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MFC 1.0 β

Matched Flow Collector Model for simulation and testing

User's manual

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1 General description

MFC is a TRNSYS component. Thus, it is a subroutine compatible with TRNSYS and as such it is named TYPE52. MFC models the thermal performance of a flat plate collector. It is based on a plug flow model that accounts for

- The heat capacity of the collector and the fluid
- The transport time of the fluid through the collector

Further there are options to account for

- The temperature dependence of the collector U-value
- The incident angle of various solar radiation components

An overall goal driving the development of the MFC model is to link simulations closer to experiments. The MFC model is equally well suited for simulation and evaluation of transient performance data. This makes it possible to base a simulation model on measured data in a strict and unbiased way.

The MFC component includes several parameterized models. These models may be fitted to transient data of either full scale experiments or collector tests, using the identification program DF (InSitu Scientific Software, 1992). The fit produces parameter values and a measure of goodness of fit, thus providing means to rank models. The very model determined by the fit may then be included in the TRNSYS system model. To further improve the precision in comparing measured and simulated data there are options to account for the temperature dependence of the fluid heat capacity and density.

The MFC component does not put any severe restrictions on the length of the simulation time step. On the one extreme, the MFC component may be used with one hour time steps or longer since, the response approaches the steady state solution when the length of the time step increases. Further, long time steps do not cause convergence problems or long running times. The execution time per simulation time step is not affected by the length of the time step. On the other extreme, the MFC component produces meaningful information on the dynamic behaviour for time steps in the one minute range. Long-term averages of the collector output do not depend on the length of the simulation time step. However, they do depend on the time resolution of the weather data. The reasons for these characteristics are the facts that the MFC model is based on an algebraic expression of the collector outlet temperature and that the implementation includes only few and minor approximations.

Steady state theory is used to model the heat flow reaching the absorber pipe, i.e. the optical properties, the fin efficiency, and the collector heat losses.

Four MFC components may be included in a system model. This number may be increased as needed or decreased to save on computer memory.

1.1 Local U-value.

The U-value is calculated on the basis of the local temperature $T(x,t)$. Thus, for a given point in time the U-value typically increases along the collector. On the other hand, most steady state models take the U-value to be constant along the collector. That is a direct consequence of the assumption that the U-value depend on average collector temperature, rather than the local temperature. For low flow collectors in particular, this constitutes a significant difference.

The local U-value of the MFC model is equivalent to the TYPE 1 solar collector model using a large number of **collector modules in series**. The MFC-model does not distinguish between a single collector module, collectors in series or collectors in parallel, since, with the local U-value there is no difference. It is only the heat capacity flow rate per unit area of collector that counts.

1.2 Non-TRNSYS

The MFC component differs from the TRNSYS TYPE1 in several respects beside the underlying mathematical model.

The MFC component is strictly limited to the collector. It does not include any features to convert between radiation components, neither does it calculate incident angles nor view angles. All radiation component inputs are irradiance in the plane of the collector and each component is complemented by an incident angle.

The MFC model was first implemented as an external model to the parameter identification program DF (InSitu Scientific Software, 1992). The MFC component does not call any TRNSYS routines besides TypeCk. Especially, the routine DATA is not used to read and interpolate user supplied data.

The lists of parameters, inputs, and outputs are made to facilitate the design of PRESIM components. PRESIM (Broman) is a graphical pre-processor to TRNSYS. Thus, the symbols are chosen to be compatible with PRESIM's short label. Further, since the number of parameters, inputs, and outputs are fixed in a PRESIM component the number of combinations is kept to a minimum in the MFC component. Consequently, some parameters and inputs are just place-holders in certain combinations of modes.

2 Nomenclature

This list includes two sets of symbols for the quantities that appear in the lists of Parameters, Inputs, and Outputs. The two sets differ in style. The first set of symbols is used in the mathematical description and adheres to a mathematical style. The second set used for Parameters, Inputs, and Outputs is in plain text. That makes it possible to use exactly the same symbols in the MFC model interface to DF and as "short labels" in the pre-processor PRESIM.

A quick look at the list reveals the quantities to which values must be input.

SI-units are included in the list. However in the TRNSYS deck "TRNSYS SI" unit must be used (see the list of parameters).

Symbol	SI-Unit	Description	Par/ In/ Out
A_c	m ²	Total collector reference area	Ac
a	W/K·m ²	Negative of the slope of collector efficiency versus $\Delta T/G$	a
a_1	W/K·m ²	Constant in U-value model (3.19)	a1
a_2	W/K ² · m ²	Constant in U-value model (3.19)	a2
a_r	W/K·m ²	Constant in U-value model (3.19)	ar
a_w	J/K·m ³	Constant in U-value model (3.19)	aw
b	-	Intercept of collector efficiency versus $\Delta T/G$	b
b_0	-	Constant in incident angle modifier model (3.51)	b0
\mathbf{b}_n	-	The boundary conditions of the n:th simulation time step	
C_{eff}	J/K·m ²	Effective heat capacity of collector (exc. fluid)	Ceff
$C_{collector}$	J/K·m ²	Effective heat capacity of collector (exc. fluid). See (3.42)	
$Cmode$	-	Collector mode	Cmode
C_{pc}	J/K·kg	Specific heat capacity of collector fluid	Cpc
C_{test}	W/K·m ²	Heat capacity flow rate at test conditions	Ctest
c_p	J/K·kg	Specific heat capacity of collector fluid	
$Dmode$	-	Dynamic mode	Dmode
$Emode$	-	Collector efficiency mode	Emode
$F_{av}(\tau\alpha)_n$	-	Intercept of collector efficiency vs. $(T_{av}-T_a)/G_T$	

$F_{av}U_L$	W/K·m ²	Negative of slope of collector efficiency vs. $(T_{av}-T_a)/G_T$	
$F_o(\tau\alpha)_n$	-	Intercept of collector efficiency vs. $(T_o-T_a)/G_T$	
F_oU_L	W/K·m ²	Negative of slope of collector efficiency vs. $(T_o-T_a)/G_T$	
$F_R(\tau\alpha)_n$	-	Intercept of collector efficiency vs. $(T_i-T_a)/G_T$	
F_RU_L	W/K·m ²	Negative of slope of collector efficiency vs. $(T_i-T_a)/G_T$	
F'	-	Collector efficiency factor	
f_0	-	Constant in collector efficiency factor (3.24)	f0
f_1	K ⁻¹	Constant in collector efficiency factor (3.24)	f1
G_b	W/m ²	Beam irradiance in the plane of the collector (direct)	Gb
G_{bx}	W/m ²	Beam irradiance in the plane of the collector (reflected)	Gbx
G_d	W/m ²	Diffuse irradiance in the plane of the collector (sky)	Gd
G_{dx}	W/m ²	Diffuse irradiance in the plane of the collector (reflected)	Gdx
G_g	W/m ²	Diffuse irradiance in the plane of the collector (ground)	Gg
G_r	W/m ²	Beam irradiance in the plane of the collector (reflected)	Gr
h	W/K·m ²	Heat transfer coefficient between outer cover and ambient	
h_c	W/K·m ²	Convective heat transfer coefficient; outer cover to ambient	
h_r	W/K·m ²	Radiative heat transfer coefficient; outer cover to "sky"	
h_{fp}	W/K·m ²	Heat transfer coefficient between fluid and pipe wall	hfp
IAM	-	Incident angle modifier	
I_b	deg	Incident angle of G_b	Ib
I_{bT}	deg	Incident angle of G_b projected in the transverse plane	IbT
I_{bx}	deg	Incident angle of G_{bx}	Ibx
I_{bxT}	deg	Incident angle of G_{bx} projected in the transverse plane	IbxT
I_d	deg	Effective incident angle of G_d	Id
I_{dx}	deg	Effective incident angle of G_{dx}	Idx
I_g	deg	Effective incident angle of G_g	Ig
I_r	deg	Incident angle of G_r	Ir
I_{rT}	deg	Incident angle of G_r projected in the transverse plane	IrT
LUi	-	Fortran logical unit through which IAM data is accessed	LUi
m_c	kg/s	Collector inlet fluid mass flow rate	mc
m_o	kg/s	Collector outlet fluid mass flow rate	mo
n	-	Number of simulation time step	

