A new DX cooling coil model with subcool and reheat modes in EnergyPlus

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Abstract
Precise temperature and humidity control is crucial for human health and comfort. Standard air conditioners often struggle to achieve accurate control of both temperature and humidity simultaneously. The Humidi-MiZer Adaptive Dehumidification (HMAD) system addresses this challenge by incorporating a Humidi-Mizer coil, a hot gas solenoid valve, and a liquid line solenoid valve. This paper shows how HMAD is simulated in EnergyPlus.

The cooling coil in the HMAD system has three operation modes with associated sensible heat ratios (SHR): Normal, Subcool and Reheat. To achieve precise temperature and humidity control, the system’s outputs must deliver requested sensible and latent capacities through the SHR and total capacity. This is accomplished by combining Normal mode and either Subcool or Reheat mode together. In other words, the coil operates as Normal mode for a fraction of a single time step and as Subcool or Reheat mode for the remaining time within that time step. The fraction of time spent in either Subcool or Reheat is defined as mode ratio (MR). Additionally, the total delivered capacity is adjusted by the system’s part load ratio (PLR) within the same time step. Solving for both the PLR and MR simultaneously is necessary to achieve precise temperature and humidity control. A simplified approach assumes linear relationship between coil capacity and PLR. Therefore, MR can be obtained by the linear relationship transferred from given load SHR to the coil SHR, the part load ratio can then be solved using existing 1-D root solver.

Simulation results demonstrate that the proposed coil model effectively provides simultaneous temperature and humidity control with high precision. Compared to cases where humidity control is achieved using a normal cooling coil supplemented by a reheat coil, the new model significantly reduces energy consumption by eliminating overcooling and reheat coil heating. This enhanced capability enables EnergyPlus users to design and operate energy-efficient systems with a wider range of cooling coil options.

Highlights
Operation modes of normal, subcool and reheat, Combined operation with two modes, Precise temperature and humidity controls. Load and coil sensible heat ratios, Simplified algorithm.

Introduction
Indoor humidity control is of utmost importance for human health and comfort. Standard air conditioners are able to provide simultaneous sensible cooling and dehumidification based on their inherent characteristics. When the indoor sensible and latent loads do not align with the equipment capabilities, indoor control is limited to sensible or latent only. Simultaneous sensible and latent controls are possible to be accomplished using other reheat coils after overcooling sometimes (Kittler, 1996). However, extra energy has to be used due to overcooling and reheating.

Various other methods have been proposed to achieve indoor temperature and humidity control. One of approaches involving installing a heat exchanger after the evaporator to reheat cooled air. Taras (2004) evaluated four different mechanical dehumidification designs: Warm liquid refrigerant cycle, Sequential hot gas refrigerant cycle, Hot gas reheat, Parallel hot gas refrigerant cycle, and Two phase mixture refrigerant cycle. The hybrid cycle is a possible design and can operate in several of the four dehumidification modes by opening and closing the appropriate flow control devices to reroute the refrigerant through a particular branch of the cycle.

Lennox (Hanson and Uselton, 2005) has developed a residential split-system heat pump with add-on components that allows normal operation in cooling and heating modes, as well as operation in an enhanced dehumidification mode. One of the additional components is a reheat coil located after the evaporator. Cooled air passing through the evaporator will be heated by the reheat coil. During dehumidification operation, refrigerant from the condenser coil is not completed condensed. The refrigerant completes condensation and is subcooled as it passes through the reheat coil.

Carrier’s Humidi-MiZer Adaptive Dehumidification (HMAD) system provides precise sensible and latent capacities to control indoor temperature and humidity.
simultaneously (Carrier, 2014). Using a simple space thermostat and humidistat input, the Humidi-MiZer Adaptive Dehumidification system changes the refrigerant flow by adjusting the position of the refrigerant solenoid valves. There are three operation modes: Normal, Sub-Cooling and Hot Gas ReHeat. The system configuration is shown in Figure 1, copied from Carrier, 2014. The main differences are that 3 additional components are added as Humid-Mizer coil, Hot gas solenoid valve (HGSV), and Liquid line solenoid valve (LLSV).

