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Appendix A

A1 Fortran code for the PV/T TRNSYS component

```
SUBROUTINE TYPE262 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C***********************************************************************
C       PV/THERMAL COLLECTOR SUBROUTINE
C
C Author: Joe Coventry
C Date commenced:      9/7/2001 last modified: 10/2/2004
C
C This component is a detailed model of a concentrating PV/thermal collector.
C The model considers capacitance effects.  The model is a detailed
C model, where the various quantities of heat transfer between cover,
C cells, plate, tube and fluid are calculated by iteratively solving the
C equations that physically describe the modes of heat transfer.
C
C***********************************************************************
C               STANDARD TRNSYS DECLARATIONS
                        DOUBLE PRECISION XIN,OUT
                        PARAMETER (NIMAX=7,NPMAX=34,NO=13,ND=0)
                        INTEGER*4 INFO,ICNTRL,NP
                        REAL T,DTDT,PAR,TIME
                        DIMENSION XIN(NIMAX),OUT(NO),PAR(NPMAX),INFO(15)
                        CHARACTER*3 YCHECK(NIMAX),OCHECK(NO)
C               Declaration specific to this model

C               TRNSYS common variables needed for using the store S and the
C               simulation time step DELT

                INCLUDE '..\INCLUDE\PARAM.INC'
                COMMON /SIM/ TIME0,TIMEF,DELT,IWARN
                COMMON /STORE/ NSTORE,IAV,S(NUMSTR)
                COMMON/LUNITS/LUR,LUW,IFORM,LUK

C               Maximum number of discrete elements (this can be changed)
                PARAMETER (MAXCELLS=100)

C               External functions
```

```
      EXTERNAL QTHFUNC1, CPWATER

C     Some constants used in the model (temp in K at 0 DegC, Stefan-Boltzmann constant)
      DATA IUNIT/0/,TZERO/273.15/,SBC/20.41E-8/

C     Declaration of parameters (commented below)
      INTEGER MODE
      INTEGER CELLS
      REAL REFEFF
      REAL REFTEMP
      REAL BETA
      REAL UNIFORMITY
      REAL LENGTH
      REAL WIDTH
      REAL REFLM
      REAL SHAPE
      REAL TRANSABS
      REAL COVERABS
      REAL EMIS
      REAL MASS
      REAL CP
      REAL TSTART
      REAL WGLASS
      REAL UCG
      REAL WCG
      REAL UCP
      REAL WCP
      REAL UPT
      REAL WPT
      REAL UINSUL
      REAL WINSUL
      REAL WCOVER
      REAL EMISCOV
      REAL CW0,CW1,CW2
      REAL TOL
      REAL HCTF
      REAL PERIM
      REAL XSAREA
      REAL FH

C     Counters
      INTEGER J
```

```
C           Inputs used in the model (commented below)
                REAL TFI
                REAL FLOW
                REAL ID
                REAL TAMB
                REAL WIND
                REAL SHADE
                REAL DIRT

C           Variables used within the model (in order of appearance)

C               Capacitance of each node
                REAL CAPNODE
C               Sum of thermal output
                REAL QTHSUM
C               Sum of electrical output
                REAL QELECSUM
C               Sum of losses through insulation
                REAL QINSULSUM
C               Sum of convection losses from the glass
                REAL QCONVSUM
C               Sum of radation losses from the glass
                REAL QRADSUM
C               Sum of cell temperatures (used to give an average cell temp)
                REAL TCSUM
C               Sum of glass temperatures (used to give an average glass temp)
                REAL TGSUM
C               Sum of plate temperatures (used to give an average plate temp)
                REAL TPSUM
C               Sum of cell temperatures (used to give an average tube temp)
                REAL TTSUM
C               Sum of mid glass temperatures (used to give an average mid glass temp)
                REAL TGMIDSUM
C               Sum of insulation cover temperatures (used to give an average ins. cover
temp)
                REAL TCOVSUM
C               Temperature of the inlet of the node
                REAL TFIN(MAXCELLS)
C               Average temperature of the fluid in the node
                REAL TBAR(MAXCELLS)
C               Temperature of the fluid in the node at the previous time step
                REAL TFINIT(MAXCELLS)
```

```
C       Temperatre at the inlet of the node at the previous time step
        REAL TFINPREV(MAXCELLS)
C       Temperature of the fluid at the outlet of the node
        REAL TFINAL(MAXCELLS)
C       Upper and lower guesses for the bisection
        REAL QTHUPPER,QTHLOWER
C       Boolean flag to indicate if the solution is in the guessed bounds
        LOGICAL SUCCESS
C       Thermal output
        REAL QTH
C       Array of thermal outputs
        REAL QTHARRAY(MAXCELLS)
C       Electrical output
        REAL QELEC
C       Array of electrical output
        REAL QELECARRAY(MAXCELLS)
C       Convective heat loss from glass
        REAL QCONV
C       Array of convective heat loss from glass
        REAL QCONVARRAY(MAXCELLS)
C       Radiative heat loss from glass
        REAL QRAD
C       Array of radiative heat loss from glass
        REAL QRADARRAY(MAXCELLS)
C       Heat loss through the insulation
        REAL QINS
C       Array of heat loss through the insulation
        REAL QINSARRAY(MAXCELLS)
C       Tube temperature
        REAL TT
C       Array of tube temperatures
        REAL TTARRAY(MAXCELLS)
C       Plate temperature
        REAL TP
C       Array of plate temperatures
        REAL TPARRAY(MAXCELLS)
C       Cell temperature
        REAL TC
C       Array of cell temperatures
        REAL TCARRAY(MAXCELLS)
C       Glass surface temperature
        REAL TG
```

```
C                     Array of glass surface temperatues
                      REAL TGARRAY(MAXCELLS)
C                     Mid glass/silicone temperature
                      REAL TGMID
C                     Array of mid glass/silicone temperatures
                      REAL TGMIDARRAY(MAXCELLS)
C                     Insulation cover temperature
                      REAL TCOVER
C                     Array of insulation cover temperatures
                      REAL TCOVARRAY(MAXCELLS)
C                     Coefficients for the differential equation Dt/dt = AT +B
                      REAL AA, BB
C                     Heat capacity of the water
                      REAL CPF

C                     Common block variables used in functions
      COMMON/PVTPARAMS/ID,WIDTH,LENGTH,CELLS,REFLM,SHAPE,SHADE,DIRT,CW0,
      1               CW1,CW2,WIND,MODE,TF,XSAREA,PERIM,FLOW,FH,HCTF,TT,TP,UPT,
      1               WPT,UINSUL,WINSUL,TAMB,SBC,EMISCOV,WCOVER,TCOVER,QINS,
      1               QCP,UCP,WCP,QELEC,REFEFF,BETA,REFTEMP,TC,QABSCELLS,
      1               TRANSABS,QCG1,TGMID,UCG,WCG,QABSGLASS,COVERABS,QCG2,TG,
      1               QCONV,WGLASS,QRAD,EMIS,UNIFORMITY

C-------------------------------------------------------------------
C           If it is the very first call of the simulation then continue,
C           with these initialisation things otherwise go down to parameters.

            IF (INFO(7).GE.0) GO TO 10

C           Set this to number of outputs
                      INFO(6)=NO

C           Set to 1 as routine depends on passage of time
                      INFO(9)=1

C           Set the common store size to the maximum number of cells
                      INFO(10)=2*MAXCELLS

C           Check that the user has provided the right number of inputs, outputs
C           and derivatives

                      CALL TYPECK(1,INFO,NIMAX,NPMAX,ND)
```

```
C                 Set the input and ouput variable types

                         DATA YCHECK/'TE1','MF1','IR1','TE1','VE1','DM1','DM1'/
                         DATA OCHECK/'TE1','MF1','PW1','PW1','PW1','PW1','PW1',
        1                        'TE1','TE1','TE1','TE1','TE1','TE1'/
                         CALL RCHECK(INFO,YCHECK,OCHECK)

C                 Set the first storage place in the middle of the allocated variables
                         ISTORE=INFO(10)
C-------------------------------------------------------------------
C                 Get the values of the parameter for this component (only once)
10                IF(INFO(1) .EQ. IUNIT) GO TO 30
                  IUNIT=INFO(1)

C                 First do common parameters

C                 MODE - whether or not the fluid convection coefficient is calculated
C                 explicitly  1 = no, 2 = yes
                         MODE=INT(PAR(1)+0.1)

C                 CELLS - number of nodes in the receiver is divided into along its length
                         CELLS=INT(PAR(2)+0.1)

C                 REFEFF - the reference efficiency of an encapsulated the solar cell
                         REFEFF=PAR(3)

C                 REFTEMP  - the reference temperature for calculation of solar cell efficiency
                         REFTEMP=PAR(4)+TZERO

C                 BETA - the coefficient relating cell efficiency and temperature
                         BETA=PAR(5)

C         UNIFORMITY - Scaling factor to account for the drop in electrical performance of the
C         receiver due to both longitudinal and transverse non-uniform radiation and temperature

                         UNIFORMITY = PAR(6)

C                 LENGTH - Length of the troughs
                         LENGTH = PAR(7)

C                 WIDTH - Width of the mirror (ie unshaded bit)
```

```
                WIDTH=PAR(8)

C       REFLM - Reflectivity of the mirror
                REFLM=PAR(9)

C       SHAPE - Optical accuracy of the mirror (1 = perfect)
                SHAPE=PAR(10)

C       TRANSABS - the transmission absorption coefficient for the cells
                TRANSABS = PAR(11)

C       COVERABS - the fraction of light passing through the cover that is absorbed
                COVERABS = PAR(12)

C       EMIS  - the emissivity of the surface of the cell encapsulation
                EMIS=PAR(13)

C       MASS - mass of the receiver and fluid combined
                MASS=PAR(14)+0.01

C       CP  - thermal capacitance of the receiver and fluid combined
                CP=PAR(15)

C       TSTART - initial temperature of the receiver and fluid
                TSTART=PAR(16)+TZERO

C       WGLASS - Width of glass cover for the purposes of calculating convection
C       and radiation losses
                WGLASS=PAR(17)

C       UCG  - U value between the cells and the glass
                UCG=PAR(18)

C       WCG  - Width of the connection between cells and glass for heat transfer purposes
                WCG = PAR(19)

C       UCP - U value between the cells and the plate
                UCP=PAR(20)

C       WCP - Width of interface between the cells and the plate
                WCP = PAR(21)
```

```
C          UPT - U value between the plate and tube
                UPT=PAR(22)

C          WPT- Width of the interface between plate and tube
                WPT = PAR(23)

C          UINSUL -  U value for the insulation
                UINSUL=PAR(24)

C          WINSUL - Perimeter length for calculating insulation losses
                WINSUL = PAR(25)

C          WCOVER - Perimeter length for calculating convection and radiation losses
C               from the insulation cover
                WCOVER = PAR(26)

C          EMISCOV - Emissivity of the insulation cover
                EMISCOV = PAR(27)

C     CW0, CW1, CW2  - Coefficients for calculation of convective heat loss from
C     all outer surfaces of the receiver.  hc = CW0 + CW1 * Wind speed + CW2 * Wind speed^2
                CW0=PAR(28)
                CW1=PAR(29)
                CW2=PAR(30)

C          TOL - tolerance of the iterative calculation of Qth
                TOL=PAR(31)

C-------------------------------------------------------------------------------------------

C          Now do parameters specific to modes of operation

C          Firstly, the input mode determines whether the convection
C          coefficient should be calculated explicitly or entered
C          as a parameter

           IF (MODE.EQ.1) THEN

C          HCTF - coefficient of convection for the fluid set as a parameter
                HCTF=PAR(32)/CELLS

           ELSEIF (MODE.EQ.2) THEN
```

```
C             PERIM - Wetted perimeter of the flow passage in the tube
                    PERIM=PAR(32)

C             XSAREA - cross-sectional area of the flow passage in the tube
                    XSAREA = PAR(33)

C             FH - Correction for Nusselt number to account for the internal fins
C             (ie. Using the Carnavos relation gives 0.74 for the CHAPS receiver)
                    FH=PAR(34)

              ENDIF

C-----------------------------------------------------------------------------
C             Set the intial values for fluid temperature in the receiver

              IF(INFO(7).EQ.-1) THEN
                    DO 20 J=1,CELLS
                          S(ISTORE+(J-1))=TSTART
20                  CONTINUE
              Return 1
              ENDIF
C-----------------------------------------------------------------------------
30      CONTINUE

C             Set the  storage place for this particular component
                    ISTORE=INFO(10)

C             Get the common values for the inputs for this component

C             TFI - Inlet fluid temperature (degC)
                    TFI=XIN(1)+TZERO

C             FLOW - Flow rate (kg/hr)
                    FLOW=XIN(2)

C             ID - Direct beam radiation (kJ/hr.m2)
                    ID=XIN(3)

C             TAMB- Ambient temperature (degC)
                    TAMB=XIN(4)+TZERO
```

```
C       WIND - Wind speed (m/s)
            WIND=XIN(5)

C       SHADE - fraction of the mirrors that are unshaded by adjacent mirrors
C           1 = no shading, 0 = full shading
            SHADE=XIN(6)

C       DIRT - Measure of cleanliness of the mirrors (1 = perfectly clean)
            DIRT=XIN(7)

C-----------------------------------------------------------------------------
C       Retrieve the outlet temps from the previous time step
            DO 40 J=1,CELLS
                TFINIT(J)= S(ISTORE+(J-1))
40          CONTINUE

C       Retrieve inlet temps from the previous time step
            DO 45 J=1,CELLS
                TFINPREV(J)= S(ISTORE+(J-1)+CELLS)
45          CONTINUE

C-----------------------------------------------------------------------------
C       Thermal performance
C-----------------------------------------------------------------------------

C       Set the capacitance for each cell node

        CAPNODE=(MASS*CP)/CELLS

C       Initialise energy sums for this timestep
        QTHSUM=0
        QELECSUM=0
        QINSULSUM=0
        QCONVSUM=0
        QRADSUM=0

C       Initialise temp sums (to be used to calculate mean temperature)
        TCSUM=0
        TGSUM=0
        TPSUM=0
        TTSUM=0
        TGMIDSUM=0
```

```
                    TCOVSUM=0

C                   Set up the loop for the cells

50                  DO 60 J=1,CELLS

C                   Set the inlet fluid temp

                        IF (J.EQ.1) THEN
                            TFIN(J)=TFI
                        ELSE
                            TFIN(J)=TBAR(J-1)
