IMPROVEMENT OF THE ASHRAE SECONDARY HVAC TOOLKIT SIMPLE COOLING COIL MODEL FOR SIMULATION

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ABSTRACT

The simple cooling coil "CCSIM" model of the ASHRAE Secondary HVAC Toolkit approximates the performance of cooling coil as either completely dry or completely wet with wet dry fraction value of 1 or 0. This model also generates an abrupt discontinuity in all output values, such as leaving air temperature, total heat transfer, sensible heat transfer etc., in the wet-dry transition region. This model will fail to work for simulations in the transition range between wet and dry coil sections where a continuous function in output values is necessary.

This paper shows how to maintain the simpler input parameters and still have enough information to use the Wet-Dry coil model to eliminate the abrupt discontinuity in the output values in the transition region. This is achieved by addition and amalgamation of certain formulas and modules present in the detailed cooling coil model "CCDET", with the simple cooling coil model. The simplicity of the model in terms of inputs is retained; the discontinuities are eliminated and it also gives value of fraction wet-dry of the simple coil.

INTRODUCTION

Building simulation is used through various phases of building design. Building simulation can be done from preliminary design when information about the building is scarce, all the way to as-built and retrofit analysis. The amount of cooling coil information that the user knows during these design stages varies as well. In initial design stages the user has more access to information involving the coil load and performance for design conditions at rated capacity. At this stage trying to determine coil geometry and configuration is very difficult when trying to get the simulation to work with reasonable results. At the other end of the simulation spectrum for retrofit or as-built analysis with the actual equipment specifications available, the inputs for the detailed coil are more feasible to enter. The simulation user has to be able to run the analysis at both extremes and anywhere in between, yet still needs a cooling coil model with results that are suitable.

In simulation programs the aim is to minimize the user inputs while keeping the results accurate, hence its essential that a simple model exists which generates results without discontinuity, and outputs desired results.

Chilled water-cooling coil models are required for many simulation programs. The ASHRAE Secondary HVAC Toolkit has simple and detailed cooling coils models. The simple coil model has the advantage of simple inputs but the drawback is the output discontinuities when transitioning between a completely wet or dry coil, on the other hand the detailed cooling coil model has continuous results from all wet to all dry, but needs a great deal of inputs, especially the coil geometries.

This paper explains the two existing models in the ASHRAE Secondary HVAC Toolkit, brings out the disadvantages of the discontinuous behavior of the simple model when used for simulation. Then proposes formulas and amalgamations of the two models with reasonable assumptions. It eliminates the discontinuities in the output variables of the simple cooling coil model, gives appropriate wet-dry fractions subsequently giving increased suitability for building simulation and a better and more "detailed" ASHRAE Toolkit simple cooling coil model.

SIMPLE COOLING COIL MODEL: CCSIM

The capacity and rated conditions input for the simple cooling coil are advantageous for use in simulation programs especially in initial phases of building analysis. The Simple cooling coil requires two types of inputs, the first set of inputs is the coil operating conditions: MLiq, TliqEnt, MAir, TairEnt, WairEnt.

The second set of inputs is the rated inputs, which are used to define the coil performance parameters such as UA. The rated inputs are MliqRat, TliqRat, MairRat,

TairRat, WAirRat, QtotRat, QsenRat. The coil is first designed using rated inputs and then simulated with operating conditions. The outputs of the simple cooling coil model are: TliqLvg, TairLvg ,WAirLvg, QTot, QSen, and Fwet.

Simple Cooling Coil Model Functions:

With the above inputs CCSIM calculates the following: properties of air and water at rated conditions using psychrometric functions, and UAExt and UAInt using Effectiveness-NTU relationships. Using air properties, UAExt, and UAInt the coil model simulates the subroutines DryCoil and WetCoil with the logic shown below.

Step 1: If TDewPt is less than TLiqEnt then the Coil is assumed completely dry. CCSIM calls the Drycoil function for outputs. DryCoil calculates the outlet air-conditions assuming that the coil is completely dry, there is no moisture condensation and QSenSim = QTotSim, and FWetSim = 0.