Below is a brief description of 3 operation:
Normal Operation Mode (HGSV closed, LLSV open)
When there is a call for cooling only (the indoor temperature level is above the thermostat setpoint), the dehumidification system is inactive and the refrigerant circulates per a typical packaged system.
Sub-Cooling Operation Mode (HGSV closed, LLSV closed)
During part load conditions when the room temperature and humidity are above the setpoint, the unit will initiate the sub-cooling mode of operation; a call for cooling and dehumidification. The end result is a conditioned space that is cooled and significantly more dehumidified, but not over-cooled. This also helps eliminate short cycling of the rooftop unit and improves space temperature and humidity control.

To simulate the HMAD system performance, a mathematical model of the system, and an algorithm were developed, and then the model was implemented in EnergyPlus version 9.3 (https://energyplus.net/). EnergyPlus is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption – for heating, cooling, ventilation, lighting and plug and process loads - and water use in buildings.

EnergyPlus allows users to perform sensible and latent control simultaneously. This is typically accomplished by using a single DX cooling coil with the help of a supplemental heating coil. A UnitarySystem object is available to accomplish this goal (Ver. 9.3). A typical example file of UnitarySystem_FurnaceWithDXSystemRHcontrol.idf demonstrates how the indoor RH and temperature are controlled. RH control is accomplished by overcooling and reheating using a reheat coil. Unfortunately, the indoor air temperature and RH are not controlled very well. The results raised a question that whether the cooling and reheating combination can control the indoor temperature and RH well or not. Do we have a good way to control both accurately and simultaneously? Fortunately, the coil system described below can meet the requirements.

Although there are many dehumidification modes have been proposed, and several real systems have been developed, these systems cannot be simulated in EnergyPlus. The EnergyPlus does not have a single coil model to perform precise temperature and humidity control by providing exact amount of sensible and latent capacities to a conditioned zone. In order to provide design tools to utilize these system and understand system performance in a whole building, the model development for these systems needs to be implemented in EnergyPlus. The objective of this paper is to present the simulation model for the HMAD system.

**Definition of two important parameters**

In order to develop the model to simulate the performance of HMAD system, two important parameters should be defined as Load Sensible Heat Ratio (LSHR) and Coil Sensible Heat Ratio (CSHR) before developing model algorithm and simulation logic, and implementation.

**Load sensible heat ratio (LSHR)**

Load SHR is defined as the ratio of requested zone sensible load divided by the requested zone total load. The zone sensible load is determined by the thermostat setpoint from the predictor to predict how much load is required by the system to make the zone reach the thermal setpoint, defined in Eq. (1). The zone latent load is determined by the dehumidification setpoint from the predictor to predict how much load the system will provide to make the zone reach the dehumidification setpoint, defined in Eq. (2). The total zone load is given...
by Eq. (3). The ratio is determined by zone loads between supply node and the zone node in Eq. (4), as also shown in Figure 2 below.

\[
\text{Load}_{\text{sen}} = m \cdot C_p \cdot (T_{\text{sup}} - T_{\text{zone}}) \\
\text{Load}_{\text{lat}} = m \cdot h_g \cdot (W_{\text{sup}} - W_{\text{zone}}) \\
\text{Load}_{\text{total}} = \text{Load}_{\text{sen}} + \text{Load}_{\text{lat}} \\
\text{LSHR} = \frac{\text{Load}_{\text{sen}}}{\text{Load}_{\text{total}}}
\]

**Figure 2** Supply air configuration with nodes and coil

**Coil sensible heat ratio (CSHR)**

Coil SHR is defined as the ratio of the delivered coil sensible capacity divided by the coil total capacity, defined in Eq. (8). The coil sensible capacity is determined by temperature difference between coil inlet and outlet, defined in Eq. (5). The coil latent capacity is determined by the humidity ratio difference between the coil inlet and outlet, defined in Eq. (6). The total coil load is defined in Eq. (7).

\[
\text{Coil}_{\text{sen}} = m \cdot C_p \cdot (T_{\text{sup}} - T_{\text{inlet}}) \\
\text{Coil}_{\text{lat}} = m \cdot h_g \cdot (W_{\text{sup}} - W_{\text{inlet}}) \\
\text{Coil}_{\text{total}} = \text{Coil}_{\text{sen}} + \text{Coil}_{\text{lat}} \\
\text{CSHR} = \frac{\text{Coil}_{\text{sen}}}{\text{Coil}_{\text{total}}}
\]

It should be noted that the air properties at the coil inlet may not be the same as air properties at the zone node, due to the supply fan heat and the mixed air between recirculate air and outdoor air.

