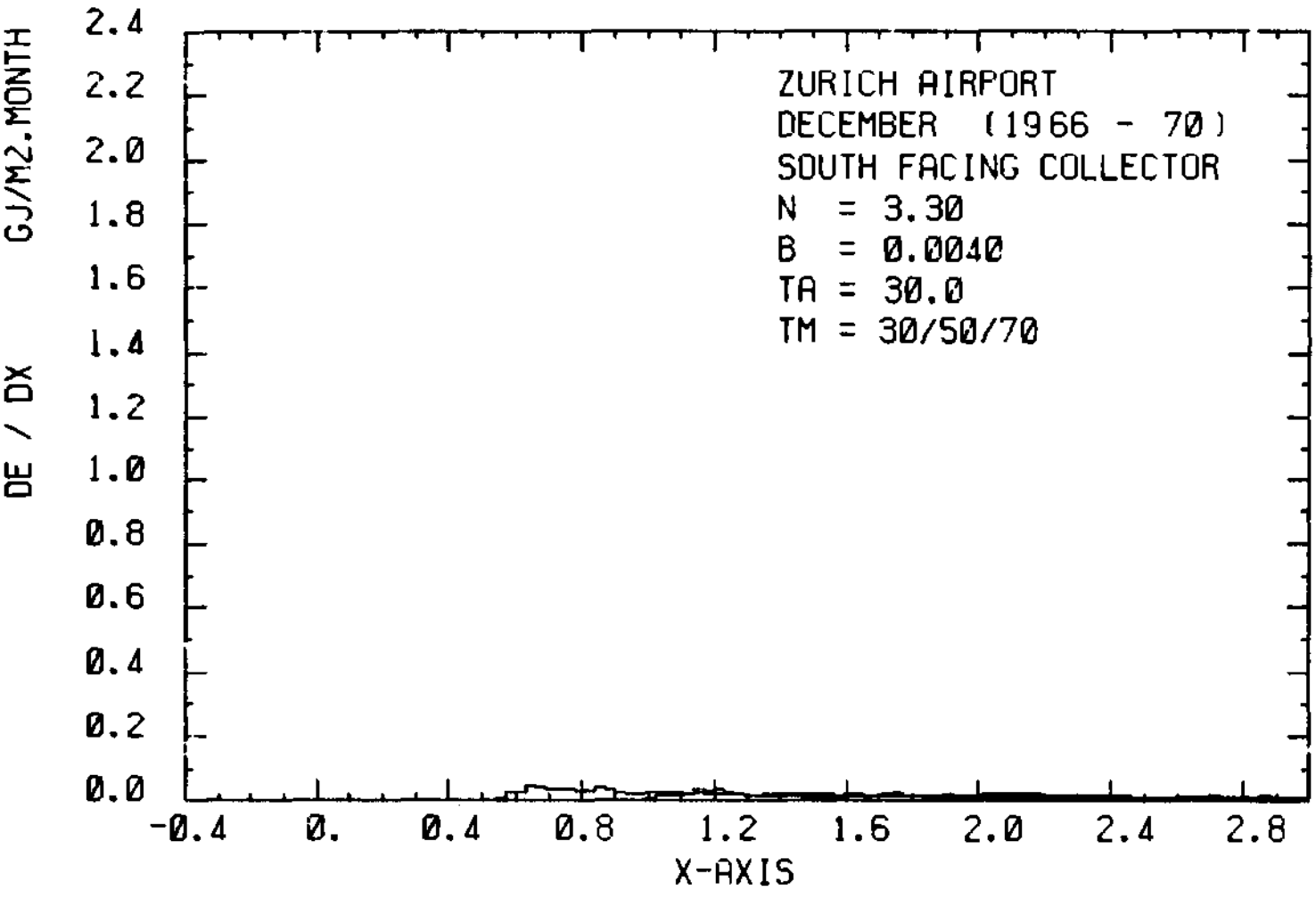
On the following pages, first an example for the MURD-tables is given (the complete set of tables is available c.. magnetic tape), then the graphs of the MURD-functions are represented completely and finally, the complete tables of monthly mean gain values are quoted.

