Errata to
HVAC2 Toolkit: Algorithms and Subroutines for Secondary HVAC System Energy Calculations
(1993)

January 27, 2020

Pages 4-28 through 4-31, 4-102 through 4-103, and 6-32 through 6-33	These pages were missing from a recent reprint. If you do not have these pages in your copy of the PDF or print version of the book, they are supplied on the following pages.

```
50      CONTINUE

C2*** Boundary temperature not converged after maximum specified iterations.
C2*** Print error message, set return error flag

        WRITE(*,1001) itmax
1001    FORMAT(/1X,'*** ERROR IN SUBROUTINE PARTWET ***'/
     &         1X,'    Liquid temperature not converged at boundary ',
     &            'after ',I2,' iterations'/)
        ErrStat = 1

C1*** Estimate new value for fraction wet surface area

60      CONTINUE

C1*** If surface is dry, calculate dry coil performance and return

        IF(FWet .LE. 0.0 .AND. tSurfBnd .GE. TDewPt) THEN

          dryUA = aTot/(1./UIntTot+1./DryUExtTot)
          CALL DRYCOIL(Prop,MLiq,TLiqEnt,MAir,TAirEnt,WAirEnt,
     &                 dryUA,configHX,
     &                 TLiqLvg,TAirLvg,WAirLvg,QTot,
     &                 ErrStat)
          QSen = QTot
          FWet = 0.
          GO TO 999
        ENDIF

        error = tSurfBnd - TDewPt

        FWet = XITERATE(FWet,error,X1,F1,X2,F2,iter,icvg)

C1*** If converged, leave iteration loop

        IF (icvg .EQ. 1) GO TO 110

C2*** Surface temperature not converged.  Repeat calculations with new
C2*** estimate of fraction wet surface area.

        IF(FWet .GT. 1) FWet = 1.
        IF(FWet .LT. 0) FWet = 0.

100   CONTINUE

C2*** Surface temperature not converged after maximum specified iterations.
C2*** Print error message, set return error flag

      WRITE(*,1002) itmax
1002  FORMAT(/1X,'*** ERROR IN SUBROUTINE PARTWET ***'/
     &       1X,'    Wet/Dry boundary surface temperature not '
     &          'converged after ',I2,' iterations'/)
      ErrStat = 1

110   CONTINUE

C1*** Calculate sum of total and sensible heat transfer from dry
C1*** and wet parts.

      QTot = qDry+qTotWet
      QSen = qDry+qSenWet

999   RETURN
      END
```

4.1.6 WCOILOUT: Outlet Conditions for Wet Coil

GENERAL DESCRIPTION

This subroutine calculates the leaving air temperature, the leaving air humidity ratio, and the sensible cooling capacity for a wet or partially wet coil given the total capacity, entering air conditions, and air-side overall heat transfer coefficient.

MATHEMATICAL DESCRIPTION

The leaving air dry bulb temperature is calculated using an effectiveness method. The condensate temperature on the coil is unknown but assumed to be constant. Therefore, the condensate represents a fluid stream with infinite thermal capacity rate, and the following effectiveness relationship applies.

(4-19)

Using this relationship together with the known air enthalpy at the entrance to the wet coil and leaving air enthalpy, the saturated enthalpy at the condensate temperature for the calculated effectiveness can be determined.

$$h_{sat,cond} = h_{a,ent} - \frac{h_{a,ent} - h_{a,lvg}}{e} \qquad (4\text{-}20)$$

If the coil surface is part wet, the air conditions at the wet/dry boundary are used as entering conditions. The temperature of the condensate (surface) is determined from the saturated enthalpy using standard psychrometric relationships. Given condensate temperature, t_c, the leaving dry bulb temperature is calculated by the following.