**Model algorithm**

The above brief description of the 3 modes of operation shows how each operation mode works. This section will show how the 3 modes work together in EnergyPlus to provide both temperature and humidity control simultaneously.

**Normal Mode**

During part load conditions when the room temperature is above the thermostat setpoints, and the room humidity is below the humidistat setpoint, the unit enters Normal mode; a cooling only request. The coil operates for a fraction of single time step as normal operation mode and is turned off for the remaining of time. The mode is equivalent to normal AC operation.

**Subcool Mode**

The subcool operation mode is made with LLSV valve fully closed, while normal operation mode is based on the LLSV valve fully open. System performance is assumed to be linear between two operation modes. For example, when LLSV is 40% closed, it is equivalent that the normal operation mode operating 60% of a single time step, while the subcool operation mode operates in the remaining time in the same time step.

During part load conditions when the coil SHR is greater than the Reheat SHR and less than the subcool SHR, the unit will operate the subcool mode; a call for cooling and dehumidification. The coil operates in a fraction of the single time step as subcool operation mode and the remaining time as Normal mode to achieve simultaneous temperature and humidity control. The mode is also called in the working range of the subcool mode operation.

**Reheat Mode**

The Reheat mode is based on HGSV valve fully open, while normal mode is based on HGSV valve fully closed. It is assumed that linear system performance between two operation modes. For example, when HGSV is 40% closed, it is equivalent that the normal operation mode operates 60% of a single time step, while the Reheat operation mode operates in the rest of the time in the same single time step.

During part load conditions when the coil SHR is less than the subcool SHR, the unit will operate the reheat mode; a call for cooling and dehumidification. The coil operates in a fraction of the single time step as reheat operation mode and the remaining time as Normal mode to achieve simultaneous temperature and humidity control. The mode is also called in the working range of the reheat mode operation.

**Simulation logic**

In general, the subcool operation mode has lower SHR than the normal operation mode, while the reheat operation mode can provide lowest SHR. The computer model provides 3 mode operations based on the LSHR. The following simulation logic is implemented in EnergyPlus.

1. **Calculate the requested CSHR based on the LSHR**
2. **Compare normal mode SHR.**
3. **If the normal SHR is less than the CSHR, perform the normal mode operation to obtain the coil sensible capacity to meet the sensible load by varying the coil part load ratio (PLR), then complete calculation with the normal mode operation.**

Note: Normal mode operation only provides precise thermal control to meet thermostat setpoint by varying PLR, while dehumidification is based on the available latent capacity at the same PLR. The available latent capacity is obtained from the characteristics of coil itself with a given sensible capacity. Therefore,
dehumidification still occurs, while the indoor humidity is not controlled precisely.

\[
\text{Coil}_{\text{del,Sen}} = \text{Coil}_{\text{Normal,Sen}} \times \text{PLR}
\]

\[
= \text{Coil}_{\text{Normal,Total}} \times \text{SHR}_{\text{Normal}} \times \text{PLR} = \text{Coil}_{\text{Sen}}\#(9)
\]

\[
\text{Coil}_{\text{del,Lat}} = \text{Coil}_{\text{Normal,Lat}} \times (1 - \text{SHR}_{\text{Normal}}) \times \text{PLR} \neq \text{Coil}_{\text{Lat}}\#(10)
\]

