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

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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 developped:

- 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 developped by A. Duppenthaler 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 refering to the integrated global radiation power on a horizontal surface. The mean collector gain is a function of the optical efficiency η_o 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)

$$\eta = \eta_o - a_1 \cdot T^* \qquad (1)$$

with $T^* = U_o \cdot (T_m - T_a) / I$

and $U_o = 10 \ W/m^2K$

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:

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

with the effective radiation I_e:

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

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:

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

$$k = 1 + b \cdot (T_m - T_a) \tag{5}$$

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

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

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

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

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

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

The corresponding transformation of the integral (6) yields

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

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

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

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):

Global radiation on a tilted plane	$G_\alpha = D_o + g\cdot\cos\theta$	(11)
Diffuse radiation on a tilted plane	$D_\alpha = D_o + d\cdot\cos\theta$	(12)
Global radiation on horiz. plane (α=0)	$G_h = D_{oo} + g\cdot\sin h_s$	(13)
Diffuse radiation on horiz. plane (α=0)	$D_h = D_{oo} + d\cdot\sin h_s$	(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

$$d = f_\mu\cdot\mu\cdot I_v \qquad (15)$$

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

with $\mu = D_h/G_h$ (17)

$$f_\alpha = \tfrac{1}{2}(1+\cos\alpha) \qquad (18)$$

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

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 $0.15 \leqslant \mu \leqslant 0.99$. The best fits were obtained with the values:

$$f_\mu = 1$$

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

Thus the following relationships were found:

$$d = \mu \cdot (G_h - D_h)/\sin h_s \tag{20}$$

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

$$D_{oo} = \mu \cdot D_h \tag{22}$$

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

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:

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

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

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

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

$$a_{diff} = \frac{\int\limits_{o}^{\pi/2} a(\theta)\cos\theta\sin\theta d\theta - \int\limits_{\pi/2-\alpha}^{\pi/2} \frac{\psi}{\pi}\, a(0)\cos\theta\sin\theta d\theta}{\int\limits_{o}^{\pi/2} \cos\theta\sin\theta d\theta - \int\limits_{\pi/2-\alpha}^{\pi/2} \frac{\psi}{\pi}\cos\theta\sin\theta d\theta} \qquad (26)$$

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:

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

$$a_{diff,o} = 0.51535+0.16668\cdot n\cdot(1-0.10217\cdot n) \qquad (28)$$

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

and α in radians.

<u>Remark</u>: 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

$$D_o = G_\alpha - g\cdot\cos\theta \qquad (29)$$

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 $\eta(\theta)/\eta_o$ for various collector types; the following averages were found:

cover type	η
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

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

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

$$k(T_m,T_a,v_w) = 1+6\cdot\frac{\varepsilon\sigma}{a_1U_o}\cdot f_b\cdot T_a^2\cdot(T_m-T_a)+c\cdot v_w \qquad (30)$$

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).

<u>Remark</u>: 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

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

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

- Calculation of x_i and $I_{e,i}$ for each measuring point (t_i, $T_{a,i}$, $G_{h,i}$, $D_{h,i}$) 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

$$x(t)_i = a_i\cdot t^2+b_i\cdot t+c_i \tag{32}$$

$$I_e(t)_i = A_i\cdot t^2+B_i\cdot t+C_i \tag{33}$$

The coefficients a_i, b_i, c_i, 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 intervall 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):

  $x(t) = x$ with the solutions t_j $(j=1,n)$

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

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

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

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

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

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

  with $\Delta t_j = |t_j^*-t_j|$

1.1.3 Numerical relations used in ETA

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

$$\int_{x_{min}}^{x_o} (1 - \frac{x}{x_o}) \cdot \frac{dE}{dx} \cdot dx = \int_{o}^{x_o} (1 - \frac{x}{x_o}) \cdot \frac{dE}{dx} \cdot dx \qquad (34)$$

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

$$\int_{x_{min}}^{x_o} (1 - \frac{x}{x_o}) \cdot \frac{dE}{dx} \cdot dx = \int_{o}^{\xi_o} (1 - \frac{\xi + x_{min}}{\xi_o + x_{min}}) \cdot \frac{dE}{d\xi} \cdot d\xi \qquad (35)$$

with $\xi = x - x_{min}$ and $\xi_o = x_o - x_{min}$.

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. $F(x_o)$ is then given by

$$F(x_o) = \frac{1}{x_o} \int_{o}^{\xi_o} (\xi - \xi_o) \cdot E'(\xi) d\xi + \sum_{i=1}^{3} \frac{c_i}{i} \cdot \xi_{min}^{i} \qquad (36)$$

with $\xi_o = x_o - x_z$, $\xi_{min} = x_{min} - x_z$, $x_z = -3.0$

and $c_1 = -\xi_o \cdot E'(o)/x_o$

$c_2 = (1-\xi_o/(100+x_z))\cdot E'(o)/x_o$

$c_3 = (1/(100+x_z))\cdot E'(o)/x_o$

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

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 $F(x_o)$ 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 $\Sigma_j \Delta t_j(x)$ 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_z	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·m^2 (1 kcal/h·m^2 = 1.163 W/m^2, this conversion is also done by the program)
- IDI(J)	diffuse radiation power on a horizontal plane in kcal/h·m^2
- IGP(J)	global radiation power on the collector surface (α, γ) in kcal/h·m^2; 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_α 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:

$$\begin{aligned} ITE(J) = IWI(J) &= 99 \\ IGE(J) = IDI(J) &= 9999 \end{aligned} \tag{37}$$

  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 $F(x_o)$ 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_o-values = number of columns per table
- TLO	initial (lowest) value of x_o
- DTL	steps of x_o (DTL = Δx_o)
- 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

$$\int_0^{t_o} G_h \, dt = \Delta t \cdot \sum_i G_{h,i} \tag{38}$$

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

- the monthly (periodic) mean value of

$$\int_0^{t_o} G_{\alpha,\gamma} dt = \Delta t \cdot \sum_i G_{\alpha,\gamma,i} \tag{39}$$

  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:

$$\bar{\eta}_h = F(x_o) \Big/ \int_o^{t_o} G_h \, dt \qquad (40)$$

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

$$q = \eta_o \cdot \bar{\eta}_h \cdot \int_o^{t_o} G_h \, dt \qquad (41)$$

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

$$a_{diff} = 1/co \qquad (42)$$

co 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_o is extended to $x_{o,max} = 4.0$ ($\xi_{o,max} = 8.0$) 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 MURD (INPUT,OUTPUT,TAPE1,TAPE2)
C
C     NEW VERSION OF THE FIX-PROGRAM FOR THE DETERMINATION OF THE MEAN
C     USABLE RADIATION DENSITY FUNCTION  DE/DX(X)  FOR GIVEN METEO-DATA
C     AND COLLECTOR PARAMETERS, WRITTEN BY J.P. WIDDER
C
      REAL NKOL
      DIMENSION ZEITA(3),STA(3),RA(3),IT1(200),IG1(200),ID1(200)
      DIMENSION IW1(200),IP1(200),SDT(200),KPRINT(5),TITLE(3)
      COMMON  ITE(200),IGF(200),IDF(200),IWF(200),ICP(200),DEX(200),
     1        ZEIT(200),R(200),SI(200),ST(200),PHI,FLAZ,DL,IND,INT,
     2        TK,ALPHA,NKOL,GAM,BR,CR
      DATA DR,PARF,MAXC/0.009,100,1347/
C
  500 FORMAT (7I4)
  501 FORMAT (F8.4,F12.4,F8.1,4X,3A8)
  502 FORMAT (F8.4,F12.4,F8.1,2I6)
  510 FORMAT (F5.1,2F8.2,3F8.4)
  900 FORMAT(12H1OUTPUT MURD,11X,3A8)
  901 FORMAT(/50X,*NP =*,I5,11X,*NZ =*,I5,15X,*NN =*,I5,15X,*XZERO=*,
     1F6.3//)
 1001 FORMAT (///////,1X,*YEARS:*,I4,*  -*,I4,5X,*DAYS:*,I5,*  -*,I5, 9X,
     1*TK =*,F6.1,* (CEL)    ALPHA =*,F6.1,* (DEG)     GAMMA =*,F6.1,* (
     2DEG)*//50X,*NKOL =*,F6.2,6X,*BR =*,F7.4,* (1/REL)     CR = *,F6.3,
     3* (SEC/M)*)
 1002 FORMAT (//,1X,*MEAN USABLE RADIATION DENSITY FOR THE WHOLE PERIOD*
     1,10X,*XI FROM *,F6.3,* TO *,F6.3,10X,*( XI = X - XZERO )*/)
 1003 FORMAT (10F13.5)
 1004 FORMAT (//,1X,*USABLE RADIATION DENSITY UP TO THE *,I5,*. DAY*,
     111X,*XI FROM *,F6.3,* TO *,F6.3,10X,*( XI = X - XZERO )*/)
 1005 FORMAT (/,1X,*LOCAL TIME (HRS) *,16F7.1)
 1006 FORMAT (1X,*I            (W/M2) *,15F7.1)
 1007 FORMAT (1X,*R        (REL M2/M) *,16F7.3)
 1008 FORMAT (1X,*HRS             (HRS) *,7X,14F7.2)
C
C     PROGRAM CONTROL PARAMETERS
C
      READ 500,KMAX,KPRINT,IND
C
C     KMAX              NUMBER OF PROGRAM ITERATIONS / PERIODS
C     KPRINT(1) # 0  PRINT SPECIFICATIONS OF PERIOD AND COLLECTOR PARAM.
C     KPRINT(2) # 0  PRINT DE/DX-VALUES OF ONE PERIOD
C     KPRINT(3) # 0  PRINT DE/DX-VALUES OF EACH DAY
C     KPRINT(4) # 0  PRINT DE/DX,R(I),SI(I),HRS OF EACH DAY
C     KPRINT(5) # 0  WRITE DE/DX-VALUES OF ONE PERIOD ON PERMF.(TAPE1)
C     IND # 0        SEE SUBROUTINE WINKEL
C
C     LOCAL PARAMETERS
C
      READ 501,PHI,FLAM,FLAZ,TITLE
      READ 502,ZANF,ZEND,DELT,IA,IE
      DL = FLAM - FLAZ
      DELT = DELT/60.
      NINT = IFIX((ZEND-ZANF)/DELT+0.5)+1
      INT = NINT+1    $   INT = INT+1
      IF(INT.GT.200) STOP*INT.GT.200*
C
C     COLLECTOR PARAMETERS
C
      READ 510,TK,ALPHA,GAM,NKOL,BR,CR
```

```
      TK = TK + 0.01                                                    MURO  61
      ALPA = ALPH  $  GAMA = GAM                                        MURO  62
      BO = ATAN(1.)/45.                                                 MURO  63
      ALPH = ALPH*BO  $  GAM = GAM*BO                                   MURO  64
      PRINT 930, TITLE                                                  MURO  65
C                                                                       MURO  66
C     LOOP OF PERIODS                                                   MURO  67
C                                                                       MURO  68
      DO 999 K = 1,NMAX                                                 MURO  69
      KL = 0                                                            MURO  70
C                                                                       MURO  71
C     DEFINITION OF PERIOD                                              MURO  72
C                                                                       MURO  73
      READ 500,JAA,JAE,NA,NE                                            MURO  74
      IF(JAA.LT.14) STOP*JAA TOO SMALL*                                 MURO  75
      IF(JAE.GT.IE) STOP*JAE TOO LARGE*                                 MURO  76
      IF (KPRINT(1).EQ.0.0) GO TO 9001                                  MURO  77
      PRINT 1001,JAA,JAE,NA,NE,TK,ALPA,GAMA,NKOL,BK,CK                  MURO  78
 9001 CONTINUE                                                          MURO  79
C                                                                       MURO  80
C     INITIALIZATION                                                    MURO  81
C                                                                       MURO  82
      IF(NKOL.LT.1.) MAX = MAXC                                         MURO  83
      IF(NKOL.GT.1.) MAX = MAXF                                         MURO  84
      XIM = MAX*DX                                                      MURO  85
      XNULL = 0.0                                                       MURO  86
  800 REWIND 2                                                          MURO  87
      KL = KL+1                                                         MURO  88
      IF(KL.EQ.1) GOTO 810                                              MURO  89
      IF(PN.EQ.0.0.AND.KZ.EQ.0) GOTO 810                                MURO  90
      MAX = 2*MAX                                                       MURO  91
      XIM = 2.*XIM                                                      MURO  92
      XNULL = -XIM/2.                                                   MURO  93
  810 KP = KZ = KN = 0                                                  MURO  94
      XMIN = XIM                                                        MURO  95
      DUM = 0.                                                          MURO  96
      SI(1) = SI(INT) = 0.0                                             MURO  97
      DO 30 J = 1,INT                                                   MURO  98
   30 ZEIT(J) = ZANF + DELT*(J-2)                                       MURO  99
      DO 35 L = 1,MAX                                                   MURO 100
   35 DE(L) = 0.0                                                       MURO 101
      SIS = SIG = 0.0                                                   MURO 102
      JWIS = 0                                                          MURO 103
      DO 36 J = 2,INT                                                   MURO 104
      ITS(J) = 0                                                        MURO 105
      IWS(J) = 0                                                        MURO 106
      IPS(J) = 0                                                        MURO 107
      IGS(J) = 0                                                        MURO 108
   36 IDS(J) = 0                                                        MURO 109
      F = 0                                                             MURO 110
C                                                                       MURO 111
C     MAIN PROGRAM                                                      MURO 112
C                                                                       MURO 113
      DO 10 JA = JAA,JAE                                                MURO 114
      DO 20 N = 1,356                                                   MURO 115
C                                                                       MURO 116
C     INPUT OF LOCAL METEO DATA  (TAPE2)                                MURO 117
C                                                                       MURO 118
C     (IF THE GLOBAL RADIATION IN THE COLLECTOR PLANE IS KNOWN          MURO 119
C      OMIT CARDS 125 AND 126 AND REPLACE CARD 129 BY                   MURO 120
```