<i>Omode</i>		Optical mode	<i>Omode</i>
p		A set of parameters describing the collector	
Q_c	W	Collector output power	<i>Qc</i>
q	W/m ²	Source term in partial differential equation (3.1)	
r	-	Parameter in an incident angle modifier model (3.52)	<i>r</i>
S	W/m ²	Solar energy absorbed as defined by (3.45) or (3.46)	
<i>Smode</i>		Solar radiation mode	<i>Smode</i>
T	°C	Collector fluid temperature in (3.1)	
T_0	°C	Collector fluid temperature at (t_0, x_0) in (3.1)	
T_1	°C	Inlet temperature of process P. See (3.42)	
T_2	°C	Outlet temperature of process P. See (3.42)	
T_a	°C	Ambient air temperature	<i>Ta</i>
T_c	°C	Outer cover temperature	
T_e	°C	Effective environmental temperature (3.30)	
T_i	°C	Collector inlet temperature	
<i>Tmode</i>		Testing mode	<i>Tmode</i>
T_o	°C	Modelled collector outlet temperature	
T_p	°C	Absorber surface temperature	
T_r	°C	Effective radiation temperature	
T_{st}	°C	Collector fluid stagnation temperature in (3.1). See (3.10)	
T_{xo}	°C	Measured (experimental) collector outlet temperature	<i>Txo</i>
t	s	Time	
t_0	s	Time	
t_n	s	Time at start of n:th simulation time step	
U_b	W/K·m ²	Backside loss coefficient of collector	<i>Ub</i>
U_g	W/K·m ²	Heat loss coefficient of glazing; plate to outer cover	
U_L	W/K·m ²	Overall loss coefficient of collector	
U_t	W/K·m ²	Top loss coefficient of collector	
U_w	J/K·m ³	Wind dependent loss coefficient of collector	<i>Uw</i>
u_0	W/K·m ²	Constant in U-value model (3.26)	<i>u1</i>
u_1	W/K ² ·m ²	Constant in U-value model (3.26)	<i>u2</i>
V_f	m ³ /m ²	Volume of absorber channels	<i>Vf</i>

v_c	$\text{m}^3/\text{s}\cdot\text{m}^2$	Collector fluid volume flow rate	
v_w	m/s	Wind velocity	vw
w	$1/\text{s}$	Normalized velocity of thermal plug. See (3.3)	
x	-	Normalized spatial coordinate parallel to the collector flow (3.1). $x = 0$ at the inlet of the collector and $x = 1$ at the outlet	
ρ	kg/m^3	Average density of collector fluid	Rho
$\Delta T/G$	$\text{K}\cdot\text{m}^2/\text{W}$	Normalised temperature difference	
ΔT_g	K	Temperature difference defined by (3.33)	
Δt_n	s	Length of n:th simulation time step	
θ	deg	Incident angle	
θ_L	deg	Angle between the normal to the collector surface and the direction of the radiation into the longitudinal plane. (See Figure 4.2.1.2 of TYPE 1)	
θ_T	deg	Angle between the normal to the collector surface and the direction of the radiation into the transverse plane. (See Figure 4.2.1.2 of TYPE 1)	
α_0	W/m^2	Coefficient in source term (3.7)	
α_1	$\text{W}/\text{K}\cdot\text{m}^2$	Coefficient in source term (3.7)	
α_2	$\text{W}/\text{K}^2\cdot\text{m}^2$	Coefficient in source term (3.7)	
β_1	s^{-1}	Constant in outlet temperature expression (3.2). See (3.8)	
β_2	s^{-1}	Constant in outlet temperature expression (3.2). See (3.9)	
τ	s	Time in simulation time step	
$(\tau\alpha)_n$	-	Transmittance-absorptance product for normal incidence	tan
ζ	-	Correction factor defined by (3.32)	

3 Mathematical description

The mathematical model underlying the MFC component is not described in literature. Thus, it is appropriate to describe it in some detail here.

3.1 The dynamic model

The component model is based on the partial differential equation

$$(C_{eff} + V_f \rho c_p) \cdot \frac{\partial T}{\partial t} + m_c \cdot c_p \cdot \frac{\partial T}{\partial x} = q(T) \quad (3.1)$$

where the source term $q(T)$ is a second order polynomial in the temperature $T = T(x, t)$. The equation is derived from the energy balance of a control element taking into account

- The change in energy content of the element
- The energy transfer by the fluid flow
- The temperature dependent energy flow between the element and the surrounding
- A line heat source.

Thus, the temperature gradient perpendicular to the flow and the conductive heat transfer parallel to the flow are neglected.

Given constant boundary and initial conditions the PDE (3.1) can be solved analytically. The solutions has the form

$$\left\{ \begin{array}{l} T(x(t), t) = \frac{\exp(-\beta_1 \cdot (t-t_0)) \cdot (T_0 - T_{st})}{1 + \frac{\beta_2}{\beta_1} \cdot (1 - \exp(-\beta_1 \cdot (t-t_0)))} \cdot (T_0 - T_{st}) + T_{st} \\ x(t) = x_0 + \frac{\dot{m}_c \cdot c_p}{C_{eff} + V_f \rho c_p} \cdot (t-t_0) \end{array} \right. \quad (3.2)$$

where $T_0 = T(x_0, t_0)$ is an upstream temperature of an earlier point in time. Further, β_1 , β_2 , and T_{st} are functions of

- the coefficients in the PDE (3.1), i.e. the collector characteristics, and
- the boundary conditions, i.e. the ambient temperature, the solar radiation, etc.