(4-21)

The sensible cooling capacity can now be determined using a simple energy balance.

$$q_{sen} = (\dot{m}\, c_p)_a (t_{a,ent} - t_{a,lvg}) \qquad (4\text{-}22)$$

REFERENCES

ARI. 1972. "Standard for Forced Circulation Air-Cooling and Air Heating Coils," ARI Standard 410-72, Air-Conditioning and Refrigeration Institute, Washington, D.C.

NOMENCLATURE

		Description	Units	Minimum	Maximum
Input Variables					
m_a	MAir	Dry air mass flow rate	(kg/s)	0	BIG
$t_{a,ent}$	TAirEnt	Entering air dry bulb temperature	(C)	-100	200
$w_{a,ent}$	WAirEnt	Entering air humidity ratio	(-)	0	$w_{sat}(t_{a,i})$
$h_{a,ent}$	HAirEnt	Entering air enthalpy	(J/kg)	0	$h(t_{a,i},w_{a,i})$
$h_{a,lvg}$	HAirLvg	Leaving air enthalpy	(J/kg)	-BIG	$h_{a,i}$
	UAExt	Heat transfer coefficient for external surface	(W/C)		
Output Variables					
$t_{a,lvg}$	TAirLvg	Leaving air dry bulb temperature	(C)		
$w_{a,lvg}$	WAirLvg	Leaving air humidity ratio	(-)		
q_{sen}	QSen	Sensible heat transfer rate	(W)		
Properties					
$c_{p,a}$	CpAir	Specific heat of air	(J/kg C)	SMALL	BIG
$c_{p,v}$	CpVap	Specific heat of water vapor	(J/kg C)	SMALL	BIG
Selected Internal Variables					
Ntu	ntu	Number of heat transfer units	(-)		
ϵ	effectivenes	Heat exchanger effectiveness	(-)		
$h_{sat,cond}$	hSatCond	Saturated air enthalpy at condensate temp	(J/kg)		

ALGORITHM

- Determine the effectiveness of heat exchange between the air and the condensate, noting that the condensate temperature is constant ($C_{min}/C_{max} = 0$).
- Calculate coil surface enthalpy using the effectiveness relationships.
- Calculate condensate temperature from saturated enthalpy by psychrometric.
- Calculate leaving air conditions and sensible capacity using condensate temperature.

SOURCE CODE

```
      SUBROUTINE WCOILOUT (Prop,MAir,TAirEnt,WAirEnt,HAirEnt,HAirLvg,
     &                     UAExt,TAirLvg,WAirLvg,QSen,ErrStat)
C***********************************************************************
C*    Copyright ASHRAE.  Toolkit for HVAC System Energy Calculations
C***********************************************************************
C*    SUBROUTINE:              WCOILOUT
C*
C*    LANGUAGE:                FORTRAN 77
C*
C*    PURPOSE:                 Calculate the leaving air temperature,
C*                             the leaving air humidity ratio and the
C*                             sensible cooling capacity of wet cooling
C*                             coil.
C***********************************************************************
C*    INPUT VARIABLES
C*    MAir          Dry air mass flow rate                        (kg/s)
C*    TAirEnt       Entering air dry bulb temperature               (C)
C*    WAirEnt       Entering air humidity ratio                     (-)
C*    HAirEnt       Entering air enthalpy                        (J/kg)
C*    HAirLvg       Leaving air enthalpy                         (J/kg)
C*    UAExt         Heat transfer coefficient for external surface (W/C)
C*
C*    OUTPUT VARIABLES
C*    TAirLvg       Leaving air dry bulb temperature                (C)
C*    WAirLvg       Leaving air humidity ratio                      (-)
C*    Qsen          Sensible heat transfer rate                     (W)
C*    ErrStat       Error status indicator, 0 = ok, 1 = error       (-)
C*
C*    PROPERTIES
C*    Patm          Atmospheric pressure                            (-)
C*    CpAir         Specific heat of air                       (J/kg C)
C*    CpVap         Specific heat of water vapor               (J/kg C)
C***********************************************************************
C     MAJOR RESTRICTIONS:      Assumes condensate at uniform temperature.
C
C     DEVELOPER:               Shauna Gabel
C                              Michael J. Brandemuehl, PhD, PE
C                              University of Colorado at Boulder
C
C     DATE:                    January 1, 1992
C
C     INCLUDE FILES:           prop.inc
C     SUBROUTINES CALLED:      None
C     FUNCTIONS CALLED:        TAIRSAT
C                              DRYBULB
C                              HUMTH
C                              DEWPOINT
C
C     REVISION HISTORY:        None
C
C     REFERENCE:               Elmahdy, A.H. and Mitalas, G.P.  1977.
C                              "A Simple Model for Cooling and
C                              Dehumidifying Coils for Use In Calculating
C                              Energy Requirements for Buildings,"
C                              ASHRAE Transactions,Vol.83 Part 2,
C                              pp. 103-117.
C***********************************************************************
C     INTERNAL VARIABLES:
C     capAir        Air capacity rate                               (W/C)
C     ntu           Number of heat transfer units                     (-)
C     effectiveness Heat exchanger effectiveness                      (-)
C     hCondSat      Saturated air enthalpy at temperature of
C                   condensate                                     (J/kg)
C     tempCond      Temperature of condensate                         (C)
C***********************************************************************

$INCLUDE: 'prop.inc'

      INTEGER ErrStat
      REAL ntu,MAir
      DATA small/1.E-9/

      ErrStat = 0
```