                        ENDIF

C                   Set fluid temp as average temp in the element at the previous time step
                        TF=(TFINPREV(J)+TFINIT(J))/2

C                   The following uses the Bisection Algorithm routine to solve the
C                   simultaneous equations describing this system.

C                   For a concentrating collector

C                   Set the lower limit for the bisection (zero heat transfer)
                        QTHLOWER=0

C                   Set the upper limit for the bisection (extraterrestrial radiation)
                        QTHUPPER=4760*WIDTH*LENGTH/CELLS

C                   Check if the limits bound the solution by using a bracketing algortithm
                        CALL ZBRAC(QTHFUNC1,QTHLOWER,QTHUPPER,SUCCESS)

C                   If the solution is bounded, then proceed to calculate the thermal heat
C                   transfer, Qth

                IF (SUCCESS) THEN CALL BISECTION(QTHFUNC1,QTHLOWER,QTHUPPER,TOL,QTH)

C                   Otherwise there is a problem
                    END IF

C                   Store energy transfer values in arrays
                        QTHARRAY(J)=QTH
                        QINSARRAY(J)=QINS
```

```
            QELECARRAY(J)=QELEC
            QRADARRAY(J)=QRAD
            QCONVARRAY(J)=QCONV

C       Store various temperatures in arrays
            TTARRAY(J)=TT
            TPARRAY(J)=TP
            TCARRAY(J)=TC
            TGARRAY(J)=TG
            TGMIDARRAY(J)=TGMID
            TCOVARRAY(J)=TCOVER

C       Find heat capacity of the fluid

            CPF = CPWATER(TF)/1000

C       Set up the differential equation for the collector in the form dT/dt=AT+B

            BB=QTH/CAPNODE+FLOW*CPF*TFIN(J)/CAPNODE
            AA=-FLOW*CPF/CAPNODE

C       Solve the differential equation analytically.

            IF(AA.EQ.0.) THEN
                TFINAL(J)=TFINIT(J)+BB*DELT
                TBAR(J)=TFINIT(J)+BB*DELT/2.
            ELSE
                TFINAL(J)=TFINIT(J)*(EXP(AA*DELT))
    1           +BB/AA*(EXP(AA*DELT))-BB/AA

                TBAR(J)=1./AA/DELT*(TFINIT(J)+BB/AA)*
    1           ((EXP(AA*DELT))-1.)-BB/AA
            ENDIF

C       Update energy sums and temp sums

            QTHSUM=QTHSUM+QTH
            QELECSUM=QELECSUM+QELEC
            QINSULSUM=QINSULSUM+QINS
            QCONVSUM=QCONVSUM+QCONV
            QRADSUM=QRADSUM+QRAD
            TGSUM=TGSUM+TG
```

```
            TTSUM=TTSUM+TT
            TPSUM=TPSUM+TP
            TCSUM=TCSUM+TC
            TGMIDSUM = TGMIDSUM+TGMID
            TCOVSUM = TCOVSUM + TCOVER

60        CONTINUE

C         SET THE OUTPUTS
70     CONTINUE

C          Outlet fluid temperature (degC)
            OUT(1)=TBAR(CELLS)-TZERO
C          Outlet flow rate (kg/hr)
            OUT(2)=FLOW
C          Electrical output (kJ/hr)
            OUT(3)=QELECSUM
C          Thermal output (kJ/hr)
            OUT(4)=QTHSUM
C          Insulation losses (kJ/hr)
            OUT(5)=QINSULSUM
C          Convection losses (kJ/hr)
            OUT(6)=QCONVSUM
C          Radiation losses (kJ/hr)
            OUT(7)=QRADSUM
C          Mean cell temperature (degC)
            OUT(8)=TCSUM/CELLS-TZERO
C          Mean glass temperature (degC)
            OUT(9)=TGSUM/CELLS-TZERO
C          Mean plate temperature (degC)
            OUT(10)=TPSUM/CELLS-TZERO
C          Mean tube temperature (degC)
            OUT(11)=TTSUM/CELLS-TZERO
C          Mean mid glass/silicone temperature (degC)
            OUT(12)=TGMIDSUM/CELLS-TZERO
C          Mean insulation cover temperature (degC)
            OUT(13)=TCOVSUM/CELLS-TZERO

C          Enter final temp data into store for next timestep
            DO 80 J=1,CELLS
                 S(ISTORE+(J-1))=TFINAL(J)
80          CONTINUE
```

```
C               Enter inlet temp data into store for next timestep
                     DO 90 J=1,CELLS
                          S(ISTORE+(J-1)+CELLS)=TFIN(J)
90                   CONTINUE

                     RETURN 1
                     END


C------------------------------------------
          REAL FUNCTION QTHFUNC1(QTHERMAL)

C         This function calculates the equations that
C         describe the collector.
C         The physically meaningless objective function
C         is returned.
C         QTHERMAL is the guess,
C         TF is the known fluid temp that varies for each node

c               External functions

                EXTERNAL VISCOSITY,CONDUCTIVITY,CPWATER, DENSITY

C               Internal variables

C               Radiation incident on the receiver
                REAL QSUN
C               Coefficient of convection for air past the receiver
                REAL HCCONV
C               Viscosity of water at atmospheric pressure
                REAL MU_W
C               Conductivity of water at atmospheric pressure
                REAL K_W
C               CP value of water at atmospheric pressure
                REAL CP_W
C               Density of water at atmospheric pressure
                REAL DENSITY_W
C               Prandtl number of water at atmospheric pressure
                REAL PR
C               Hydraulic diameter of receiver
                REAL DH
```

```
C          Bulk fluid velocity through receiver
           REAL VF
C          Reynolds number
           REAL RE
C          Nusselt number
           REAL NU
C          Coefficient of convection for water in the tube
           REAL HC
C          Short term variable for heat transfer
           REAL H1, H2, H3
C          Estimate of average of insulation cover temp and ambient temp
           REAL TMEAN

C          Common block variables used in functions
      COMMON/PVTPARAMS/ID,WIDTH,LENGTH,CELLS,REFLM,SHAPE,SHADE,DIRT,CW0,
      1          CW1,CW2,WIND,MODE,TF,XSAREA,PERIM,FLOW,FH,HCTF,TT,TP,UPT,
      1          WPT,UINSUL,WINSUL,TAMB,SBC,EMISCOV,WCOVER,TCOVER,QINS,
      1          QCP,UCP,WCP,QELEC,REFEFF,BETA,REFTEMP,TC,QABSCELLS,
      1          TRANSABS,QCG1,TGMID,UCG,WCG,QABSGLASS,COVERABS,QCG2,TG,
      1          QCONV,WGLASS,QRAD,EMIS,UNIFORMITY

C          Re-declaration of parameters (from main program)
                INTEGER MODE
                INTEGER CELLS
                REAL REFEFF
                REAL REFTEMP
                REAL BETA
                REAL UNIFORMITY
                REAL LENGTH
                REAL WIDTH
                REAL REFLM
                REAL SHAPE
                REAL TRANSABS
                REAL COVERABS
                REAL EMIS
                REAL MASS
                REAL CP
                REAL TSTART
                REAL WGLASS
                REAL UCG
                REAL WCG
                REAL UCP
```

```
                      REAL WCP
                      REAL UPT
                      REAL WPT
                      REAL UINSUL
                      REAL WINSUL
                      REAL WCOVER
                      REAL EMISCOV
                      REAL CW0,CW1,CW2
                      REAL HCTF
                      REAL PERIM
                      REAL XSAREA
                      REAL FH


C             Inputs used in the model
                      REAL TFI
                      REAL FLOW
                      REAL ID
                      REAL TAMB
                      REAL WIND
                      REAL SHADE
                      REAL DIRT

C             Variables used within the model

C                     Electrical output
                      REAL QELEC
C                     Convective heat loss from glass
                      REAL QCONV
C                     Radiative heat loss from glass
                      REAL QRAD
C                     Heat loss through the insulation
                      REAL QINS
C                     Tube temperature
                      REAL TT
C                     Plate temperature
                      REAL TP
C                     Cell temperature
                      REAL TC
C                     Glass surface temperature
                      REAL TG
C                     Mid glass/silicone temperature
```

```
                    REAL TGMID
C                   Insulation cover temperature
                    REAL TCOVER

C     Calculate the radiation incident on the cells
      QSUN=ID*WIDTH*LENGTH/CELLS*REFLM*SHAPE*SHADE*DIRT

C     Calculate the convection coefficient due to wind
      HCCONV=CW0+CW1*WIND+CW2*WIND*WIND

C     Calculate convection coeff in the pipe if required
      IF (MODE.EQ.2) THEN

C     Calculate saturated water properties at atmospheric pressure
C     based on curve fits from Incropera and De Witt, 'Fundamentals
C     of Heat and Mass Transfer'

            MU_W=VISCOSITY(TF)
            K_W=CONDUCTIVITY(TF)
            CP_W=CPWATER(TF)
            DENSITY_W = DENSITY(TF)

C           Prandtl number
            PR = CP_W*MU_W/K_W

C           DH - Hydraulic diameter - defined as 4 x Flow cross sectional area / wetted perimeter
            DH = 4*XSAREA/PERIM

C           VF - Fluid velocity (m/s) (also convert kg/hr to m3/s)
            VF = FLOW/3600000/XSAREA

C           Reynolds number (based on hydraulic diameter)
            RE = DENSITY_W*VF*DH/MU_W

C           The accuracy of this method is not so good for Reynolds numbers below about 4000
C           Experimentally, it was found that using unmodified Dittus-Boelter seemed to produce
C           a decent fit down to about Re = 1000 (reasons given in thesis).  Below 1000 the
C           Nusselt is set to 5 but this is only so the model doesn't crash. Not recommended.

            IF (RE.LT.1000) THEN

                  NU = 10  !  Rough value to stop model crashing when there is no flow
```

```
            ELSEIF ((RE.GE.1000).AND.(RE.LE.4000)) THEN

C                 Use Dittus - Boelter to calculate Nu
                  NU = 0.023*RE**0.8*PR**0.4
            ELSE
C                 Use Dittus - Boelter to calculate Nu
                  NU = 0.023*RE**0.8*PR**0.4

C                 Adjust to account for the internal fins
                  NU = NU * FH
            ENDIF

C           Calculate coefficient of convection based on the hydraulic diameter
            HC = NU*K_W/DH

C           Convert units back from W/m2.K to kJ/hr.m2.K
            HC = HC * 3.6

C           Multiply HC through but the wetted surface area
            HCTF = HC*PERIM*LENGTH/CELLS

      END IF

C     Write equations that describe system without air gap

C     Calculate tube temperature
      TT=QTHERMAL/HCTF+TF

C     Calculate plate temperature
      TP=QTHERMAL/(UPT*LENGTH/CELLS*WPT)+TT

C     Calculate cover temperature by working out heat transfer coeffs for
C     a) conduction through insulation
      H1 = UINSUL*LENGTH/CELLS*WINSUL
C     b) radiation loss from the cover
C           estimate of mean temp between cover and ambient
      TMEAN = TAMB + 5
      H2 = 4*SBC*EMISCOV*WCOVER*LENGTH/CELLS*TMEAN**3
C     c)  convection loss from the cover
      H3 = HCCONV*WCOVER*LENGTH/CELLS
C     Now put it together to calculate temperature of the cover
```

```
      TCOVER = (H1*TP+(H2+H3)*TAMB)/(H1+H2+H3)

C     Calculate losses through the insulation
      QINS = H1 * (TP-TCOVER)

C     Calculate heat transfer from the cells to the plate
      QCP = QTHERMAL + QINS

C     Calculate the temperature of the cells
      TC = QCP/(UCP*LENGTH/CELLS*WCP)+TP

C     Calculate the electrical output
      QELEC=QSUN*REFEFF*EXP(BETA*(TC-REFTEMP))*UNIFORMITY

C     Calculate the solar absorption by the cells
      QABSCELLS = QSUN*TRANSABS*(1-COVERABS)

C     Calculate QCG1
      QCG1=QABSCELLS-QELEC-QCP

C     Calculate temperature at glass midpoint
      TGMID = TC-QCG1/(2*UCG*WCG*LENGTH/CELLS)

C     Calculate the solar absorption in the cover glass/silicone
      QABSGLASS = QSUN*TRANSABS*COVERABS

C     Calculate QCG2
      QCG2=QCG1+QABSGLASS

C     Calculate the glass temperature
      TG = TGMID - QCG2/(2*UCG*WCG*LENGTH/CELLS)

C     Calculate convection losses from the glass cover
      QCONV=HCCONV*WGLASS*LENGTH/CELLS*(TG-TAMB)

C     Calculate radiation losses from the glass cover
      QRAD=SBC*EMIS*WGLASS*LENGTH/CELLS*(TG**4-TAMB**4)

C     Calculate objective function that is to be solved
      QTHFUNC1=QCG2-(QRAD+QCONV)

      END
```

```
C-----------------------------------------------------------------------

C                       Bisection method

            RECURSIVE SUBROUTINE BISECTION(FUNC,X1,X2,XACC,XROOT)

C           Using bisection, finds the root of a function FUNC known to lie between
C           X1 and X2.  The root, returned as XROOT, will be refined until its accuracy
C           is +/- XACC

      COMMON/LUNITS/LUR,LUW,IFORM,LUK
            REAL FMID,F,XROOT,DX,XMID
            PARAMETER (JMAX=50)

            FMID=FUNC(X2)
            F=FUNC(X1)

            IF(F*FMID.GE.0.) THEN
                        WRITE(LUW,'(A,I3,A,I3,A)')' ERROR at Type 262 (Unit',unit,
    1             '): Bisection method out of range'
          CALL MYSTOP(1001)
            ENDIF

            IF(F.LT.0.) THEN
                        XROOT=X1
                        DX=X2-X1
            ELSE
                        XROOT=X2
                        DX=X1-X2
            ENDIF

            DO 15000 J=1,JMAX
                        DX=DX*.5
                        XMID=XROOT+DX
                        FMID=FUNC(XMID)
                        IF(FMID.LT.0.) XROOT=XMID
                        IF(ABS(DX).LT.XACC .OR. FMID.EQ.0.) RETURN
15000    CONTINUE
            END
```

```
C--------------------------------------------------------------------------------

          SUBROUTINE ZBRAC (FUNC,X1,X2,SUCCESS)

C         Given a function FUNC and an initial guessed range X1 to X2, the routine
C         expands the range geometrically until a root is bracketed by the returned
C         values of X1 and X2.

          PARAMETER (FACTOR=1.6,NTRY=50)
          LOGICAL SUCCESS
          IF(X1.EQ.X2)PAUSE 'You have to guess an initial range'
          F1=FUNC(X1)
          F2=FUNC(X2)
          SUCCESS =.TRUE.
          DO 16000 J=1,NTRY
                    IF (F1*F2.LT.0.)RETURN
                    IF(ABS(F1).LT.ABS(F2))THEN
                              X1=X1+FACTOR*(X1-X2)
                              F1=FUNC(X1)
                    ELSE
                              X2=X2+FACTOR*(X2-X1)
                              F2=FUNC(X2)
                    END IF
16000     CONTINUE
          SUCCESS=.FALSE.
          RETURN
          END
C         ---------------------------------------------------------------
C
c    WATER PROPERTIES - from curve fits to Incropera and De Witt, Saturated water
C         at atmospheric pressure
c
     Real FUNCTION CPWATER(T)
     real T
          CPWATER=0.0000032759702*T**4 - 0.0043807394*T**3 + 2.2005092*T**2
          1          - 491.60617*T + 45358.904
     end

     Real FUNCTION CONDUCTIVITY(T)
     real T
     CONDUCTIVITY=-0.48064+0.0058471*T-0.0000073317*T**2
     end
```

```
REAL FUNCTION VISCOSITY(T)
real T
VISCOSITY=0.000000000028665*T**4 - 0.000000039376*T**3
1         + 0.000020328*T**2 - 0.0046803*T + 0.40639
END

REAL FUNCTION DENSITY(T)
real T
T = T - 273.15
DENSITY=0.0000149*T**3 - 0.0057637*T**2 + 0.0063843*T + 1000.2418616
T = T + 273.15
END
```