```
C      1,(ID1(J),J=2,INT),(IGP(J),J=2,IPT')
C
      READ (2) JA1,N1,((ITE(J),J=2,INT),(IWE(J),J=2,INT),(IGE(J),J=2,INT)
     1,(IDI(J),J=2,INT)
      DO 37 J=2,INT
   37 IGP(J) = -9999
      IF (JA.LT.JAA) GO TO 20
      IF (N.LT.NA.OR.N.GT.NE) GO TO 20
C
C      DATA CONTROL
C
      IGES = IDIS = 0
      DO 25 J = 2,INT
      IGES = IGES+IGE(J)
   25 IDIS = IDIS+IDI(J)
      IF (IGES.LT.9999.AND.IDIS.LT.9999) GO TO 27
      IF (N1.NE.63) GO TO 29
      IF ((JA1.AND.3).NE.0) GO TO 20
   29 DO 26 J = 2,INT
      ITE(J) = IT1(J)
      IWE(J) = IW1(J)
      IGP(J) = IP1(J)
      IGE(J) = IG1(J)
   26 IDI(J) = ID1(J)
   27 M = M+1
      DO 28 J = 2,INT
      IT1(J) = (IT1(J)*(M-1)+ITE(J))/M
      IW1(J) = (IW1(J)*(M-1)+IWE(J))/M
      IP1(J) = (IP1(J)*(M-1)+IGP(J))/M
      IG1(J) = (IG1(J)*(M-1)+IGE(J))/M
   28 ID1(J) = (ID1(J)*(M-1)+IDI(J))/M
C
      CALL XISIT
C
      DO 400 J=2,INT
      IF(X(J).GT.0.) KP=KP+1
      IF(X(J).LT.0.) KN=KN+1
      IF(X(J).EQ.0.) KZ = KZ+1
      IF(X(J).LT.XMIN) XMIN = X(J)
  400 CONTINUE
      IF(KL.EQ.1) GOTO 20
      S1 = X(3)-X(2)
      IF(S1.GT.0.) X(1) = -10.0
      IF(S1.LE.0.) X(1) =  10.0
      S16 = X(INT) - X(INT-1)
      IF(S16.LT.0.) X(INT) = -10.0
      IF(S16.GE.0.) X(INT) =  10.0
C
C      CALCULATION OF  DE/DX (X)  =  SUM(S1(T)*DT/DX)
C
      DO 40 J = 2,INT
      SIG = SIG + DELT*FLOAT(IGE(J))*1.E3
      IWIS = IWIS+IW1(J)
      SIS = SIS + DELT*SY(J)
      SDT(J) = 0.0
      ZEITA(1) = ZEIT(J-1) + 0.5*DELT
      ZEITA(2) = ZEIT(J)
      ZEITA(3) = ZEIT(J+1) - 0.5*DELT
      XA(1) = (X(J-1)+X(J))/2. - XNULL
      XA(2) = X(J) - XNULL
```

```
      XA(3) = (X(J+1)+X(J))/2. - XNULL
      SIA(1) = (SI(J-1)+SI(J))/2.
      SIA(2) = SI(J)
      SIA(3) = (SI(J+1)+SI(J))/2.
      EPS = 0.2
      U = ABS(XA(1)-XA(2))
      V = ABS(XA(2)-XA(3))
      IF ((0.2*U).GT.V.OR.(0.2*V).GT.U) EPS = 0.3
      CALL PARABE (ZEITA,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.OR.(0.2*V).GT.U) EPS = 0.3
      CALL PARABE (ZEITA,SIA,A2,B2,C2,DUM,DUM,EPS)
C
C     IF  X(T) = CONSTANT      /      A1 = B1 = 0
C
      IF (A1.NE.0.0.OR.B1.NE.0.0) GO TO 50
      L = IFIX(C1/DX) + 1
      IF (L.GT.MAX.OR.L.LT.1) GO TO 40
      DTL = DELT
      SIL = A2*ZEIT(J)*ZEIT(J)+B2*ZEIT(J)+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
      GO TO 40
C
C     IF  X(T)  IS A LINEAR FUNCTION      /      A1 = 0
C
   50 IF (A1.NE.0.) GO TO 55
      DO 65 L = 1,MAX
      XL = DX*FLOAT(L-1)
      ZU = ZEIT(J)-0.5*DELT
      ZO = ZEIT(J)+0.5*DELT
      ZEIT1 = (XL-C1)/B1
      IF (ZEIT1.LE.ZU.OR.ZEIT1.GT.ZO) GO TO 65
      SIL = (XL-C1)/B1
      SIL = A2*SIL*SIL+B2*SIL+C2
      DTL = ABS(DX/B1)
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
   65 CONTINUE
      GO TO 40
C
C     IF  X(T)  IS A PARABOLIC FUNCTION      /      A1 ≠ 0 , B1 ≠ 0
C
   55 DO 60 L = 1,MAX
      XL = DX*FLOAT(L-1)
      WURZ = B1*B1-4.*A1*(C1-XL)
      W = B1*B1-4.*A1*(C1-XL-DX)
      ZU = ZEIT(J)-0.5*DELT
      ZO = ZEIT(J)+0.5*DELT
      IF (WURZ.LT.0.0.AND.W.LT.0.0) GO TO 60
C
C     IF X(T) SHOWS A MAXIMUM OR A MINIMUM WITHIN THE INTERVAL DX
C
      IF (WURZ.GE.0.0.OR.W.LT.0.0) GO TO 100
      W = SQRT(W)
      ZEIT1 = (-B1+W)/(2.*A1)
      ZEIT2 = (-B1-W)/(2.*A1)
      GO TO 101
```

```
  100 IF (WURZ.GE.0.0.AND.W.GE.0.0) GO TO 105
      WURZ = SQRT(WURZ)
      ZEIT1 = (-B1+WURZ)/(2.*A1)
      ZEIT2 = (-B1-WURZ)/(2.*A1)
  101 Z1 = ZEIT1
      Z2 = ZEIT2
      IF (ZEIT1.LT.ZEIT2) GO TO 102
      Z1 = ZEIT2
      Z2 = ZEIT1
  102 IF ((Z1.LT.ZU.OR.Z1.GT.ZO).AND.(Z2.LT.ZU.OR.Z2.GT.ZO)) GO TO 60
      IF (Z1.GE.ZU.AND.Z2.LE.ZO) GO TO 103
      IF (Z1.GE.ZU) GO TO 104
      DTL = Z2-ZU
      SIL = A2*Z2*Z2+B2*Z2+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
      GO TO 60
  104 DTL = ZO-Z1
      SIL = A2*Z1*Z1+B2*Z1+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
      GO TO 60
  103 DTL = Z2-Z1
      ZM = (Z2+Z1)/2.
      SIL = A2*ZM*ZM+B2*ZM+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
      GO TO 60
C
C     IF W(T) INTERSECTS THE INTERVAL DX
C
  105 WURZ = SQRT(WURZ)
      ZEIT1 = (-B1+WURZ)/(2.*A1)
      ZEIT2 = (-B1-WURZ)/(2.*A1)
      Z1 = ZEIT1
      Z2 = ZEIT2
      IF (ZEIT1.LT.ZEIT2) GO TO 106
      Z1 = ZEIT2
      Z2 = ZEIT1
  106 W = SQRT(W)
      ZEITV1 = (-B1+W)/(2.*A1)
      ZEITV2 = (-B1-W)/(2.*A1)
      ZV1 = ZEITV1
      ZV2 = ZEITV2
      IF (ZEITV1.LT.ZEITV2) GO TO 70
      ZV1 = ZEITV2
      ZV2 = ZEITV1
   70 IF ((Z1.LT.ZU.OR.Z1.GT.ZO).AND.(ZV1.LT.ZU.OR.ZV1.GT.ZO)) GO TO 80
      DTL = ABS(ZV1-Z1)
      IF (Z1.GT.ZO) DTL = ZO-ZV1
      IF (ZV1.GT.ZO) DTL = ZO-Z1
      IF (Z1.LT.ZU) DTL = ZV1-ZU
      IF (ZV1.LT.ZU) DTL = Z1-ZU
      SIL = A2*Z1*Z1+B2*Z1+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
   80 IF ((Z2.LT.ZU.OR.Z2.GT.ZO).AND.(ZV2.LT.ZU.OR.ZV2.GT.ZO)) GO TO 60
      DTL = ABS(ZV2-Z2)
      IF (Z2.GT.ZO) DTL = ZO-ZV2
      IF (ZV2.GT.ZO) DTL = ZO-Z2
```

```
      IF (Z2.LT.ZU) DTL = ZV2-ZU
      IF (ZV2.LT.ZU) DTL = Z2-ZU
      SIL = A2*Z2*Z2+B2*Z2+C2
      DEX(L) = DEX(L)+SIL*DTL/DX
      SDT(J) = SDT(J)+DTL
   60 CONTINUE
      IF (SDT(J).NE.0.0)GO TO 40
      XL = A1*ZL(T(J))**2+B1*ZL(T(J))+C1
      L = IFIX(XL/DX) + 1
      IF (L.GT.MAX.OR.L.LT.1) GO TO 40
      SDT(J) = DELT
      DEX(L) = DEX(L) + SI(J)*DELT/DX
   40 CONTINUE
C
C     OUTPUT SPECIFICATION
C
      IF (NPRINT(3).EQ.0) GO TO 9003
      PRINT 1004,M,DX,XIN
      PRINT 1003,(DEX(L),L=1,MAX)
 9003 CONTINUE
      IF (NPRINT(4).EQ.0) GO TO 9004
      PRINT 1004,M,DX,XIN
      PRINT 1003,(DEX(L),L=1,MAX)
      PRINT 1005,ZETT
      PRINT 1006,SI
      PRINT 1007,T
      PRINT 1008,(SDT(J),J=2,IRI)
 9004 CONTINUE
   20 CONTINUE
   10 CONTINUE
      IF(NL.EQ.1) GOTO 800
C
      IF (NPRINT(2).EQ.0) GO TO 9002
      PRINT 901,SP,R2,KN,XNULL
      PRINT 1002,DX,XIN
      PRINT 1003,(DEX(L),L=1,MAX)
 9002 CONTINUE
      IF (NPRINT(5).EQ.0) GO TO 9005
C
C     DATA ON PERMANENT FILE  (TAPE1)
C
      WRITE (1) JAA,JAE,NA,NE,TH,ALPA,JAMA,NKOL,BK,CK,MAX,DX,XNULL,XMIN,
     1NINT,SIS,SIG,IWIS,(DEX(I),I=1,MAX)
 9005 CONTINUE
  999 CONTINUE
      STOP
      END
```

```
      SUBROUTINE  PARABE(X,Y,A,B,C,XC,YC,EPS)
C
C     DETERMINATION OF THE INTERPOLATION FUNCTIONS FOR X(T) AND Y(T)
C     F(T) = A*T**2 + B*T + C
C
      DIMENSION X(3),Y(3)
      X1 = X(1)   $   Y1 = Y(1)
      X2 = X(2)   $   Y2 = Y(2)
      X3 = X(3)   $   Y3 = Y(3)
      Z = (X3-X2)*(X3-X1)*(X2-X1)
      IF( ABS(Z) - EPS) 50,50,10
   10 CONTINUE
      A = ((X2-X1)*(Y3-Y2)-(X3-X2)*(Y2-Y1))/Z
      B = (Y3-Y1)/(X3-X1)-A*(X1+X3)
      C = Y2-X2*(A*X2+B)
      RETURN
   50 A   = 0.0
      B = (Y3-Y1)/(X3-X1)
      C = Y3-B*X3
      RETURN
      END
```

```
      SUBROUTINE XISIT
C
C     CALCULATION OF THE ORDERING PARAMETER X(T),
C     THE INSOLATION ON COLLECTOR SURFACE SY(T) AND
C     THE INCIDENT RADIATION ON THE ABSORBER SI(T)
C
C     NKOL.GT.1 : EXPONENT OF INCIDENT ANGLE MODIFIER FOR FLAT-PLATE
C                 COLLECTORS WITH ONE OR TWO COVER WINDOWS
C
C     NKOL.LT.1 : DIFFUSE RADIATION EFFICIENCY OF CONCENTRATING,
C                 EAST-WEST TRACKING COLLECTORS WITHOUT COVER WINDOW
C                 ( NKOL = ADIF )
C
      REAL NKOL
      COMMON  ITE(200),IGE(200),IDI(200),IWI(200),IGP(200),DEX(200),
     1        ZEIT(200),X(200),SI(200),SY(200),FI,FLAZ,DL,IND,INT,
     2        TK,ALPH,N1,NKOL,GAM,RK,CK
C
      IF(NKOL.GT.1) GOTO 5
      ADIFO = NKOL   $   CON = 0.0   $   GOTO 6
    5 ADIFO = 0.51535+0.16560*NKOL*(1.-0.10217*NKOL)
      CON = 0.056672-0.015167*NKOL*(1.-0.06660*NKOL)
    6 ADIF = ADIFO*(1.+CON*ALPH*(2.467-ALPH**2))
      DO 10 J = 2,INT
      CALL WINKEL (ZEIT(J),N1,IND,FI,DL,FLAZ,H,A)
      C = SIN(H)*COS(ALPH)+COS(H)*SIN(ALPH)*COS(A-GAM)
      IF (H.LT.0.05.OR.C.LT.0.) C = 0.
      D = SIN(ALPH)*SIN(H)-COS(ALPH)*COS(H)*COS(A-GAM)
      IF(ABS(D).GT.1.) D=1.0
      D = SQRT(1.-D*D)
      IF(H.LT.0.05.OR.D.LT.0.) D=0.0
      IF (IGE(J).EQ.0) GO TO 30
      U = FLOAT(IDI(J))/FLOAT(IGE(J))
      DIR = FLOAT(IGE(J))*(1.-U*U)/SIN(H)
      IF(IGP(J).LT.0) GOTO 15
      DIF = IGP(J) - DIR*C   $   GO TO 16
   15 V = (1.-COS(ALPH))/2.
      DIF = FLOAT(IDI(J))*U*(1.-U*V)
   16 SY(J) = (DIR*C + DIF)*1.163
      PHI = ACOS(C)
      IF(NKOL.GT.1.) DIR = DIR*C*APHI(PHI,NKOL)
      IF(NKOL.LT.1.) DIR = DIR*D
      IF(C.EQ.0.) DIR = 0.0
      DIF = DIF*ADIF
      SI(J) = (DIR + DIF)*1.163
      IF(SI(J)) 30,30,20
   20 DET = TK-FLOAT(ITE(J))
      VW = 0.51444*FLOAT(IWI(J))
      X(J) = DET*(1.+RK*DET+CK*VW)/SI(J)
      IF(ABS(X(J)).GT.10.) GOTO 30
      GO TO 10
   30 VORZ = TK-FLOAT(ITE(J))
      IF(VORZ.EQ.0.) VORZ = 1.
      VORZ = VORZ/ABS(VORZ)
      X(J) = 10.0*VORZ
      SI(J) = 0.0
      IF(IGE(J).EQ.0) SY(J)=0.0
   10 CONTINUE
      RETURN
      END
```

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