4.9 EVAPHUM: Direct Evaporative Humidifier/Cooler

GENERAL DESCRIPTION

This subroutine calculates the leaving air temperature and humidity ratio using an adiabatic saturation effectiveness model. The model represents an air stream passing over a pan of water or through a saturated porous medium, adiabatically increasing the humidity and decreasing the temperature of the air. The temperature of the water is assumed to be equal to the leaving temperature of the humidified air.

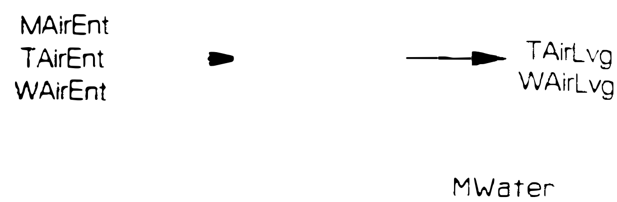

Figure 4-10: Schematic of direct evaporative cooler.

MATHEMATICAL DESCRIPTION

The leaving humidity ratio is calculated using a saturation effectiveness method. The model performs effectiveness calculations using heat exchanger effectiveness-Ntu relationships assuming that the effective capacity rate of the evaporation source is infinite. The effectiveness-Ntu calculations are performed in the utility routine HEATEX. Using these relationships, the leaving humidity ratio is calculated by the following.

$$w_{a,lvg} = w_{a,ent} + (w_{a,lvg,sat} - w_{a,ent})\,\epsilon_{sat} \tag{6-3}$$

The outlet saturated humidity ratio, $w_{a,lvg,sat}$, is evaluated at the inlet wet bulb temperature. The saturation effectiveness can be determined from the following relationship as described in the documentation for HEATEX.

$$\epsilon_{sat} = 1 - e^{-N}$$

$$N = \frac{UA_{sat}}{C_{sat}} \tag{6-4}$$

For this model, the saturation capacity rate, C_{sat}, is the mass flow rate of the air and the overall saturation transfer coefficient, UA_{sat}, is a measure of the size of the evaporative humidifier. The value of UA_{sat} is determined from a single point of performance data. Given the flow rate and entering air conditions and the corresponding saturation effectiveness at some operating conditions, the overall coefficient can be determined as described above using the UAHX routine.

REFERENCE

Clark, D.R.. 1985. HVACSIM+ Building Systems and Equipment Simulation Program: Reference Manual. NBSIR 84-2996, U.S. Department of Commerce, Washington, D.C.