A2 Fortran code for the End Loss TRNSYS component

```
SUBROUTINE TYPE123 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C*********************************************************************
C Object: End Loss Modifier
C IISiBat Model: EndLoss
C
C Author: Joe Coventry
C Editor: Joe Coventry
C Date:   20/6/2000 last modified: 20/6/2000
C
C Calculates the end losses from a parabolic mirror
C*********************************************************************

C       STANDARD TRNSYS DECLARATIONS
        DOUBLE PRECISION XIN,OUT
        INTEGER NI,NP,ND,NO
        PARAMETER (NI=1,NP=3,NO=1,ND=0)
        INTEGER*4 INFO,ICNTRL
        REAL T,DTDT,PAR,TIME
        DIMENSION XIN(NI),OUT(NO),PAR(NP),INFO(15)
        CHARACTER*3 YCHECK(NI),OCHECK(NO)
        DATA RDCONV/0.017453/

C-----------------------------------------------------------------------

C       IF ITS THE FIRST CALL TO THIS UNIT, DO SOME BOOKKEEPING
        IF (INFO(7).GE.0) GO TO 100

C       FIRST CALL OF SIMULATION, CALL THE TYPECK SUBROUTINE TO CHECK THAT THE
C       USER HAS PROVIDED THE CORRECT NUMBER OF INPUTS, PARAMETERS, AND
        DERIVS

        INFO(6)=NO
        INFO(9)=1
        CALL TYPECK(1,INFO,NI,NP,ND)
        RETURN 1

C       END OF THE FIRST ITERATION BOOKKEEPING

C-----------------------------------------------------------------------
```

```
C       GET THE VALUES OF THE PARAMETERS FOR THIS COMPONENT
100     CONTINUE
        Trough_Length=PAR(1)
        Trough_Width=PAR(2)
        Focal_Length=PAR(3)

C       GET THE VALUES OF THE INPUTS TO THIS COMPONENT
        Incidence_Angle=XIN(1)

C-----------------------------------------------------------------------

C       End losses calculated based on the geometry of the trough and
C       the incidence angle of light on a single axis tracking trough

        AAA = Focal_Length/Trough_Length
        BBB = (Trough_Width**2)/(48*Focal_Length**2)

        End_Loss_Factor = 1-AAA*(1+BBB)*tan(Incidence_Angle*RDCONV)

C-----------------------------------------------------------------------

C       SET THE OUTPUTS
200     CONTINUE

C       End Loss Factor
        OUT(1)=End_Loss_Factor

        RETURN 1
        END
```