```
      SUBROUTINE WINKEL (ZEITW,NTAG,INDEX,FI,DL,FLAZ,SH,SA)
C
C     CALCULATION OF ELEVATION AND AZIMUTH OF THE SUN
C     AS A FUNCTION OF TIME OF DAY
C
C     IF TIME IS GIVEN IN ZONAL TIME (CLOCK)   :  INDEX = 0
C     IF TIME IS GIVEN IN REAL LOCAL TIME      :  INDEX = 1
C
      PI=3.14159265   $   BO = 2.*PI/365.2422
      EPS = 0.40914   $   EKZ = 0.016754
      PHI = FI*PI/180.
      FK = 81.10-FLAZ/360.
      EM = FLOAT(NTAG)-1.95+FLAZ/360.
      XLM = (FLOAT(NTAG)-FK)*BO
      XL = XLM + 2.*EKZ*SIN(EM*BO)
      DE = SIN(XL)*SIN(EPS)    $    DE = ASIN(DE)
      AL = COS(XL)/COS(DE)    $    AL = ACOS(AL)
      AL = SIGN(AL,XL)
      IF(XL.GE.PI) AL = 2.*PI-AL
      ZGL = (XLM-AL)
      ZKO = 12.*ZGL/PI - DL/15.
      IF(INDEX.EQ.1) ZKO = 0.0
      T = (ZEITW+ZKO-12.)*PI/12.
      SH = SIN(PHI)*SIN(DE)+COS(PHI)*COS(DE)*COS(T)
      SH = ASIN(SH)
      SA = (SIN(PHI)*COS(DE)*COS(T)-COS(PHI)*SIN(DE))/COS(SH)
      SA = ACOS(SA)    $    SA = SIGN(SA,T)
      RETURN
      END
```

```
      PROGRAM ETA (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3,TAPE4,TAPE5,TAPE6,
     +TAPE7,TAPE8,TAPE9)
C
C     PROGRAM FOR THE CALCULATION OF MEAN COLLECTOR GAINS BY MEANS OF
C     THE  DE/DX-VALUES PROVIDED BY RUHD
C
      REAL NKOL, KR
      COMMON DEX(269), AO, NG, XNULL, DX
      DIMENSION ET(12,4,13),TL(10),PI(9),X(12),Y(12),KTEXT(3,3)
      DIMENSION C(3),Z(12),TITLE(3,3),TI(12)
      EXTERNAL FUNCT
      DATA (KTEXT(I,1),I=1,3) /30H( FLAT-PLATE , SINGLE WINDOW )/
      DATA (KTEXT(I,2),I=1,3) /30H( FLAT-PLATE , DOUBLE WINDOW )/
      DATA (KTEXT(I,3),I=1,3) /30H(CONCENTRATING,WITHOUT WINDOW)/
C
  500 FORMAT(3A8,4X,3A8,4X,3A8)
 1000 FORMAT(I2,F10.2,F8.2,4I4)
 1001 FORMAT(11H1OUTPUT ETA,11X,3A8,10X,7HALPHA =,F5.1,10X,7HGAMMA =,F6.
     +1,10X,8HNKOL  =,F6.3//56X,5HBR  =,F7.4,10X,7HCR    =,F6.3,10X,3A10)
 1002 FORMAT(//////4X,10F6.2,7X,10F6.2)
 1003 FORMAT(//1X,I3,3F12.1)
 1004 FORMAT(1H+,69X,I2,3F12.3/)
 1005 FORMAT(1X,I3,10F6.1)
 1006 FORMAT(1H+,60X,I2,10F6.1)
 1007 FORMAT(1X)
C
      READ 500,((TITLE(I,J),I=1,3),J=1,3)
  200 READ 1000,NTL,TLO,DTL,MC,LM,LMA,LMB
      IF(NTL.EQ.0) STOP
      AO = 1.0
      DO 10 N =1,NTL
   10 TL(N) = TLO + DTL*FLOAT(N-1)
      DO 100 L = 1,LM
      REWIND L
      DO 20 J = 1,MC
      READ (L) JAA,JAE,MA,ME,TR,ALPH,GAMA,NKOL,BR,CR,MAX,DX,XNULL,XMIN,
     1NINT,SIS,SIG,INIS,(DEX(I),I=1,MAX)
      XIM = MAX*DX
      XI = XMIN - XNULL
      MINI = IFIX(XI/DX)
      IF(MINI.LT.0) MINI=0
      MIX = MAX-MINI   $   XMI = MINI*DX
      IF(NKOL.GT.9.) K = 1
      IF(NKOL.LT.9.) K = 2
      IF(NKOL.LT.1.) K = 3
      PI(J) = ME/30
      AJA = FLOAT(JAE-JAA+1)
      AD1 = FLOAT(ME-MA+1)
      TRI(L) = TR
      NT = L  $  M = 1
      IF(L.GT.LMA) NT=L-LMA
      IF(L.GT.LMA) M = 2
      IF(L.GT.LMB) NT=L-LMB
      IF(L.GT.LMB) M = 3
      X(J) = (SIG/AJA)/1000.
      Y(J) = (SIS/AJA)/1000.
      Z(J) = 0.01444*INIS/(NINT*AJA*AD1)
      DO 30 I=1,MAX
   30 DEX(I) =DEX(I)/AJA
      DO 40 N = 1,NTL
```

```
      IF((TL(M)/10.01).GT.(XIM+XNULL)) STOP*X0 TOO LARGE*               ETA   61
      X0 = 10./TL(M)                                                     ETA   62
      DEX0 = DEX(1)/(1.+0.5*DB/(10.+XNULL))                              ETA   63
      IF(XI.GT.0.) DEX0 = 0.0                                            ETA   64
      CA = X0*(XNULL-A)   $   CB = X0                                    ETA   65
      CC = DEX0   $   CD = CC/(10.+XNULL)                                ETA   66
      C(1) = CA*CC                                                       ETA   67
      C(2) = CB*CC + CA*CD                                               ETA   68
      C(3) = CB*CD                                                       ETA   69
      ZW = 0.0                                                           ETA   70
      DO 35 I=1,3                                                        ETA   71
   35 ZW = ZW + C(I)*XI**I/I                                             ETA   72
   40 ET(J,NT,N) = (SIMPSE(PIX,XNI,XIM,FUNCT1)+ZW)/(10.+X(J))            ETA   73
   20 CONTINUE                                                           ETA   74
      IF(L.NE.LMA.AND.L.NE.LMB.AND.L.NE.LM) GOTO 100                     ETA   75
      PRINT 1001,(TITLE(I,M),I=1,3),ALPH,GAMA,XNOL,BK,CK,(KTEXT(I,K),    ETA   76
     1I=1,3)                                                             ETA   77
      PRINT 1002,(TL(N),N=1,NTL),(TL(N),N=1,NTL)                         ETA   78
      DO 50 J=1,MD,2                                                     ETA   79
      DO 50 NI=1,NT                                                      ETA   80
      ITK = IFIX(TK1(NI)+0.5)                                            ETA   81
      IF(NI.NE.1) GOTO 45                                                ETA   82
      PRINT 1003,MI(J),X(J),Y(J),Z(J)                                    ETA   83
      IF(J.EQ.MD) GOTO 45                                                ETA   84
      PRINT 1004,MI(J+1),X(J+1),Y(J+1),Z(J+1)                            ETA   85
   45 IF(J.EQ.MD.AND.NI.EQ.1) PRINT 1007                                 ETA   86
      PRINT 1005,ITK,(ET(J,NI,N),N=1,NTL)                                ETA   87
      IF(J.EQ.MD) GOTO 50                                                ETA   88
      PRINT 1006,ITK,(ET(J+1,NI,N),N=1,NTL)                              ETA   89
   50 CONTINUE                                                           ETA   90
  100 CONTINUE                                                           ETA   91
      GO TO 200                                                          ETA   92
      END                                                                ETA   93
```

```
      FUNCTION SIMPSE(N,X0,X1,F)
      IF(2*(N/2)-N) 5,10,5
    5 N    = N+1
   10 H    =(X1-X0)/N
      SUM =(F(X0)+F(X1))/2.
      N1  = N-1
      DO 15 I=1,N1,2
      XI1 = X0 + H*I
      XI2 = XI1+ H
   15 SUM = SUM + 2.*F(XI1) + F(XI2)
      SIMPSE= 2.*H*SUM/3.0
      RETURN
      END
```

```
      FUNCTION FUNCT1(X)
      REAL K0
      COMMON DEX(260),A0,K0,X0,DX
      L = IFIX(X/DX+0.5)
      IF(L.EQ.0) GOTO 10
      F = DEX(L)*(A0-K0*(X+X0))
      IF (F.LT.0.0) GOTO 10
      FUNCT1 = F
      RETURN
   10 FUNCT1 = 0.0
      RETURN
      END
```

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:

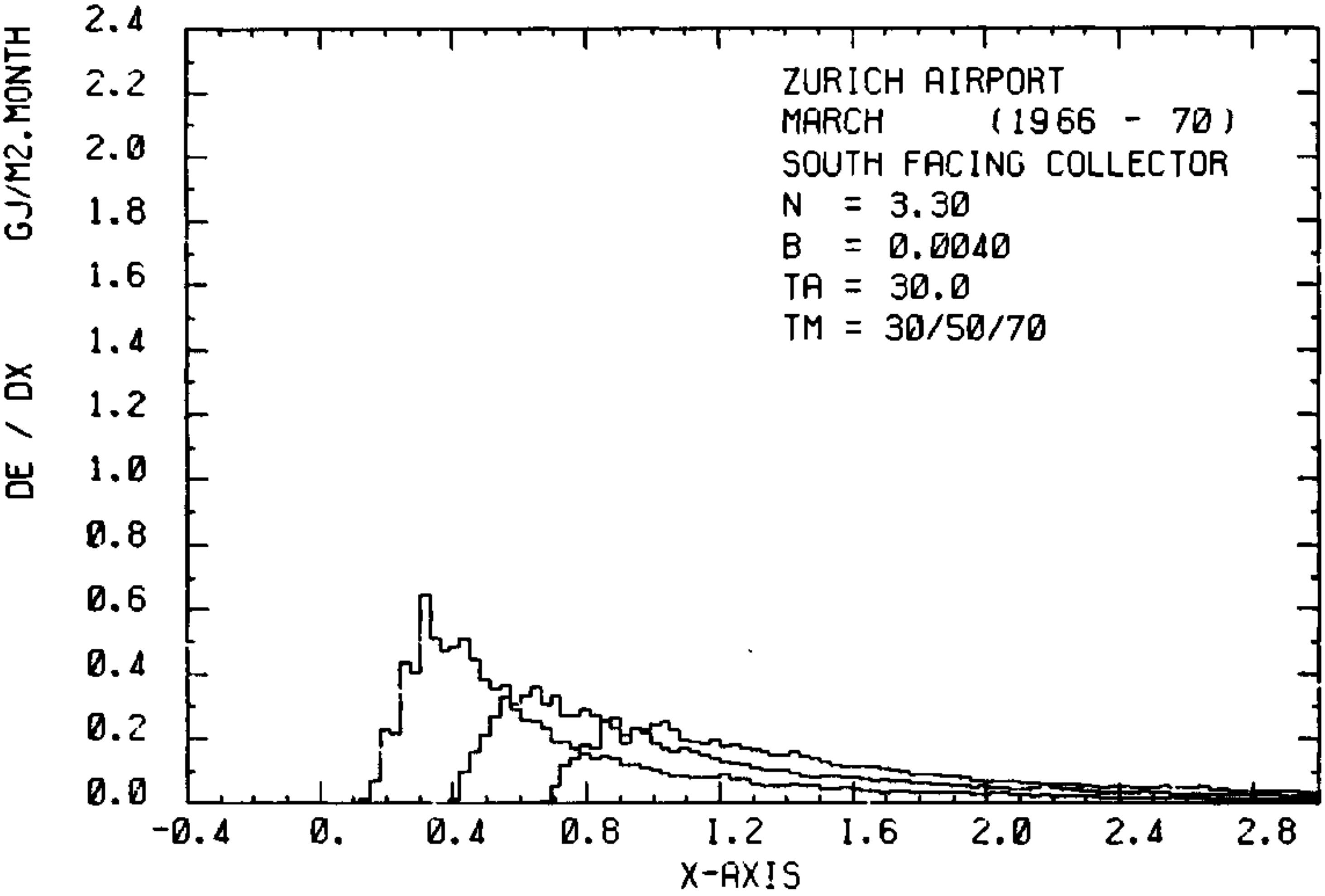
Collector orientation (γ):	South facing (0)
Collector class (n, b):	(3.3, 0.004 K^{-1}) (2.5, 0.004 K^{-1})
Collector tilt angle TA (α):	30°, 60°
Monthly tables for month MO:	March, June, September, December
Values for constant collector temperature T_m:	30, 50, 70° C

(How to get results for constant <u>inlet</u> temperatures T_i, see appendix I).

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

2.1 MURD-functions

```
YEARS: 66 - 70     DAYS:  61 - 91          TK =  30.0 (CEL)     ALPHA =  60.0 (DEG)      GAMMA =   0.0 (DEG)

                                           HKOL =  3.30         BK =  .0040 (1/KEL)      CK = 0.000 (SEC/M)

                                           KP = 2170            NZ =     0               NN =     0                   XZERO= 0.000


MEAN USABLE RADIATION DENSITY FOR THE WHOLE PERIOD          XI FROM .003 TO .300          ( XI = X - XZERO )