Thus, we have a function, valid within a simulation time step, that relate $T(x, t)$ to one upstream temperature. We may write

$$T(1, t_n + \tau) = F(T(1 - w_n \tau, t_n); \mathbf{p}, \mathbf{b}_n) \quad (3.3)$$

where

t_n = start of n:th time step

τ = running time within the time step

$w_n = \frac{\dot{m}_c \cdot c_p}{A_c \cdot (C_{eff} + V_f \rho c_p)}$ "thermal plug velocity" of the n:th simulation time step

\mathbf{p} = a set of parameters describing the collector

\mathbf{b}_n = the boundary conditions of the n:th simulation time step

At a point along the collector the temperature at the beginning of one time step is equal to the temperature at the end of previous time step. The inlet temperature change abruptly from one time step to the next, thus producing discontinuities that propagate downstream. Avoiding the discontinuities, the upstream temperature of (3.3) may be written as a function of a temperature further upstream using the boundary conditions of the previous simulation time step.

$$T(1-w_n \cdot \tau, t_n) = F(T(1-w_n \cdot \tau - w_{n-1} \cdot \Delta t_{n-1}, t_{n-1}); \mathbf{p}, \mathbf{b}_{n-1}) \quad (3.4)$$

This may be repeated until we get a temperature that depends on the inlet temperature, i.e. the spatial expression $x = 1 - w_n \cdot \tau - w_{n-1} \cdot \Delta t_{n-1} \dots = 0$. Thus, a particular sample outlet temperature depends on a particular sample inlet temperature via a series of equations like (3.4).

This is an important characteristic of this model. Firstly, it makes it straight forward to implement the model. Secondly, it highlights the role the collector heat capacity plays in the model. The heat capacity delays the downstream propagation of a temperature profile; i.e. the velocity of the temperature profile is lower than that of the fluid. However, the heat capacity does not smear out or damp the profile. The latter is a major simplification compared to the behaviour of a real world collector.

We may use this characteristic to devise a metaphor. A row of **thermal plugs** propagates downstream the collector. One thermal plug is created at the collector inlet during each simulation time step. The thermal plug then propagates downstream the collector with the velocity w according to the second equation of (3.2). The temperature of the thermal plug develops with time due to heat exchange with the surrounding, according to the first equation of (3.2). Fractions of two or more, typically of two, thermal plugs appear at the collector outlet during each simulation time step.

The collector outlet temperature returned by the MFC component is a weighted average of averages calculated for each thermal plug passing the outlet.

3.1.1 No flow conditions

The above description of the dynamic model apply to flow conditions. When the flow is off, a slightly different algorithm is needed. The outlet temperature at the end of the simulation time step $T(1, t_n + \Delta t_n)$ is calculated and stored. With zero flow this is done using

$$\begin{cases} T(1, t_n + \Delta t_n) = \frac{\exp(-\beta_1 \cdot \Delta t_n) \cdot (T(1, t_n) - T_{st})}{1 + \frac{\beta_2}{\beta_1} \cdot (1 - \exp(-\beta_1 \cdot \Delta t_n))} + T_{st} \\ T(1, t_n) = T(1, t_{n-1} + \Delta t_{n-1}) \end{cases} \quad (3.5)$$

When the flow is off, the outlet temperature returned by the MFC component is the time average of the temperature at the collector outlet. It is calculated using the analytical solution of the integral

$$T_o = \frac{1}{\Delta} \int_0^{\Delta} \left(\frac{\exp(-\beta_1 \cdot \tau) \cdot (T(1, t_n) - T_{st})}{1 + \frac{\beta_2}{\beta_1} \cdot (1 - \exp(-\beta_1 \cdot \tau))} + T_{st} \right) \cdot d\tau \quad (3.6)$$

Periods without flow presents a special problem to the implementation. Boundary conditions of previous time steps are stored as long as they may influence on future outlet temperatures. The outlet temperatures after a period with no flow will depend on the boundary conditions during the period with no flow and some of the most recent time steps with flow. Thus, if data for all time steps are stored long periods with no flow would require a large memory. However, when needed two adjacent time steps with no flow are replaced by one equivalent time step. This is repeated for the time step -20 and -21 so that a continuous sequence of time steps are replaced by one equivalent time step. (The time step twenty steps before the current time step is denoted -20.) The price is a small loss in accuracy.

3.2 The source term $q(T)$ and the Cmode

The structure of the source term $q(T)$ is a compromise. It should permit an analytical solution to (3.1) and a fair description of the heat exchange between the collector and the surrounding. The source term chosen has the form

$$q(T) = \alpha_0 - \alpha_1 \cdot T - \alpha_2 \cdot T^2 \quad (3.7)$$

The coefficients β_1 , β_2 , and T_{st} of (3.2) are related to the coefficients α_0 , α_1 and, α_2 through

$$\beta_1 = \frac{\sqrt{\alpha_1^2 + 4 \cdot \alpha_2 \cdot \alpha_0}}{C_{eff} + V_f \cdot \rho \cdot c_p} \quad (3.8)$$

$$\beta_2 = \frac{\alpha_2}{C_{eff} + V_f \cdot \rho \cdot c_p} \quad (3.9)$$

and T_{st} which is the stagnation temperature

$$T_{st} = \frac{2 \cdot \alpha_0}{\alpha_1 + \sqrt{\alpha_1^2 + 4 \cdot \alpha_2 \cdot \alpha_0}} \quad (3.10)$$

The value of Cmode controls the way the coefficients α_0 , α_1 and, α_2 are calculated based on the collector performance parameters.

3.2.1 Cmode = 1. Linear Efficiency

This case mimics the base case of the standard TRNSYS TYPE1 (Mode = 1: Linear Efficiency) that is based on the steady state collector model

$$\eta = F_R(\tau\alpha)_n - F_R U_L \cdot \frac{T_i - T_o}{G_T} \quad (3.11)$$

This efficiency model is often displayed as a straight line plot of η versus $(T_i - T_a)/G_T$ with an intercept of $F_R(\tau\alpha)_n$ and a slope of $-F_R U_L$. However, collector test results may also be presented as η versus $(T_{av} - T_a)/G_T$ or even η versus $(T_o - T_a)/G_T$, where T_i , T_{av} , T_o are the inlet, the average, and the outlet temperature, respectively. In the latter two cases the intercept and the slope are $F_{av}(\tau\alpha)_n$, $F_{av} U_L$, and $F_o(\tau\alpha)_n$, $F_o U_L$, respectively.

The source term is based on the collector average temperature T_{av}

$$q(T) = F_{av}(\tau\alpha)_n \cdot G_T - F_{av} U_L \cdot (T - T_a) \quad (3.12)$$

which yields the following set of coefficients

$$\alpha_0 = F_{av}(\tau\alpha)_n \cdot G_T + F_{av} U_L \cdot T_a \quad (3.13)$$

$$\alpha_1 = F_{av} U_L \quad (3.14)$$

$$\alpha_2 = 0 \quad (3.15)$$

However, the efficiency may be given in terms of, either one of these three temperatures. The following relations (Duffie and Beckmann, 1991) are used to convert to average temperature parameters

$$F_{av}(\tau\alpha)_n = F_R(\tau\alpha)_n \frac{C_{test}}{C_{test} - \frac{F_R U_L}{2}} = F_o(\tau\alpha)_n \frac{C_{test}}{C_{test} + \frac{F_o U_L}{2}} \quad (3.16)$$

$$F_{av} U_L = F_R U_L \frac{C_{test}}{C_{test} - \frac{F_R U_L}{2}} = F_o U_L \frac{C_{test}}{C_{test} + \frac{F_o U_L}{2}} \quad (3.17)$$

In this case the discussion above (Chapter 1) on **local U-value** is not relevant since the collector U-value is constant and may be excluded from the integration.

$$\int U_L \cdot T(x) \cdot dx = U_L \cdot \int T(x) \cdot dx \quad (3.18)$$

However, there is a definition problem regarding the average temperature.