Threlkeld, J.L. 1970. Thermal Environmental Engineering, 2nd Edition, Englewood Cliffs: Prentice-Hall, Inc.

NOMENCLATURE

		Description	Units	Minimum	Maximum
Variables					
m_a	MAir	Dry air mass flow rate	(kg/s)	0	BIG
$t_{a,ent}$	TAirEnt	Entering air temperature	(C)	-100	200
$w_{a,ent}$	WAirEnt	Entering air humidity ratio	(-)	0	$w_{sat}(t_{a,ent})$
Output Variables					
$t_{a,lvg}$	TAirLvg	Leaving air temperature	(C)		
$W_{a,lvg}$	WAirLvg	Leaving air humidity ratio	(-)		
Parameters					
$\epsilon_{evap,rat}$	EffEvapRat	Humidity effectiveness at rating	(-)	0	1
$m_{evap,rat}$	MEvapRat	Humidifier dry air mass flow rate at rating	(kg/s)	0	BIG
$t_{evap,rat}$	TEvapRat	Humidifier air dry bulb temperature at rating	(C)	-100	200
$w_{evap,rat}$	WEvapRat	Humidifier air humidity ratio at rating	(-)	0	$w_{sat}(t_{a,ent})$
Properties					
P_{atm}	Patm	Atmospheric pressure	(Pa)		
$c_{p,a}$	CpAir	Specific heat of air	(J/kg C)		
$c_{p,v}$	CpVap	Specific heat of water vapor	(J/kg C)		
Selected Internal Variables					
C_{sat}	capAir	Capacity rate of air stream	(kg/s)		
UA_{sat}	P(UAEvap)	Overall transfer coefficient	(kg/s)		
ϵ_{sat}		Saturation effectiveness	(-)		
N		Number of transfer coefficients	(-)		