 0.            0.            0.            .59390E+05    .48845E+06    .24156E+07    .36749E+07    .67528E+07    .67364E+07    .95867E+07
  .64745E+07    .63039E+07    .94417E+07    .32948E+07    .58448E+07    .50710E+07    .48927E+07    .42127E+07    .43917E+07    .32303E+07
  .20087E+07    .20449E+07    .25603E+07    .22844E+07    .21926E+07    .14682E+07    .17287E+07    .16202E+07    .15640E+07    .16419E+07
  .14313E+07    .12563E+07    .12711E+07    .12023E+07    .11492E+07    .11037E+07    .96712E+06    .99879E+06    .92174E+06    .84630E+06
  .77706E+06    .68924E+06    .70735E+06    .75374E+06    .73121E+06    .72503E+06    .65959E+06    .60893E+06    .62267E+06    .69332E+06
  .61808E+06    .49448E+06    .46730E+06    .49862E+06    .51539E+06    .47212E+06    .43285E+06    .44484E+06    .44841E+06    .42021E+06
  .38626E+06    .34905E+06    .37803E+06    .41941E+06    .40950E+06    .34803E+06    .34721E+06    .30876E+06    .30799E+06    .31190E+06
  .31236E+06    .30632E+06    .29926E+06    .28951E+06    .27216E+06    .26375E+06    .26178E+06    .31179E+06    .30426E+06    .27727E+06
  .26457E+06    .29230E+06    .25079E+06    .23932E+06    .23037E+06    .22068E+06    .24171E+06    .21560E+06    .22370E+06    .20634E+06
  .19862E+06    .20916E+06    .20635E+06    .19300E+06    .18574E+06    .17970E+06    .16445E+06    .17124E+06    .17451E+06    .16292E+06


YEARS: 66 - 70     DAYS: 153 - 192         TK =  30.0 (CEL)     ALPHA =  60.0 (DEG)      GAMMA =   0.0 (DEG)

                                           HKOL =  3.30         BK =  .0040 (1/KEL)      CK = 0.000 (SEC/M)

                                           KP = 2097            NZ =     0               NN =     3                   XZERO= -.300


MEAN USABLE RADIATION DENSITY FOR THE WHOLE PERIOD          XI FROM .003 TO .600          ( XI = X - XZERO )