A3 Fortran code for the Fin-tube TRNSYS component

```
SUBROUTINE TYPE273 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C*********************************************************************
C Object: Improved fin tube model
C IISiBat Model: Type 273
C
C Author: Joe Coventry
C Editor:
C Date:   6/8/2002 last modified: 24/5/2004
C
C           STANDARD TRNSYS DECLARATIONS
                  DOUBLE PRECISION XIN,OUT
                  INTEGER NIMAX,NPMAX,ND,NO
                  PARAMETER (NIMAX=4,NPMAX=11,NO=2,ND=0)
                  INTEGER*4 INFO,ICNTRL
                  REAL T,DTDT,PAR,TIME
                  DIMENSION XIN(NIMAX),OUT(NO),PAR(NPMAX),INFO(15)
                  CHARACTER*3 YCHECK(NIMAX),OCHECK(NO)

C           My declarations

C           Some constants used in the model
                  DATA CPF/4.18/IUNIT/0/


C                 PARAMETERS

C                 Length of the finned tube
                  REAL L
C                 Number of fins
                  REAL NFINS
C                 Area of the fins
                  REAL AFINS
C                 Diameter of the tube
                  REAL DTUBE
c                 Thickness of the fins
                  REAL TFINS
C                 Conductivity of the fins
                  REAL KFINS
C                 Number of discrete elements
                  REAL NODES
```

```
C       Heat capacity of the fluid
        REAL CPF
C       Heat capacity of the pipe
        REAL CPP
C       Mass of the fluid
        REAL MASSF
C       Mass of the pipe
        REAL MASSP

C       INPUTS

C       Inlet temperature to the fin-tube
        REAL TIN
C       Ambient temperature
        REAL TAMB
C       Flow rate (kg/hr)
        REAL FLOW
C       Wind speed (m/s)
        REAL WS

C       VARIABLES IN CALCULATION

C       Energy transfer through an element of the fin-tube
        EXTERNAL QTHFIN
C       Maximum number of discrete elements
        PARAMETER (MAXNODES=100)
C       Sum of thermal energy transfer through the fin-tube
        REAL QTHSUM
C       Fluid temperature
        REAL TF
C       Temperature of the inlet of the node
        REAL TFIN(MAXNODES)
C       Average temperature of the fluid in the node
        REAL TBAR(MAXNODES)
C       Temperature of the fluid in the node at the previous time step
        REAL TFINIT(MAXNODES)
C       Temperature of the fluid at the outlet of the node
        REAL TFINAL(MAXNODES)
C       Boolean indicator of success of bisection method
        LOGICAL SUCCESS
C       Need to include this file
        INCLUDE '..\INCLUDE\PARAM.INC'
```

```
C                 Common variables to be used in other subroutines
                  COMMON/FINPARAMS/ L, NFINS, AFINS, DTUBE, TFINS, KFINS,
     1            TIN, TAMB, FLOW, WS, TF, NODES
          COMMON /SIM/ TIME0,TIMEF,DELT,IWARN
                  COMMON /STORE/ NSTORE,IAV,S(NUMSTR)
          COMMON/LUNITS/LUR,LUW,IFORM,LUK

C-------------------------------------------------------------------

C           If it is the very first call of the simulation then continue,
C           with these initialisation things otherwise go down to parameters.

            IF (INFO(7).GE.0) GO TO 10

C           Set this to number of outputs
                  INFO(6)=NO

C           Set to 1 as routine depends on passage of time
                  INFO(9)=1

C           Set the common store size to the maximum number of cells
                  INFO(10)=MAXNODES

C           Check that the user has provided the right number of inputs, outputs
C           and derivatives

                  CALL TYPECK(1,INFO,NIMAX,NPMAX,ND)

C           Set the first storage place in the middle of the allocated variables
                  ISTORE=INFO(10)
C-------------------------------------------------------------------
C           Get the values of the parameter for this component (only once)
10          IF(INFO(1) .EQ. IUNIT) GO TO 30
            IUNIT=INFO(1)

                  L=PAR(1)
                  NFINS=PAR(2)
                  AFINS=PAR(3)
                  DTUBE=PAR(4)
                  TFINS=PAR(5)
                  KFINS=PAR(6)
                  NODES=INT(PAR(7)+0.001)
```

```
            CPP=PAR(8)
            MASSP=PAR(9)+0.01
            CPF=PAR(10)
            MASSF=PAR(11)+0.01

C       Set the intial values for fluid temperature, equivalent the average temp
C       if the collector was left for a while with no losses after inital conditions.
C       Also set initial values of QOLD to zero
        IF(INFO(7).EQ.-1) THEN
            TSTART=300
            DO 20 J=1,NODES
                S(ISTORE+(J-1))=TSTART
20          CONTINUE
        Return 1
        ENDIF
C-----------------------------------------------------------------------------

30    CONTINUE

C       Set the  storage place for this particular component
            ISTORE=INFO(10)

C       GET THE VALUES OF THE INPUTS TO THIS COMPONENT
            TIN=XIN(1)+273.13
            FLOW=XIN(2)
            TAMB=XIN(3)+273.13
            WS=XIN(4)

C       Retrieve initial fluid temps and QOLD from the s-array
            DO 40 J=1,NODES
                TFINIT(J)= S(ISTORE+(J-1))
40          CONTINUE
C-----------------------------------------------------------------------------
C       Thermal performance
C-----------------------------------------------------------------------------

        IF (FLOW.EQ.0.) GO TO 70

C       Set the capacitance for each cell node

        CAPNODE=(MASSF*CPF+MASSP*CPP)/NODES
        QTHSUM = 0
```

```
50          DO 60 J=1,NODES

C           Set the inlet fluid temp
                IF (J.EQ.1) THEN
                    TFIN(J)=TIN
                ELSE
                    TFIN(J)=TBAR(J-1)
                ENDIF

C           Set fluid temp to original fluid temp of the node (at prev. time step)
                TF=TFINIT(J)

c           Note: because of this assumption the model may be unstable in the intial time
C           steps if mass flow is low, or the heat exchanger is a lot longer than it needs
C           to be.

C           The following uses the Bisection Algorithm routine to solve the
C           simultaneous equations describing this system.

C           Make guess of values
                QTHLOWER=0
                QTHUPPER=4760*L/NODES
                CALL ZBRAC3(QTHFIN,QTHLOWER,QTHUPPER,SUCCESS)
                CALL BISECTION3(QTHFIN,QTHLOWER,QTHUPPER,0.1,QTH)
C           Set up the differential equation for the collector in the form dT/dt=AT+B

                BB=-QTH/CAPNODE+FLOW*CPF*TFIN(J)/CAPNODE
                AA=-FLOW*CPF/CAPNODE


C           Solve the differential equation analytically.

                IF(AA.EQ.0.) THEN
                    TFINAL(J)=TFINIT(J)+BB*DELT
                    TBAR(J)=TFINIT(J)+BB*DELT/2.
                ELSE
                    TFINAL(J)=TFINIT(J)*(EXP(AA*DELT))
     1              +BB/AA*(EXP(AA*DELT))-BB/AA
                    TBAR(J)=1./AA/DELT*(TFINIT(J)+BB/AA)*
     1              ((EXP(AA*DELT))-1.)-BB/AA
```

```
                    ENDIF

C             Update energy sums and temp sums
                    QTHSUM=QTHSUM+QTH

60            CONTINUE

C             SET THE OUTPUTS
70      CONTINUE
C              Outlet fluid temperature
                    IF (FLOW.EQ.0) THEN
                          OUT(1) = TAMB-273.13
                          DO 75 J=1,NODES
                                S(ISTORE+(J-1))=TFINIT(J)
75                        CONTINUE
                    ELSE
                          OUT(1)=TBAR(NODES)-273.13
                          DO 80 J=1,NODES
                                S(ISTORE+(J-1))=TFINAL(J)
80                        CONTINUE
                    ENDIF

C              Outlet flow rate
                    OUT(2)=FLOW

                    RETURN 1
                    END

C*****************************************************************************
C
C  THIS FUNCTION CALCULATES THE FIN EFFICIENCY (EFFECTIVENESS)
C  OF AN ANNULAR FIN OF CONSTANT THICKNESS.
C
C   ALPHA = RADIUS AT FIN BASE / RADIUS AT FIN TIP
C   BETA  = RADIUS AT FIN TIP *
C         (SQRT (2 * CONVECTION COEFFICIENT /
C               FIN CONDUCTIVITY * FIN THICKNESS))
C
      FUNCTION FINEFF(ALPHA,BETA)
        REAL I0,I1,K0,K1
        ALPBET = ALPHA * BETA
        CALL BESSEL2(ALPBET,I0,I1,K0,K1)
```

```
      XI0 = I0
      XI1 = I1
      XK0 = K0
      XK1 = K1
      CALL BESSEL2(BETA,I0,I1,K0,K1)
      YI0 = I0
      YI1 = I1
      YK0 = K0
      YK1 = K1
      FINEFF = 2.*ALPHA/BETA/(1. - ALPHA**2)*(XK1*YI1 - XI1*YK1)/
     .      (XK0*YI1 + XI0*YK1)
      RETURN
      END
C
C****************************************************************************
C****************************************************************************
C
C  THIS SUBROUTINE USES POLYNOMIAL APPROXIMATIONS TO EVALUATE
C  THE BESSEL FUNCTIONS.  THE APPROXIMATIONS ARE FROM ABRAMOWITZ
C  AND STEGUN, HANDBOOD OF MATHEMATICAL FUNCTIONS, DOVER
C  PUBLICATIONS, INC., NEW YORK, NY.
C
    SUBROUTINE BESSEL2(X,I0,I1,K0,K1)
    COMMON /LUNITS/ LUR,LUW,IFORM,LUK
    REAL X,I0,I1,K0,K1,IT
C
C  THE FOLLOWING DATA STATEMENTS CONTAIN THE COEFFICIENTS TO
C  THE POLYNOMIALS.
C
C  I0
    DATA A0/1.0/,A1/3.5156229/,A2/3.0899424/,A3/1.2067492/
    DATA A4/0.2659732/,A5/0.0360768/,A6/0.0045813/
C  I0
    DATA B0/0.39894228/,B1/0.01328592/,B2/0.00225319/
    DATA B3/-0.00157565/,B4/0.00916281/,B5/-0.02057706/
    DATA B6/0.02635537/,B7/-0.01647633/,B8/0.00392377/
C  I1
    DATA C0/0.5/,C1/0.87890594/,C2/0.51498869/,C3/0.15084934/
    DATA C4/0.02658733/,C5/0.00301532/,C6/0.00032411/
C  I1
    DATA D0/0.39894228/,D1/-0.03988024/,D2/-0.00362018/
    DATA D3/0.00163801/,D4/-0.01031555/,D5/0.02282967/
```

```
      DATA D6/-0.02895312/,D7/0.01787654/,D8/-0.00420059/
C  K0
      DATA E0/-0.57721566/,E1/0.4227842/,E2/0.23069756/
      DATA E3/0.0348859/,E4/0.00262698/,E5/0.0001075/,E6/0.0000074/
C  K0
      DATA F0/1.25331414/,F1/-0.07832358/,F2/0.02189568/
      DATA F3/-0.01062446/,F4/0.00587872/,F5/-0.0025154/
      DATA F6/0.00053208/
C  K1
      DATA G0/1.0/,G1/0.15443144/,G2/-0.67278579/,G3/-0.18156897/
      DATA G4/-0.01919402/,G5/-0.00110404/,G6/-0.00004686/
C  K1
      DATA H0/1.25331414/,H1/0.23498619/,H2/-0.0365562/
      DATA H3/0.01504268/,H4/-0.00780353/,H5/0.00325614/
      DATA H6/-0.00068245/
C
      IF (X .LT. -3.75) THEN
          WRITE(LUW,100) 164,52,52,X
          CALL MYSTOP(164)
          RETURN
      END IF
      T=X/3.75
      TT=T*T
C
C I0
C
      IF (X .LE. 3.75) THEN
          I0=A0+TT*(A1+TT*(A2+TT*(A3+TT*(A4+TT*(A5+TT*A6)))))
      ELSE
          IT=1/T
          I0=(B0+IT*(B1+IT*(B2+IT*(B3+IT*(B4+IT*(B5+IT*(B6+IT*
     .        (B7+IT*B8))))))))/(SQRT(X)*EXP(-X))
      END IF
C
C  I1
C
      IF (X .LE. 3.75) THEN
          I1=(C0+TT*(C1+TT*(C2+TT*(C3+TT*(C4+TT*(C5+TT*C6))))))*X
      ELSE
          IT=1/T
          I1=(D0+IT*(D1+IT*(D2+IT*(D3+IT*(D4+IT*(D5+IT*(D6+IT*
     .        (D7+IT*D8))))))))/(SQRT(X)*EXP(-X))
```

```
      END IF
C
C  K0
C
      IF (X .LE. 0.0) THEN
        WRITE(LUW,100) X
        CALL MYSTOP(1001)
        RETURN
      END IF
      X1 = (X/2.)**2
      X2 = 2./X
      IF (X .LE. 2.0) THEN
        K0=-ALOG(X/2)*I0+E0+X1*(E1+X1*(E2+X1*(E3+X1*(E4+X1*
     .      (E5+X1*E6)))))
      ELSE
        K0=(F0+X2*(F1+X2*(F2+X2*(F3+X2*(F4+X2*(F5+X2*F6))))))
     .      /(SQRT(X)*EXP(X))
      END IF
C
C  K1
C
      IF (X .LE. 2.0) THEN
        K1=(X*ALOG(X/2.)*I1+G0+X1*(G1+X1*(G2+X1*(G3+X1*(G4+X1*
     .      (G5+X1*G6))))))/X
      ELSE
        K1=(H0+X2*(H1+X2*(H2+X2*(H3+X2*(H4+X2*(H5+X2*H6))))))
     .      /(SQRT(X)*EXP(X))
      END IF
      RETURN
C
C  FORMATS
C
100   FORMAT(//,1X,'***** ERROR *****',8X,'TRNSYS ERROR # ',I3,/1X,
     .'UNIT ',I3,' TYPE ',I3,' COOLING COIL',/1X,
     .'THE BESSEL FUNCTION CALLED FROM THE COOLING COIL SUBROUTINE COULD
     . NOT BE'/1X,'EVALUATED AT THE GIVEN VALUE OF ',F5.2,'.')
      END
C

C-------------------------------------------------------------------------------
```

```
C                 Function that calculates the heat lost from the fins

        REAL FUNCTION QTHFIN(QGUESS)

                  COMMON/FINPARAMS/ L, NFINS, AFINS, DTUBE, TFINS, KFINS,
        1                   TIN, TAMB, FLOW, WS, TF, NODES
C                 Redeclare the common variables
                  REAL L, NFINS, AFINS, DTUBE, TFINS, KFINS, QTHSUM
                  REAL TIN, TAMB, FLOW, WS, TF, NODES

C                 Nusselt number, forced convection in air
                  REAL NUF
C                 Nusselt number, natural convection in air
                  REAL NUN
C                 Reynolds number, forced convection in air
                  REAL REF
C                 Equivalent diameter of the fins
                  REAL DFIN
C                 Temperature at the base of the fins
                  REAL TBASE
C                 Rayleigh number
                  REAL RA
C                 Maximum of forced and natural convection nusselt numbers
                  REAL NU
C                 Nusselt number for the fluid in the pipe
                  REAL NUFLUID
C                 Coefficient of convection between fin and ambient air
                  REAL HCFA
C                 Reynolds number for fluid
                  REAL REFLUID
C                 Prandtl number for fluid
                  REAL PRFLUID
C                 Viscosity for water
                  REAL MU_W
C                 Conductivity of water
                  REAL K_W
C                 Specific heat, water
                  REAL CP_W
C                 Coefficient of convection between the fin base and the water
                  REAL HCFF
C                 Variables used in calculation
                  REAL A,B, Q1, Q2
```

```
C          Note:  these are in SI units from the back of Holman
           DATA PRAIR/0.708/, CONDAIR/0.02624/,PI/3.14159/
           DATA VISAIR/15.69E-6/, ALPHA/0.22160E-4/

C          Reynolds number and prandtl number for the fluid in the pipe

           MU_W=VISCOSITY2(TF)
           K_W=CONDUCTIVITY2(TF)
           CP_W=CPWATER2(TF)

           REFLUID = 4.*FLOW/(3600.*PI*DTUBE*MU_W)
           PRFLUID = CP_W*MU_W/K_W

C          Nusselt number for the fluid in the pipe

           IF (REFLUID.GE.2300) THEN      ! then turbulent

                NUFLUID = 0.023*REFLUID**0.8*PRFLUID**0.4
           ELSE                                        !  else laminar
                NUFLUID = 3.66 + (0.0668*(DTUBE/L)*REFLUID*PRFLUID)/
     1          (1+0.04*((DTUBE/L)*REFLUID*PRFLUID)**0.666)
           ENDIF

C          Calculate convection coefficient between finbase and fluid

           HCFF = NUFLUID * K_W / DTUBE *3.6

C          Area of the tube inner surface

           AREAT = L/NODES * DTUBE*PI

C          Calculate the temperature at the base of the fin by assuming a
C          guessed energy transfer

           TBASE = TF - QGUESS/(HCFF*AREAT)

C          Equivalent diameter for fins

           DFIN = (4.*AFINS/PI)**0.5

C          Nusselt for forced convection of air
```

```
            REF = WS*DFIN/2/VISAIR
            NUF = 0.332*REF**0.5*PRAIR**0.33

C           Nusselt for natural convection of air (use TF instead of TBASE)

            RA = 9.81*(1/TAMB)*ABS(TF-TAMB)*(DFIN/2)**3/(VISAIR*ALPHA)

            NUN = 0.68 + 0.670*RA**0.25/(1+(0.492/PRAIR)**(9/16))**(4/9)

C           Take whichever nusselt number is largest

            NU = MAX(NUN,NUF)

C           Calculate convection coefficient between fin and ambient air

            HCFA = NU * CONDAIR / (DFIN/2) * 3.6

C           Calculate the fin efficiency

C            ALPHA = RADIUS AT FIN BASE / RADIUS AT FIN TIP
C        BETA  = RADIUS AT FIN TIP *
C     (SQRT (2 * CONVECTION COEFFICIENT /
C          FIN CONDUCTIVITY / FIN THICKNESS))

            A = DTUBE/DFIN
            B = DFIN/2*(SQRT(2*HCFA/KFINS/TFINS))

            FEFF = FINEFF(A,B)

C           Calculate the area of the fin (x2 to include both sides)

            AREAF = NFINS*L/NODES*AFINS*2

C           Find the value of Q using the base temp and calculate error

            Q1 = FEFF*HCFA*(TBASE-TAMB)*AREAF

            QTHFIN = Q1-QGUESS

      END
```

```
c     ************************************************************************
c     WATER PROPERTIES, taken from the Type 60 tank model

      Real FUNCTION CPWATER2(T)
      real T
      CPWATER2=45359-491.6*T+2.2005*T*T-.0043807*T**3+
     &     3.276d-6*T**4
      end

      Real FUNCTION CONDUCTIVITY2(T)
      real T
      CONDUCTIVITY2=-.48064+.0058471*T-7.3317d-6*T*T
      end

        REAL FUNCTION VISCOSITY2(T)
        real T
        VISCOSITY2 =0.23873 - 0.26422e-02*T + 1.1062e-05*T**2
     &    -2.0705e-08*T**3 + 1.4593e-11*T**4
        END

C-----------------------------------------------------------------------
C                     Bisection method

        RECURSIVE SUBROUTINE BISECTION3(FUNC,X1,X2,XACC,XROOT)

C       Using bisection, finds the root of a function FUNC known to lie between
C       X1 and X2.  The root, returned as XROOT, will be refined until its accuracy
C       is +/- XACC

      COMMON/LUNITS/LUR,LUW,IFORM,LUK
        REAL FMID,F,XROOT,DX,XMID
        PARAMETER (JMAX=50)

        FMID=FUNC(X2)
        F=FUNC(X1)

        IF(F*FMID.GE.0.) THEN
                WRITE(LUW,'(A,I3,A,I3,A)')' ERROR at Type 262 (Unit',unit,
     1          '): Bisection method out of range'
       CALL MYSTOP(1001)
        ENDIF
```

```
      IF(F.LT.0.) THEN
            XROOT=X1
            DX=X2-X1
      ELSE
            XROOT=X2
            DX=X1-X2
      ENDIF

      DO 15000 J=1,JMAX
            DX=DX*.5
            XMID=XROOT+DX
            FMID=FUNC(XMID)
            IF(FMID.LT.0.) XROOT=XMID
            IF(ABS(DX).LT.XACC .OR. FMID.EQ.0.) RETURN
15000 CONTINUE
      END
C--------------------------------------------------------------------------------
      SUBROUTINE ZBRAC3 (FUNC,X1,X2,SUCCESS)

C     Given a function FUNC and an initial guessed range X1 to X2, the routine
C     expands the range geometrically until a root is bracketed by the returned
C     values of X1 and X2.

      PARAMETER (FACTOR=1.6,NTRY=50)
      LOGICAL SUCCESS
      IF(X1.EQ.X2)PAUSE 'You have to guess an initial range'
      F1=FUNC(X1)
      F2=FUNC(X2)
      SUCCESS =.TRUE.
      DO 16000 J=1,NTRY
            IF (F1*F2.LT.0.)RETURN
            IF(ABS(F1).LT.ABS(F2))THEN
                  X1=X1+FACTOR*(X1-X2)
                  F1=FUNC(X1)
            ELSE
                  X2=X2+FACTOR*(X2-X1)
                  F2=FUNC(X2)
            END IF
16000 CONTINUE
      SUCCESS=.FALSE.
      RETURN
      END
```

