MODELING OF THE SINGLE COIL, TWIN FAN AIR-CONDITIONING SYSTEM IN ENERGYPLUS

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ABSTRACT

This paper outlines the conceptual development of a building energy simulation model for the Single Coil, Twin Fan Air Conditioning (SCTF) system in the whole building simulation program EnergyPlus. The SCTF system is a unitary, multi-zone system which conditions the outdoor ventilation and recirculated return air in two separate streams through a single compartmented cooling coil and supplies these unmixed streams via two variable speed fans and a dual duct arrangement to zonal mixing boxes. The main challenges addressed in EnergyPlus include the existing inability to concurrently simulate unmixed air streams within a centralized VAV system, supply and control outdoor air and recirculated air independently to a space via dual duct network, and prediction of performance of a compartmented cooling coil – all of which have potential applications in other innovative systems.

INTRODUCTION

In hot and humid tropical climates, the cooling and ventilation systems account for a significant portion of the energy consumed within a building; moreover, dehumidification is key in maintaining thermal comfort and indoor air quality. Recently a new type of cooling and air distribution system, the Single Coil, Twin Fan (SCTF) system, was developed as a means of achieving these objectives in a more effective and energy efficient method (Sekhar et. al., 2004). The SCTF system is a type of Dedicated Outdoor Air System (DOAS) which separates the cooling and dehumidification processes of the outdoor air (OA) and recirculated return (RA) air streams with the goal of independent distribution and control to each zone served by the system. This approach is opposed to the conventional practice of simply combining the ventilation air and return air at the economizer or mixing section of an air handling unit and conditioning this mixed air stream according to system-level requirements.

Previous research has established initial performance data through the development and testing of a prototype model. This setup was subjected to a series of scenarios with varying sensible load and occupant profiles in order to establish the perfromance of the system at typical operating conditions. A psychrometric comparative analysis between the airflow rates specified for a conventional coil used in a typical VAV system and that of the compartmented coil in a SCTF system revealed that the estimated energy-saving potential with the SCTF system was approximately 12% (Sekhar et. al., 2004).

The purpose of the current study of the SCTF system is to create the ability to simulate the performance of the system in a detailed whole building energy simulation program. EnergyPlus (Crawley et al. 2001) was selected as a suitable platform for this purpose based on its developer-friendly modular structure and flexible approach to modeling central air systems. EnergyPlus (2009) is an integrated simulation environment in which the zone, system, and plant are solved simulatenously using fundamental heat balance principles. Within EnergyPlus, the airside system can be simulated using the HVAC Airloop Module (Fisher et al. 1999). The Air Loop is a system-level object which describes the individual components that make up the air-side conditioning and distribution system, establishes the relationships each component has with each other, and divides them into the supply and demand section categories.

An initial investigation of the Air Loop Module yielded the following deficiencies identified in EnergyPlus with regards to simulation of the SCTF system:

1. Modeling of the decoupled outdoor air and recirculated air streams in a centralized air distribution system
2. Zone-by-zone flow control of the two airstreams based on individual ventilation and thermal load requirements

3. Performance prediction of the compartmented cooling coil

In response to these deficiences, a series of improvements to the HVAC Air Loop simulation within EnergyPlus is in the process of implementation which will allow for the capability to simulate the SCTF system.

SCTF SYSTEM OVERVIEW

The SCTF system is composed of a multi-zone air handling unit with two inlet air streams, a single, compartmented cooling coil, two variable speed fans, and two outlet air streams. The unit supplies and conditions the outdoor (OA) and recirculated air (RA) in the two separate decks as shown in the topology diagram in Figure 1.