  .12017E+03    .12015E+03    .12013E+03    .12011E+03    .12008E+03    .12006E+03    .12004E+03    .12001E+03    .11999E+03    .11997E+03
  .11994E+03    .11992E+03    .11990E+03    .11987E+03    .11985E+03    .11982E+03    .11980E+03    .11978E+03    .11975E+03    .11973E+03
  .11970E+03    .11968E+03    .11966E+03    .11963E+03    .11961E+03    .11958E+03    .11956E+03    .11953E+03    .11951E+03    .11948E+03
  .11946E+03    .11943E+03    .11941E+03    .11938E+03    .11936E+03    .11933E+03    .11931E+03    .11928E+03    .11926E+03    .11923E+03
  .11921E+03    .11918E+03    .11915E+03    .11913E+03    .11910E+03    .11908E+03    .11905E+03    .11902E+03    .11900E+03    .11897E+03
  .11894E+03    .11892E+03    .11889E+03    .11886E+03    .11884E+03    .11881E+03    .11878E+03    .11876E+03    .11873E+03    .11870E+03
  .11868E+03    .11865E+03    .11862E+03    .11859E+03    .11857E+03    .11854E+03    .11851E+03    .11848E+03    .11845E+03    .11843E+03
  .11840E+03    .11837E+03    .11834E+03    .11831E+03    .11829E+03    .11826E+03    .11823E+03    .11820E+03    .11817E+03    .11814E+03
  .11811E+03    .11808E+03    .11806E+03    .11803E+03    .11800E+03    .11797E+03    .11794E+03    .11791E+03    .33577E+06    .89974E+04
  .40209E+04    .37726E+04    .32128E+04    .16677E+04    .74597E+04    .80371E+04    .97421E+04    .12143E+05    .44054E+05    .12586E+06
  .22195E+07    .50424E+07    .13993E+08    .17161E+08    .17573E+08    .16798E+08    .13609E+08    .13581E+08    .11493E+08    .78075E+07
  .64526E+07    .51200E+07    .44562E+07    .36795E+07    .33199E+07    .36519E+07    .24273E+07    .21753E+07    .19716E+07    .17871E+07
  .16121E+07    .15279E+07    .14465E+07    .13434E+07    .12832E+07    .11980E+07    .10060E+07    .95326E+06    .92153E+06    .79515E+06
  .74291E+06    .65279E+06    .59428E+06    .58047E+06    .57179E+06    .52754E+06    .44861E+06    .51614E+06    .49196E+06    .48132E+06
  .50287E+06    .48575E+06    .47987E+06    .45745E+06    .43191E+06    .36909E+06    .37502E+06    .37631E+06    .36646E+06    .33375E+06
  .35007E+06    .37808E+06    .34929E+06    .34861E+06    .32455E+06    .32967E+06    .31526E+06    .31433E+06    .28192E+06    .27486E+06
  .26162E+06    .26723E+06    .24518E+06    .23391E+06    .21923E+06    .21067E+06    .21394E+06    .20386E+06    .20290E+06    .21627E+06