A4 Fortran code for the controller component

```
SUBROUTINE TYPE275 (TIME,XIN,OUT,T,DTDT,PAR,INFO,ICNTRL,*)
C*********************************************************************
C Object: Bruce Hall Controller
C IISiBat Model: Bruce Hall controller
C
C Author: Joe Coventry
C Editor:
C Date:   2/9/2002 last modified: 25/5/2002
C
C Controller for Bruce Hall project.  Note that this component is also useful
C for CHAPS systems with a single pump.  The second 'tank pump' can simply be
C ignored.

C                 STANDARD TRNSYS DECLARATIONS
                          DOUBLE PRECISION XIN,OUT
                          INTEGER NI,NP,ND,NO
                          PARAMETER (NI=6,NP=9,NO=5,ND=0)
                          INTEGER*4 INFO,ICNTRL
                          REAL T,DTDT,PAR,TIME
                          DIMENSION XIN(NI),OUT(NO),PAR(NP),INFO(15)
                          CHARACTER*3 YCHECK(NI),OCHECK(NO)

C                 PARAMETERS

C                         Controller mode 1:  Delta T.  2: Fixed outlet temp (not yet available)
                          INTEGER ControllerMode
C                         Bypass setpoint for tank temperature for diverting flow to the cooling fins
                          REAL TTset
C                         Upper deadband for the collector pump (pump 1)
                          REAL DBupperC
C                         Lower deadband for the collector pump (pump 1)
                          REAL DBlowerC
C                         Upper deadband for the tank pump (pump 2)
                          REAL DBupperT
C                         Lower deadband for the tank pump (pump 2)
                          REAL DBlowerT
C                         Upper deadband for the bypass valve operation.
                          REAL DBupperV
C                         Lower deadband for the bypass valve operation
```

```
                        REAL DBlowerV
C                       Temperature difference between ambient and the control setpoint for
C                       operation of the pumps when the valve is bypassing fluid to the cooling fins
                        REAL TVDT

C               INPUTS
C                       Temperature at the outlet of the collectors
                        REAL TCout
C                       Monitoring temperature for the tank
                        REAL TTout
C                       Control signal for pump 1 at the previous iteration
                        INTEGER CFpump1old
C                       Control signal for pump 2 at the previous iteration
                        INTEGER CFpump2old
C                       Control signal for the bypass valve at the previous iteration
                        INTEGER CFvalveold
C                       Ambient temperature
                        REAL Tamb

C               OUTPUTS

C                       Control signal for pump 1
                        INTEGER CFpump1
C                       Control signal for pump 2
                        INTEGER CFpump2
C                       Control signal for the bypass valve
                        INTEGER CFvalve

C               OTHER VARIABLES

C                       Setpoint for control of the bypass valve
                        REAL TVSet

C-----------------------------------------------------------------------

C               IF ITS THE FIRST CALL TO THIS UNIT, DO SOME BOOKKEEPING
                        IF (INFO(7).GE.0) GO TO 100

C       FIRST CALL OF SIMULATION, CALL THE TYPECK SUBROUTINE TO CHECK THAT THE
C       USER HAS PROVIDED THE CORRECT NUMBER OF INPUTS,PARAMETERS, AND DERIVS
                        INFO(6)=NO
                        INFO(9)=1
```

```
            CALL TYPECK(1,INFO,NI,NP,ND)

            RETURN 1

C        END OF THE FIRST ITERATION BOOKKEEPING
C---------------------------------------------------------------------
C        GET THE VALUES OF THE PARAMETERS FOR THIS COMPONENT
100     CONTINUE

C           Mode 2 not enabled
            ControllerMode=INT(PAR(1)+0.01)
            TTset=PAR(2)
            DBupperC=PAR(3)
            DBlowerC=PAR(4)
            DBupperV=PAR(5)
            DBlowerV=PAR(6)
            DBupperT=PAR(7)
            DBlowerT=PAR(8)
            TVDT=PAR(9)

C        GET THE VALUES OF THE INPUTS TO THIS COMPONENT
            TCout=XIN(1)
            TTout=XIN(2)
            CFpump1old=INT(XIN(3)+0.01)
            CFvalveold=INT(XIN(4)+0.01)
            CFpump2old=INT(XIN(5)+0.01)
            Tamb = XIN(6)
C---------------------------------------------------------------------
C           Set the control temp for the bypass valve
            TVset = Tamb + TVDT

C        Put in something to stop the controller sticking

            IF (INFO(7).EQ.0) THEN
                OUT(4)=0
                OUT(5)=0
            END IF
C        Main logic
C        Mode 1 - Delta T
    IF (ControllerMode.EQ.1) THEN

C        Bypass solenoid valve control
```

```
                IF ((CFvalveold.EQ.1).AND.(TTout-TTset).GE.DBlowerV) THEN
                        CFvalve=1
                ELSEIF ((CFvalveold.EQ.1).AND.(TTout-TTset).LT.DBlowerV) THEN
                        CFvalve=0
                ELSEIF ((CFvalveold.EQ.0).AND.(TTout-TTset).GE.DBupperV) THEN
                        CFvalve=1
                ELSEIF ((CFvalveold.EQ.0).AND.(TTout-TTset).LT.DBupperV) THEN
                        CFvalve=0
                ENDIF

C       Case 1  - If valve is off
        IF (CFvalve.EQ.0) THEN

                IF ((CFpump2old.EQ.1).AND.((TCout-TTout).GE.DBlowerT)) THEN
                        CFpump2=1
                        CFpump1=1
                ELSEIF((CFpump2old.EQ.1).AND.((TCout-TTout).LT.DBlowerT))THEN
                        CFpump2=0
                        CFpump1=0
                ELSEIF((CFpump2old.EQ.0).AND.((TCout-TTout).GE.DBupperT))THEN
                        CFpump2=1
                        CFpump1=1
                ELSEIF((CFpump2old.EQ.0).AND.((TCout-TTout).LT.DBupperT))THEN
                        CFpump2=0
                        CFpump1=0
                ENDIF
C               Case 2 - when the control valve is on
                        ELSEIF (CFvalve.EQ.1) THEN
C               Pump2 is always off
                        CFpump2=0

C               Collector pump control

                        IF ((CFpump1old.EQ.1).AND.(TCout-TVset).GE.DBlowerC) THEN
                                CFpump1=1
                        ELSEIF ((CFpump1old.EQ.1).AND.(TCout-TVset).LT.DBlowerC) THEN
                                CFpump1=0
                        ELSEIF ((CFpump1old.EQ.0).AND.(TCout-TVset).GE.DBupperC) THEN
                                CFpump1=1
                        ELSEIF ((CFpump1old.EQ.0).AND.(TCout-TVset).LT.DBupperC) THEN
                        CFpump1=0
```

```
                ENDIF
            ENDIF
        ENDIF

C           Has pump1 status changed?
            IF (CFpump1.EQ.CFpump1old) THEN
C           No
                OUT(4) = INT(OUT(4)+0.1)
            ELSE
C           Yes
            OUT(4) = INT(OUT(4) +1.1)
            END IF

C           Has pump 2 status changed?
            IF (CFpump2.EQ.CFpump2old) THEN
C           No
                OUT(5) = INT(OUT(5)+0.1)
            ELSE
C           Yes
            OUT(5) = INT(OUT(5) +1.1)
            END IF

C           If this component is called 5 times or more in a timestep, then
C           simply stick to a value
            IF (OUT(4).GE.5) THEN
                CFpump1=1
            ENDIF

            IF (OUT(5).GE.5) THEN
                CFpump2=1
            ENDIF

C           SET THE OUTPUTS
200     CONTINUE
C            Collector Pump output control function
            OUT(1)=CFpump1
C            Bypass valve output control function
            OUT(2)=CFvalve
C            Tank pump output control function
            OUT(3)=CFpump2
        RETURN 1
                END
```