Step 2: If TDewPt is greater than TLiqEnt: then CCSIM assumes external surface of coil as completely wet and CCSIM calls the WetCoil function for outputs. The WetCoil routine calculates the output conditions of the coil, assuming the coil surface as completely wet; or the coil fraction wet is approximated as 1.0. The WetCoil subroutine calculates TsurfEnt, surface temperature of coil at inlet, which is utilized in Step 3.

Step 3: If TDewPt is less than TSurfEnt then coil is partially wet. CCSIM calls DryCoil function for outputs and if the heat transfer calculated by drycoil is greater than the previous calculated value from wetcoil (Step 2), the coil is assumed completely dry. Otherwise it is approximated as completely wet.

In practice there is moisture condensation and hence QSenSim ≠ QTotSim and Fwet is in the range from 0 to 1.

Disadvantages of this Model

The coil is approximated as either completely wet or completely dry. Fraction dry-wet is either 0 or 1. The possibility of the coil being partially wet or dry is not accounted for. This leads to discontinuities obtained in all the output values, shown in the subsequent plots. These discontinuities can cause problems in detailed energy simulation programs particularly when the program is trying to converge on a solution. Plots 1 to 4 depict this behavior.

Relative humidity of air at outlet is not directly by CCSIM or CCDET models, but can easily be determined

from other output conditions and is discontinuous. Four plots showing the discontinuous behavior of the cooling coil model are shown below.
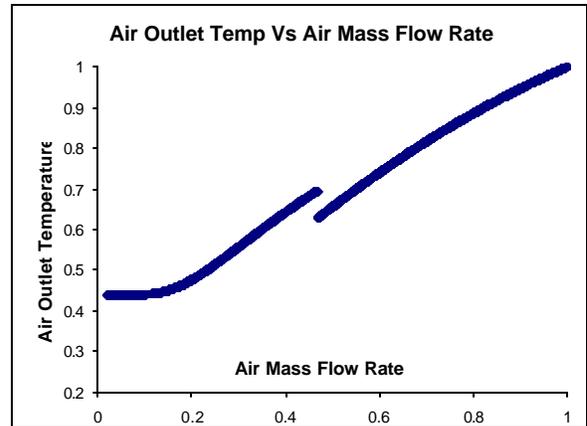

Figure 1: Discontinuous nature of outlet air temperature.
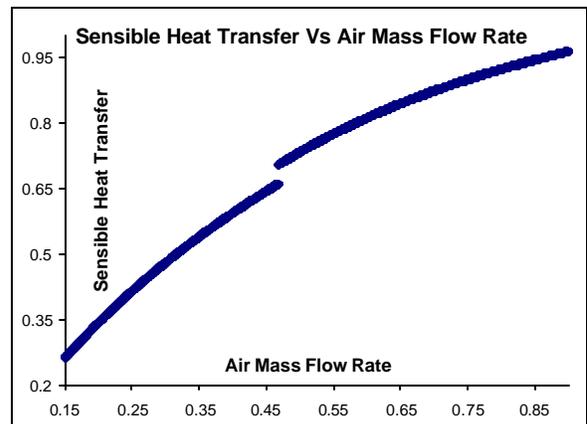

Figure 2: Discontinuous nature of sensible heat transfer rate
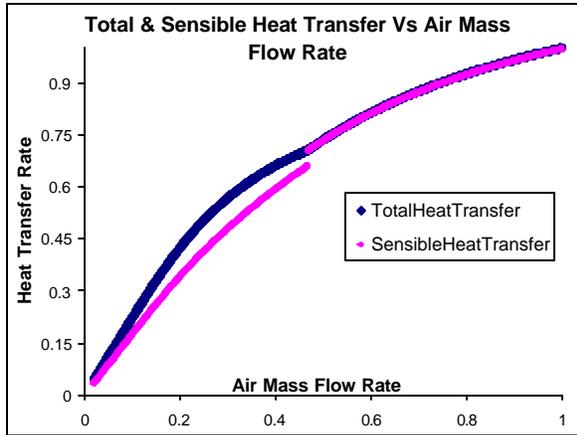
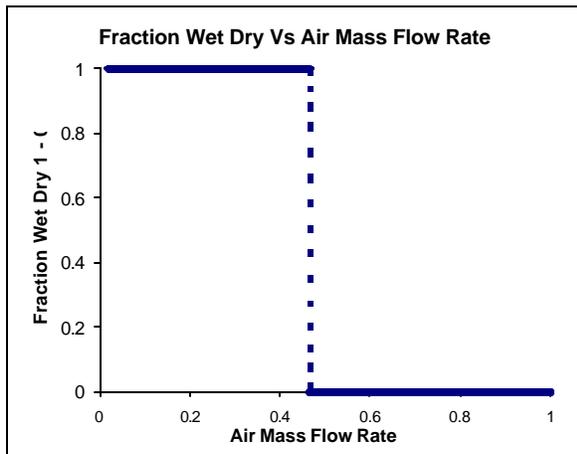Figure 3: Discontinuities in Sensible heat transfer and total heat transfer.