For Cmode = 1 there is no option to account for non-normal solar incidence.

3.2.2 Cmode = 2. Quadratic Efficiency

This case allows modeling a collector U-value that depend on the working temperature, the wind velocity, and the sky temperature. Further, it includes various options to model the dependence of the incident angle of the solar radiation. The source term is

$$q(T) = S - a_1 \cdot (T - T_a) - a_2 \cdot (T - T_a)^2 - a_w \cdot v_w \cdot (T - T_a) - a_r \cdot (T - T_r) \quad (3.19)$$

and identification between (3.7) and (3.19) yields the source term coefficients

$$\alpha_0 = S + (a_1 - a_2 \cdot T_a + a_w \cdot v_w) \cdot T_a + a_r \cdot T_r \quad (3.20)$$

$$\alpha_1 = a_1 - 2 \cdot a_2 \cdot T_a + a_w \cdot v_w + a_r \quad (3.21)$$

$$\alpha_2 = a_2 \quad (3.22)$$

where S is the absorbed solar energy defined in Chapter 3.2.5.

Cmode = 2 may be combined with all relevant combinations of Dmode, Smode, Tmode, and Omode.

3.2.3 Cmode = 3.

This mode is a result of an effort to refine the model, regarding

- The collector efficiency factor
- The surrounding temperature

The model is restricted to collectors with small top loss coefficients. The source term is

$$q(T) = F'(T) \cdot (S - U_t(T) \cdot (T - T_e) - (U_b + U_w \cdot v_w) \cdot (T - T_a)) \quad (3.23)$$

where

$F'(T)$	the collector efficiency factor	-
T_e	effective environmental temperature	°C
$U_t(T)$	collector top loss coefficient	W/K·m ²
U_b	collector back loss coefficient	W/K·m ²
U_w	collector wind dependent loss coefficient	J/K·m ³

3.2.3.1 $F'(T)$ the collector efficiency factor

The collector efficiency factor accounts for the way the energy absorbed in the black surface is split between the working fluid and the surrounding. The collector efficiency factor will depend on temperature when the collector heat loss coefficient does so. That is obvious from the definition. However, the mechanism is complex and there is no mathematical model readily available. The heat transfer coefficient between the fluid and the pipe depends on temperature. The radiation losses depend on the local fin temperature. The convection depends on temperature and the convection losses depend on the local air movement above the fin as well as on the global air movement transporting heat from the bottom to the top of the collector. As a result the collector efficiency factor will take different values for fins located above and below the nearest absorber pipe and for fins in the top and in the bottom of the collector.

It is reasonable to assume a linear temperature dependence for the collector efficiency factor

$$F'(T) = f_0 + f_1 \cdot (T - T_e) \quad (3.24)$$

where f_0 and f_1 are two constants.

3.2.3.2 $U_i(T)$ the collector top loss coefficient

The collector top loss coefficient is given by

$$U_i(T) = \frac{U_g(T) \cdot h}{U_g(T) + h} \quad (3.25)$$

where

$U_g(T)$ is the U-value between the absorber and the top cover $\text{W/K}\cdot\text{m}^2$
 h the top cover heat transfer coefficient to outside $\text{W/K}\cdot\text{m}^2$

To account for the temperature dependence of U_g the following expression is used

$$U_g(T) = u_0 + u_1 \cdot (T_p - T_c) \quad (3.26)$$

where

T_p the absorber surface temperature (plate) $^{\circ}\text{C}$
 T_c the temperature of the outer cover $^{\circ}\text{C}$

The heat loss from the top cover to the surrounding occurs through convection and radiation, thus

$$h = h_c + h_r \quad (3.27)$$

$$h_r = \varepsilon \cdot \sigma \cdot (T_c^2 + T_r^2) \cdot (T_c + T_r) \quad (3.28)$$

$$h_c = 2.8 + 3.0 \cdot v_w \quad (3.29)$$

where

h_r	radiation heat transfer coefficient	W/K·m ²
h_c	convective heat transfer coefficient	W/K·m ²
T_c	the outer cover temperature	°C
T_r	equivalent radiation temperature	°C
v_w	wind velocity	m/s

3.2.3.3 T_e , the effective environmental temperature

An effective environmental temperature, T_e , is used to calculate the heat losses from the top cover.

$$T_e = \frac{h_c \cdot T_a + h_r \cdot T_r}{h_c + h_r} \quad (3.30)$$

3.2.3.4 $q(T)$ final expression

Substituting (3.24), (3.25), and (3.26) in (3.23) yields

$$q(T) = (f_0 + f_1 \cdot (T - T_e)) \cdot (S - \zeta \cdot (u_0 + u_1 \cdot (T - T_e - \Delta T_g))) \cdot (T - T_e) - (U_b + U_w \cdot v_w) \cdot (T - T_a) \quad (3.31)$$

where

$$\zeta = \frac{h}{h + U_g(T)} \quad (3.32)$$

$$\Delta T_g = (T - T_p) + (T_c - T_e) \quad (3.33)$$

Inspection of the equations (3.31) together with the assumption $h > U_g(T)$ discloses that $q(T)$ is approximately described by a cubic polynomial in T . To apply the analytical solution a quadratic approximation to $q(T)$ is required.

Approximate values for ζ (3.32) and ΔT_g (3.33) are evaluated using the classical flat plate solar collector theory (Duffie and Beckman, 1991). These values are assumed constant during a time step. First, constant values of F' and U_L are calculated on the basis of the user supplied collector data and the collector inlet temperature. Secondly, the energy gain and the collector outlet temperature are calculated and, finally, ζ and ΔT_g .