4. If the CSHR is less than the normal SHR and greater than the subcool SHR, perform the subcool mode operation, which combines both the normal and subcool operation modes by assuming the subcool operation mode works in a fraction of a single time step, and the normal operation mode works in the rest of the same time step. The fraction of time is defined as mode ratio (MR). The supplied combined sensible and latent capacities are given in Eqs (11) and (12) below:

\[
\text{Coil}_{\text{del,Sen}} = \left( \text{Coil}_{\text{Normal,Sen}} \times (1 - \text{MR}) + \text{Coil}_{\text{Subcool,Sen}} \times \text{MR} \right) \times \text{PLR} = \text{Coil}_{\text{Sen}}\#(11)
\]

\[
\text{Coil}_{\text{del,Lat}} = \left( \text{Coil}_{\text{Normal,Lat}} \times (1 - \text{MR}) + \text{Coil}_{\text{Subcool,Lat}} \times \text{MR} \right) \times \text{PLR} = \text{Coil}_{\text{Lat}}\#(12)
\]

\[
\text{CSHR} = \frac{\text{Coil}_{\text{Sen}}}{\text{Coil}_{\text{Total}}} = \frac{\text{Coil}_{\text{del,Sen}}}{\text{Coil}_{\text{del,Sen}} + \text{Coil}_{\text{del,Lat}}}\#(13)
\]

It is obvious that in order to provide simultaneous temperature and humidity control, the exact delivered coil sensible and latent capacities are required. In other words, the supplied CSHR should be the same as the requested CSHR derived from the LSHR. There are two independent variables of PLR and MR that can be adjusted to obtain required sensible and latent capacities for a single cooling coil due to partial operation for both operation modes. Therefore, a problem arises that requires a 2-dimensional root finder to find a solution from two independent variables.

EnergyPlus has a 1-D root finder. It provides 2 types of solver methods: bisection and Regula-Falsi. Unfortunately, it does not provide a 2-D solver. When I did web search, a few papers addressed this issue. The bisection approach did not seem to work in 2D (LeBoeuf, 2009). A reliable 2-D solver was not found. A simplified approach was implemented. A special section below deals with the approach.

Coil performance calculation is completed based on subcool mode operation, when the requested coil SHR is within the subcool mode operation range.

5. If the CSHR is less than the subcool SHR and greater than the reheat SHR, perform the reheat mode operation, that combines both normal and reheat operation modes by assuming that reheat mode works in a fraction of a single time step, and the normal mode operates for the remainder of the same time step. The fraction of time is defined as mode ratio (MR). The supplied combined sensible and latent capacities are given in Eqs (14) and (15) below:

\[
\text{Coil}_{\text{del,Sen}} = \left( \text{Coil}_{\text{Normal,Sen}} \times (1 - \text{MR}) + \text{Coil}_{\text{Reheat,Sen}} \times \text{MR} \right) \times \text{PLR} = \text{Coil}_{\text{Sen}}\#(14)
\]

\[
\text{Coil}_{\text{del,Lat}} = \left( \text{Coil}_{\text{Normal,Lat}} \times (1 - \text{MR}) + \text{Coil}_{\text{Reheat,Lat}} \times \text{MR} \right) \times \text{PLR} = \text{Coil}_{\text{Lat}}\#(15)
\]

\[
\text{CSHR}_{\text{coil}} = \frac{\text{Coil}_{\text{Sen}}}{\text{Coil}_{\text{Total}}} = \frac{\text{Coil}_{\text{del,Sen}}}{\text{Coil}_{\text{del,Sen}} + \text{Coil}_{\text{del,Lat}}}\#(16)
\]

Coil capacity calculation is completed based on reheat mode operation.

6. If the CSHR is less than the reheat SHR, only reheat mode operation is performed. Accurate temperature control is invoked, while latent control is not forced. Dehumidification is performed based on the available latent capacity. The supplied sensible and latent capacities are shown below:

\[
\text{Coil}_{\text{del,Sen}} = \left( \text{Coil}_{\text{Reheat,Sen}} \times \text{MR} \right) \times \text{PLR} = \text{Coil}_{\text{Sen}}\#(17)
\]

\[
\text{Coil}_{\text{del,Lat}} = \left( \text{Coil}_{\text{Reheat,Lat}} \times \text{MR} \right) \times \text{PLR} \neq \text{Coil}_{\text{Lat}}\#(18)
\]

\[
\text{CSHR} = \frac{\text{Coil}_{\text{del,Sen}}}{\text{Coil}_{\text{del,Sen}} + \text{Coil}_{\text{del,Lat}}}\#(19)
\]

Coil capacity calculation is completed based on reheat mode operation without latent control.