  .21176E+06    .16974E+06    .17115E+06    .15920E+06    .15215E+06    .15080E+06    .16457E+06    .14240E+06    .13768E+06    .13766E+06
  .13284E+06    .12189E+06    .11396E+06    .11594E+06    .11017E+06    .10590E+06    .99335E+05    .94476E+05    .92061E+05    .90624E+05
  .95209E+05    .92863E+05    .68371E+05    .86255E+05    .88301E+05    .86754E+05    .84548E+05    .96422E+05    .82160E+05    .76475E+05
```



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TM = 30/50/70
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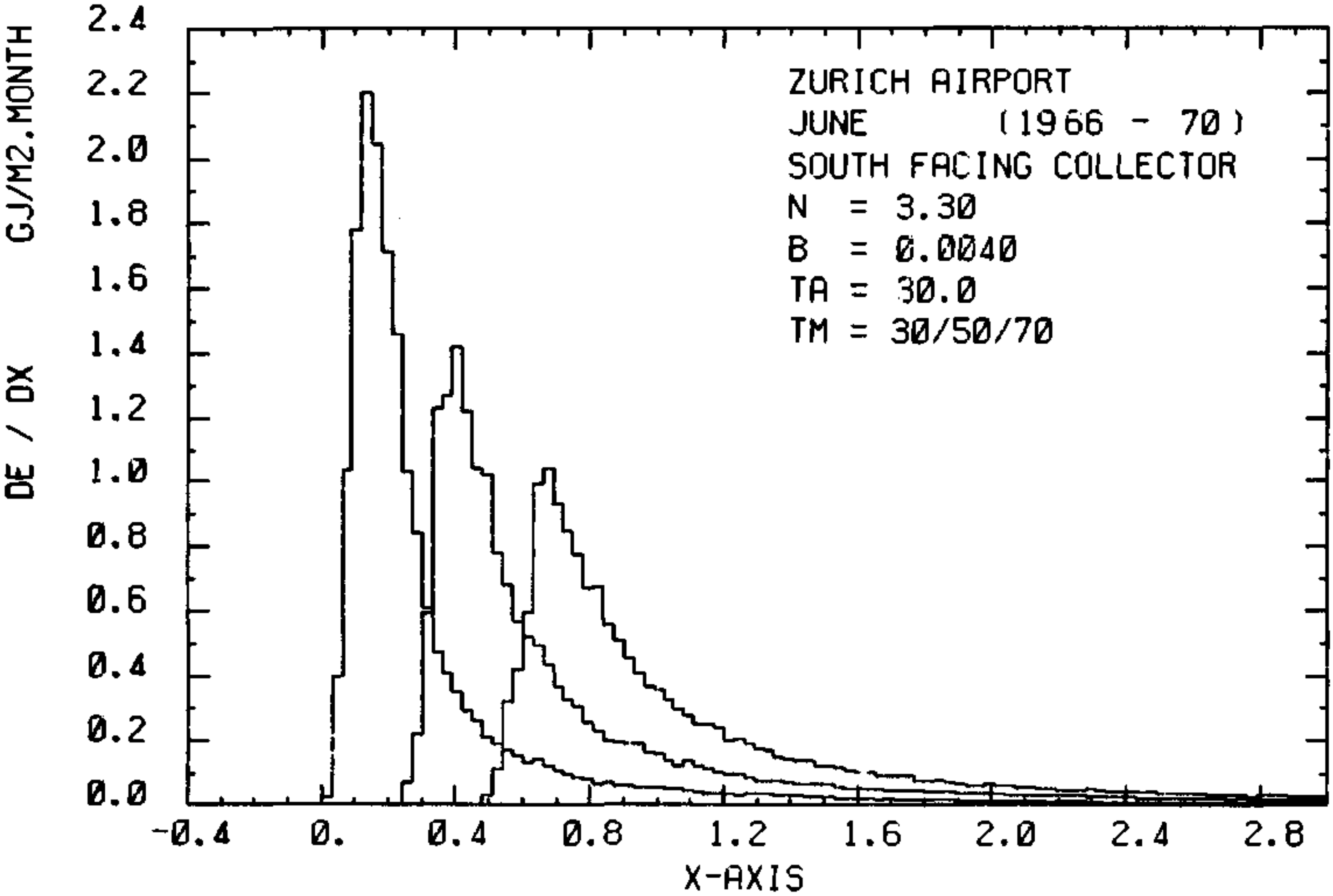
DE / DX
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS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2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
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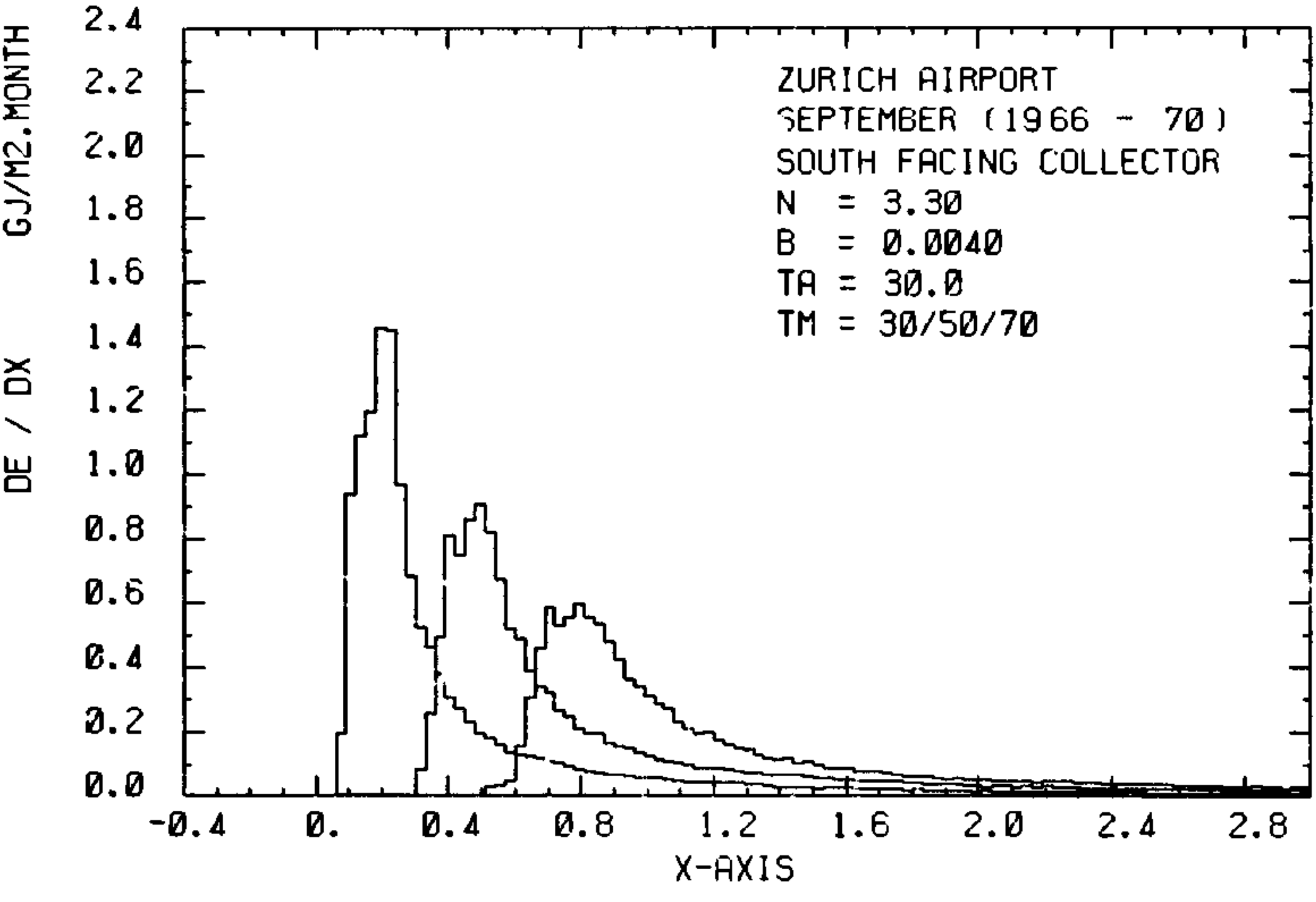
0.8
1.2
1.6
2.0
2.4
2.8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2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
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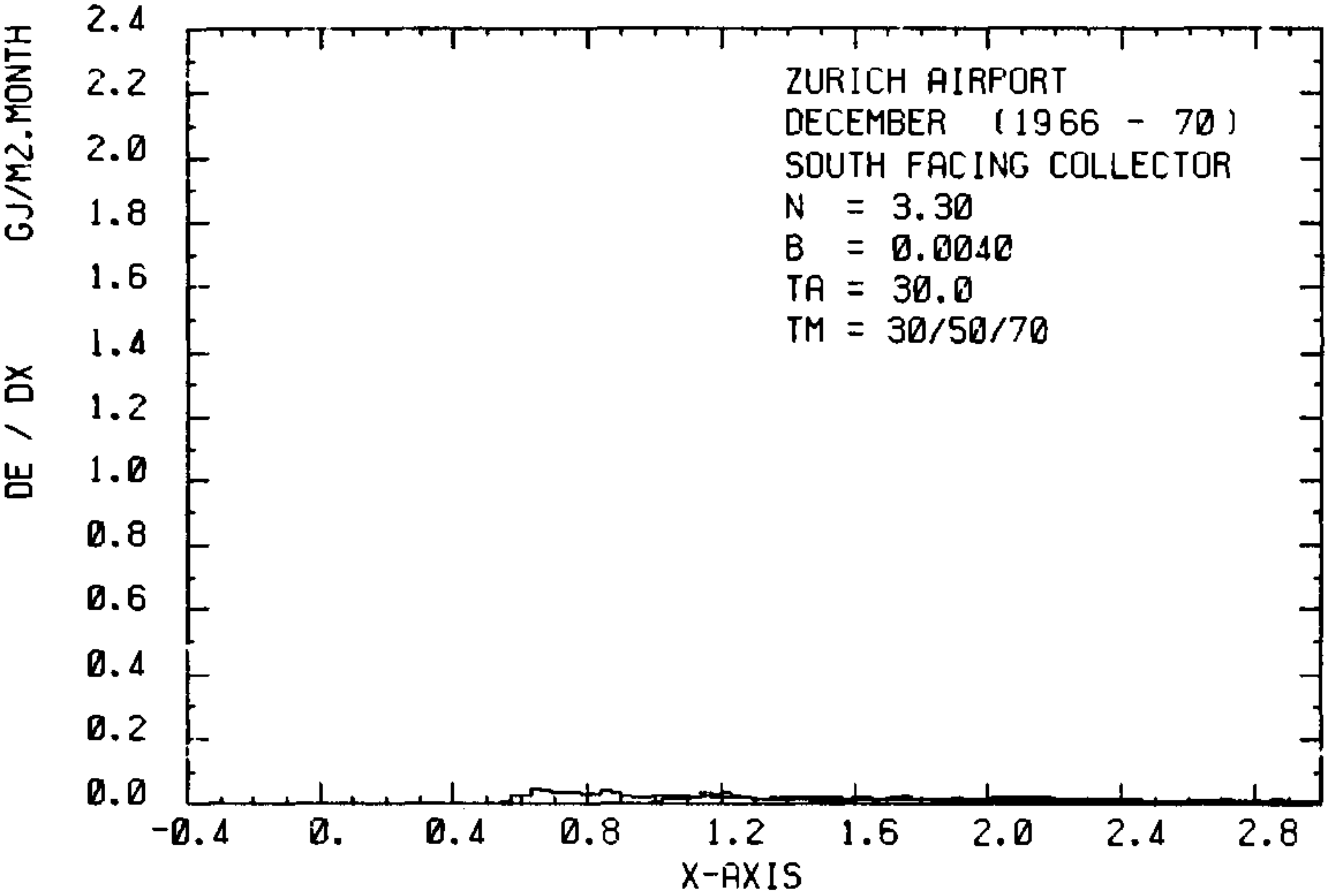
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS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DECEMBER (1966 - 70)
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TM = 30/50/70
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2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
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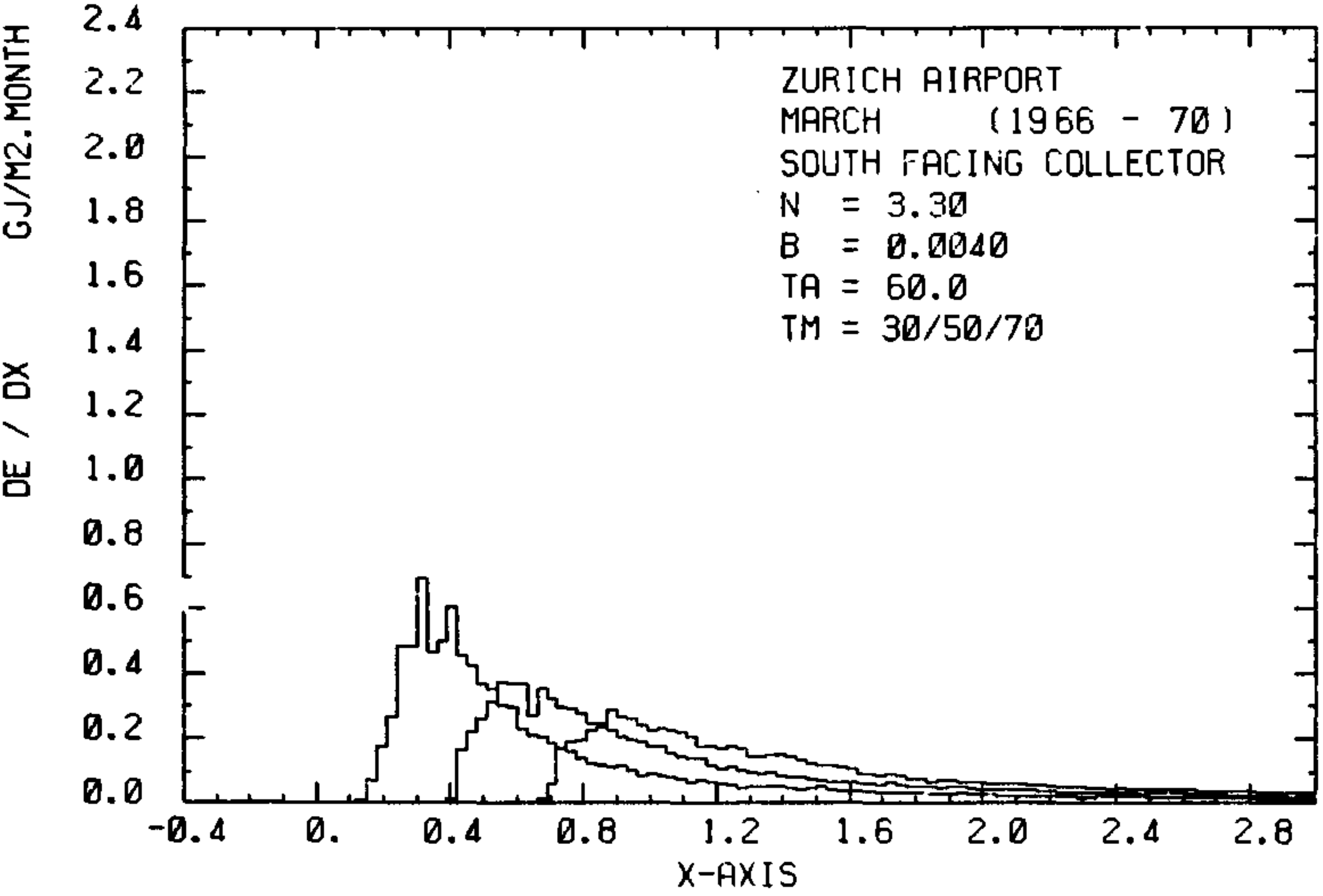
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS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TM = 30/50/70
GJ/M2.MONTH
DE / DX
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2.0
1.8
1.6
1.4
1.2
1.0
0.8
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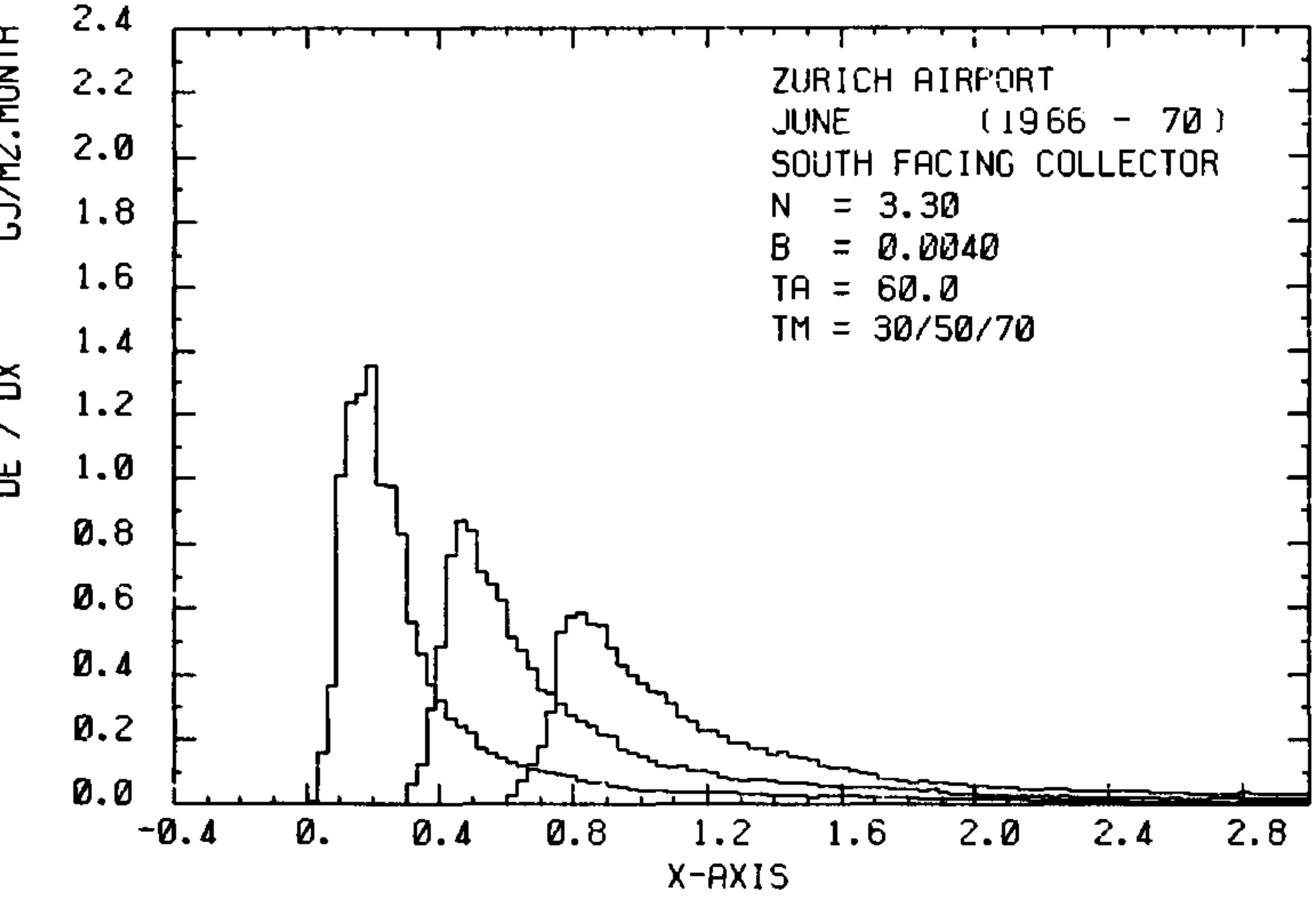
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TM = 30/50/70
DE / DX GJ/M2.MONTH
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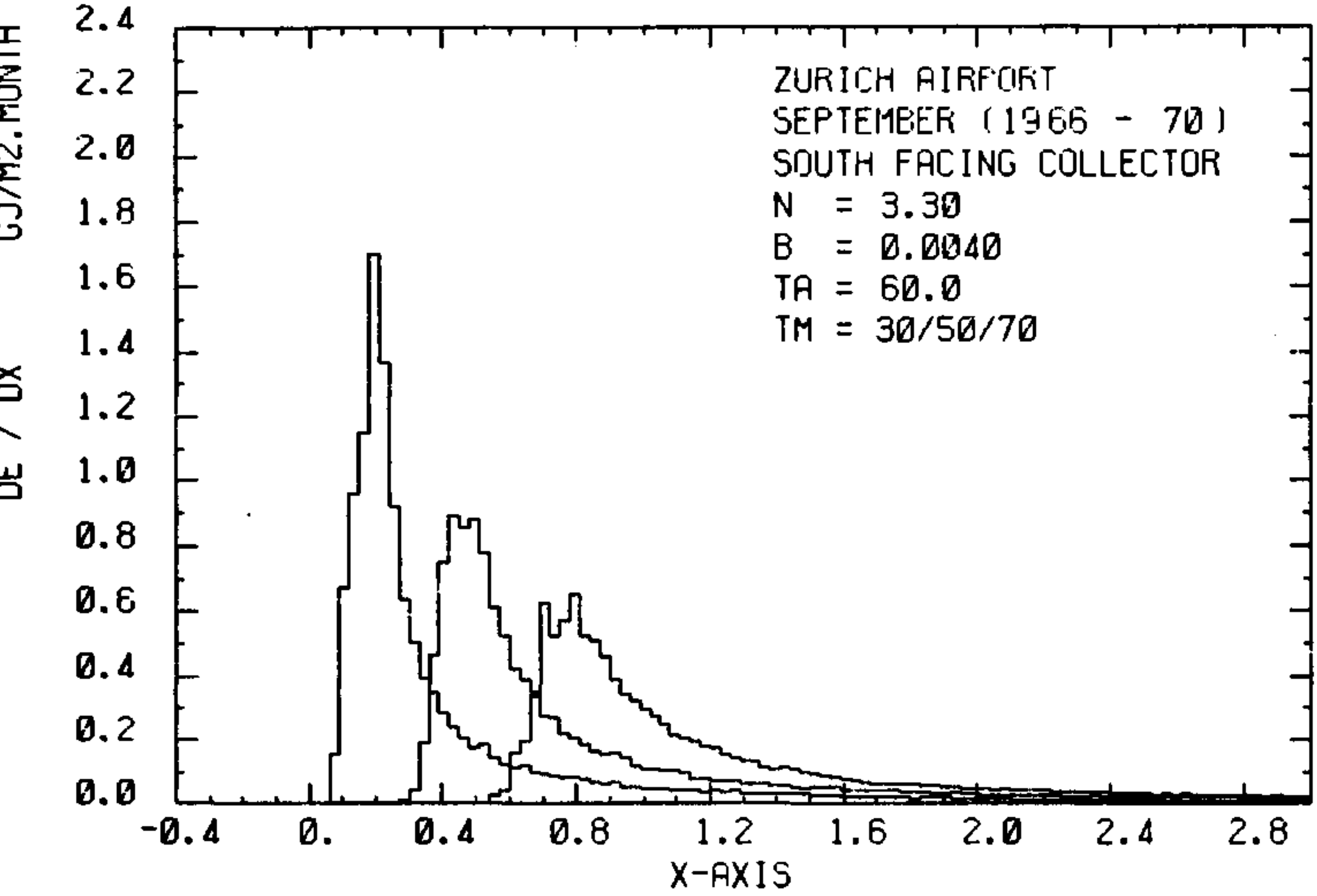
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS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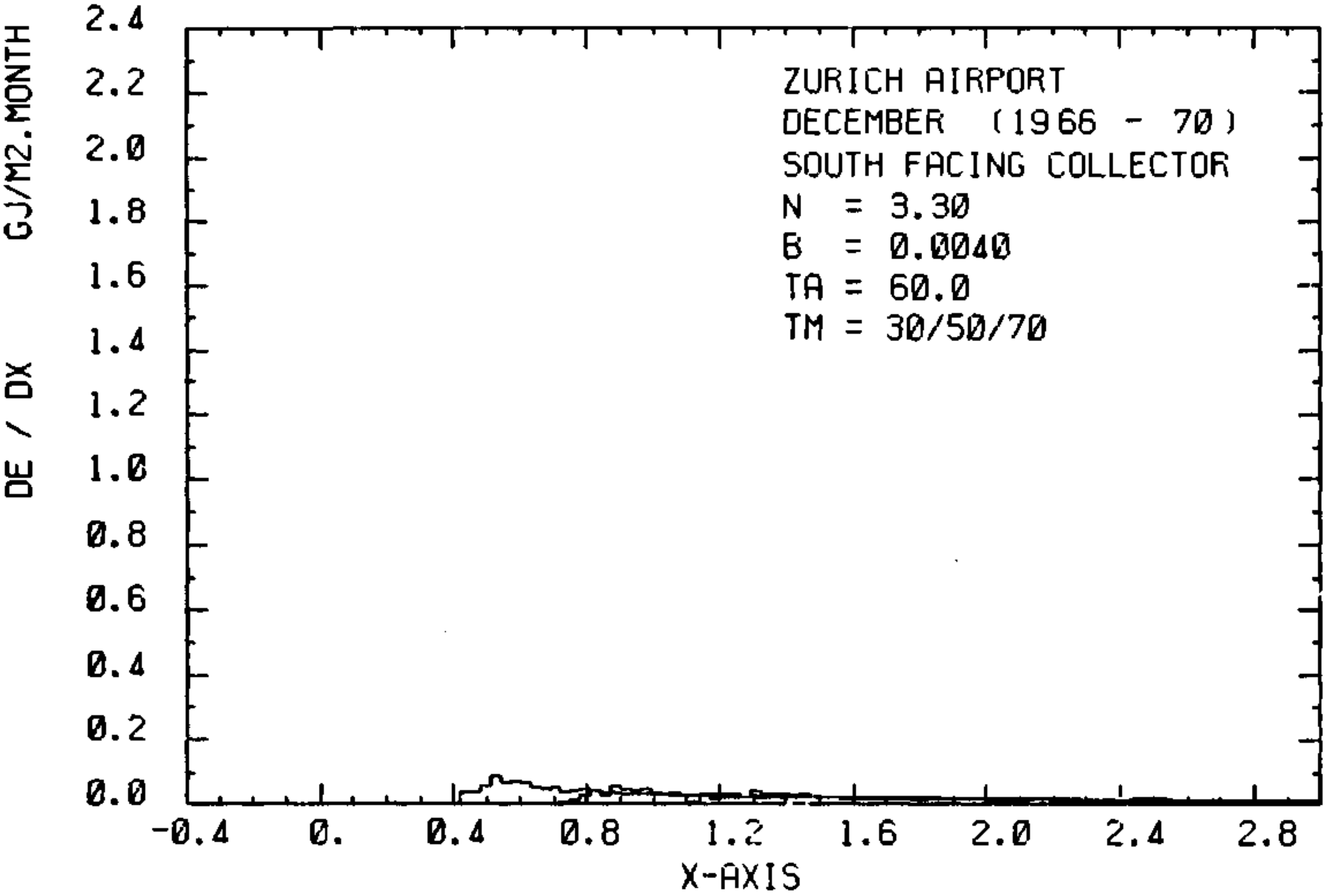
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS
ZURICH AIRPORT
SEPTEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 3.30
B = 0.0040
TA = 60.0