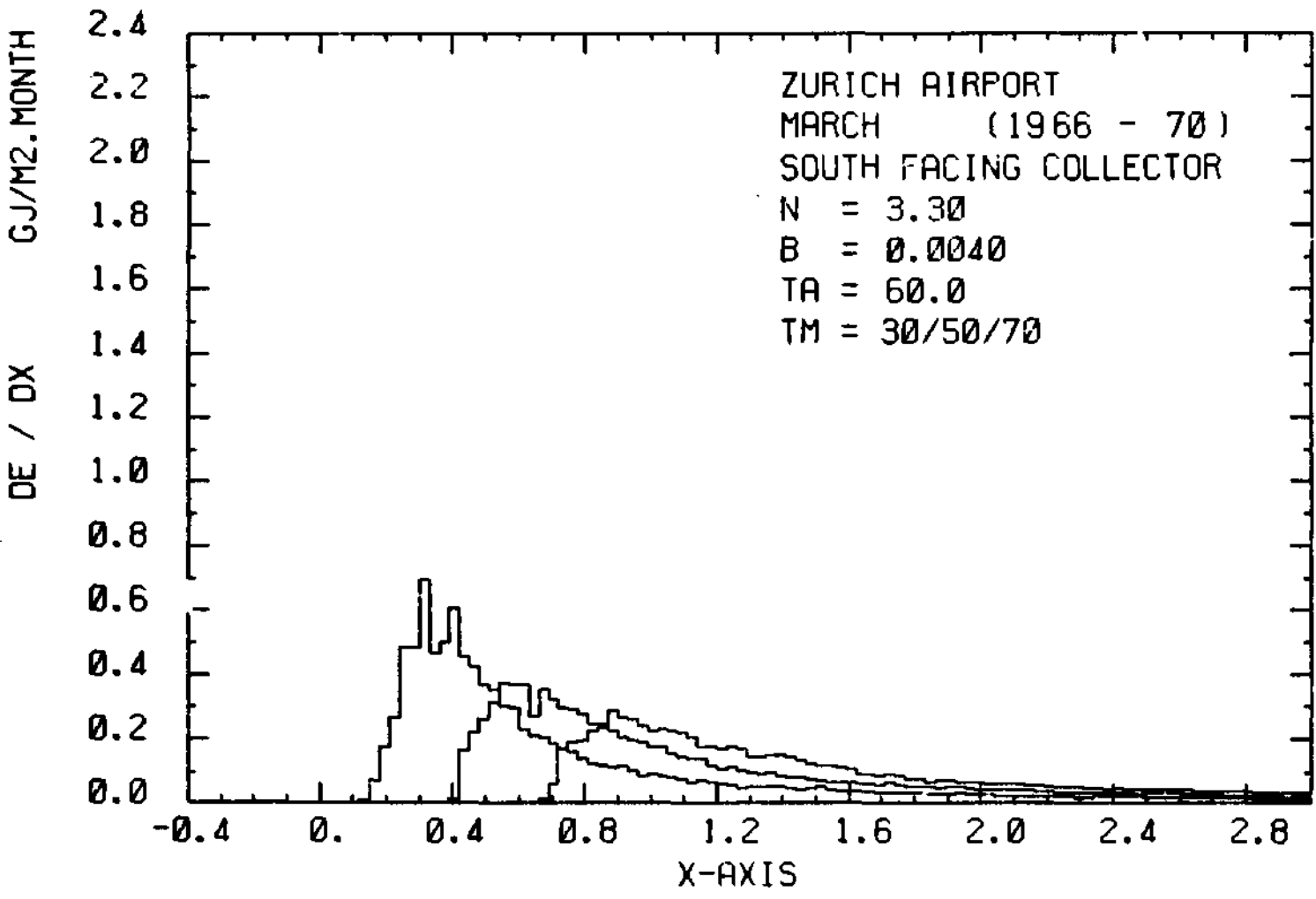
DE / DX GJ/M2.MONTH

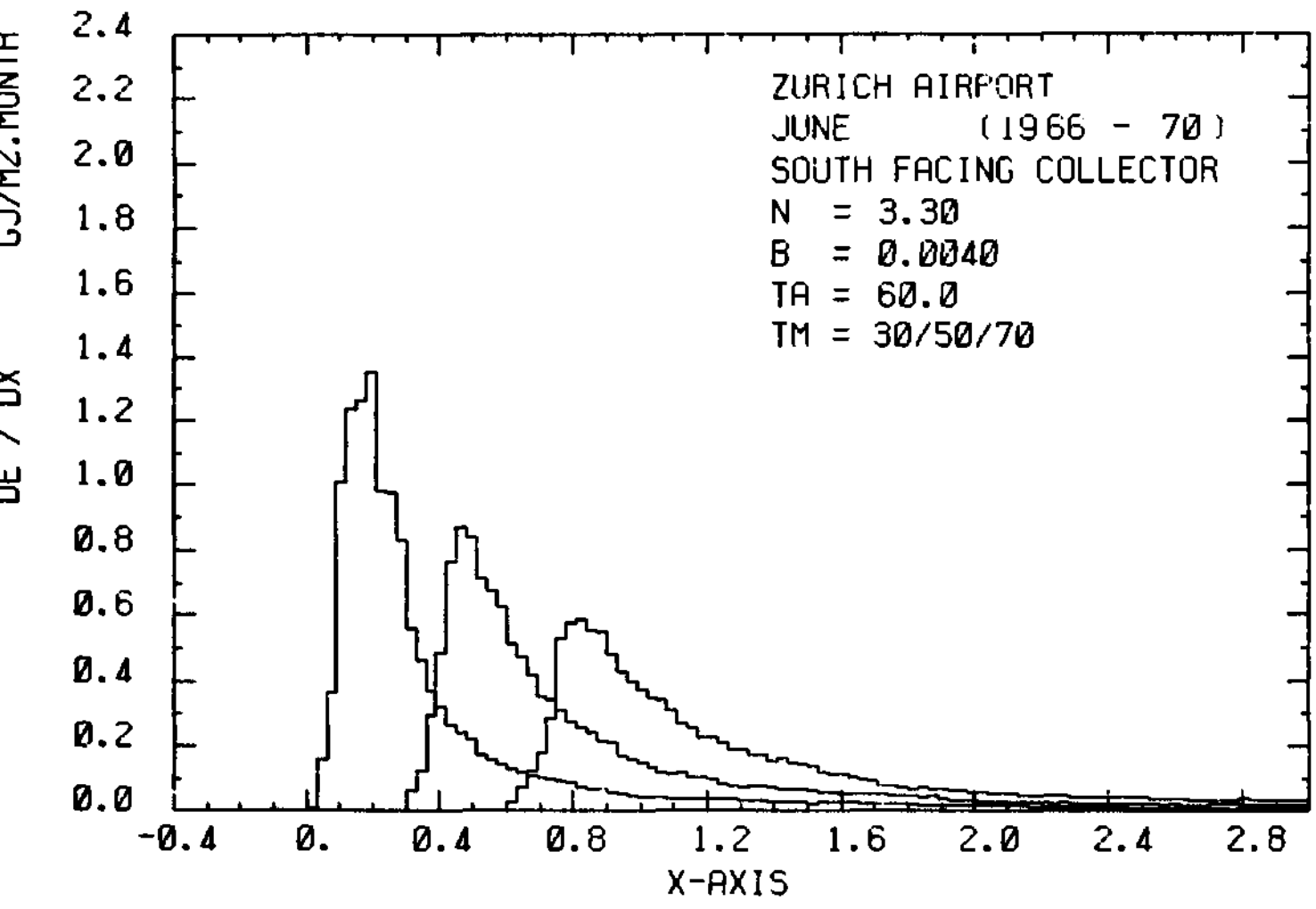




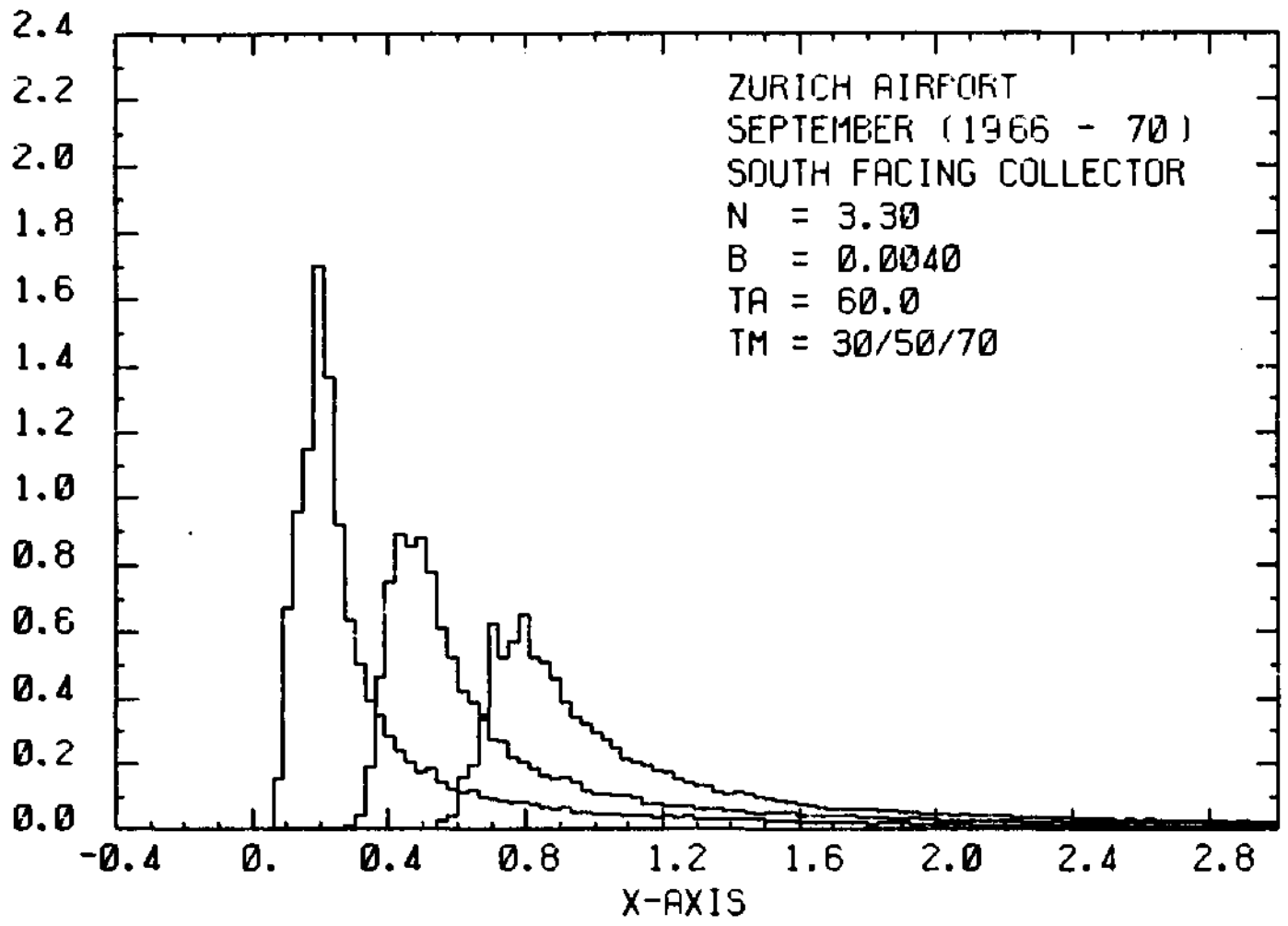


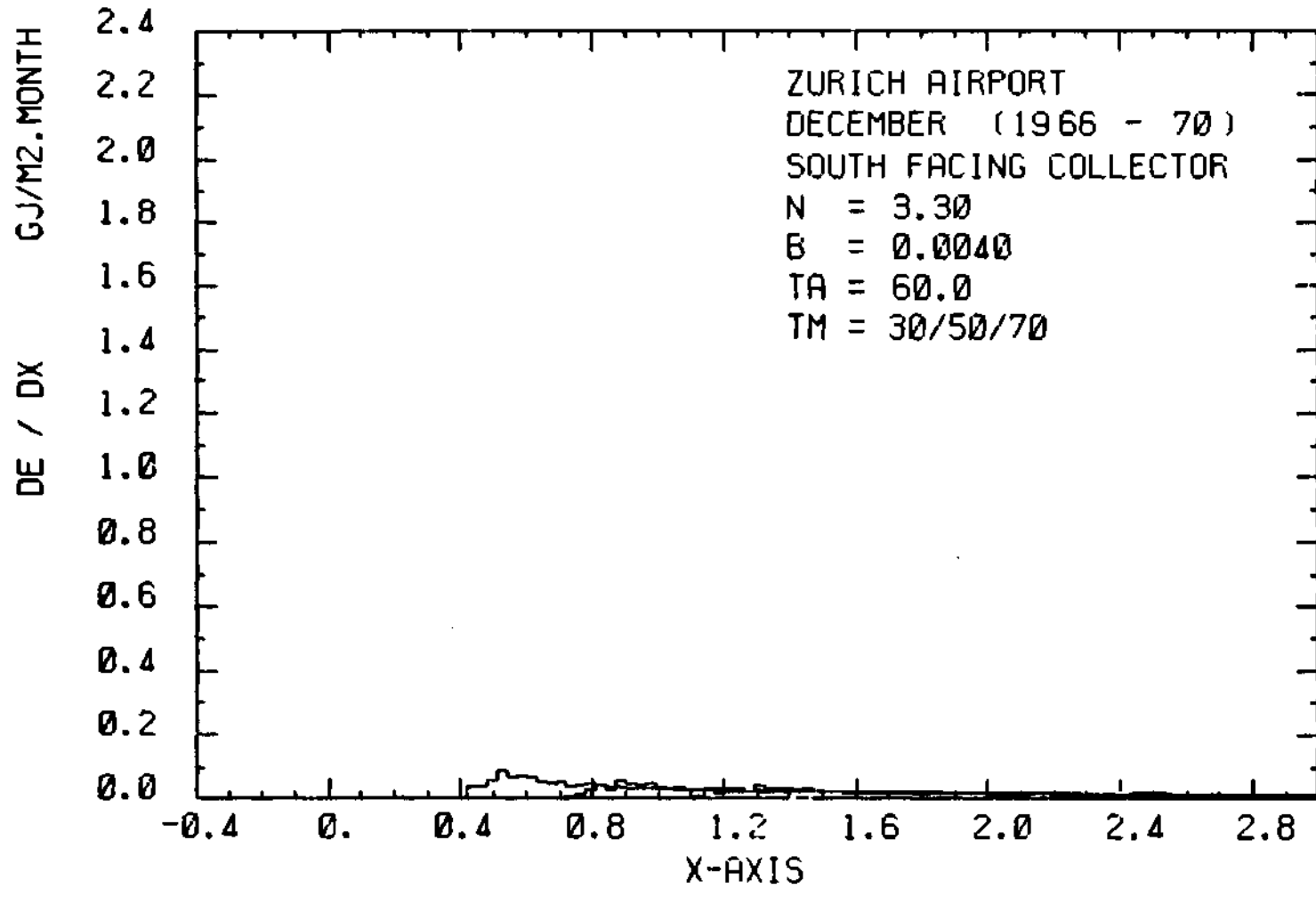


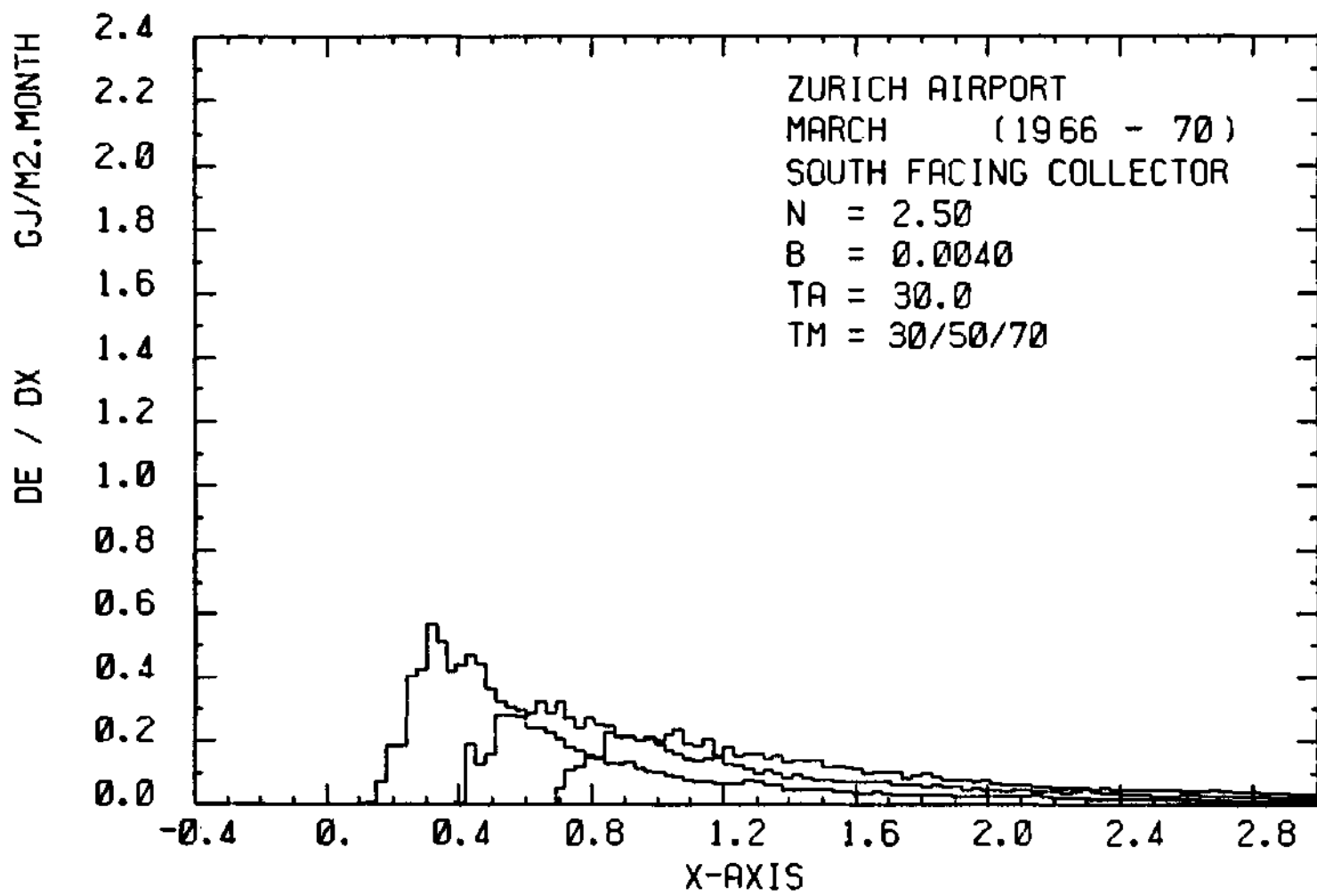




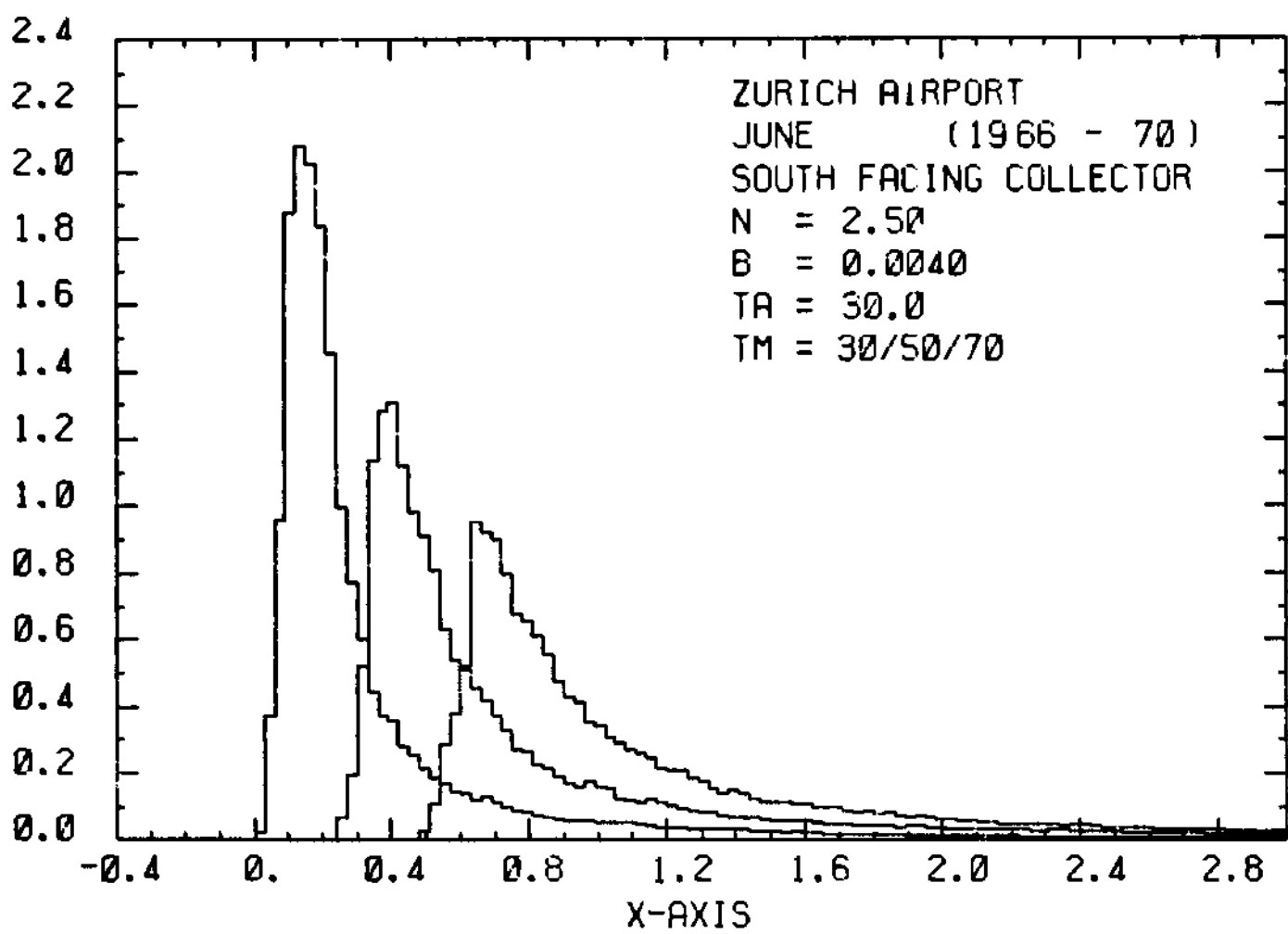
DE / DX
GJ/M2.MONTH

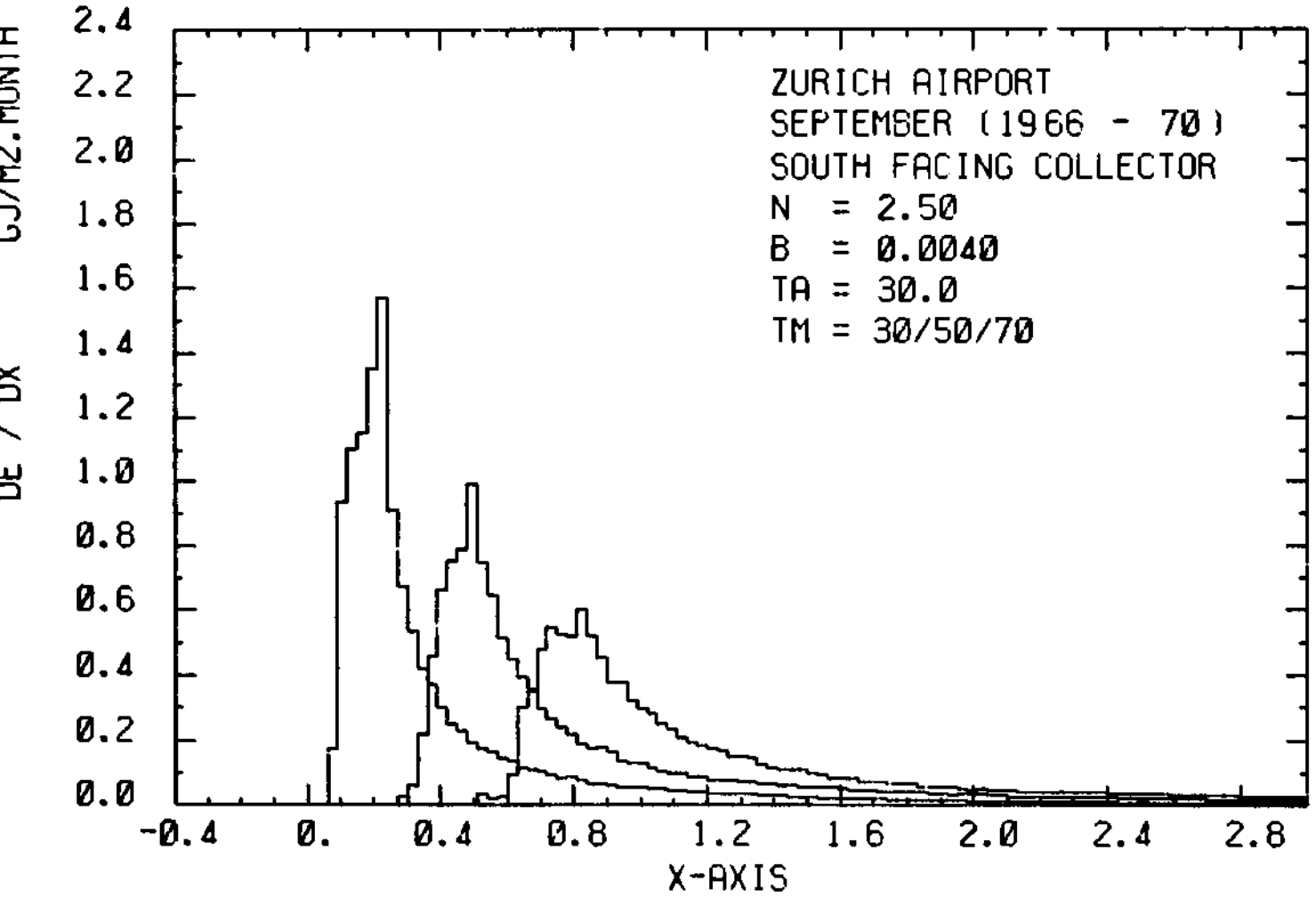


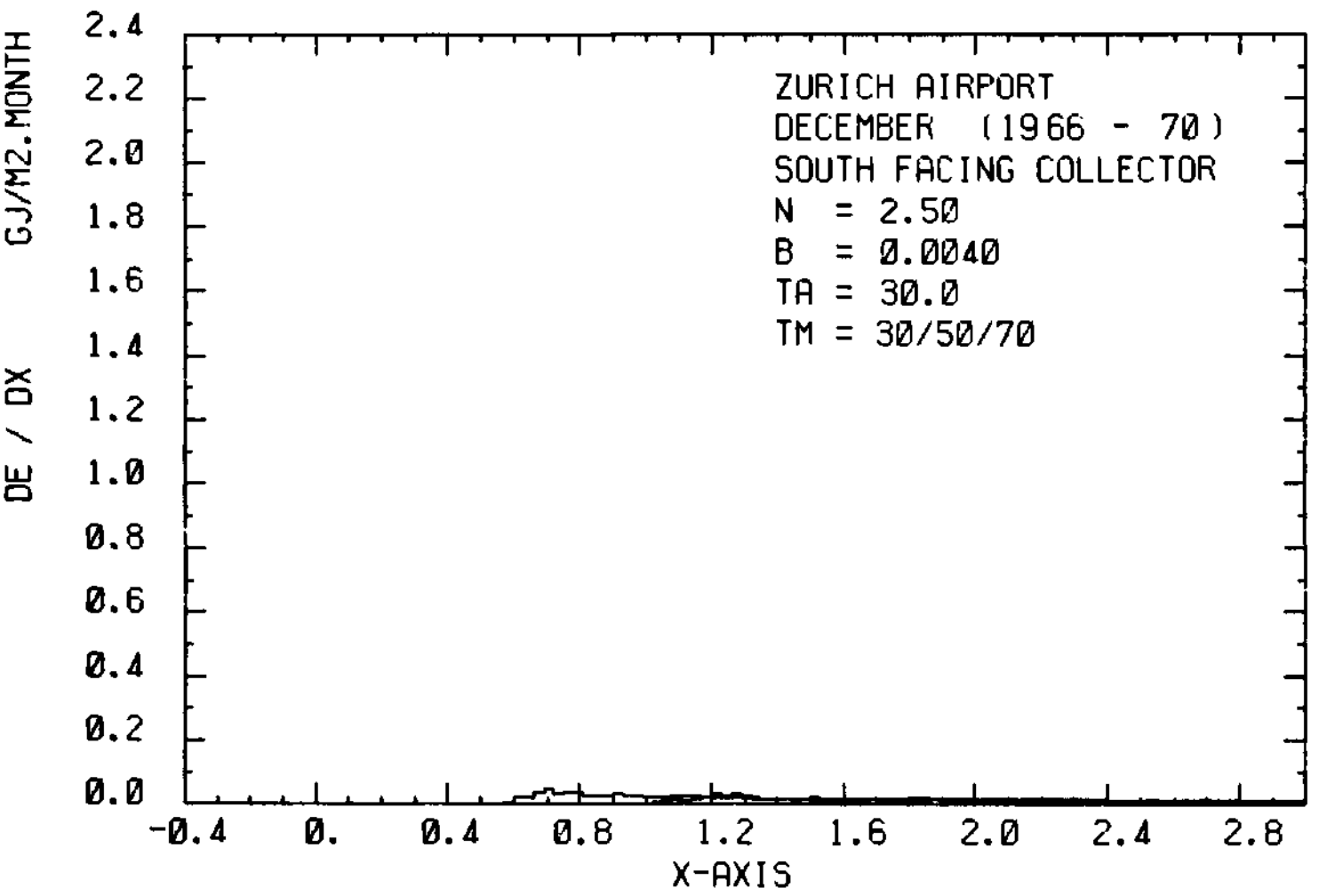


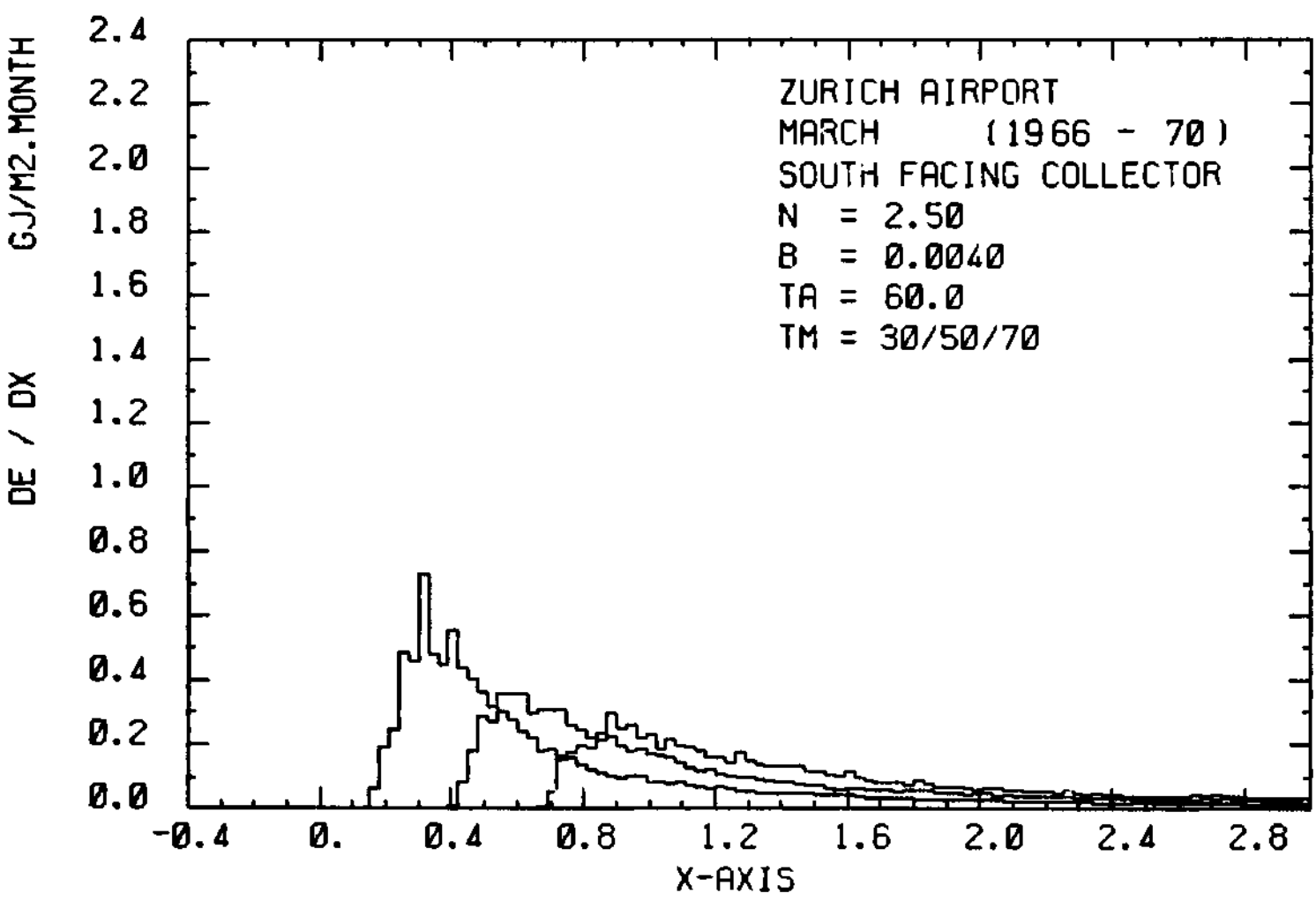


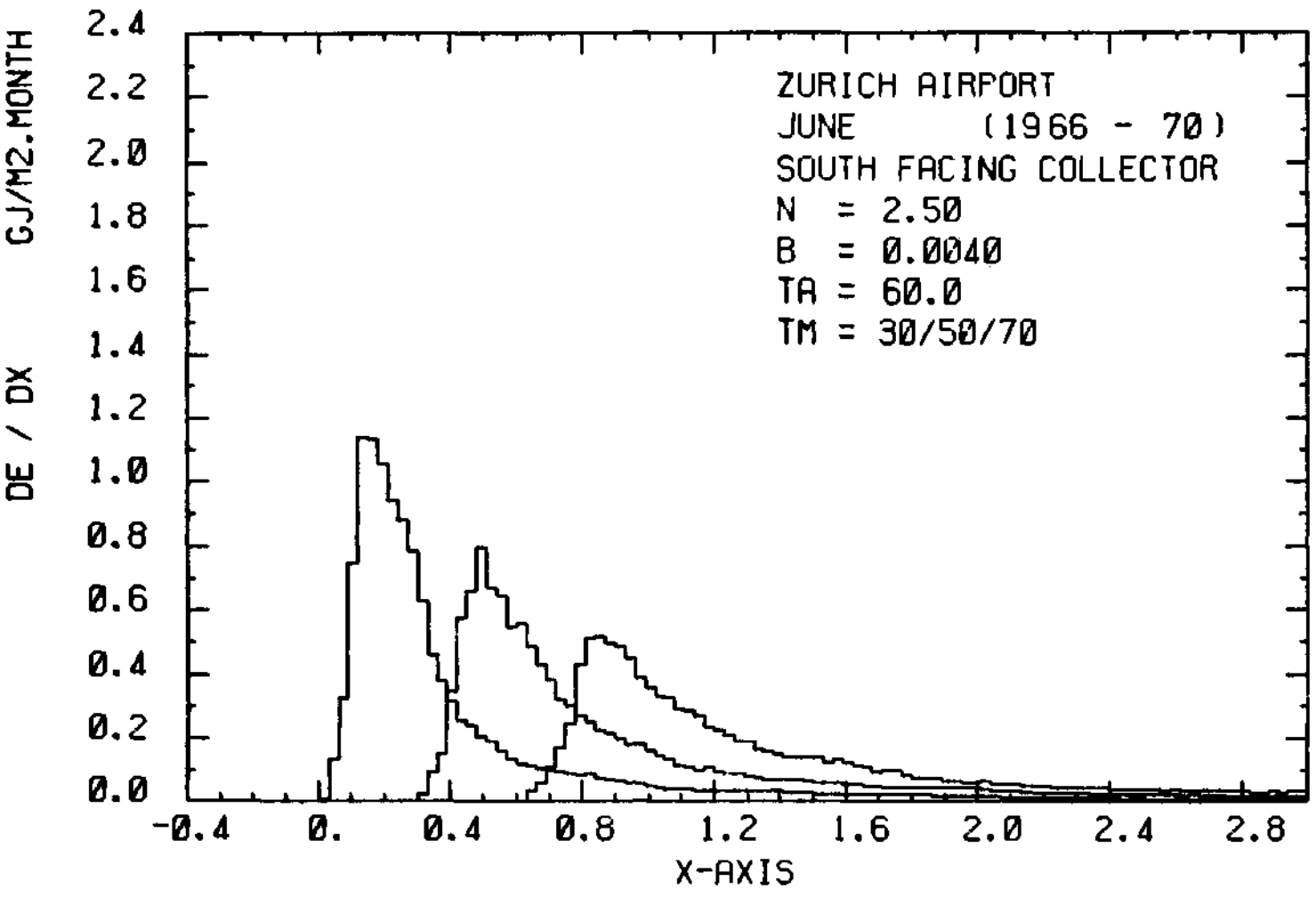
UE / DX
GJ/MZ.MONTH

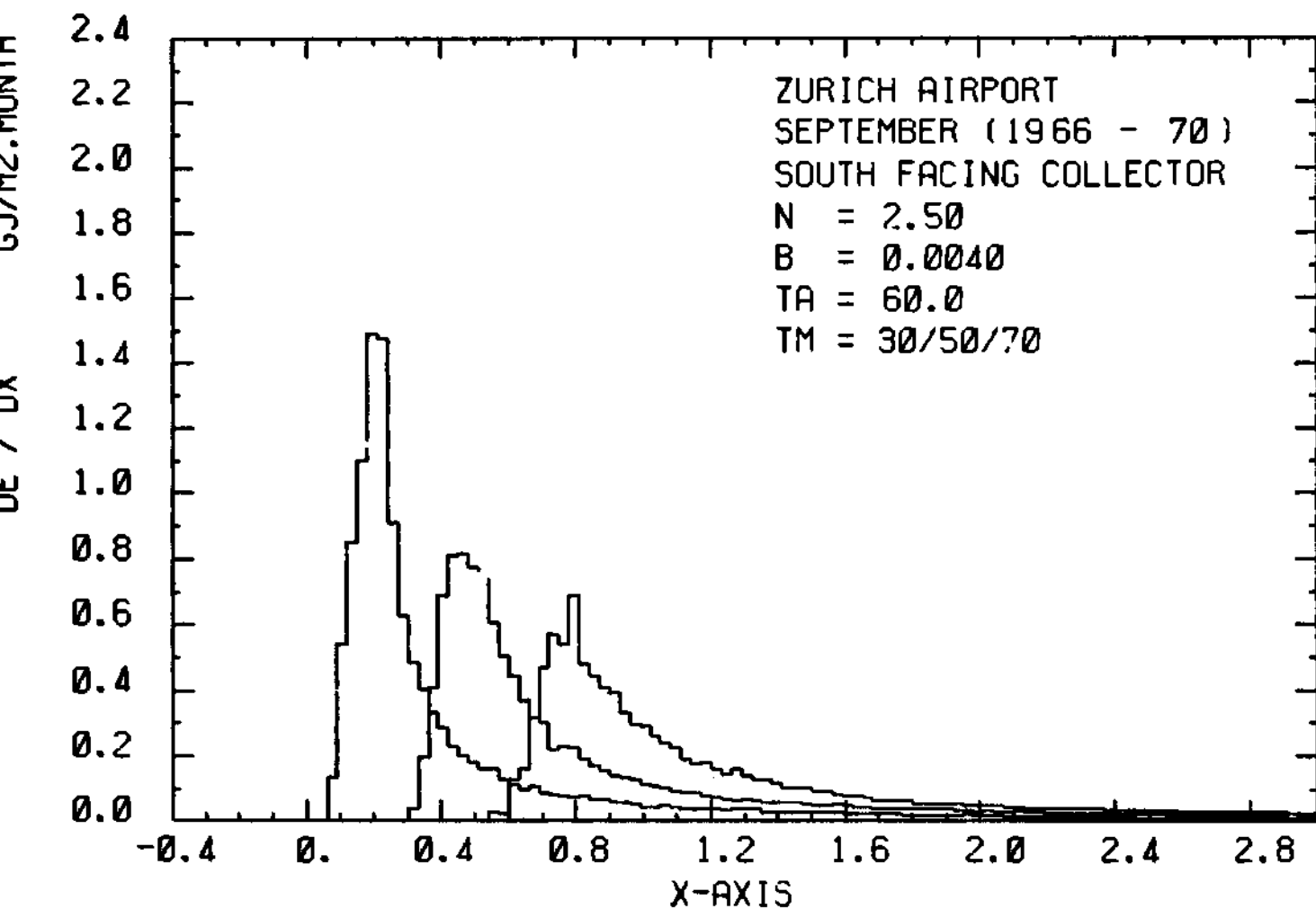




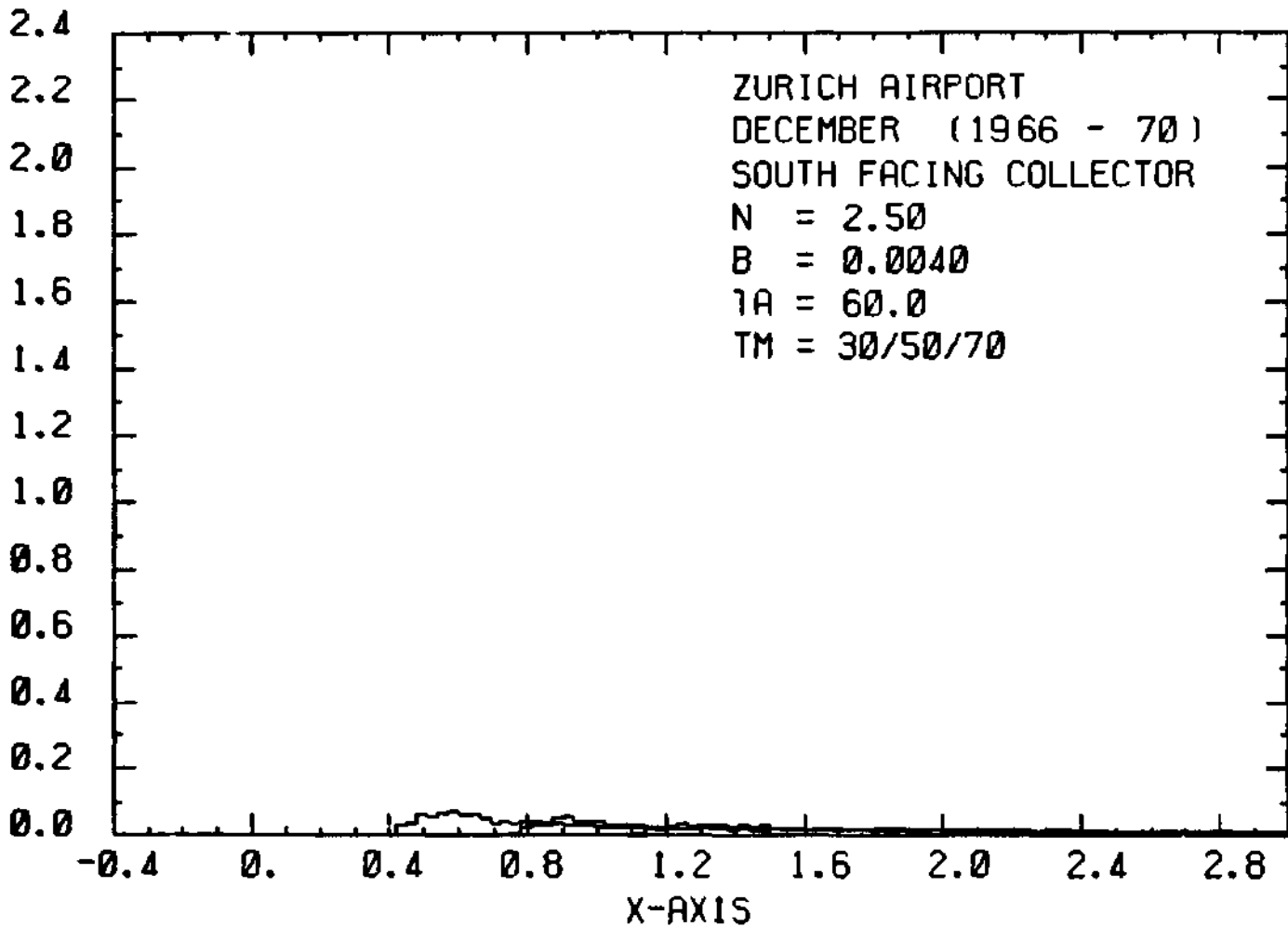








GJ/M2.MONTH
DE / DX



2.2 Mean collector gains

OUTPUT c7A	ZusfICH ALPHABET	1965-70	ALPHA = 30.0	GAMMA = 0.0	MMOL = 3.300					
			OK = .006C	CK = C.CCC	(FLAT-PLATE , SINGLE WINDOW)					