Figure 4: Shows approximation of Fraction Wet-Dry as either 1 or 0.

DETAILED COOLING COIL MODEL: CCDET

This model requires information on the coil geometry as user input. The algorithms used by this model have the advantage of continuous functions as outputs of fraction wet-dry of the coil; the value varies between 0 and 1. But this model requires the geometry and configuration of the coil from user, which is unsuitable for load or energy simulations of buildings in initial stages of design.

Detailed Cooling Coil Model Functions:

This models calculates intermediate variables (mainly UA's) from the coil geometries, air and water inlet

conditions, the coil proceeds in the almost the same algorithm logic as CCSIM.

Step 1: If TDewPt is less than TLiqEnt then the Coil is assumed as completely dry. CCDET calls the DryCoil subroutine for outputs. CCDET DryCoil subroutine calculates value of coil DryUA. This variable is utilized later in the modified CCSIM model.

Step 2: If TDewPt is greater than TLiqEnt the program assumes external surface of coil is completely wet and CCDET calls the WetCoil subroutine for outputs. The calculated intermediate variables in CCDET WetCoil are WetUAInt and WetUAExt. The wet coil routine gives the outlet air conditions. WetUAInt and WetUAExt are utilized in the modified CCSIM Model.

Step 3: If TDewPt is less than TsurfEnt then coil is partially wet and the detailed model now calls a new subroutine DRY-WET COIL.

This is where the detailed model differs in logic from the simple model. The subroutine DryWetCoil calculates the performance of a partially wet coil. Inputs variables to DryWetCoil are: MLiq, TLiqEnt, MAir, TAirEnt, WAirEnt, TDewPt, ATot, UIntTot, DryUExtTot, and WetUExtTot. The additional inputs required by CCDET DryWetCoil subroutine are ATot, UIntTot, DryUExtTot, WetUExtTot. These variables are absent in the CCSIM model.

This DRY-WET COIL subroutine iterates on an assumed value of Fraction Wet-Dry until convergence is achieved. The use of this subroutine in the CCDET model enables it to output continuous results for all output variables

MODIFIED SIMPLE COOLING COIL MODEL: CCSIM NEW

The CCDET results require a larger number of user inputs, namely coil configuration and geometric details. At early stages of simulation these inputs are unknown or difficult to obtain, since object of the early design phase simulations is to help the user decide the coil specifications; hence use of CCDET is difficult at early stages of building simulation. This shows the need of a coil model with simple inputs, namely CCSIM. Once again the discontinuous nature of the CCSIM outputs can make it difficult for use in simulation program. We show below how a continuous-output simple input cooling coil model can be developed from CCSIM without any additional user inputs, by addition of formulas and amalgamations of the two models, CCDET and CCSIM

In the next sections are shown the steps that can achieve a simple cooling model with continuous curves, knowledge of fraction wet-dry, sensible heat transfer rate, and relative humidity of air at the outlet.

Step1. Amalgamation of subroutines of the two models

Addition of the DryWetCoil subroutine from CCDET to the CCSIM model.

In the CCSIM subroutine when TDewPt is less than TsurfEnt (Step 3) then call upon the newly added subroutine DryWetCoil, instead of calling the subroutine DryCoil.