After some algebraic manipulation of (3.31) we arrive at the expression

$$q(T) = -f_1 \cdot \zeta \cdot u_1 \cdot (T - T_e)^3 - (f_0 \cdot \zeta \cdot u_1 - f_1 \cdot \zeta \cdot (u_0 + u_1 \cdot \Delta T)) \cdot (T - T_e)^2 - f_1 \cdot (U_b + U_w \cdot v_w) \cdot (T - T_e) \cdot (T - T_a) + (f_1 \cdot S - f_0 \cdot \zeta \cdot (u_0 + u_1 \cdot \Delta T)) \cdot (T - T_e) + f_0 \cdot S - f_0 \cdot (U_b + U_w \cdot v_w) \cdot (T - T_a) \quad (3.34)$$

This equation contains a cubic term, which is too large to be neglected. However, for a given interval of T the term $(T-T_e)^3$ may be approximated by a quadratic polynomial. An approximation, that minimises the maximum error can be found using the Chebyshev polynomial, $T_3(x) = 4 \cdot x^3 - 3 \cdot x$. This polynomial has the property: $|T_3(x)| < 1$ when $|x| \leq 1$. Thus the approximation in the interval $T_{CH} - \Delta T_{CH} \leq (T - T_e) \leq T_{CH} + \Delta T_{CH}$ is given by

$$\left(\frac{(T-T_e)-T_{CH}}{\Delta T_{CH}} \right)^3 = \frac{3}{4} \cdot \frac{(T-T_e)-T_{CH}}{\Delta T_{CH}} + \frac{1}{4} \cdot T_3 \left(\frac{(T-T_e)-T_{CH}}{\Delta T_{CH}} \right) \quad (3.35)$$

Solving for $(T-T_e)^3$ yields:

$$\begin{aligned} (T-T_e)^3 &= 3 \cdot T_{CH} \cdot (T-T_e)^2 - \\ &\quad -3 \cdot T_{CH}^2 \cdot (T-T_e) + 0.75 \cdot \Delta T_{CH}^2 \cdot (T-T_e) + \\ &\quad + T_{CH}^3 - 0.75 \cdot \Delta T_{CH}^2 \cdot T_{CH} + \\ &\quad + \frac{\Delta T_{CH}^3}{4} \cdot T_3 \left(\frac{(T-T_e)-T_{CH}}{\Delta T_{CH}} \right) \end{aligned} \quad (3.36)$$

Chebyshev polynomial

Substituting equation (3.36) into equation (3.34) and neglecting the last term of equation (3.36) yields the quadratic polynomial needed.

$$\begin{aligned} q(T) &= -(f_1 \cdot \zeta \cdot (u_0 - u_1 \cdot \Delta T_g) + f_0 \cdot \zeta \cdot u_1 + 3 \cdot f_1 \cdot \zeta \cdot u_1 \cdot T_{CH}) \cdot (T-T_e)^2 - \\ &\quad - f_1 \cdot (U_b + U_w \cdot v_w) \cdot (T-T_a) \cdot (T-T_e) + \\ &\quad + (f_1 \cdot S - f_0 \cdot \zeta \cdot (u_0 - u_1 \cdot \Delta T_g) - f_1 \cdot \zeta \cdot u_1 \cdot (0.75 \cdot \Delta T_{CH}^2 - 3 \cdot T_{CH}^2)) \cdot (T-T_e) - \\ &\quad + f_0 \cdot (S - (U_b + U_w \cdot v_w) \cdot (T-T_a)) + \\ &\quad + f_1 \cdot \zeta \cdot u_1 \cdot (0.75 \cdot \Delta T_{CH}^2 - T_{CH}^2) \cdot T_{CH} \end{aligned} \quad (3.37)$$

The neglected term represents the error introduced by this approximation. The magnitude of this error is proportional to the third power of the interval width, $2 \cdot \Delta T_{CH}$. For a typical solar collector the error can be estimated

$$\left| f_1 \cdot \zeta \cdot u_1 \cdot \frac{\Delta T_{CH}^3}{4} \cdot T_3 \left(\frac{(T-T_e)-T_{CH}}{\Delta T_{CH}} \right) \right| \leq 0.3 \text{ [W} \cdot \text{m}^{-2}] \quad (3.38)$$

$|T_3| \leq 1$

where $f_1 = -0.0005$, $\zeta = 1.0$, $u_1 = 0.02$, $\Delta T_{CH} = 50$.

Identification between equation (3.37) and (3.7) results in

$$\begin{aligned} \alpha_0 = & f_0 \cdot (S + \zeta \cdot u_0 \cdot T_e + U_b \cdot T_a + \zeta \cdot u_1 \cdot \Delta T_g \cdot T_e + \zeta \cdot u_1 \cdot T_e^2) - \\ & - f_1 \cdot (S + \zeta \cdot u_0 \cdot T_e^2 + \zeta \cdot u_1 \cdot \Delta T_g \cdot T_e^2 + U_b \cdot T_a \cdot T_e) + \\ & + f_1 \cdot \zeta \cdot u_1 \cdot \left\{ (0.75 \cdot \Delta T_{CH}^2 - T_{CH}^2) \cdot T_{CH} - 3 \cdot T_{CH} \cdot T_e^2 \right\} \end{aligned} \quad (3.39)$$

$$\begin{aligned} \alpha_1 = & \zeta \cdot f_0 \cdot (u_0 - 2 \cdot u_1 \cdot T_e) - 2 \cdot \zeta \cdot f_1 \cdot u_0 \cdot T_e - \zeta \cdot (f_0 - 2 \cdot f_1 \cdot T_e) \cdot u_1 \cdot \Delta T_g + \\ & + (f_0 - f_1 \cdot (T_e + T_a)) \cdot (U_b + U_w \cdot v_w) - \\ & - f_1 \cdot S - \zeta \cdot f_1 \cdot u_1 \cdot (6 \cdot T_{CH} \cdot T_e + 3 \cdot T_{CH}^2 - 0.75 \cdot \Delta T_{CH}^2) \end{aligned} \quad (3.40)$$

$$\alpha_2 = \zeta \cdot f_0 \cdot u_1 + \zeta \cdot f_1 \cdot (u_0 - u_1 \cdot \Delta T_g) + f_1 \cdot (U_b + U_w \cdot v_w) + \zeta \cdot f_1 \cdot u_1 \cdot T_{CH} \quad (3.41)$$

Cmode = 3 may be combined with all relevant combinations of Dmode, Smode, Tmode, and Omode.

3.2.4 Dmode = 1. An improved dynamic model.

The basic dynamic model of the MFC component is described in Chapter 3.1 and it is accessed by **Dmode = 0**. The basic dynamic model, however simple, should be the first choice.

Dmode = 1. This mode is specially designed for evaluation of transient collector test data where the collector inlet temperature is changed in steps. It is restricted to tests using fairly high flow rates and high sampling rates. The flow rate must not change abruptly and it must not be switched off.

A.J. de Ron (1980) designed and validated a detailed model of a flat plate collector. He used three nodes perpendicular to the flow; the glazing, the absorber plate, and the fluid. Further, he let the number of nodes in the flow direction tend to infinity. He solved the system of equations using Laplace transformation and derived a set of transfer functions. Based on simplifications of these transfer functions he proposed some simplified models, one of which is implemented in the MFC component (See especially his equation 6, Figure 12, and Appendix E.)

The transfer function that relate the outlet to the inlet temperature may be divided into three transfer function representing the attenuation, the time delay, and a dynamic process P. The latter in the most simplified form may be written as a differential equation

$$T_2 + \frac{C_{collector}}{m_c \cdot c_p \cdot (1-E)} \cdot \frac{dT_2}{dt} = T_1 + \frac{C_{collector} \cdot E}{m_c \cdot c_p \cdot (1-E)} \cdot \frac{dT_1}{dt} \quad (3.42)$$

where

$$E = \exp\left(\frac{-h_{fp}}{m_c \cdot c_p}\right) \quad (3.43)$$

and where T_1 and T_2 are the inlet and outlet temperature of the process P, respectively. In de Ron's study (3.42) is derived for $C_{\text{collector}}$ equal to the absorber heat capacity.