Note: Simultaneous temperature and humidity control is available in steps 4 and 5, respectively, by linear interpolation between normal mode and either subcool or reheat mode. Step 3 handles cases without latent control at higher CSHR. Step 6 deals with the lowest CSHR. Since the requested CSHR is lower than the reheat SHR, the coil continues to operate in the reheat operation mode until CSHR is higher that reheat SHR. In other words, the precise temperature and humidity control is performed as sensible loads increase.

The provided simulation logic offers a comprehensive approach to determining the appropriate coil operation mode, accurately calculating the sensible and latent capacities, and achieving precise temperature and humidity control in a cooling system.

**Simplified approach**

The simplified approach assumes linear relationship between a coil’s sensible capacity, or latent capacity or total capacity, and PLR. The linear relationship includes the supplied system outputs and coil output capacities. The supplied system outputs are proportional to the differences of air properties between the system outlet node and the zone node. The coil output capacities are proportional to the differences in air properties between
the coil inlet and outlet nodes are the same as the node of coil outlet. The coil operating condition includes all 3 operation modes: Normal, Subcool and Reheat. The assumption is valid based on the following observation. The linear relationship is used to convert LSHR to CSHR.

**Validate linear relationship assumption for normal mode**

In order to provide precise temperature and humidity control, the coil will provide outputs to match the zone sensible and latent loads by combining two operation modes, such as between normal and sub-cooling operation modes via MR. The MR represents how long the subcool mode runs as a fraction of the system timestep, and the normal mode runs in the rest of the system timestep. To solve MR directly without using a 2-D solver, the linear relationship between sensible, or latent, or total capacity, and PLR is required. This section uses normal mode as an example. The linear relationship is also valid for both subcool and reheat operation modes.

Figure 3 shows the unitary system outputs as PLR varies. The system outputs are sensible, latent, and total ones defined in Eq. 1, 2 and 3, respectively, with given inlet conditions, fan heat, and outdoor air introduction. In order to ensure linearity, linear regressions are performed to provide regression coefficients and associated R² values. The linear equations are also shown in the figure. Since all 3 R² values are 1.0, the linear relationship is assured.

![Figure 3 Sensible, latent and total system outputs with different part load ratio at normal operation mode](image1)

![Figure 4 Sensible, latent and total coil outputs with different part load ratio at normal operation mode](image2)

Figure 4 shows the cooling coil outputs as PLR changes. The coil outputs are sensible, latent, and total ones defined in Eq. 5, 6 and 7, respectively, with given inlet conditions, fan heat, and outdoor air introduction. To ensure linearity, linear regressions are performed to provide regression coefficients and associated R² values. The linear equations are also shown in the figure. Since all 3 R² values are 1.0, the linear relationship is assured.

**Derive CSHR from LSHR**

After validating linear relationship of system and coil outputs, the following procedure is provided to derive the CSHR from the LSHR:

1. Call up a unitary system with normal mode at full capacity (PLR = 1)
2. Calculate sensible and latent PLR based on system sensible and latent loads

\[
PLR_{sen} = \frac{Load_{sen}}{Cap_{sys, sen}} \tag{20}
\]

\[
PLR_{lat} = \frac{Load_{lat}}{Cap_{sys, lat}} \tag{21}
\]

It should be noted that the system PLR is the same as the coil PLR.
3. Calculate required delivered coil sensible and latent capacity with given sensible and latent PLR

\[
 Coil_{del, sen} = PLR_{sen} \times Cap_{coil, sen} \tag{22}
\]

\[
 Coil_{del, lat} = PLR_{lat} \times Cap_{coil, lat} \tag{23}
\]

4. Calculate Coil SHR based on coil sensible and latent capacities

\[
SHR_{c} = \frac{Coil_{del, sen} + Coil_{del, lat}}{Cap_{coil}} \tag{24}
\]

Although the above derivation is based on the normal operation mode, the CSHR will be the same at different operation modes, because the differences caused by fan heat and outdoor air introduction between load SHR and coil SHR are the same at different coil operation modes. Therefore, the conversion from LSHR to CSHR at normal operation mode is accurate enough to be applied to other mode operation.