.75	1.00	1.00	1.75	1.00	1.75	2.00	2.25	2.50	2.75	3.00
3	63.5	122.4	6.2	170.5	30.5					
30	31.4	62.7	51.0	27.0	67.3	72.9	74.0	76.0	78.0	
50	6.3	22.1	23.0	33.5	33.5	47.1	51.0	54.7	57.0	
70	.1	2.3	9.4	13.0	17.5	20.7	24.0	27.0	31.0	
9	102.1	123.2	2.9	19.3	20.2					
30	61.7	62.2	73.4	74.4	75.4	77.7	78.0	81.0	82.4	
50	21.0	34.5	43.9	51.4	56.9	61.6	69.3	71.4	73.5	
70	1.9	13.9	20.2	23.0	31.7	41.4	45.1	50.2	54.1	

OUTPUT c7A	ZusfICH ALPHABET	1965-70	ALPHA = 00.0	GAMMA = 0.0	MMOL = 3.300					
			OK = .0060	CK = 0.C000	(FLAT-PLATE , SINGLE WINDOW)					
.75	1.00	1.00	1.75	1.00	1.75	2.00	2.25	2.50	2.75	3.00
3	63.5	122.4	6.2	170.5	120.0					
30	31.7	62.5	33.0	36.7	65.5	67.0	71.0	76.1	76.5	
50	7.3	18.0	24.0	32.0	39.1	47.4	54.4	54.7	57.0	
70	.1	3.4	4.0	15.1	20.5	26.3	30.0	34.2	35.5	
9	102.1	123.7	2.9	19.3	31.5					