The solution (3.2) comprises an attenuation, and a time delay. Thus, using de Ron's nomenclature the basic MFC model may be described as a series of

- An attenuation that account for a temperature dependent U-value
- A time delay corrected for the collector heat capacity
- A dynamic process $P \equiv 1$

He calls this model simplistic. The MFC model with $D_{\text{mode}} = 1$ is a combination of the basic MFC model (3.2) and de Ron's dynamic process P (3.42). Thus, for $D_{\text{mode}} = 1$ the MFC component is a combination of (3.2) with $C_{\text{eff}} = 0$ and the (3.42) with $C_{\text{collector}} = C_{\text{eff}}$.

It must be underlined that (3.42) models the response to changes in the inlet temperature assuming other driving signals are constant. However, numerical experiments suggest that the MFC model with $D_{\text{mode}} = 1$ does actually model the response to step changes in the solar radiation better than does the basic MFC model.

de Ron shows that for high flow the simplified model (3.42) does agree well to his detailed model, but he does not discuss the range of validity. However, it is obviously not valid for true low flow conditions. A necessary condition for (3.42) to be valid might be that a step change in the inlet temperature appears at the outlet delayed by the hydraulic time constant, i.e. the fluid control volume associated with the step change shall not get too close to the temperature equilibrium with the absorber. Thus, tentatively, a necessary condition is

$$\exp\left(\frac{-h_{fp}}{m_c \cdot c_p}\right) > 0.2 \quad (3.44)$$

The process P (3.42) is implemented as a difference equation and thus convergence becomes an issue. This mode requires a simulation time step no longer than a couple of minutes.

3.2.5 Smode. S the solar radiation absorbed

Solar radiation may simultaneously strike a flat plate collector from many directions, e.g. directly from the sun, from the sky, from the ground and from special reflectors. The MFC components allow for six radiation components each having its own incident angle. The solar radiation absorbed S is a sum over products of incident angle modifier and irradiance for the components prescribed by the Smode value.

$$S = E \cdot \left(\underbrace{IAM(I_b) \cdot G_b + IAM(I_d) \cdot G_d + IAM(I_g) \cdot G_g}_{\text{Smode} = 0, 2} + \underbrace{IAM(I_r) \cdot G_r + IAM(I_{bx}) \cdot G_{bx} + IAM(I_{dx}) \cdot G_{dx}}_{\text{Smode} = 2} \right) \quad (3.45)$$

$$\begin{aligned}
S = E \cdot & \left(\underbrace{IAM(I_b, I_{bT}) \cdot G_b + IAM(I_d, I_d) \cdot G_d + IAM(I_g, I_g) \cdot G_g}_{S_{mode} = 1, 3} + \right. \\
& \left. + \underbrace{IAM(I_r, I_{rT}) \cdot G_r + IAM(I_{bx}, I_{bxT}) \cdot G_{bx} + IAM(I_{dx}, I_{dx}) \cdot G_{dx}}_{S_{mode} = 3} \right)
\end{aligned} \quad (3.46)$$

where

$$E = \begin{cases} \eta_0 & C_{mode}=2 \\ (\tau\alpha)_n & C_{mode}=3 \end{cases} \quad (3.47)$$

Thus, for $S_{mode} = 0$ or 1 , S is a sum over three radiation components, and for $S_{mode} = 2$ or 3 , S is a sum over six components. The same incident angle modifier function $IAM(*)$ is used for all radiation components. The choice of the IAM function is controlled by the value of O_{mode} (see Chapter 3.2.7).

In summary the following inputs are required for different values of S_{mode} :

S_{mode}	Radiation components	Incident angles
0	Gb, Gd, Gg	Ib, Id, Ig
1	Gb, Gd, Gg	Ib, Id, Ig, IbT
2	Gb, Gd, Gg, Gr, Gbx, Gdx	Ib, Id, Ig, IbT, Ir, Ibx, Idx
3	Gb, Gd, Gg, Gr, Gbx, Gdx	Ib, Id, Ig, IbT, Ir, Ibx, Idx, IrT, IbxT

3.2.6 Tmode: Flow rate, fluid density, and heat capacity

In a full scale experiment the collector loop typically includes a volume flow meter rather than a mass flow meter and some anti-freeze working fluid rather than pure water. Further, in a low flow system the fluid temperature at the flow meter typically differs significantly from the average collector temperature.

The specific heat capacity c_p and the density ρ of the working fluid enter into the PDE (3.1). However, it is difficult to account for the temperature dependence by introducing $c_p(T)$ and $\rho(T)$ in (3.1). Thus, during a simulation time step c_p and ρ are kept constant. The values of the parameters Cpc, Rho, and Tmode control how c_p , ρ , and the mass flow rate m_c are assigned values.

$$c_p = \begin{cases} \text{LookUp} \left(\frac{T_i(n) + T_o(n-1)}{2} \right) & T_{mode}=0,10 & \text{Par } Cpc < 0 \\ \text{LookUp} \left(\frac{T_i(n) + T_{xo}(n)}{2} \right) & T_{mode}=1,11 & \text{Par } Cpc < 0 \\ \text{Parameter } Cpc & T_{mode}=0,1,10,11 & \text{Par } Cpc > 0 \\ \text{Input } Cpc & T_{mode}=2,12 & \end{cases} \quad (3.48)$$

The function LookUp(\cdot) indicates that the value is looked up from a table provided in a text file. In these cases the logical number of the file is hold by the parameters Cpc and Rho (LU = - Cpc, and LU = - Rho), respectively.

$$\rho = \begin{cases} \text{LookUp}(T_i(n)) & \text{Tmode}=0,1,10,11 \quad \text{Parameter } Rho < 0 \\ \text{Parameter } Rho & \text{Tmode}=0,1,10,11 \quad \text{Pararameter } Rho > 0 \\ \text{Input } Rho & \text{Tmode}=2,12 \end{cases} \quad (3.49)$$

$$m_c = \begin{cases} mc & \text{Tmode}=0,1,2 \\ \rho \cdot vc & \text{Tmode}=10,11,12 \end{cases} \quad (3.50)$$

3.2.7 Omode. Incident angle modifier

The parameter Omode controls the choice of a specific IAM function out of six alternatives. *The same IAM function is used both for direct and diffuse radiation.* The user supplies an effective incident angle for each diffuse component, the value of which might be critical especially for CPC-collectors.

Omode = 0 prescribes $IAM(\theta) \equiv 1$

Omode = 1 prescribes

$$IAM(\theta) = \begin{cases} 1 - b_0 \cdot \left(\frac{1}{\cos(\theta)} - 1 \right) & 0 < b_0, 0 \leq \theta \leq 60 \\ (1 - b_0) \cdot \left(1 - \frac{\theta - 60}{30} \right) & 0 < b_0, 60 < \theta \leq 90 \\ 1 & b_0 = 0 \end{cases} \quad (3.51)$$

This is function is identical to the corresponding function in TRNSYS TYPE 1 (optical mode = 1), except for the third case ($b_0 = 0$). In TYPE 1 the two upper functions are valid even for $b_0 = 0$.