As mentioned earlier this DryWetCoil subroutine requires additional inputs: ATot, UIntTot, DryUExtTot & WetUExtTot. These are not calculated in the CCSIM model and are calculated in CCDET model using the coil geometric data. Since the inputs for CCSIM are not the coil geometries we would like to calculate those variables without additional inputs in CCSIM model.

Step2. Generation of additional inputs for DryWetCoil Subroutine

Using formulations and approximations already present in the Simple and Detailed Cooling Coil Models, CCSIM and CCDET, these additional inputs can be calculated as follows.

Atot: Total surface area of coil is calculated from the rated inputs using the following relation, Equations 1.1 to 1.6. This is a reasonable approximation since all the existing variables in this coil are calculated from rated conditions. Considering cross flow arrangement for the coil model:

Note value of LMTD can be changed for the type of heat exchanger arrangement (cross, counter etc).

$$QTotRat = UATot \times Atot \times (LMTD)_{CrossFlow} \quad (1.1)$$

$$LMTD_{CrossFlow} = \frac{T_{LiqOutRat} - T_{LiqInRat}}{Log\left[\dfrac{R}{R + Log(1 - R \times P)}\right]} \quad (1.2)$$

$$where\ R = \frac{T_{AirInRat} - T_{AirOutRat}}{T_{LiqOutRat} - T_{LiqInRat}} \quad (1.3)$$

$$P = \frac{T_{LiqOutRat} - T_{LiqInRat}}{T_{AirInRat} - T_{LiqInRat}} \quad (1.4)$$

$$T_{LiqOutRat} = T_{LiqInRat} + \frac{(MairRat \times C_{Pair} \times \Delta T_{AirRat})}{(MliqRat \times C_{PWater})} \quad (1.5)$$

$$where\ \Delta T_{AirRat} = T_{AirInRat} - T_{AirOutRat} \quad (1.6)$$

UIntTot: Overall Internal UA per unit external area of the coil W/m2 C

$$UIntTot = \frac{Overall\ Internal\ UA}{Atot} = \frac{UAInt}{Atot} \quad (2.1)$$

where Atot is calculated from equation 1.1 and

$$UAInt = \frac{CpSat}{\dfrac{1}{UAH} - \dfrac{CpAir}{UAExt}} \quad (2.2)$$

DryUExtTot: Overall External Dry UA of coil per unit external area W/m2C. The formulation for calculating this variable is determined by rearranging a formula from the CCDET Detailed Cooling Model as shown in Equations 3.1 and 3.2.

$$DryUA = \frac{Atot}{\dfrac{1}{DryUExtTot} - \dfrac{1}{U\,int\,Tot}} \quad (3.1)$$

Rearrange Equation 3.1 to obtain DryUExtTot.

$$DryUExtTot = \frac{DryUA \times U\,int\,Tot}{Atot \times U\,int\,Tot - DryUA} \quad (3.2)$$

Analysis of the CCSIM and CCDET model shows that the value of DryUA in the CCDET model is approximated by the value of UATot in the CCSIM model. This is a good assumption in the simple cooling coil model since it assumes DryUA as UATot. Using this assumption and replacing DryUA by UATot, which is already a calculated variable in CCSIM model, Equation 3.3 is obtained.

$$DryUExtTot = \frac{UATot \times U\,int\,Tot}{Atot \times U\,int\,Tot - UATot} \quad (3.3)$$

WetUExtTot: Overall External WetUA of coil per unit external area W/m2 C variable has been used in the Detailed Cooling Coil Model CCDET. From CCDET the following form of equation 4.1 is obtained.

$$WetUExtTot = \frac{WetUAExt}{Atot} \quad (4.1)$$

In the simple cooling coil model the variable WetUAExt is approximated by UAExt, using this form of approximation from CCSIM into the New Model we get:

$$\text{WetUExtTot} = \frac{UAExt}{Atot} \qquad (4.2)$$

Analysis of the CCSIM and CCDET model shows that the value of WetUExtTot in the Modified Model is approximately equal to the value of DryUExtTot. The derivations to obtain Equations 3.3 and 4.2 justify this assumption.

Relative Humidity of Air: The ASHRAE Psychrometric, RelHum determines the relative humidity of air at inlet and outlet conditions, which is desired in a coil simulation. With the temperature dry bulb, humidity ratio, and atmospheric pressure the Relative Humidity of air at inlet and outlet of the coil is determined.