30	57.7	63.7	74.0	75.0	76.0	78.2	78.0	81.0	82.4	
50	20.0	33.1	41.0	49.0	54.0	61.0	64.0	69.0	73.0	
70	1.0	13.4	19.5	27.4	31.0	36.0	41.0	46.0	51.0	

ZURICH AIRPORT 1965-70											ALPHA = 30.0				GAMMA = 0.0				MMOL = 2.500			
BK = .0060											CK = 0.000				(FLAT-PLATE , DOUBLE WIN)							
.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75				
3	63.6		122.4		4.0					6	170.5		166.5		3.6							
30	28.7	30.4	47.4	53.7	58.0	62.3	65.4	69.3	71.9	74.1	30	56.1	62.2	66.3	69.2	71.5	73.3	74.7	75.9	77.0		
50	5.9	14.2	22.1	29.2	35.0	40.1	44.5	47.4	51.0	54.8	50	21.6	31.5	38.7	44.1	48.3	51.7	54.5	56.8	58.9		
70	.1	2.4	7.2	12.6	17.9	22.9	27.4	31.5	35.1	38.5	70	3.4	11.7	19.5	26.0	31.3	35.7	39.5	42.6	45.4		
9	162.1		123.5		2.9					12	19.3		26.2		3.2							
30	54.1	67.4	73.2	77.4	80.7	83.3	85.5	87.3	88.8	90.1	30	.4	4.1	7.8	11.5	15.1	18.5	21.9	25.1	28.3		
50	20.3	32.5	41.6	47.5	51.0	54.5	57.2	59.4	61.1	70.5	50	0.0	.0	.5	2.2	4.1	6.2	8.4	10.5	12.5		
70	1.6	9.4	14.1	17.1	19.7	21.9	24.0	25.0	25.6	24.7	70	0.0	0.0	0.0	.0	.3	1.1	2.3	3.5	4.9		

ZURICH AIRPORT 1965-70											ALPHA = 60.0				GAMMA = 0.0				MMOL = 2.500			
BK = .0060											CK = 0.000				(FLAT-PLATE , DOUBLE WIN)							
.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75				
3	63.6		94.5		4.0					6	170.5		126.0		3.6							
30	24.4	40.4	44.2	46.7	49.0	49.3	49.3	49.0	71.5	73.4	30	34.2	39.1	42.4	44.9	46.7	48.3	49.5	50.6	51.5		
50	6.4	19.5	23.2	26.0	27.7	29.5	30.7	31.5	51.5	54.3	50	9.1	16.7	22.2	26.5	29.9	32.7	35.1	37.1	38.7		