A5 TRNSYS deck file for the system base case

```
VERSION 15
*******************************************************************************
*** TRNSYS input file (deck) generated by IISiBat 3
*** on Wednesday, May 26, 2004 at 13:24
***
*** If you edit this file, use the File/Import TRNSYS Input File function in
*** IISiBat 3 to update the project.
***
*** If you have problems, questions or suggestions please contact your local
*** TRNSYS distributor or mailto:iisibat@cstb.fr
***
*******************************************************************************
ASSIGN C:\trnsys15\IISiBat3\Data\Joe\modeld.LST 6
*******************************************************************************
*** Control cards
*******************************************************************************
* START, STOP and STEP
CONSTANTS 3
START=1
STOP=8760
STEP=.1
*SIMULATION Start time   End time      Time step
SIMULATION      START   STOP    STEP

* User defined CONSTANTS
*                                  Integration      Convergence
TOLERANCES 0.001 0.001
*                                  Max iterations   Max warnings   Trace limit
LIMITS 25 999 25
*                                  TRNSYS numerical integration solver method
DFQ 1
*                                  TRNSYS output file width, number of characters
WIDTH 80
*                                  NOLIST statement
LIST
*                                  MAP statement
MAP
*                                  Solver statement
SOLVER 0
```

```
*******************************************************************************
*** Units
*******************************************************************************

* EQUATIONS "Calc. modified load"
*
EQUATIONS 1
Modload = 10*[7,1]

*------------------------------------------------------------------------------
* EQUATIONS "Calc. HW flow"
EQUATIONS 1
mdot = Modload/(4.18*(45-[7,2]+eql(45,[7,2])))
*------------------------------------------------------------------------------
* EQUATIONS "Calc. solar input"
EQUATIONS 1
Qsun = 37.5*[6,8]
*------------------------------------------------------------------------------
* EQUATIONS "Otemp calc."
EQUATIONS 1
Idbout = [6,8]*(1-[17,1])
*------------------------------------------------------------------------------
* Model "Canberra weather" (Type 9)
UNIT 5 TYPE 9    Canberra weather

PARAMETERS 36
* 1 Mode
-1
* 2 Header Lines to Skip
0
* 3 No. of values to read
10
* 4 Time interval of data
1
* 5 Interpolate or not?-1
-1
* 6 Multiplication factor-1
1.0
* 7 Addition factor-1
0
* 8 Interpolate or not?-2
-1
```

* 9 Multiplication factor-2
1.0
* 10 Addition factor-2
0
* 11 Interpolate or not?-3
-3
* 12 Multiplication factor-3
1.0
* 13 Addition factor-3
0
* 14 Interpolate or not?-4
-4
* 15 Multiplication factor-4
10
* 16 Addition factor-4
0
* 17 Interpolate or not?-5
-5
* 18 Multiplication factor-5
10
* 19 Addition factor-5
0
* 20 Interpolate or not?-6
6
* 21 Multiplication factor-6
0.1
* 22 Addition factor-6
0
* 23 Interpolate or not?-7
7
* 24 Multiplication factor-7
0.1
* 25 Addition factor-7
0
* 26 Interpolate or not?-8
8
* 27 Multiplication factor-8
0.1
* 28 Addition factor-8
0
* 29 Interpolate or not?-9
-9

```
* 30 Multiplication factor-9
1.0
* 31 Addition factor-9
0
* 32 Interpolate or not?-10
-10
* 33 Multiplication factor-10
1.0
* 34 Addition factor-10
0
* 35 Logical unit
14
* 36 Format specification
1
(1x,3F2.0,5F3.0,F2.0,F1.0)
*** External files
ASSIGN C:\trnsys15\Weather\canberra.tmy 14
*------------------------------------------------------------------------------

* Model "Tracking" (Type 16)
UNIT 6 TYPE 16  Tracking

PARAMETERS 9
* 1 Horiz. radiation mode
4
* 2 Tracking mode
3
* 3 Tilted surface mode
2
* 4 Starting day
1
* 5 Latitude
-35.2
* 6 Solar constant
4871
* 7 Shift in solar time
0.8
* 8 Not used
2
* 9 Solar time?
-1
INPUTS 7
```

* Canberra weather:Output 4 ->Total radiation on horizontal surface
5,4
* Canberra weather:Output 5 ->Direct normal beam radiation on horizontal
5,5
* Canberra weather:Time of last read ->Time of last data read
5,99
* Canberra weather:Time of next read ->Time of next data read
5,100
* [unconnected] Ground reflectance
0,0
* [unconnected] Slope of surface
0,0
* [unconnected] Azimuth of surface
0,0
*** INITIAL INPUT VALUES
0 0 0.0 1 0.2 19.18
36.03
*--