Omode = 2. Values for $IAM(\theta)$ are supplied in a file accessed as the Fortran logical unit LU_i. These data are read and interpolated by the function IAM of the MFC component.

Omode = 3 is not implemented

Omode = 4 allows modeling of collectors that are optically asymmetric using $IAM(\theta_L, \theta_T) = IAM_L(\theta_L) * IAM_T(\theta_T)$. Values for $IAM_L(\theta)$ and $IAM_T(\theta)$ are supplied in a file accessed as the Fortran logical unit LU_i. The data are read and interpolated by the function IAM of the MFC component. θ_L , and θ_T are the incident angle projected in longitudinal and the transversal planes, respectively. They are defined in the TRNSYS 13.2 manual page 4.2.1-8.

Omode = 5 allows modeling of collectors that are optically asymmetrical. Values for $IAM(\theta_L, \theta_T)$ are supplied in a file accessed as the Fortran logical unit LUI. The data are read and interpolated by the function IAM of the MFC component.

Omode = 6 prescribes

$$IAM(\theta) = 1 - \left(\tan\left(\frac{\theta}{2}\right) \right)^{1/r} \quad (3.52)$$

This model that is copied from the collector model DynColl (W. Spirk1,) is ascribed to Amrosetti. However, in the MFC component this model is used for both beam and diffuse radiation whereas in DynColl an integral over the half-sphere is used for diffuse radiation.

3.2.8 A pitfall for PRESIM users

TRNSYS requires TRNSYS SI units. In PRESIM the user may use other units and PRESIM makes the conversions required. However, that might cause problems when the parameters Cpc are Rho are used to provide FORTARAN logical unit numbers. If the value is converted a different number will be submitted to TRNSYS and an error will occur. Thus, one need to use TRNSYS units or better use change "Quantity" to No. dimensionless number.

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4 TRNSYS Component Description

4.1 PARAMETERS Cmode = 1

No	Symbol	Description	Unit
1	Cmode	Collector mode 1	-
2	NA	Not used	-
3	Ac	Collector aperture area	m ²
4	Ceff	Effective heat capacity of collector	kJ/(K.m ²)
5	Vf	Volume of absorber channels	m ³ /m ²
6	Cpc	Specific heat of collector fluid	kJ/(K.kg)
7	Rho	Average density of collector fluid	kg/m ³
8	Emode	Efficiency mode	-
		1 η vs. $(T_i - T_a)/G$	
		2 η vs. $(T_{av} - T_a)/G$	
		3 η vs. $(T_o - T_a)/G$	
9	ctest	Heat capacity flow rate at test conditions	kJ/(h.m ² .K)
10	a	Intercept of collector efficiency	-
11	b	Negative slope of collector efficiency curve	kJ/(h.m ² .K)

4.2 INPUTS Cmode = 1

No	Symbol	Description	Unit
1	Tin	Collector inlet temperature	C
2	mc	Collector fluid mass flow rate	kg/h
3	Ta	Ambient temperature	C
4	GT	Total incident radiation	kJ/(h.m ²)

4.3 OUTPUTS $C_{mode} = 1, 2, \text{ and } 3$

No	Symbol	Description	Unit
1	To	Outlet fluid temperature	C
2	mo	Outlet fluid flow rate	kg/h
3	Qc	Rate of energy gain	kJ/h

4.4 PARAMETERS $C_{mode} = 2, 3$

No	Symbol	Description	Unit
1	C_{mode}	Collector mode	-
2	D_{mode}	Dynamic mode	-
3	A_c	Collector aperture area	m ²
4	C_{eff}	Effective heat capacity of collector	kJ/(K.m ²)
5	V_f	Volume of absorber channels	m ³ /m ²
6	C_{pc} /-LU	Specific heat of collector fluid	kJ/(K.kg)
7	ρ /-LU	Average density of collector fluid	kg/m ³
<i>$C_{mode} = 2$</i>			
8	η_0	Eta zero. (Zero loss efficiency)	-
9	a_1	Constant in U-value model	kJ/(h.K.m ²)
10	a_2	Constant in U-value model	kJ/(h.K ² .m ²)
11	a_w	Constant in U-value model; wind dependence	kJ.s/(h.K.m ³)
12	a_r	Constant in U-value model; long wave dependence	kJ/(h.K.m ²)
<i>$D_{mode} = 0$</i>			
13	NA	Not used	-
<i>$D_{mode} = 1$</i>			
13	hpf	Heat transfer coefficient between pipe and fluid	kJ/(h.K.m ²)
14	NA	Not used	-

Cmode = 3

8	f0	Constant in collector efficiency relation-	-
9	f1	Constant in collector efficiency relation-	-
10	tan	Effective normal transmittance absorptance product	-
11	u0	Constant in $U_g = u_0 + u_1(T_p - T_c)$	kJ/(h.K.m2)
12	u1	Constant in $U_g = u_0 + u_1(T_p - T_c)$	kJ/(h.K2.m2)
13	Ub	Collector backside loss coefficient	kJ/(h.K.m2)
14	Uw	Collector wind dependent loss coefficient	kJ.s/(h.K.m3)

Cmode = 2, 3

15	Smode	Solar radiation mode	-
16	Tmode	Test mode	-
17	Omode	Optical mode. Incident angle modifier	-

Omode = 1

18	b0	Incident angle modifier. $1 - b_0 * (1/\cos(\theta) - 1)$	-
----	----	---	---

Omode = 2, 4, 5

18	-LUI	Logical unit containing IAM data	-
----	------	----------------------------------	---

Omode = 6

18	r	Parameter in the Ambrosetti equation	-
----	---	--------------------------------------	---

4.5 INPUTS *Cmode = 2 and 3*

No	Symbol	Description	Unit
1	Tin	Collector inlet temperature	C
<i>Tmode < 10</i>			
2	mc	Collector fluid mass flow rate	kg/h

Tmode ≥ 10

2	vc	Collector fluid volume flow rate	m ³ /h
3	Ta	Ambient temperature	C
4	Tr	Long wave radiation temperature	C
5	Wind	Wind speed	m/s
6	Gb	Incident beam radiation	kJ/(h.m ²)

OMode = 1, 2, 6

7	Ib	Incident angle of Gb	deg
---	----	----------------------	-----

OMode = 4, 5

7	IbL	Incident angle of Gb in the longitudinal plane	deg
8	Gd	Incident diffuse radiation	kJ/(h.m ²)
9	Id	Incident angle of Gd	deg
10	Gg	Incident ground reflected radiation	kJ/(h.m ²)
11	Ig	Incident angle of Gg	deg