70	.1	3.1	4.4	14.1	14.5	16.4	17.4	17.7	36.3	39.7	70	.1	3.1	7.7	12.7	16.2	19.6	22.4	25.1	27.3		
9	162.1		117.7		2.9					12	14.3		31.5		3.2							
30	53.4	61.7	67.0	70.9	74.0	76.5	78.2	79.2	81.7	82.4	30	6.0	12.6	16.7	20.3	24.2	27.9	30.0	31.9	32.8		
50	14.4	21.7	24.7	26.9	28.2	29.7	30.7	31.5	44.2	46.4	50	.1	1.7	3.3	4.1	12.7	15.3	17.7	22.2	25.8		
70	1.4	4.1	14.2	14.7	16.5	17.5	17.7	17.7	47.1	51.7	70	0.0	.0	.3	2.0	4.4	7.0	9.0	12.1	14.5		

3. CONCLUSIONS

As was already pointed out, our method of computing the all day performance of solar collectors provides a good basis for the decision in selecting a collector with an optimal gross heat output/price relation for a given application and a given climate.

Improvements of the method are still possible e.g. by taking into account the heat losses according to equation (30) as well as dynamic effects which may be described by one or two time constants for each type of collector (investigations are in progress), but it should be mentioned that the influence of natural variations of the meteo data is greater than that of those (second-order) effects.

For the layout of solar heating systems or hot water preparation systems, respectively, a cost-benefit optimization of heat-storage capacity and collector-field size is necessary. To this end an estimation of the net heat output is needed. A model for a simple and efficient assessment of cost was proposed in ref. (2). A more detailed description, including layout monograms has been published in ref. (4). Further investigations concerning the verification and validation of this model are in progress.