**Calculate MR**

The CSHR is used to determine working range. If CSHR is greater than the SHR at normal operation mode, MR is equal to 0, because the coil is operating in normal mode.

\[
MR = 0 \# \tag{25}
\]

If the CSHR is greater than the SHR in the subcool operation mode and less than the SHR in the normal operation mode, the coil operates in the subcool range and MR is calculated below using Eq. (11):

\[
MR = \frac{CSHR - SHR_{Normal}}{SHR_{Subcool} - SHR_{Normal}} \# \tag{26}
\]

When the CSHR is larger than the SHR at reheat operation mode and smaller than the SHR at subcool operation mode, the coil operates in the reheat range and MR is calculated below using Eq. (11):
MR = \frac{CSHR - SHR_{\text{Normal}}}{SHR_{\text{Reheat}} - SHR_{\text{Normal}}} \#(27)

If the CSHR is less than the SHR at reheat operation mode, the coil operates in the reheat mode without precise humidity control. The MR is equal to 1.

MR = 1\#(28)

**Calculate part load ratio**

After obtaining mode ratio from previous section, the 2-D solver is simplified into a 1-D solver, so that general Regula Falsi method can be applied to obtain a solution for PLR.

**Simulation results**

An example file has been created to demonstrate capabilities of the new coil model. The input file is available in the EnergyPlus installation, and is named as UnitarySystem_SubcoolReheatDX.idf. The simulated building is a one-story building located in Chicago. There are 5 conditioned zones: 4 perimeter zones and one core zone. Each zone has its own HVAC system to provide space cooling and heating. The cooling setpoint is 24°C between 7AM and 7PM on a working day, while the dehumidification setpoint is 60%. The new coil model is applied to one of the perimeter zones. HDAM system performance data is used to generate performance curves. The accuracy of the simulated system performance is based on the accuracy of the curve fitting. The detailed information is given in EnergyPlus Input Output reference. The simulation results for a summer design day are plotted in Figure 5. The output variables plotted are zone air temperature and relative humidity, zone LSHR, CSHR, coil operation mode (1 Normal, 2 Subcool, 3 Reheat), and MR, respectively.

The system is turned on at 7AM. Due to higher CSHR (> Normal Mode SHR), the coil operates at normal mode during this period, and LSHR is set to 1.0 until 7:45AM. Dehumidification still occurs with CSHR around 0.85, but not controlled. As the moisture load continues increase, the LSHR drops to about 0.58, and the coil starts operating in the Reheat mode with the highest dehumidification capacity. When the combined operation between normal and reheat mode is able to work together to control both temperature and humidity simultaneously, the zone air is controlled at 24°C and 60% RH about an hour. The MR varies from 0.4 to 0.2 during the dehumidification period. As the latent load decreases and the sensible load increases in the next hour, the CSHR derived from the LSHR can be met in the Subcool mode. The zone air temperature and humidity are still controlled simultaneously with the Subcool mode between 9AM and 10:30AM. The MR varies from 0.7 to 0.6 during this time. After 10:30AM, if relative humidity of the zone air is below the dehumidification setpoint at 60%, the coil operates at normal mode with LSHR = 1 without latent load. The temperature setpoint is maintained and the mode ratio is equal to 0 for the same period. As the sensible load increases between 11AM and 4PM, the coil provides enough sensible capacity to meet the sensible load. At the same time, the coil also provides enough latent capacity to dehumidify the zone air, so that the zone air RH is either equal to or below the dehumidification setpoint. As the sensible load decreases after 4PM, the LSHR decreases, the coil operates in Subcool mode to control both temperature and moisture simultaneously. As the moisture load increases and the sensible load increases after 5PM, the coil operates in the reheat mode to again meet high latent removal demand. After continuing to operate in the Reheat mode for about an hour, the LSHR increases, allowing the coil is able to operate at the Subcool mode again to control zone air temperature and relative humidity, until zone air RH is below the setpoint. After 7PM, the system is turned off and zone air conditions are uncontrolled.

It is important to know that the control strategy is to have the coil meet the sensible demand first, so that the zone air always remains at the thermal setpoint. At the same time, the coil will also deliver the available latent capacity. When the latent capacity supplied in the reheat operation mode may not be sufficient to meet latent load, the system supplies the maximum latent capacity at the reheat mode to the zone and assumes that the latent load will be met in the next time step.