SMode = 1, 2, 3

12	IbT	Incident angle of Gb in the transverse plane	deg
----	-----	--	-----

TMode = 1, 2, 11, 12

13	Tout	Measured collector outlet temperature	C
----	------	---------------------------------------	---

TMode = 2, 12

14	Cpc	Specific heat of collector fluid	kJ/(K.kg)
15	Rho	Average density of collector fluid	kg/m ³

SMode = 2, 3

16	Gr	Incident reflected radiation	kJ/(h.m ²)
18	Gbx	Incident beam radiation (extra)	deg
20	Gdx	Incident diffuse radiation (extra)	kJ/(h.m ²)

OMode = 1, 2, 6

17	Ir	Incident angle of Gr	deg
19	Ibx	Incident angle of Gbx	deg
21	Idx	Incident angle of Gdx	deg

OMode = 4, 5

17	Ir	Incident angle of Gr in the longitudinal plane	deg
19	Ibx	Incident angle of Gbx in the longitudinal plane	deg
21	Idx	Incident angle of Gdx in the longitudinal plane	deg

SMode = 3

22	IrT	Incident angle of Gr in the transverse plane	deg
23	IbxT	Incident angle of Gbx in the transverse plane	deg

5 File format for user supplied data

The MFC component read and interpolate user supplied data using a special code. Thus, it does not use the TRNSYS routine DATA. There are some differences that must be observed.

The MFC code only require one parameter per file; the Fortran logical unit number. This number must be assigned to the file name using the TRNSYS statement ASSIGN. The MFC code does not prompt the user for the file name.

The MFC code is less flexible than DATA regarding the file format. However, DATA will read and interpret the MFC data files correctly if they do not include comment lines. The files consist of comment lines and data lines. The first non-blank character of a comment line must be "*". The data lines must consist of numerical values separated by one or more spaces, one comma, or one tab. The values of the independent variables must be in ascending order, but need not be at regular intervals. The format of the MFC data files must comply with the sample files below. The size of the MFC data files are limited. Each independent variable may hold a maximum of 10 values.

The MFC component reads the files at the beginning of the simulation. Subsequently, a MFC looks up values for the dependent variables given values of the independent variables. MFC uses linearly interpolation and does not extrapolate. The position in the table of the dependent variable is stored and used as a guess in the proceeding call.

5.1 Examples

MFC data files with one independent and one dependent variable shall include two equally long data lines, the first holding the values of the indepent variable and the second holding the values of the dependent variable. The first three examples are of that kind. Note that quantities must be supplied using "TRNSYS-SI-units", thus the unit of specific heat capacity is kJ/K·kg.

Rho.tbl

* Temperature dependence of water density

5	20	30	40	50	60	70	80	90	120
1e3	998	996	992	988	983	977	971	965	943

Cpc.tbl

* Temperature dependence of water heat capacity

5	20	30	40	50	60	70	80	90	120
4.206	4.181	4.175	4.175	4.177	4.18	4.186	4.193	4.201	4.231

IAM2.tbl

* Optical mode Omode=2

0	30	60	90
1.	.98	.80	.0

The optical mode 4 requires data on two incident angle modifiers. The file shall include data for one independent and two dependent variables

IAM4.tbl

* Optical mode Omode=4

0	30	60	90
* IAML	IAMT		
1.	1.		
0.98	1.10		
0.80	0.80		
0.	0.		

IAM5.tbl

* Optical mode Omode=5

0	30	60	90		
0	15	30	45	60	90
*IAM					
1.	.98	.90	.80	.60	.0
1.1	1.0	.98	.90	.60	.0
.90	.80	.60	.40	.30	.0
.0	.0	.0	.0	.0	.0

6 Getting started

MFC 1.0 is a TRNSYS component subroutine, i.e. it complies with TRNSYS's rules concerning the parameters, inputs, outputs, the units of physical quantities, etc.

6.1 The distribution disk

Directory	Files
\MFC\FOR	source code
\MFC\LIB	type52ru.obj, lelib_ru.lib
\MFC\INC	include files
\MFC\PRESIM	PRESIM component library; MFC10.sme
\MFC\OBJ	object code

6.2 File list

AD_DERON	CC	HWB_COEF	IN_DERON	ITW_COEF
LE2_COEF	LE2_EAT	LE2_ETA0	LE2_GETL	LE2_GETV
LE2_HUNT	LE2_IAM2	LE2_INCK	LE2_LCPC	LE2_LIAM
LE2_LOG1	LE2_LOG2	LE2_LOG3	LE2_LOG4	LE2_LOG5
LE2_LOG7	LE2_LOOK	LE2_LRHO	LE2_PACK	LE2_PRCK
LE2_READ	LE2_RHOC	LE2_SCPC	LE2_SIAM	LE2_SLV0
LE2_SLV1	LE2_SLV2	LE2_SLV3	LE2_SLV4	LE2_SLV5
LE2_SRHO	LE2_STBL	LEGAL	POI_COEF	SH_DERON
TYPE52	TYPECK52	T_DATA_C		

6.3 The source code

The code is written for the Microsoft Fortran Compiler (version 5.1) and some extensions to the ANSI FORTRAN 77 standard are used. However, the code is also compatible with the Lahey compiler. The code have not been tested with other compilers. The following extensions are used

- Upper and lower case letter are used to improve readability. It is assumed that the compiler in this context does not distinguish between upper and lower case.

- Long names for both subprograms and variables
- On-line comments beginning with exclamation point "!".
- The statement SELECT CASE ... END SELECT
- The statement DO ... END DO
- The statement INCLUDE
- The statement EXIT

Except for SELECT CASE ... END SELECT and EXIT, most compilers handle these extensions.

Each source file include one subprogram. Merging the current files causes a compiling error with Microsoft Fortran. That is because, there is a local commonblock, LE2_log, defined in the include file, LE2_LOG2.INC. A SAVE command in that include file, causes the error, since SAVE may appear only once in a source file(??).

6.4 Compiling and linking

The collector TYPE-routine is currently named TYPE52, which is in conflict with the Cooling Coil in the standard TRNSYS 13.1 component library. You might need to rename it.

Using a 386/387 computer system and Microsoft Fortran 5.1 the following command may be used for compilation

```
f1 /c /FPi87 /G2 filespec
```

and for linking the following options might need to be included

```
/ST:4096 /SEG:300
```

6.5 Running

I cannot think of anything very special. However, despite the test I have done there are certainly more bugs to be discovered. Please tell me, in great detail, about the bugs you encounter. Some test are performed in TYPE52 and when errors are encountered an error message is written to the standard output unit (LUW) and TypeCk is called (IOPT=2) and TRNSYS to stop after twenty such calls. The error messages have the format

```
subprogram Ti: xxx.xxx Err: xxxxxx message
```

where

subprogram = name of subprogram in which the error was detected

Ti: xxx.xxx = simulation time in hours

Err: xxxxxx = error code. However, currently '2000' is used as a place holder

6.5.1 Checking of user input

The parameter and input values are compared to upper and lower limits and outliers trigger errors. To suppress that check comment out the following statement in TYPE52-for

```
      call ParCheck ( Modes, Par, error )  
      call InCheck ( Modes, Par, In, error )
```

6.6 PRESIM

A PRESIM library, MFC10.SME, which include some PRESIM components for the MFC component. The placement of the collector symbol inlet and outlet do fit the 4x4mm grid.