TM = 30/50/70



GJ/M2.MONTH
DE / DX
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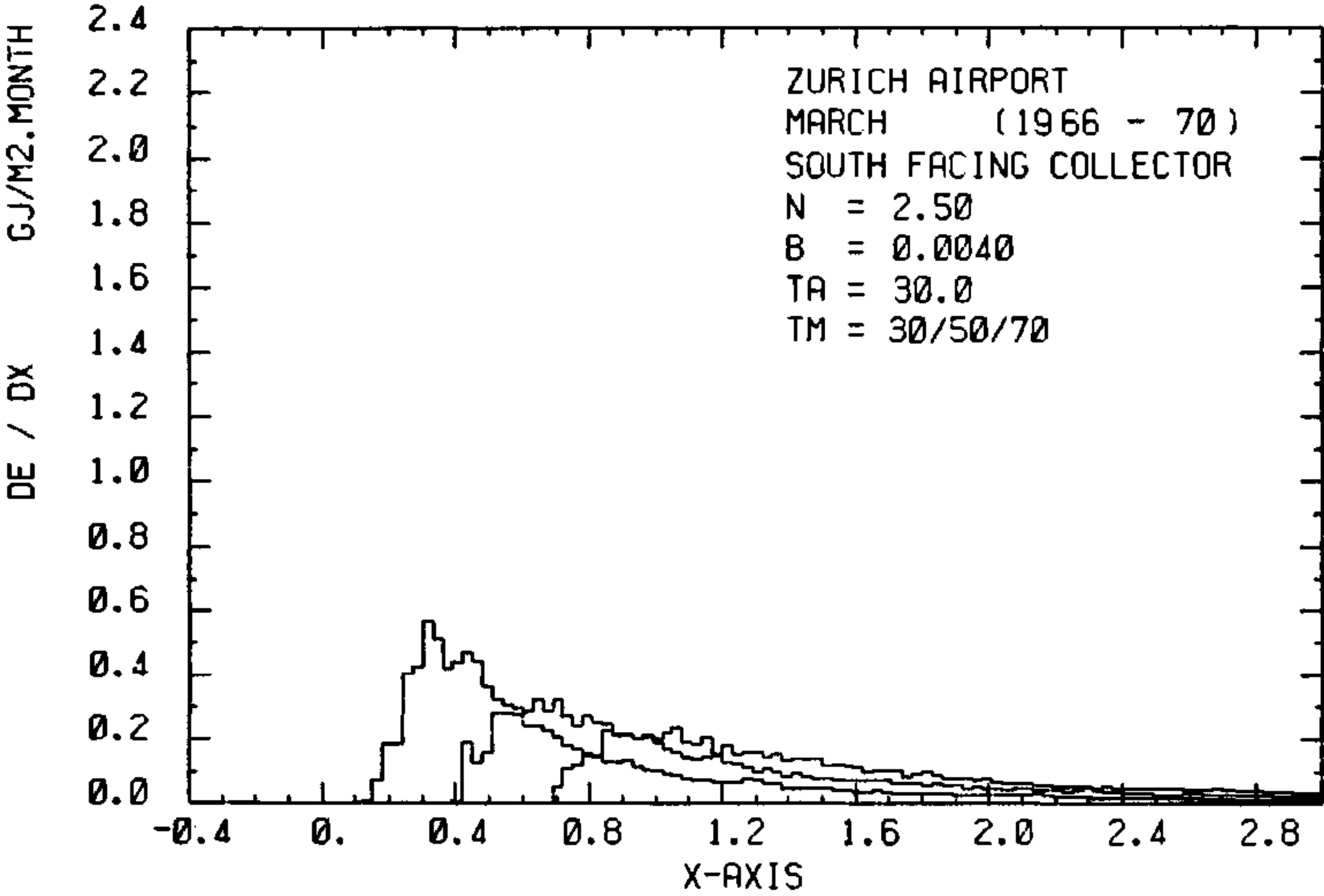
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS
ZURICH AIRPORT
DECEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 3.30
B = 0.0040
TA = 60.0
TM = 30/50/70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1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
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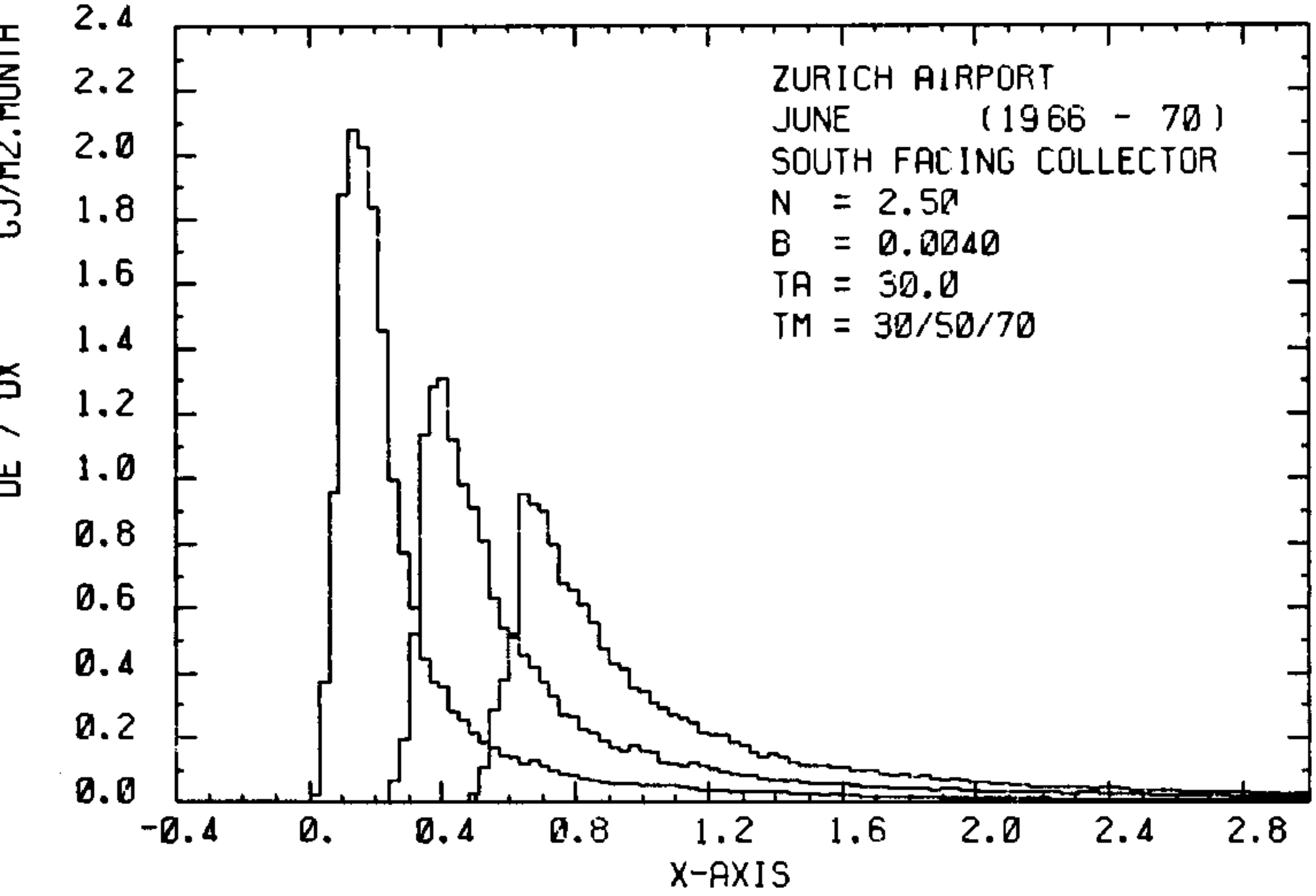
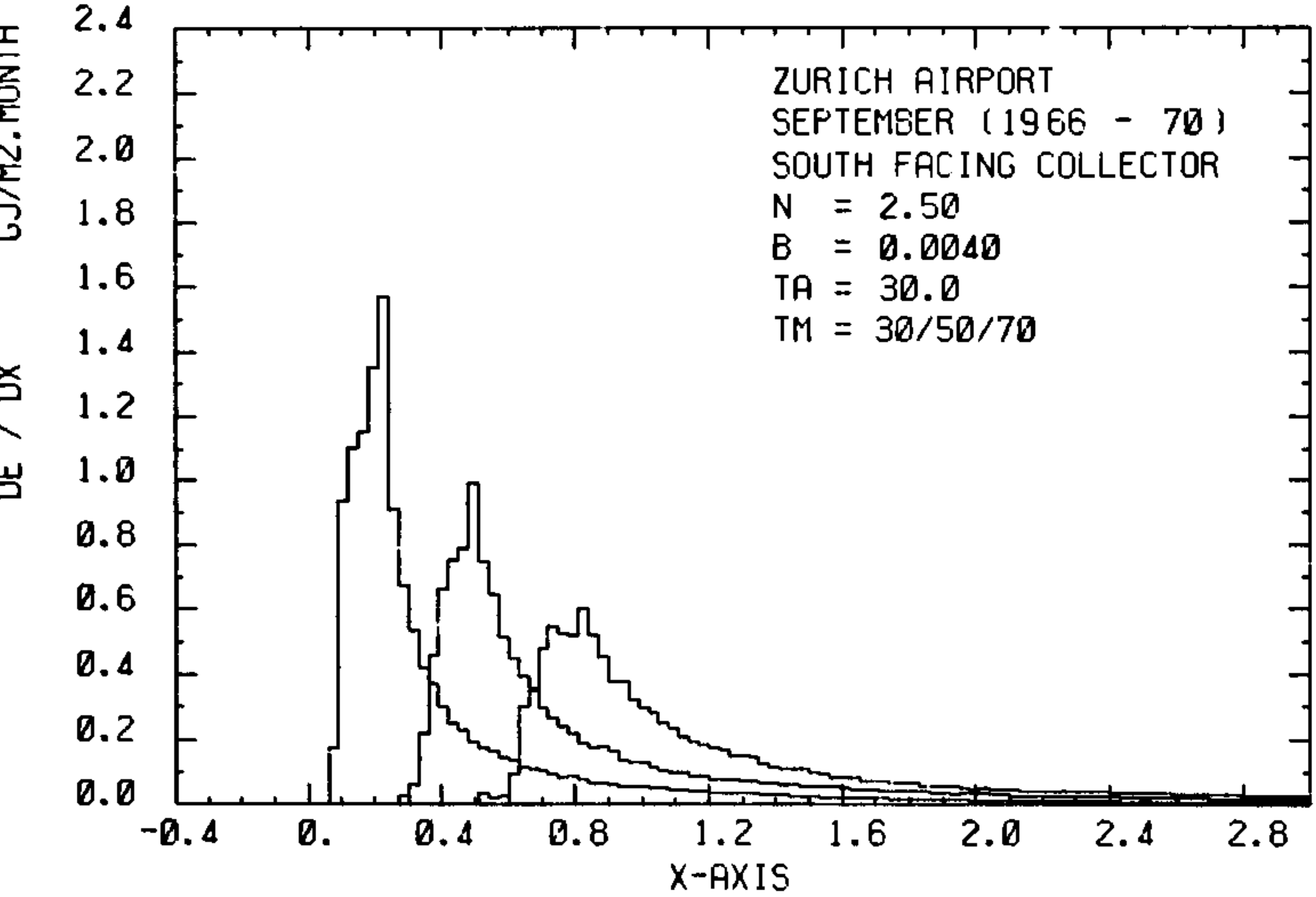
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS


DE / DX GJ/M2.MONTH
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS
ZURICH AIRPORT
JUNE (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 30.0
TM = 30/50/70


DE / DX GJ/M2.MONTH
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2.2
2.0
1.8
1.6
1.4
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1.0
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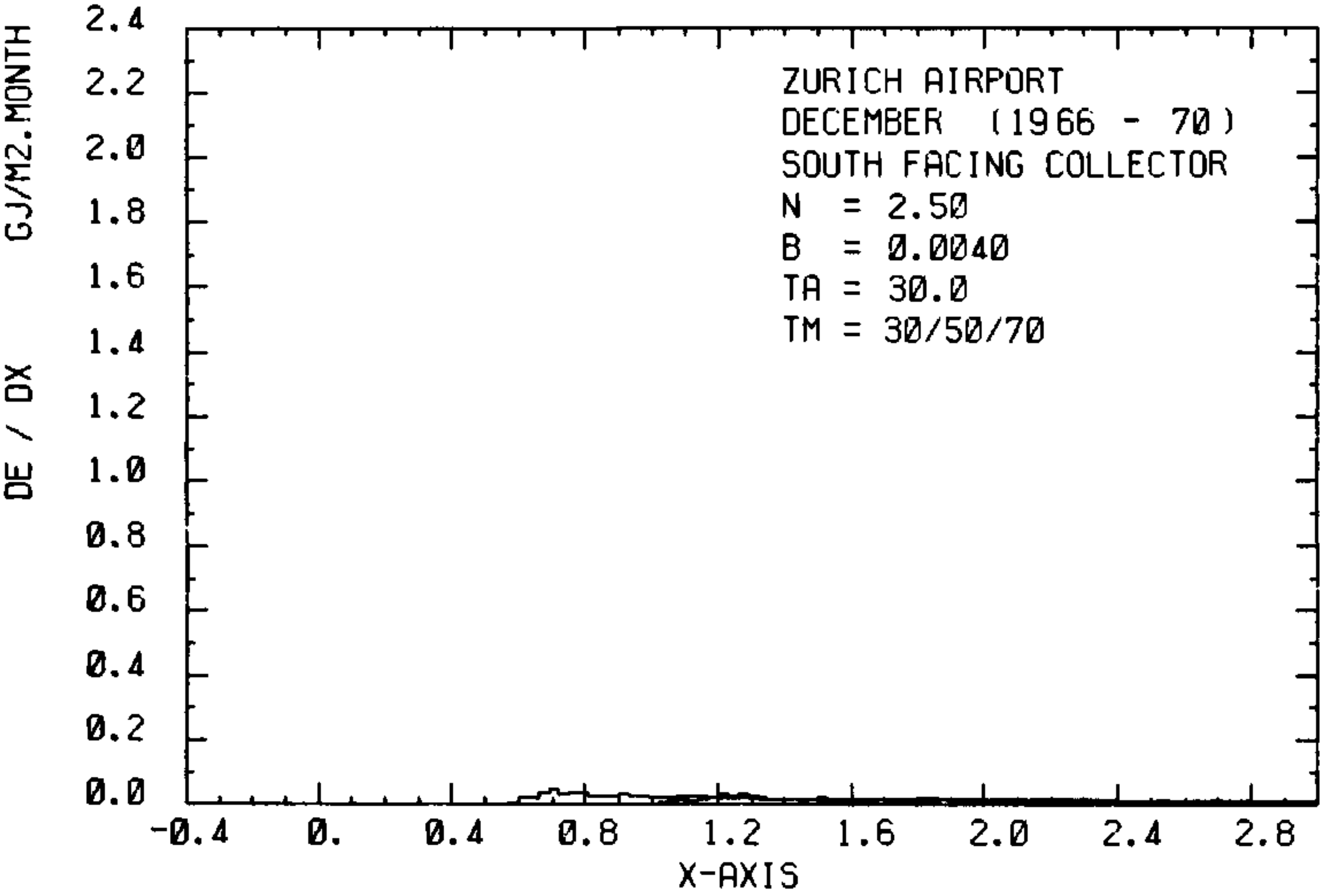
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS
ZURICH AIRPORT
SEPTEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 30.0
TM = 30/50/70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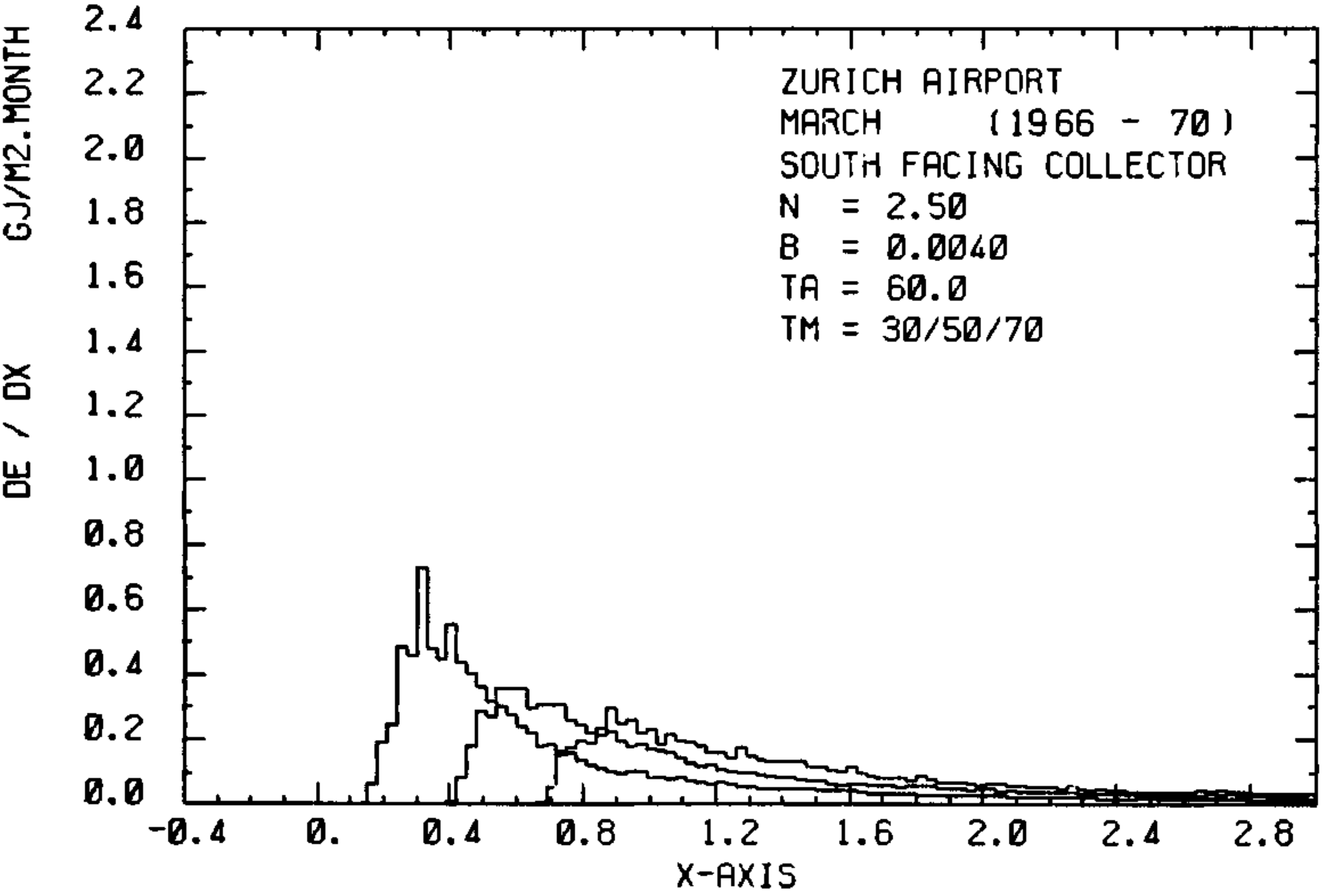
DECEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 30.0
TM = 30/50/70
DE / DX GJ/M2.MONTH
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS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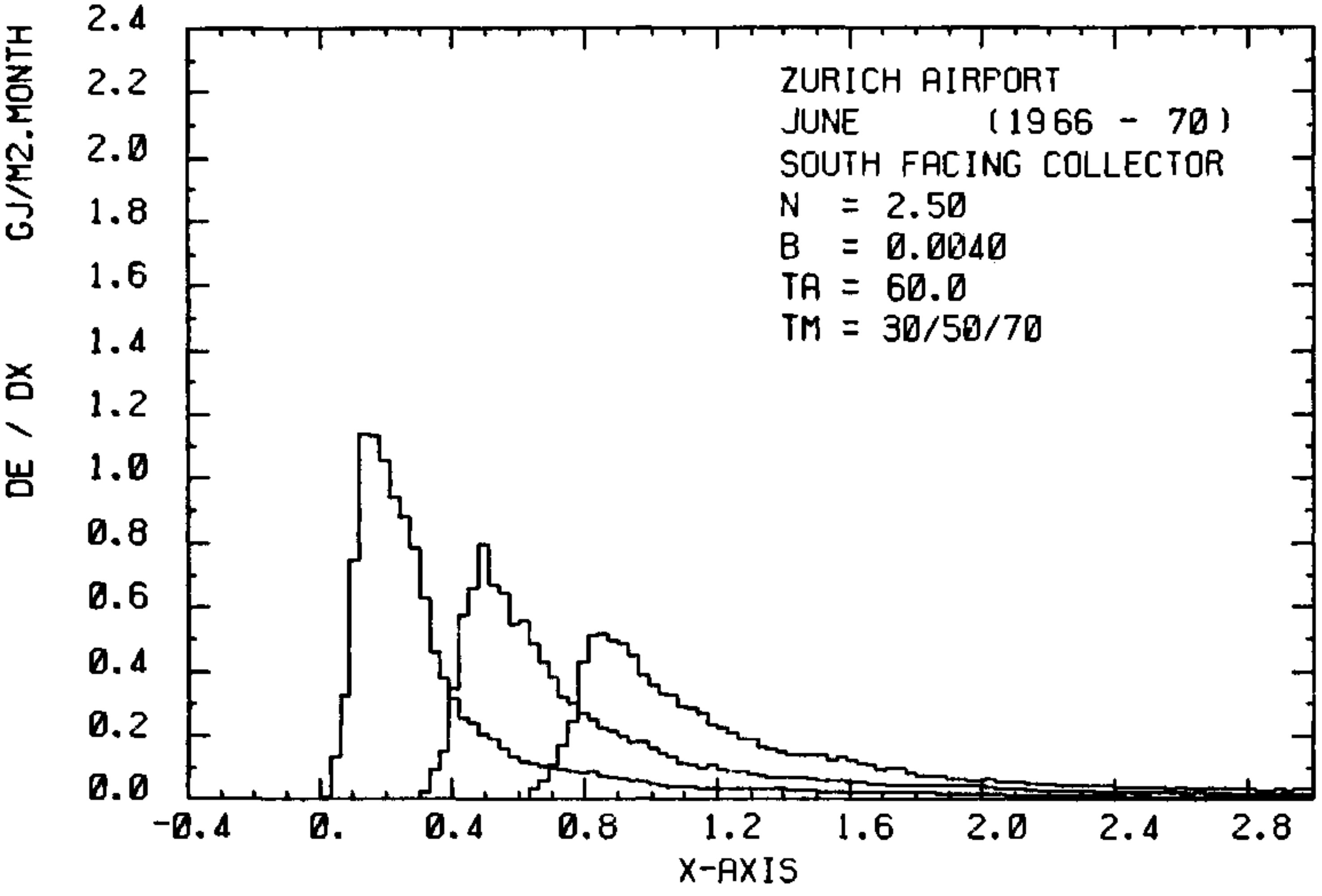
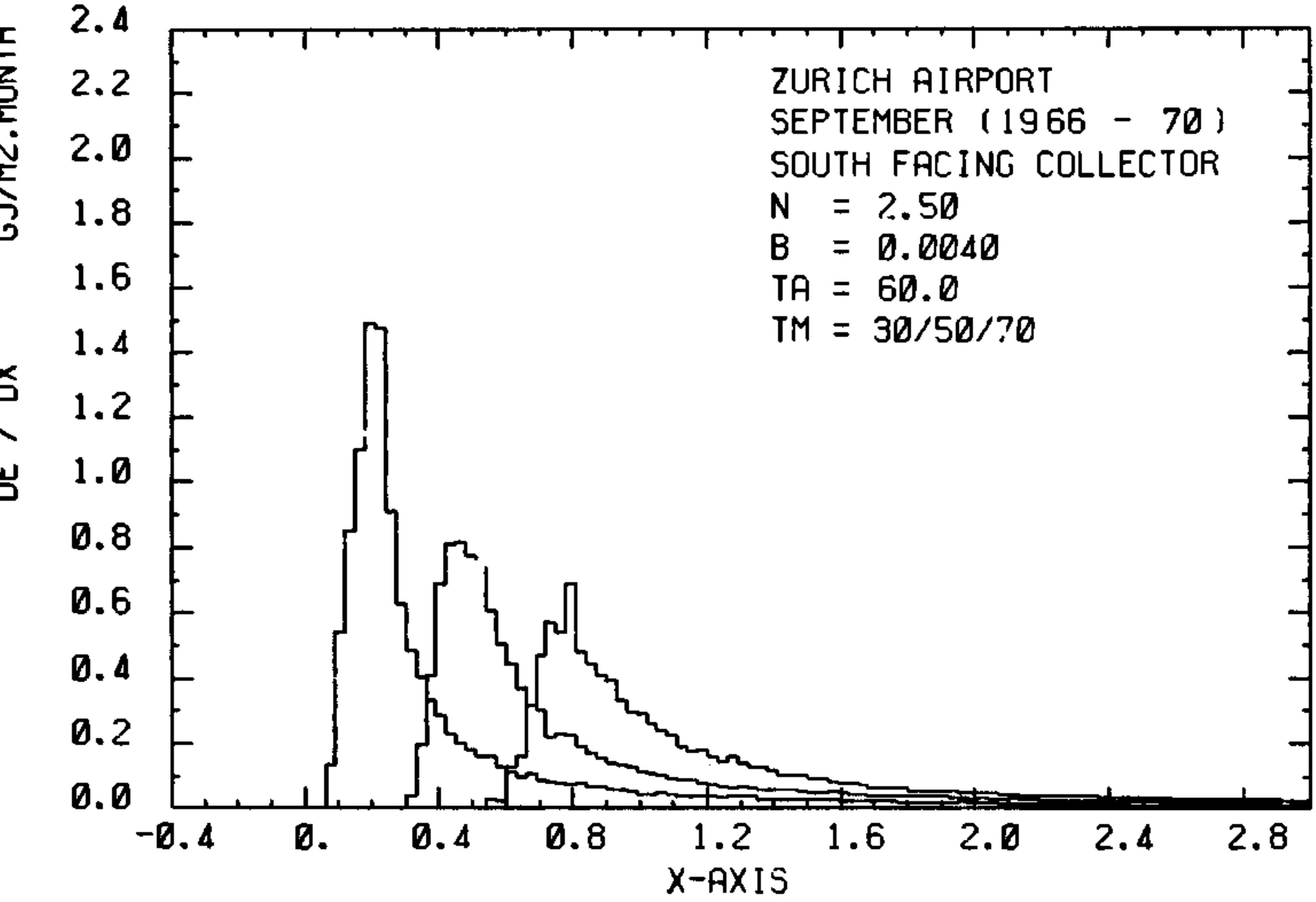
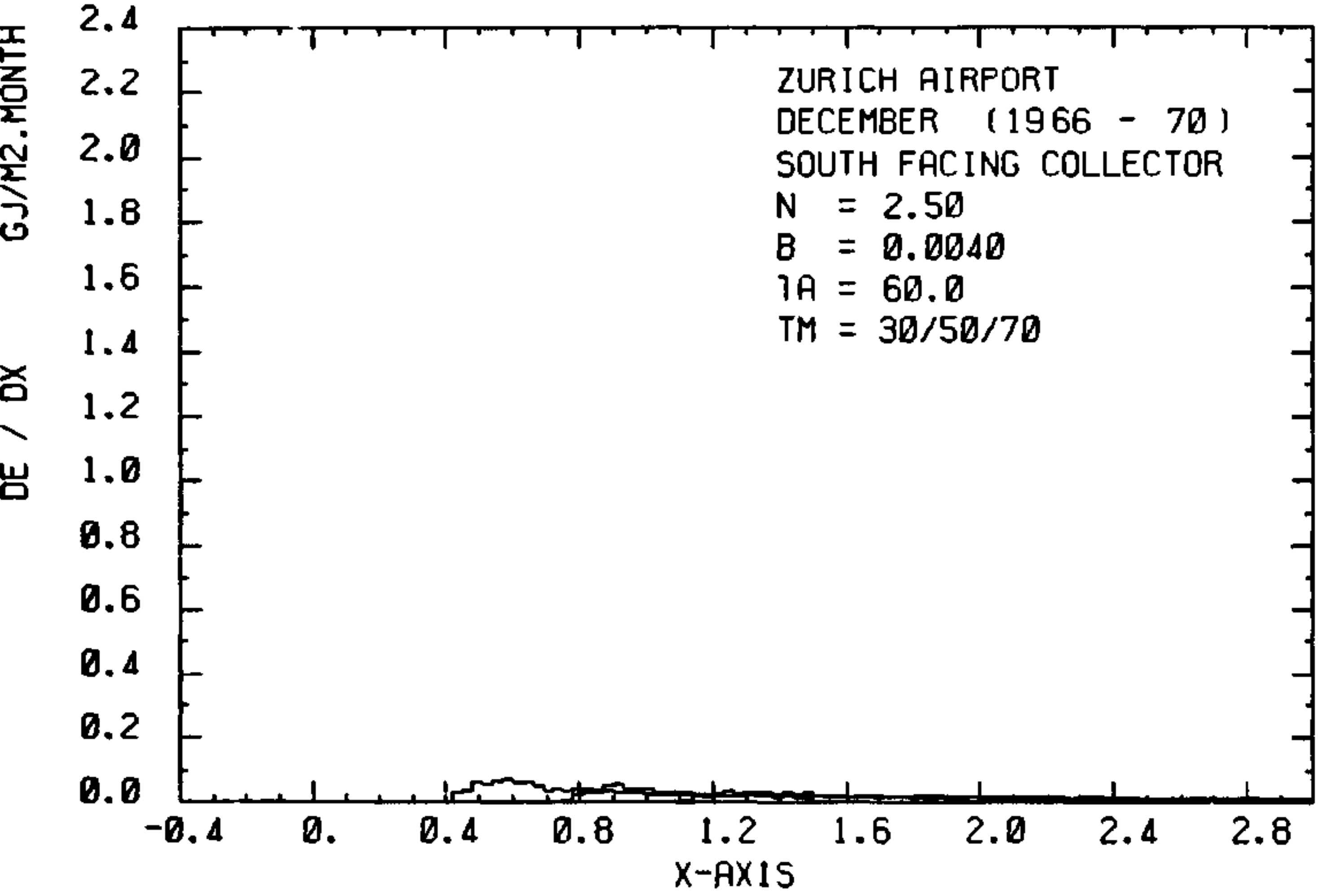
MARCH (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 60.0
TM = 30/50/70
DE / DX GJ/M2.MONTH
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS


ZURICH AIRPORT
JUNE (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 60.0
TM = 30/50/70
GJ/M2.MONTH
DE / DX
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS


ZURICH AIRPORT
SEPTEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
TA = 60.0
TM = 30/50/70
DE / DX GJ/M2.MONTH
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS


ZURICH AIRPORT
DECEMBER (1966 - 70)
SOUTH FACING COLLECTOR
N = 2.50
B = 0.0040
7A = 60.0
TM = 30/50/70
DE / DX GJ/M2.MONTH
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.4
0.
0.4
0.8
1.2
1.6
2.0
2.4
2.8
X-AXIS

2.2 Mean collector gains