* Model "AS4234 load data" (Type 9)
UNIT 7 TYPE 9 AS4234 load data

PARAMETERS 12
* 1 Mode
-1
* 2 Header Lines to Skip
2
* 3 No. of values to read
2
* 4 Time interval of data
1.0
* 5 Interpolate or not?-1
-1
* 6 Multiplication factor-1
1.0
* 7 Addition factor-1
0
* 8 Interpolate or not?-2
-2
* 9 Multiplication factor-2
1.0
* 10 Addition factor-2

```
0
* 11 Logical unit
11
* 12 Not used
-1
*** External files
ASSIGN C:\trnsys15\IISiBat3\Data\Joe\Canload.txt 11
*------------------------------------------------------------------------------

* Model "Tempering valve" (Type 11)
UNIT 8 TYPE 11   Tempering valve

PARAMETERS 2
* 1 Tempering valve mode
4
* 2 # of oscillations allowed
7
INPUTS 4
* AS4234 load data:Output 2 ->Inlet temperature
7,2
* Calc. HW flow:mdot ->Inlet flow rate
mdot
* Tank:Temperature to load ->Heat source temperature
13,3
* [unconnected] Set point temperature
0,0
*** INITIAL INPUT VALUES
20.0 100.0 55.0 45
*------------------------------------------------------------------------------

* Model "Pump" (Type 3)
UNIT 9 TYPE 3    Pump

PARAMETERS 5
* 1 Maximum flow rate
1100
* 2 Fluid specific heat
4.190
* 3 Maximum power
540
* 4 Conversion coefficient
0.10
```

```
* 5 Power coefficient
0.5
INPUTS 3
* T-piece:Outlet temperature ->Inlet fluid temperature
15,1
* T-piece:Outlet flow rate ->Inlet mass flow rate
15,2
* Controller:Collector Pump output control function ->Control signal
18,1
*** INITIAL INPUT VALUES
35 36 1.0
*------------------------------------------------------------------------------

* Model "3-way valve" (Type 11)
UNIT 10 TYPE 11          3-way valve

PARAMETERS 1
* 1 Controlled flow diverter mode
2
INPUTS 3
* CHAPS collector:TOUT ->Inlet temperature
12,1
* CHAPS collector:FLOW ->Inlet flow rate
12,2
* Controller:Bypass valve output control function ->Control signal
18,2
*** INITIAL INPUT VALUES
20.0 100.0 0.5
*------------------------------------------------------------------------------

* Model "End loss" (Type 123)
UNIT 11 TYPE 123         End loss

PARAMETERS 3
* 1 Trough Length
24.21
* 2 Trough Width
1.55
* 3 Focal Length
.845
INPUTS 1
* Tracking:Incidence angle for surface 1 ->Incidence Angle
```

```
6,10
*** INITIAL INPUT VALUES
0
*------------------------------------------------------------------------------

* Model "CHAPS collector" (Type 262)
UNIT 12 TYPE 262          CHAPS collector

PARAMETERS 34
* 1 MODE
2
* 2 CELLS
10
* 3 REFEFF
.161
* 4 REFTEMP
65
* 5 BETA
-0.004
* 6 UNIFORMITY
.845
* 7 LENGTH
23.19
* 8 WIDTH
1.47
* 9 REFLM
0.935
* 10 SHAPE
.99
* 11 TRANSABS
0.886
* 12 COVERABS
0.063
* 13 EMIS
0.88
* 14 MASS
121.9
* 15 CP
1.08
* 16 TSTART
25
* 17 WGLASS
```

0.08
* 18 UCG
327
* 19 WCG
0.07
* 20 UCP
5787
* 21 WCP
0.04
* 22 UPT
1000000
* 23 WPT
1
* 24 UINSUL
23
* 25 WINSUL
.2
* 26 WCOVER
0.2
* 27 EMISCOV
0.1
* 28 CW0
22
* 29 CW1
27.4
* 30 CW2
-2
* 31 TOL
0.1
* 32 PERIM
0.1298
* 33 XSAREA
0.0003587
* 34 FH
0.74
INPUTS 7
* Pump:Outlet fluid temperature ->TFI
9,1
* Pump:Outlet flow rate ->FLOW
9,2
* Otemp calc.:Idbout ->ID
Idbout

```
* Canberra weather:Output 6 ->TAMB
5,6
* Canberra weather:Output 7 ->WIND
5,7
* End loss:End Loss Factor ->SHADE
11,1
* [unconnected] DIRT
0,0
*** INITIAL INPUT VALUES
25 1000 1000 25 2 1
1
*------------------------------------------------------------------------------

* Model "Tank" (Type 38)
UNIT 13 TYPE 38             Tank

PARAMETERS 17
* 1 Inlet position mode
1
* 2 Tank volume
1.5
* 3 Tank height
1.53
* 4 Height of collector return
1.06
* 5 Fluid specific heat
4.190
* 6 Fluid density
1000.0
* 7 Thermal conductivity
7.2
* 8 Tank configuration
1
* 9 Overall Loss Coefficient
26.365
* 10 Insulation ratio
1.0
* 11 Initial temperature
30.0
* 12 Maximum heating rate
64800
* 13 Auxiliary height
```

```
1.2
* 14 Thermostat height
1.25
* 15 Set point temperature
65
* 16 Temperature deadband
8
* 17 Flue loss coefficient
0.0
INPUTS 6
* 3-way valve:Temperature at outlet 1 ->Hot-side temperature
10,1
* 3-way valve:Flow rate at outlet 1 ->Hot-side flowrate
10,2
* Tempering valve:Temperature at outlet 1 ->Cold-side temperature
8,1
* Tempering valve:Flowrate at outlet 1 ->Cold-side flowrate
8,2
* Canberra weather:Output 6 ->Environment temperature
5,6
* [unconnected] Control signal
0,0
*** INITIAL INPUT VALUES
45.0 100.0 20.0 100.0 22.0 1

*-----------------------------------------------------------------------------

* Model "Finned tube HE" (Type 273)
UNIT 14 TYPE 273          Finned tube HE

PARAMETERS 11
* 1 Length of heat exchanger
60
* 2 Fins per length
160
* 3 Area of each fin
0.003
* 4 Diameter of tube
0.0109
* 5 Thickness of fins
0.00025
* 6 Fin conductivity
```

637
* 7 NODES
10
* 8 Specific heat of fin-tube
0.4
* 9 Mass of fin tube
19
* 10 Specific heat of the fluid
4.18
* 11 Mass of fluid in the heat exchanger
60
INPUTS 4
* 3-way valve:Temperature at outlet 2 ->Temperature of inlet fluid
10,3
* 3-way valve:Flow rate at outlet 2 ->Flow rate of inlet fluid
10,4
* Canberra weather:Output 6 ->Ambient temperature
5,6
* Canberra weather:Output 7 ->Wind speed
5,7
*** INITIAL INPUT VALUES
55 625 25 1
*---

* Model "T-piece" (Type 11)

UNIT 15 TYPE 11 T-piece

PARAMETERS 1
* 1 Tee piece mode
1
INPUTS 4
* Tank:Temperature to heat source ->Temperature at inlet 1
13,1
* Tank:Flowrate to heat source ->Flow rate at inlet 1
13,2
* Finned tube HE:Outlet fluid temperature ->Temperature at inlet 2
14,1
* Finned tube HE:Outlet flow rate ->Flow rate at inlet 2
14,2
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0

```
*---------------------------------------------------------------------------
* Model "T-piece2" (Type 11)
UNIT 16 TYPE 11        T-piece2

PARAMETERS 1
* 1 Tee piece mode
1
INPUTS 4
* Tank:Temperature to load ->Temperature at inlet 1
13,3
* Tank:Flowrate to load ->Flow rate at inlet 1
13,4
* Tempering valve:Temperature at outlet 2 ->Temperature at inlet 2
8,3
* Tempering valve:Flow rate at outlet 2 ->Flow rate at inlet 2
8,4
*** INITIAL INPUT VALUES
20.0 100.0 20.0 100.0
*---------------------------------------------------------------------------

* Model "Otemp park" (Type 2)
UNIT 17 TYPE 2  Otemp park

PARAMETERS 2
* 1 No. of oscillations
5
* 2 High limit cut-out
200
INPUTS 6
* CHAPS collector:TOUT ->Upper input value
12,1
* [unconnected] Lower input value
0,0
* CHAPS collector:TOUT ->Monitoring value
12,1
* Otemp park:Output control function ->Input control function
17,1
* [unconnected] Upper dead band
0,0
* [unconnected] Lower dead band
0,0
*** INITIAL INPUT VALUES
```

20.0 200 20.0 0 5 0.5

*--
* Model "Controller" (Type 275)
UNIT 18 TYPE 275 Controller

PARAMETERS 9
* 1 Controller mode
1
* 2 Tank upper termperature setpoint
0
* 3 Upper deadband for pump
5
* 4 Lower deadband for pump
.5
* 5 Upper deadband for bypass valve
5
* 6 Lower deadband for bypass valve
.5
* 7 Upper deadband for tank pump
5
* 8 Lower deadband for tank pump
.5
* 9 Delta T for bypass mode
5
INPUTS 6
* CHAPS collector:TOUT ->Collector outlet temperature
12,1
* Tank:Average tank temperature ->Tank monitoring temperature
13,10
* Controller:Collector Pump output control function ->collector pump input control function
18,1
* Controller:Bypass valve output control function ->Bypass valve control function
18,2
* Controller:Tank pump output control function ->Tank pump input control function
18,3
* Canberra weather:Output 6 ->Ambient temperature
5,6
*** INITIAL INPUT VALUES
0 0 1 0 1 0

*--

```
* Model "Output" (Type 28)
UNIT 19 TYPE 28          Output

PARAMETERS 18
* 1 Summary interval
-1
* 2 Summary start time
1
* 3 Summary stop time
8760
* 4 Logical unit
19
* 5 Output mode
1
* 6 Operation code-1
1
* 7 Operation code-2
0
* 8 Operation code-3
-4
* 9 Operation code-4
0
* 10 Operation code-5
-4
* 11 Operation code-6
0
* 12 Operation code-7
-4
* 13 Operation code-8
0
* 14 Operation code-9
-4
* 15 Operation code-10
0
* 16 Operation code-11
-4
* 17 Operation code-12
0
* 18 Operation code-13
-4
INPUTS 6
```

```
* Tank:Internal energy change ->Summary input-1
13,7
* Tank:Energy rate to load ->Summary input-2
13,6
* Tank:Auxiliary heating rate ->Summary input-3
13,8
* CHAPS collector:QELEC ->Summary input-4
12,3
* [unconnected] Summary input-5
0,0
* Calc. solar input:Qsun ->Summary input-6
Qsun
LABELS 6
DE Qload Qaux Qelec1 Qelec2 Qsun
*** External files
ASSIGN C:\trnsys15\IISiBat3\Data\Joe\modeld.out 19
*------------------------------------------------------------------------------

END
```

Appendix B

Appendix B contains the experimental raw data used for TRNSYS validations. The shaded sections show the periods of steady state measurement.