REFERENCES

- (1) A. Duppenthaler, Die Berechnung des Bruttowärmeertrages von Solarkollektoren, EIR-TM-IN-670 (1977).
- (2) P. Kesselring, The Layout of Solar Hot Water Systems using Statistical Meteorological and Heat Demand Data, Contribution to the ISES 1979 Intern. Congress on Solar Energy, Atlanta, GA, USA.
- (3) A. Heimo and P. Valko, Schweizerische Meteorologische Anstalt (SMA), Zürich, Private Communication.
- (4) P. Kesselring, Die Abschätzung von Wärmenettoerträgen solarer Brauchwasseranlagen im Schweizer Mittelland, Schweizerische Technische Zeitschrift 11, Mai 1979 (Zürich).

APPENDIX I

Constant inlet temperature

From the point of view of solar energy utilization, the gross heat output as a function of the collector-fluid inlet temperature T_i instead of T_m , the mean collector-fluid temperature, is of more interest.

Starting from the expression for the heat flux per m^2 collector area

$$\dot{q} = \eta_o \cdot I_e - a_1 \cdot k \cdot U_o \cdot (T_m - T_a) \quad (2)$$

and the definition of T_m

$$T_m = T_i + \Delta T / 2 \text{ with } \Delta T = T_o - T_i \quad (43)$$

we obtain by inserting

$$\dot{q} = c_p \cdot \rho \cdot \dot{V} \cdot \Delta T / A \quad (44)$$

into (2) the following relationship

$$y \cdot \dot{q} = \eta_o \cdot I_e - a_1 \cdot k \cdot U_o \cdot (T_i - T_a) \quad (45)$$

with
$$y = 1 + \frac{a_1 k U_o A}{2 c_p \rho \dot{V}} \quad (46)$$

where T_o = collector-fluid outlet temperature (°C)

A = collector area (m^2)

c_p = specific heat of collector fluid at constant pressure (Wh/kg°C)

ρ = density of collector fluid (kg/l)

\dot{V} = collector fluid flow rate (l/h).

From eq. (45) and (46) the following procedure can be derived immediately:

If you are interested in the gross heat output of a collector as a function of the collector-fluid inlet temperature, replace the values of T_m by that of T_i , η_o by $\eta_o^* = \eta_o/\gamma$ and a_1 by $a_1^* = a_1/\gamma$. Since for reasonable working conditions, the term $a_1 k U_o A / 2c_p \rho \dot{V}$ amounts to only a few percents, it is sufficient to use the approximation

$$y \approx 1 + \frac{a_1 U_o A}{2c_p \rho \dot{V}} \quad . \quad (47)$$

The conversion of the results given by ETA can thus easily be done.

APPENDIX II

Stagnation temperature

For practical purposes, the relationship between $x_o = \eta_o/a_1$ and the stagnation temperature T_s is of some interest.

According to eq. (2), the condition for stagnation $\dot{q} = 0$ ($\eta = 0$) leads to

$$k \cdot (T_s - T_a) = \frac{\eta_o \cdot I_e}{a_1 \cdot U_o} = x_o \cdot \frac{I_e}{U_o}$$

Inserting (5), we obtain

$$(T_s - T_a) + b(T_s - T_a)^2 = x_o \cdot I_e / U_o$$

with the solution

$$T_s - T_a = \frac{1}{2b} (\sqrt{1 + 4bx_o I_e / U_o} - 1) \quad (48)$$

Assuming $I_{e,max} = 1000 \text{ W/m}^2$, which may be the case with perpendicular incidence ($\theta = 0$) and small fraction of diffuse radiation ($\mu \rightarrow 0$), we calculate the following table for our examples ($b = 0.004 \text{ K}^{-1}$):

x_o	$T_s - T_a$
1.0	77°C
1.5	105
2.0	131
2.5	155
3.0	176

APPENDIX III

List of symbols

A	collector area (m^2)
a_{diff}	incident angle modifier for diffuse radiation (-)
$a_{diff,o}$	a_{diff} related to a horizontal surface (-)
$a(\theta)$	incident angle modifier for direct radiation (-)
a_1	heat loss coefficient ($T_m = \text{const}$) (-)
a_1^*	modified heat loss coefficient ($T_i = \text{const}$) (-)
b	heat loss class parameter (radiation) (K^{-1})
c	heat loss class parameter (convection) (sec/m)
co	concentrating factor of focusing collector (-)
c_p	specific heat of collector fluid at constant pressure (Wh/kg $^{\circ}C$)
d	gradient of diffuse radiation (W/m^2)
D_h	diffuse radiation on horizontal plane (W/m^2)
D_o	isotropic part of diffuse radiation on a tilted surface (W/m^2)
D_{oo}	isotropic part of diffuse radiation on a horizontal surface (W/m^2)
D_a	diffuse radiation on a tilted surface (W/m^2)
$E'(x)$	radiation energy distribution, mean usable radiation density (Wh/ m^2)
f_b	radiation loss factor (-)

$F(x_0)$	gross heat output for a given period ($0 < t \leq t_0$) normalized to $\eta_0 = 1$
g	gradient of global radiation (W/m^2)
$GA = \gamma$	collector orientation (deg) (S.E.: -45, S.: 0, S.W.: +45)
G_h	global radiation power on horizontal plane (W/m^2)
G_α	global radiation on a south-facing, tilted surface ($TA = \alpha$) (W/m^2)
$G_{\alpha,\gamma}$	global radiation on a tilted surface with $TA = \alpha$ and $GA = \gamma$ (W/m^2)
h_s	elevation of the sun (deg)
I	incident radiation power per m^2 collector area (W/m^2)
I_e	effective radiation power per m^2 collector area (incident upon absorber) (W/m^2)
I_v	vertical component of direct radiation (W/m^2)
\ddagger	radiation density per m^2 collector surface coming from the direction to the sun (W/m^2 sterad)
$k(T_m, T_a)$	variation of the thermal loss coefficient a_1 as a function of T_m and T_a (-)
n	parameter of incident angle modifier class, exponent of Widder's formula for $a(\theta)$ (-)
\vec{n}_c	normal unit vector to the collector surface
q	gross heat output in the time interval $0 < t \leq t_0$ (Wh/m^2)

\dot{q}	heat flux per m^2 collector area (W/m^2)
t	time (h)
t_o	duration of period (h)
$TA = \alpha$	collector tilt angle (deg)
T_a	ambient temperature ($^{\circ}C$)
T_i	collector fluid inlet temperature ($^{\circ}C$)
$TM = T_m$	mean collector fluid temperature ($^{\circ}C$)
T_o	collector fluid outlet temperature ($^{\circ}C$)
T_s	stagnation temperature ($^{\circ}C$)
U_o	heat loss normalization factor = $10 W/m^2K$
v_w	velocity of wind (m/sec)
\dot{V}	collector fluid flow rate (l/h)
x	ordering parameter of the MURD-function ()
x_o	x-value corresponding to stagnation point ($\eta(x_o) = 0$)
x_{min}	minimum value of x within the time interval $0 < t \leq t_o$
x_z	zero of x-scale (MURD-tables)
Y	gross heat output conversion factor ($T_m = \text{const} + T_i = \text{const}$) (-)
α	collector tilt angle (deg)
γ	collector orientation (deg) (S.E.: -45, S.: 0, S.W.: +45)

ΔT	temperature difference $T_o - T_i$ (°C)
Δt	time interval (h)
Δx	x-interval
ϵ	emittance of absorber surface (-)
η	collector efficiency (-)
$\bar{\eta}_h$	"mean collector gain" (-)
η_o	maximum collector efficiency, optical efficiency for normal incidence (-)
η_o^*	modified maximum efficiency ($T_i = \text{const}$)
θ	angle of incidence, defined by \vec{j} and \vec{n}_c (deg)
μ	fraction of diffuse radiation on horizontal plane (-)
ξ	transformed ordering parameter = $x - x_z$
ξ_o	= $x_o - x_z$
ξ_{\min}	= $x_{\min} - x_z$
ρ	density of collector fluid (kg/l) = (g/cm ³)
σ	Stefan-Boltzmann constant = $5.67 \cdot 10^{-8} \text{ W/m}^2 \text{ K}^4$

For the symbols of the program-input parameters see page 12 ff.