RESULTS OF THE NEW MODEL:

Comparisons of the results of ASHRAE Secondary toolkit Simple Cooling Coil Model CCSIM with this New Simple Model are shown in Figures 5 - 9. Following are some of the strong points.

- This implementation eliminates the discontinuities in all outputs variables making the model suitable for simulations, especially since simulations can require continuous functions.

- It eliminates the need of approximating the coil as completely wet or completely dry. A value for fraction wet-dry is obtained and Fwet varies between 0 & 1.

- QSenSim is no longer approximated to QTotSim as done by the earlier model; this model gives independent values of QSenSim and QtotSim through a larger simulation range.
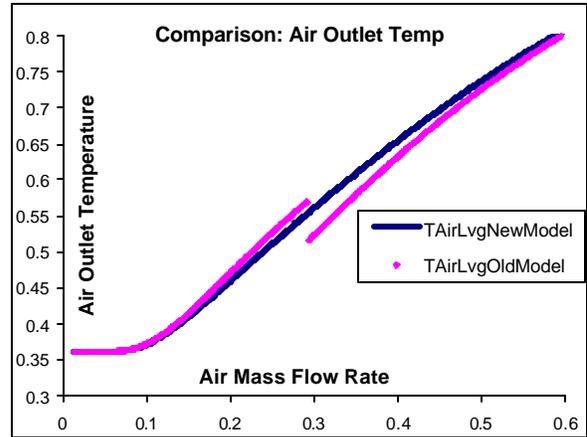
Figure 5: Comparison of the air outlet Temperatures of the discontinuous CCSIM model with the continuous Modified Coil Model.
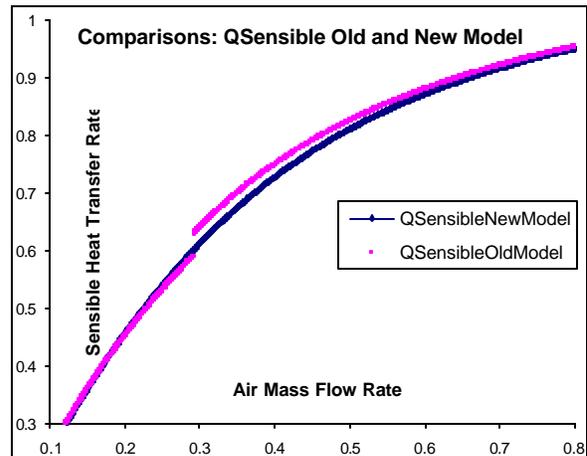
Figure 6: Comparison of Sensible Heat Transfer Rate of the discontinuous CCSIM model with the Modified Coil Model.
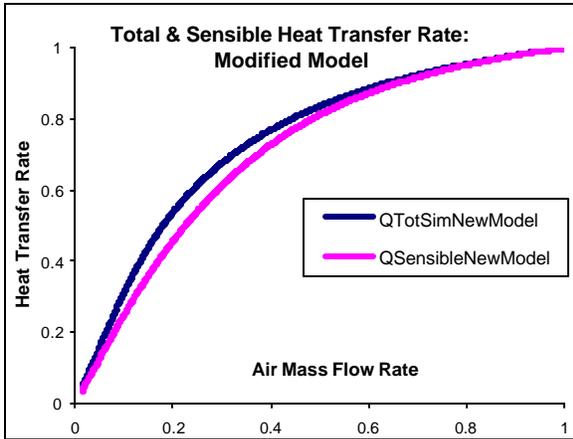
Total & Sensible Heat Transfer Rate: Modified Model

Figure7: Shows the Total and Sensible heat transfer rate for the Modified Coil Model.
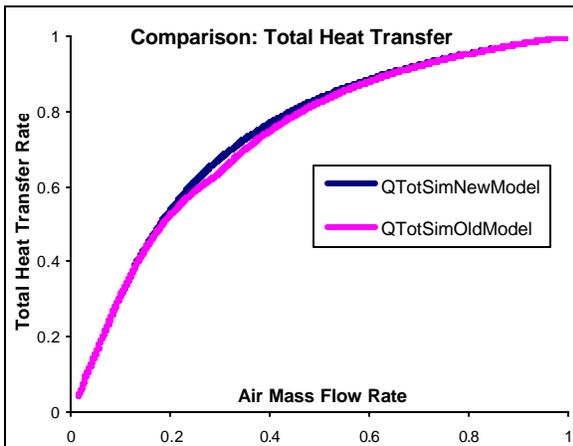
Comparison: Total Heat Transfer

Figure 8: Comparison of the Total Heat Transfer for the two models. Notice the smooth continuous function of the Modified Model.