ALGORITHM

- Calculate overall transfer coefficient from rating data
- Calculate psychrometric properties of the entering air
- Calculate saturated leaving air humidity ratio at the entering wet bulb temperature
- Calculate the leaving air humidity ratio from effectiveness-Ntu model with entering and saturated conditions
- Calculate the leaving air temperature from leaving humidity ratio and entering enthalpy

```
          READ(LUR5,*) MZDes(i),QZsen,QZlat,TZSetPt

C2*** Calculate the required zone entering air temperature to satisfy
C2*** zone sensible load

          tZSAir(i) = TZSetPt-QZsen/(Prop(CpAir)*MZDes(i))

C2*** Sum the design air mass flow rate and the total latent load
C2*** for all zones

          mZDesTot = MZDes(i)+mZDesTot
          qZlatTot = QZlat+qZlatTot

C2*** Zone return air calculation

          tAirRet = TZSetPt
          TotTAirRet = tAirRet+TotTAirRet

          WRITE(LUW,1012) i,MZDes(i),QZsen,QZlat,TZSetPt,tZSAir(i)

 200    CONTINUE

C2*** Zone calculation end

C1*** Averaged return air temperature

        tAirRet = TotTAirRet/zNum

C1*** Iterate on humidity ratio

C2*** Initial guess at cooling coil leaving air humidity ratio,
C2*** relating to air leaving conditions of 55 DB and 90% RH, and
C2*** initial guess at the heating coil leaving air humidity ratio
C2*** equivalent to the entering air humidity ratio

        wCCAirLvg = 0.0077
        wHCAirLvg = WAirAmb

        DO 300 iter=1,itmax

          oldW = wCCAirLvg
          mHotTot = 0.0
          mColdTot = 0.0

C1*** Begin zone loop for hot and cold air flow calculations

          DO 400 i = 1,zNum

C2*** Determine the hot and cold air mass flow rates for zone

            CALL MIXIAIR (Prop,MZDes(i),tZSAir(i),TColdDes,wCCAirLvg,
     &                    THotDes,wHCAirLvg,mCold,mHot,wZEnt,ErrStat)

C2*** Sum the cold and hot air mass flow rate totals

            mHotTot = mHot+mHotTot
            mColdTot = mCold+mColdTot

 400      CONTINUE

C2*** End zone loop for hot and cold air flow calculations

C1*** Return air humidity ratio calculation

          wAirRet = wZent+qZlatTot/(Prop(Hfg)*mZDesTot)

C1*** Calculate the mixed air temperature and humidity ratio using
C1*** an economizer option

          tPHSetPt = TColdDes-1.

          CALL ECON (Prop,tAirRet,wAirRet,TAirAmb,WAirAmb,mZDesTot,
     &               MAmbMin,tPHSetPt,TAirAmb,EconClose,EconMode,
     &               tAirMix,wAirMix,mAirRet,mAirAmb,ErrStat)

C1*** Determine if preheat is necessary and calculate the coil load
```

```
C1*** if required, otherwise set the cooling coil entering air
C1*** temperature and humidity ratio equal to the mixed air temperature

          IF (tAirMix .LT. tPHSetPt) THEN
            CALL COILINV (HCDET,Prop,PPHCoil,tHCLiqEnt,mZDesTot,
     &                    tAirMix,wAirMix,TPHSetPt,wAirMix,mPHLiq,
     &                    tLiqPHLvg,qPHtot,qPHsen,pHFWet,Errstat)
          ELSE
            qPHtot = 0.0
            qPHsen = 0.0
            mPHLiq = 0.0
            tPHSetPt = tAirMix
          ENDIF

C1*** Calculate the supply fan power and fan leaving air temperature

          CALL FANSIM (pROP,PSFan,mZDesTot,tPHSetPt,wAirMix,tAirMix,
     &                 wAirMix,sFanPow,Errstat)

C1*** Calculate the heating coil load

          IF (tAirMix .LT. tHotDes) THEN

            CALL COILINV (HCDET,Prop,PHCoil,tHCLiqEnt,mHotTot,tAirMix,
     &                    wAirMix,THotDes,wHCAirLvg,mHCLiq,tLiqHCLvg,
     &                    qHCtot,qHCsen,hCFWet,Errstat)
          ELSE
            mHCLiq = 0.0
            qHCtot = 0.0
            qHCsen = 0.0
          ENDIF

C1*** Calculate the cooling coil load and leaving air humidity ratio

          IF (TAirMix .GT. TColdDes) THEN

            CALL COILINV (CCDET,Prop,PCCoil,tCCLiqEnt,mColdTot,tAirMix,
     &                    wAirMix,TColdDes,wCCAirLvg,mCCLiq,tLiqCCLvg,
     &                    qCCtot,qCCsen,cCFWet,ErrStat)
          ELSE
            mCCLiq = 0.0
            qCCtot = 0.0
            qCCsen = 0.0
          ENDIF

          error = oldW-wCCAirLvg
          wCCAirLvg = XITERATE(wCCAirLvg,error,X1,F1,X2,F2,iter,icvg)

C1*** If converged, leave loop
          IF (icvg .EQ. 1) GO TO 500

300     CONTINUE
C2*** End humidity ratio loop

C1*** If not converged after itmax iterations, return error code

        WRITE(*,1010) itmax
1010    FORMAT(/1X,'*** ERROR IN PROGRAM DUAL ***'/
     &         1X,'    The humidity ratio has not converged after,'I2,
     &            iterations'/)
        ErrStat = 1

500     CONTINUE

C *** Write hourly results

      WRITE(LUW,1015) qCCtot,qCCsen,qHCsen,qPHsen,sFanPow

C1*** Sum the coil loads and fan power

        TotSFanPow = sFanPow+TotSFanPow
        TotQPHsen = qPHSen+TotQPHsen
        TotQHCsen = qHCsen+TotQHCsen
        QtotCCTot = qCCTot+QtotCCTot
        QsenCCTot = qCCSen+QsenCCTot
```