To demonstrate good dehumidification with the subcool reheat coil, two other cases are used for comparison. The first case is to perform cooling with a conventional cooling coil only, called Standard. The second case is called CoolReheat, which uses a conventional cooling coil and a reheat coil to perform overcooling and reheating to control indoor humidity. The current example file has been modified in several places to ensure that system configurations are compatible.

It should be noted that the total output is presented in the left Y-axis scale, while sensible and latent outputs are presented in the right Y-axis scale.
Figure 6 Indoor temperature and relative humidity with different humidity control on a summer day in Chicago

Figure 6 shows the indoor temperature and relative humidity level on a summer day in Chicago with 3 different humidity control strategies. The temperature profiles in both SubcoolReheat and Standard cases are almost identical, while overcooling occurs between 7AM and 11AM and between 5 and 9PM for the CoolReheat case. The Standard case shows that the indoor RH is above 60% in the morning between 8AM and 10AM and in the afternoon between 4 and 7PM, so RH is not controlled at all. The CoolReheat case provides some humidity control with lower RH levels in the morning between 8AM and 10AM and in the afternoon between 4 and 7PM. It is obvious that the indoor humidity is not well controlled. The SubcoolReheat case provides precise humidity control during the same time period, until the indoor relative humidity level is below the humidity setpoint.

Figure 7 Indoor relative humidity with different humidity control on a summer day in Miami

The above simulation assumes that the building is located in Chicago as cold climate, although a summer day is as hot and humid as a day in hot humid location. The next step is to investigate how well humidity control is performed in Miami, hot humid climate. Figure 7 shows the indoor temperature and relative humidity level on a summer day in Miami using 3 different humidity control strategies. The temperature profiles in the SubcoolReheat and Standard cases are almost identical, while overcooling occurs between 7AM and 11AM and between 5 and 9PM for the CoolReheat case. The Standard case shows no humidity control, the same as in Chicago. The CoolReheat case shows better humidity control, so that the indoor RH level is slightly higher than the humidity setpoint during the morning and afternoon hours. The subcool reheat case provides precise control, so that indoor relative humidity is either at or below the setpoint during the cooling period. Obviously, the CoolReheat case in Miami has better humidity control than the one in Chicago.

Having examined temperature and humidity control with 3 different cases, the next step is to examine energy use for these cases.

Figure 8 Coil energy use with different humidity control on a summer day in Chicago

Figure 8 shows coil energy use on a summer day in Chicago with 3 different humidity control strategies. Compared to the Standard case, the SubcoolReheat case has slightly higher energy use in the early morning between 7 and 9AM and late afternoon between 4 and 7PM, by invoking subcool and reheat modes to control indoor humidity. However, the CoolReheat case uses a lot of cooling energy for overcooling and reheat energy for reheating. The figure plots the energy uses of cooling and reheat coils separately in order to see how much reheat energy is used.

Figure 9 Coil energy use with different humidity control on a summer day in Miami

Figure 9 shows coil energy use on a summer day in Miami using 3 different humidity control strategies. Compared to the Standard case, the SubcoolReheat case has slightly higher energy use in the early morning between 7 and 10AM and late afternoon between 5 and 9PM, by invoking subcool and reheat modes to control indoor humidity. However, the CoolReheat case uses a lot
of cooling energy for overcooling and reheat energy for reheating.

The next two tables show energy use of cooling and reheat coils on a summer day and one year in Chicago and Miami, respectively.

**Table 1 Cooling and dehumidification energy use on a summer design day and a year in Chicago**

<table>
<thead>
<tr>
<th></th>
<th>Summer day</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling (MJ)</td>
<td>Reheat (MJ) %</td>
</tr>
<tr>
<td>Subcool Reheat</td>
<td>29.69</td>
<td>16.7%</td>
</tr>
<tr>
<td>Standard</td>
<td>25.43</td>
<td>11.5%</td>
</tr>
<tr>
<td>CoolReheat</td>
<td>42.54</td>
<td>7%</td>
</tr>
</tbody>
</table>

Table 1 shows cooling and dehumidification energy use in 3 different system configurations on a summer design day and one year in Chicago. By comparing energy use for the Standard case, the SubcoolReheat case requires 17% more energy use on a summer day and 25% more energy in a year. However, the CoolReheat case requires 500% more energy use on a summer day and 438% more energy in a year.