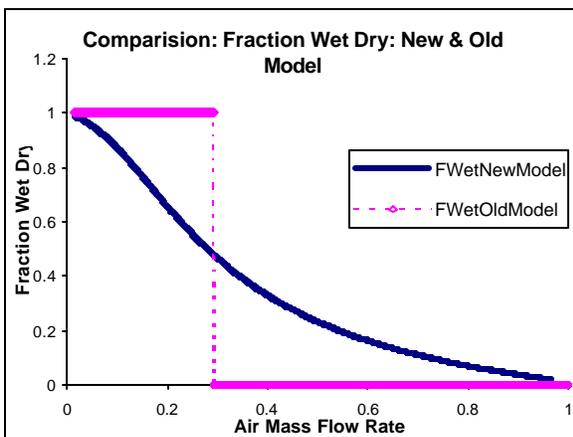**Comparision: Fraction Wet Dry: New & Old Model**

Figure 9: Comparison of the Fraction Wet Dry for the

two models. Notice the continuous curve of the Modified Model.

CONCLUSION:

The above implementation results in a continuous simple cooling coil model for simulation programs coupled with added advantages of both simple and detailed model. This model accomplishes retention of the simple inputs of the simple cooling coil model CCSIM and at achieves detailed results equivalent to the detailed cooling coil model CCDET.

This paper addresses the need for inputs that are appropriate for initial design while providing the necessary modifications for integration into large energy analysis simulations. Energy analysis simulations need continuous results for convergence to solution in its iterative process.

ACKNOWLEDGMENT

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NOMENCLATURE:

The variables used are formed by combination of various other variables/abbreviations: We have tried to keep the nomenclature as used in ASHRAE Secondary HVAC Toolkit for easier implementation.

Example: MAirRat = Mass flow rate of Air at Rated Conditions, QSenTot = Total Sensible Heat Transfer in the simulation

M:	Mass flow rate Kg/s
T:	Temperature C
Liq:	Water: liquid
W:	Humidity Ratio of air
Q:	Heat Transfer Rate Watts
Tot:	Total
Rat:	Rated Conditions
Ent:	Entering Simulation
Lvg:	Leaving Simulation
Sim:	Simulation
Fwet:	Fraction Wet
Sen:	Sensible Heat Transfer
Patm:	Pressure Atmospheric

Atot: Total airside external heat transfer area of coil.

TdewPt: Temperature Dew Point of Air

UAExt: Overall external dry UA

UAInt: Overall internal UA

UATot: Overall heat transfer coefficient

Tsurf: Coil Surface Temperature at air entrance to the coil.

DryUA: Overall heat transfer coefficient for dry coil (same as UATot)

WetUAExt: Wet External UA

UintTot: Overall Internal UA per unit external area W/m2 C

DryUExtTot: Overall External Dry UA per unit external area W/m2 C

WetUExtTot: Overall External Wet UA per unit external area W/m2 C

Rh: Relative Humdity

In: Inside

Out: Outside

CpSat: Fictitious enthalpy based specific heat (ASHRAE Secondary Toolkit)

UAH: Enthalpy-based overall transfer coefficient

CpAir: Dry air specific heat   J/kg C

CpWater: Water Specific Heat J/kg C

CCDET: Detailed Cooling Coil Model

CCSIM: Simple Cooling Coil Model

RelHum: ASHRAE Subroutine for calculating relative humidity

REFERENCES

HVAC2 Toolkit: Algorithms and Subroutines for Secondary HVAC Systems Energy Calculations, Brandemuehl, M. J., ASHRAE, 19