```
OUTPUT ETA          ZURICH AIRPORT   1965-70         ALPHA = 30.0          GAMMA =   0.0          MKOL = 3.300
                                                     BK   =  .0040         CK    = 0.000          ( FLAT-PLATE , SINGLE WINDOW )



      .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  3.00

  3        63.5        102.4        4.0                                6        175.5       164.5        3.6

 30  31.4  42.7  51.2  57.4  63.0  67.3  70.9  74.0  76.6  78.9       30  56.2  62.2  66.2  69.2  71.6  73.2  74.6  75.8  76.8  77.7
 50   6.4  15.1  23.5  30.9  37.2  42.5  47.1  51.2  54.7  57.6       50  23.1  33.4  40.9  46.5  50.9  54.3  57.2  59.7  61.7  63.5
 70    .1   2.9   9.1  13.9  19.5  24.9  29.7  34.0  37.6  41.3       70   3.7  12.7  21.0  27.0  33.4  38.0  41.9  45.2  48.0  50.5

  9       102.1        123.5        2.9                               12         19.3        26.2        3.2

 30  66.7  69.2  75.4  79.4  82.9  85.5  87.7  89.5  91.0  92.4       30   1.5   5.4   9.7  13.9  17.8  21.7  25.4  29.1  32.5  35.8
 50  21.8  34.5  43.4  51.1  56.9  61.6  65.3  69.5  71.4  73.9       50   0.0    .0    .9   2.8   5.1   7.6  10.0  12.4  14.7  17.0
 70   1.9  13.9  20.5  25.8  35.7  41.4  45.3  50.5  54.1  57.3       70   0.0   0.0   0.0    .0    .6   1.7   3.1   4.7   6.3   8.0




OUTPUT ETA          ZURICH AIRPORT   1965-70         ALPHA = 60.0          GAMMA =   0.0          MKOL = 3.303
                                                     BK   =  .0040         CK    = 0.000          ( FLAT-PLATE , SINGLE WINDOW )



      .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  3.00

  3        63.5         99.5        4.5                                6        170.5       129.0        3.6

 30  31.7  42.5  50.5  56.7  61.6  65.5  69.0  71.9  74.3  76.5       30  38.2  43.3  46.8  49.3  51.3  52.9  54.2  55.2  56.2  57.0
 50   7.3  16.6  24.3  32.1  39.1  43.2  47.6  51.4  54.7  57.6       50  11.4  19.2  25.1  29.6  33.2  36.1  38.5  40.6  42.3  43.9
 70    .1   3.4   9.0  15.1  20.5  26.3  30.6  34.9  35.5  41.5       70    .3   4.1   9.5  14.4  18.7  22.4  25.5  28.1  30.5  32.5

  9       102.1        127.7        2.9                               12         19.3        31.5        3.2

 30  57.4  69.7  74.2  75.3  79.4  81.0  83.2  84.4  86.1  87.5       30   6.7  13.9  21.4  26.3  31.5  35.4  40.9  45.0  48.9  52.4
 50  20.0  33.1  42.1  49.4  54.2  58.5  62.1  65.2  67.6  70.1       50    .6   1.0   5.5   9.4  13.3  17.3  20.5  23.4  26.4  29.7
 70   1.6  13.1  20.3  27.1  33.0  37.1  43.4  47.3  50.4  53.4       70   0.0    .0    .3   2.1   4.6   7.3  10.0  12.7  15.3  17.7
```

```
OUTPUT ETA           ZURICH AIRPORT   1965-72          ALPHA = 30.0          GAMMA =    0.0          NKDL = 2.500
                                                       BK    =  .0040        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         83.6        132.4        4.0                              6        170.5        166.5         3.6

 30  28.7  39.4  47.4  53.7  58.8  62.9  66.4  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  29.1  35.0  40.1  44.5  48.4  51.8  54.8        50   21.8  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        142.1        125.5        2.9                             12         19.3         26.2         3.2

 30  59.1  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  48.5  54.0  58.5  62.2  65.4  68.1  70.5        50    0.0    .0    .5   2.2   4.1   6.2   8.4  10.5  12.5
 70   1.6   9.9  19.1  27.1  33.7  39.3  44.0  48.0  51.6  54.7        70    0.0   0.0   0.0    .0    .3   1.1   2.3   3.5   4.9




OUTPUT ETA           ZURICH AIRPORT   1965-72          ALPHA = 60.0          GAMMA =    0.0          NKDL = 2.500
                                                       BK    =  .0040        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         83.6         94.5        4.0                              6        170.5        129.0         3.6

 30  25.9  [illegible]  [illegible]  [illegible]  [illegible]  63.3  66.3  69.0  71.5  73.6        30   34.2  39.1  42.4  44.9  46.7  48.3  49.5  50.6  51.5
 50   6.6  15.5  [illegible]  [illegible]  [illegible]  45.5  [illegible]  [illegible]  [illegible]  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   9.4  [illegible]  [illegible]  24.4  [illegible]  [illegible]  36.3  [illegible]        70     .1   3.6   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  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  81.7  [illegible]        30    6.0  [illegible]  [illegible]  24.3  [illegible]  33.9  38.0  41.9  45.6
 50  19.4  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  [illegible]  64.2  66.4        50  [illegible]   1.7  [illegible]   9.1  [illegible]  16.3  19.7  [illegible]  25.8
 70  [illegible]  [illegible]  17.2  25.7  [illegible]  37.3  42.7  [illegible]  [illegible]  51.7        70    0.0    .0    .3   2.0   4.4   7.0   9.5  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 Meteo- 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 <u>11</u>, 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 m² collector area

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

and the definition of T_m

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

we obtain by inserting

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

into (2) the following relationship

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

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

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

A = collector area (m²)

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 $\eta_o^* = \eta_o/y$ and a_1 by $a_1^* = a_1/y$. 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

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

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

$$T_s-T_a = \frac{1}{2b}\left(\sqrt{1+4bx_oI_e/U_o} - 1\right) \tag{48}$$

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

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 = const) (-)
a_1^*	modified heat loss coefficient (T_i = 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^oC)
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_α	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 (-)

$F(x_o)$	gross heat output for a given period ($o<t\leqslant t_o$) normalized to $\eta_o = 1$
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)
$\vec{j}$	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 $0<t\leqslant t_o$ (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 = α	collector tilt angle (deg)
T_a	ambient temperature (^oC)
T_i	collector fluid inlet temperature (^oC)
TM = T_m	mean collector fluid temperature (^oC)
T_o	collector fluid outlet temperature (^oC)
T_s	stagnation temperature (^oC)
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 = const $\rightarrow$ T_i = 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 ($^{\circ}C$)
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 = 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 = $5.67 \cdot 10^{-8} W/m^2K^4$

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