**Table 2 Cooling and dehumidification energy use on a summer design day and one year in Miami**

<table>
<thead>
<tr>
<th></th>
<th>Summer day</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooling (MJ)</td>
<td>Reheat (MJ) %</td>
</tr>
<tr>
<td>Subcool Reheat</td>
<td>67.53</td>
<td>23.2%</td>
</tr>
<tr>
<td>Standard</td>
<td>54.81</td>
<td>15.0%</td>
</tr>
<tr>
<td>CoolReheat</td>
<td>69.59</td>
<td>45%</td>
</tr>
</tbody>
</table>

Table 2 shows energy used for cooling and dehumidification in 3 different system configurations on a summer design day and one year in Miami. By comparing energy use for the Standard case, the SubcoolReheat case needs 23% more energy use on a summer day and 52% more energy in a year. However, the CoolReheat case requires 150% more energy use on a summer day and 494% more energy in a year.

Therefore, the SubcoolReheat system provides more economical and efficient way to simultaneously control indoor temperature and humidity, compared to the CoolReheat case.

**Conclusions**

The simulation results show that the new coil model is able to control zone air temperature and relative humidity simultaneously through combined operation by either normal mode and subcool mode or normal mode and reheat mode. The CSHR is used to determine which mode operates. Although the real coil may not operate exactly as model simulates, it is possible that the coil is capable of providing the same control, so that a single coil system is able to control both zone air temperature and relative humidity precisely and simultaneously without any help from other coils.

The major contribution in model implementation is the use of the simplified approach by deriving CSHR from LSHR, and converting the 2-D solver to a 1-D solver. The CSHR derivation utilizes the linear relationship between system outputs and part load ratio, and between coil outputs and part load ratio. The mode ratio is calculated directly from the sensible output between normal and subcool or reheat mode.

Precise indoor temperature and humidity control is provided by the subcool reheat coil model. Although slightly more energy is required to achieve precise dehumidification than in the normal case, the energy consumption is much lower than the CoolReheat approach.

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**References**


**Nomenclatures**

- \( \text{Col}_L \text{delLat} \): Coil supplied latent capacity combined with two modes
- \( \text{Col}_L \text{delSens} \): Coil supplied sensible capacity combined with two modes
- \( \text{Col}_L \text{lat} \): Latent coil capacity based on temperature difference between supply register and zone [W]
- \( \text{Col}_L \text{NormalSen} \): Coil sensible capacity at Normal mode
$Coil_{Normal} = \text{Coil latent capacity at Normal mode}$

$Coil_{Reheat} = \text{Coil sensible capacity at Reheat mode}$

$Coil_{Reheat, sen} = \text{Coil latent capacity at Reheat mode}$

$Coil_{sen} = \text{Sensible coil capacity based on temperature difference between supply register and zone [W]}$

$Coil_{Subcool} = \text{Coil sensible capacity at Subcool mode}$

$Coil_{Subcool, sen} = \text{Coil sensible capacity at subcool mode}$

$Coil_{total} = \text{Total coil capacity based on enthalpy difference between supply register and zone [J/kg]}$

$C_p = \text{Specific heat of air [J/kg.K]}$

$h_g = \text{Enthalpy of saturated vapor [J/kg]}$

$Load_{lat} = \text{Latent zone load based on temperature difference between supply register and zone [W]}$

$Load_{sen} = \text{Sensible zone load based on temperature difference between supply register and zone [W]}$

$\dot{m} = \text{Mass flow rate [kg/s]}$

$MR = \text{Mode ratio between Normal and Subcool or Reheat modes}$

$PLR_{lat} = \text{Latent part load ratio}$

$PLR_{sen} = \text{Sensible part load ratio}$

$T_{inlet} = \text{Coil inlet air temperature [C]}$

$T_{sup} = \text{Supply register air temperature [C]}$

$T_{zone} = \text{Zone air temperature [C]}$

$W_{inlet} = \text{Coil inlet humidity ratio [kg/kg]}$

$W_{sup} = \text{Supply register humidity ratio [kg/kg]}$

$W_{zone} = \text{Zone air humidity ratio [kg/kg]}$