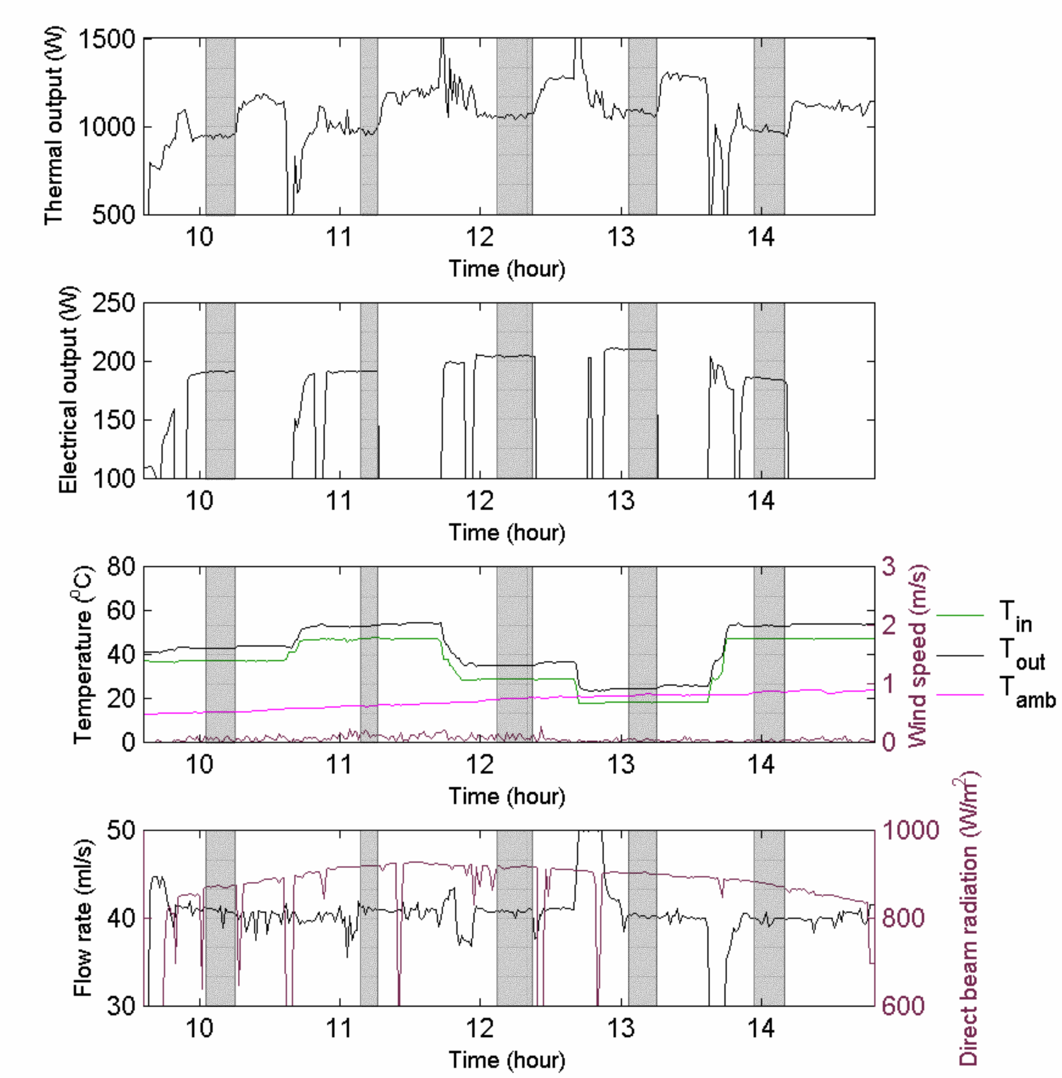

Figure B1. Measured data from 5 May 2003. The shaded areas show the steady state data used in the efficiency curves.

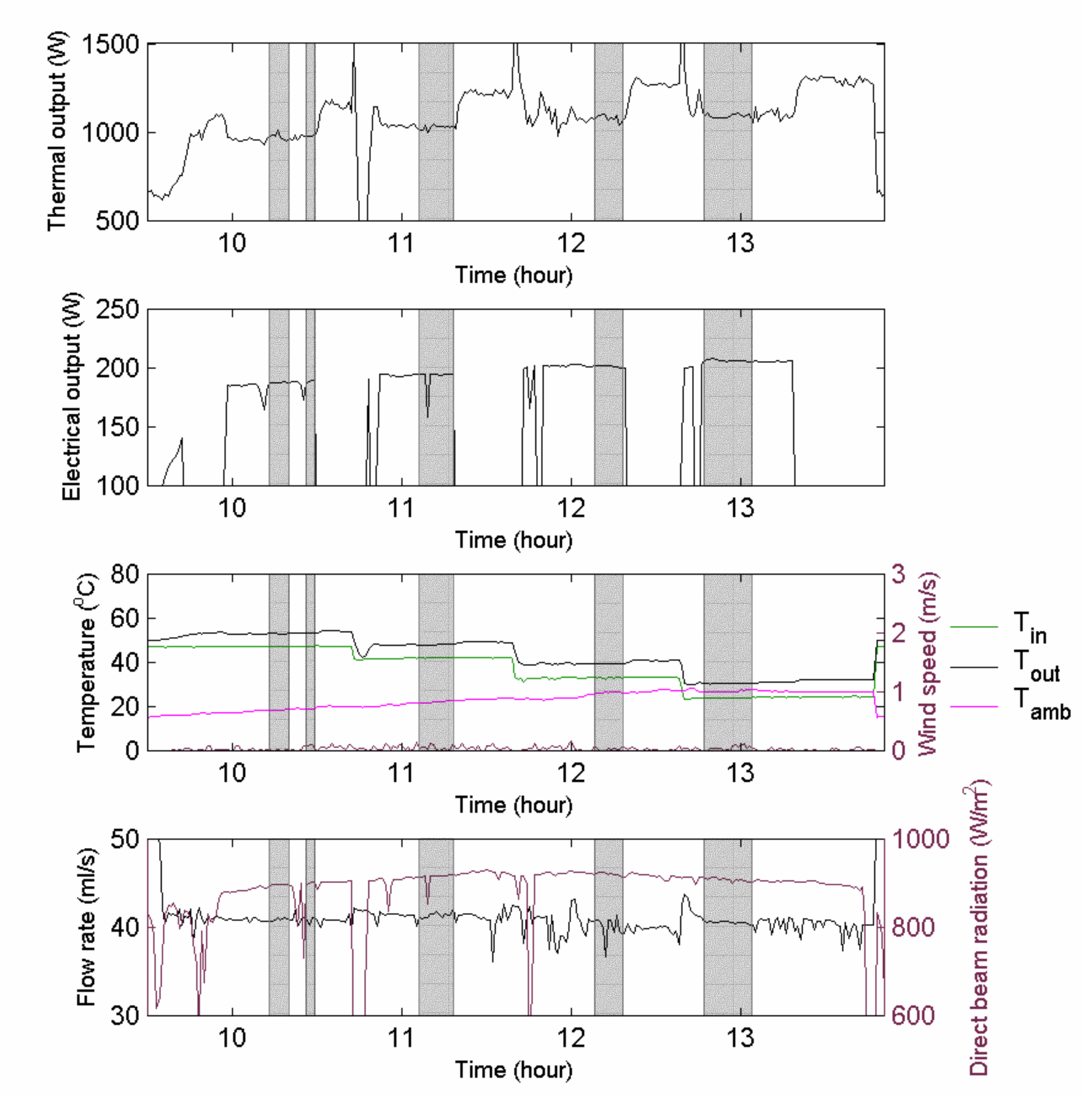

Figure B2. Measured and simulated data from 6 May 2003. The shaded areas show the steady state data used in the efficiency curves.

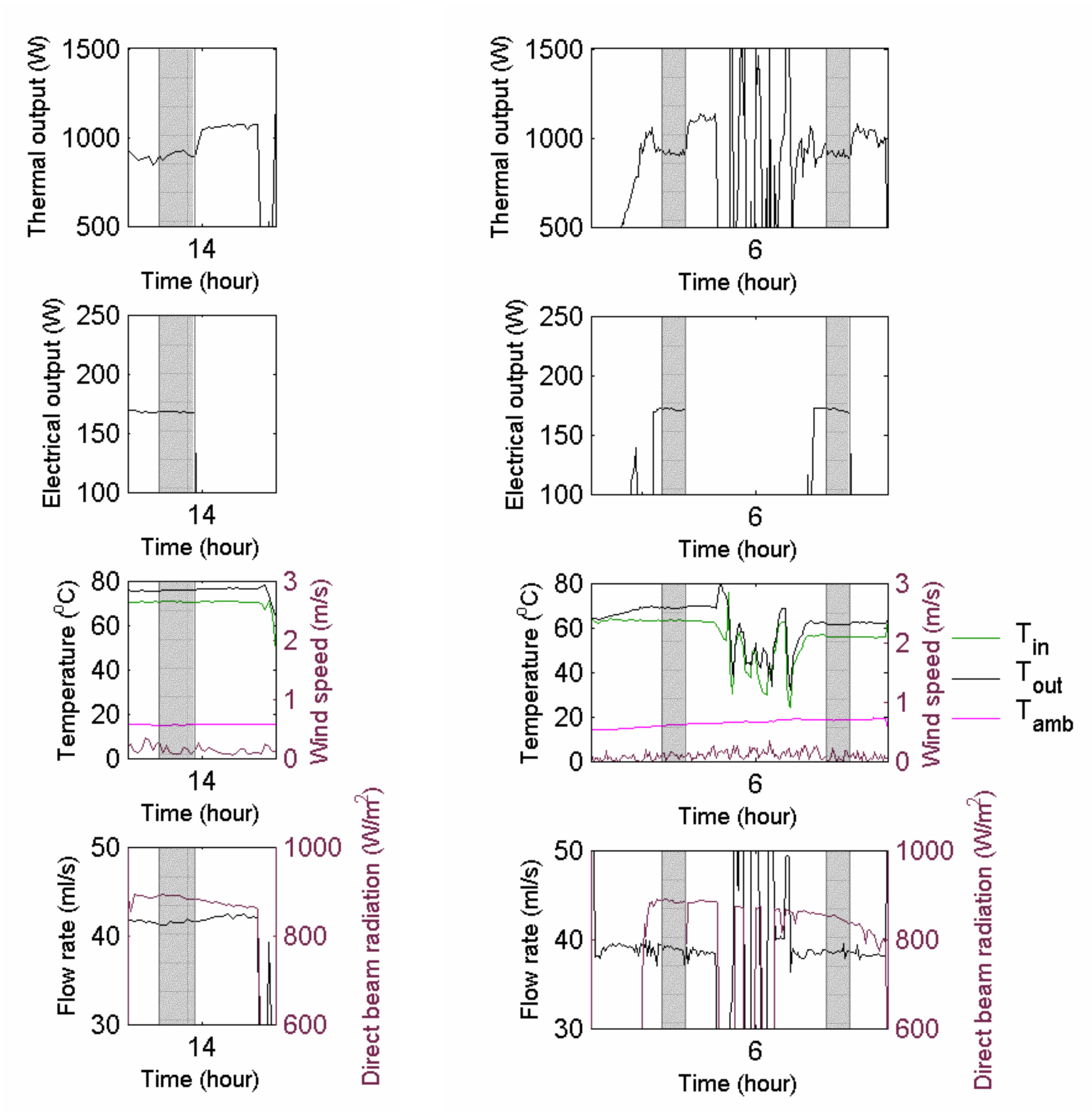

Figure B3. Measured and simulated data from 22 May 2003 (left) and the 29 May 2003 (right). The shaded areas show the steady state data used in the efficiency curves.

Appendix C

Franklin, E.T., Coventry, J.S. Effects of Highly Non-uniform Illumination Distribution on Electrical Performance of Solar Cells. *Proceedings of Solar 2002 Australian and New Zealand Solar Energy Society* Paper 1.

Copy of article available in hard copy of thesis held in Library.