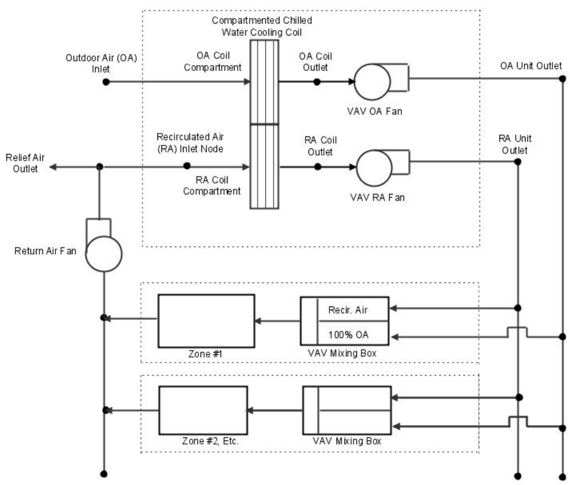

Figure 1 SCTF Airside System Topology

Outdoor air is necessary for adequate ventilation of the zone and is primarily based on occupancy and floor area. Recirculated return air accounts for the thermal heating or cooling loads not met by the conditioned ventilation air. Each air stream is separated by an insulated sheet metal partition and conditioned through a single compartmented cooling coil. The coil can be designed to have different numbers of rows, fin spacing or other characteristics in each compartment. Each air stream includes a variable air volume (VAV) fan which is controlled independently therefore allowing the outdoor air to be controlled by CO2 sensors in a demand control ventilation (DCV) scheme and recirculated air to be controlled separately based on the thermal load of the zone.

The main benefits of the SCTF system over conventional systems are most apparent in humid, tropical climates in which tight control of the ventilation air is crucial in maintaining thermal comfort through moisture removal while conserving energy. Excess ventilation air in these circumstances can impose significant energy penalities on buildings. One of the main benefits of a conventional mixed air system is air-side economizer capability which allows for "free cooling" when outdoor air conditions are such that they would meet the sensible cooling load of a building. In the tropical climate context, economizer operation is not as feasible due to the high humidity conditions that comprise a majority of the annual season.

SIMULATION APPROACH

SCTF Air Distribution and Control

Currently within the Air Loop system in EnergyPlus, outdoor air for ventilation is provided solely through the AirLoopHVAC:OutdoorAirSystem object which is a subsystem of the supply side. This object describes the components and controllers which precondition and modulate the OA based on either a minimum flow rate for the system which is derived from design conditions or a dynamic flow rate based on occupancy. The Outdoor Air system currently requires that an OutdoorAir:Mixer component be present within the arrangement. This object mixes the mandated amount of ventilation air with recirculated air to meet a mixed air temperature setpoint.

The needs of the SCTF system require that the two air streams remain unmixed and supplied through a dual duct arrangement. This arrangement was constructed using the existing EnergyPlus air loop components and branch structure by inserting a return air splitter in the recirculated air stream before the outdoor air system. This return branch is split off into the recirculated air stream while the remainder is used as an input into the outdoor air system. The outdoor air system control is overridden to provide 100% outdoor air into the OA stream and exhaust all of the return air that is passed to it. This orientation was tested for errors in node agreements and, while none were found, the system simulation wasn't stable or accurate using a conventional Dual Duct VAV Terminal unit due to the existing model's expectations of a hot and cold air stream inputs.

The determined solution for this control issue was to develop a new type of air terminal unit which will be the key component in the demand-side of the Air Loop and an alternative to the existing ventilation control in the supply-side Outdoor Air System object. This unit is designed to set the air flow setpoints of each airstream according to the individual requirements of each zone. A summation of the zone-by-zone air flow rates for each stream is then used to set the flow for the supply-side primary air system by following these control arrangements:

- Outdoor Air (OA) Stream Flowrate Control - The terminal unit is designed to set the airflow of the of the OA stream at the zone level based on the zonal ventilation requirements which are defined and calculated within the module. The summation of these zonal flow rates would set the flow rate of the outdoor air stream on the supply side of the AirLoop.
- Recirculated Air (RA) Stream Flowrate Control - The RA stream controller within the terminal unit sets the flowrate of recirculated cooling air stream in order to meet the zone temperature setpoint.
- Terminal Reheat Control - If the thermostat calls for heating when the RA stream is fully closed then the Reheat water/steam/electric coil is activated until the zone air setpoint is met. The terminal unit is modeled without a reheat coil by leaving the associated fields blank.

Figure 2 illustrates the integration of the SCTF orientation within EnergyPlus and includes the terminal unit into the Air Loop giving an overview of the component and controller relationships.

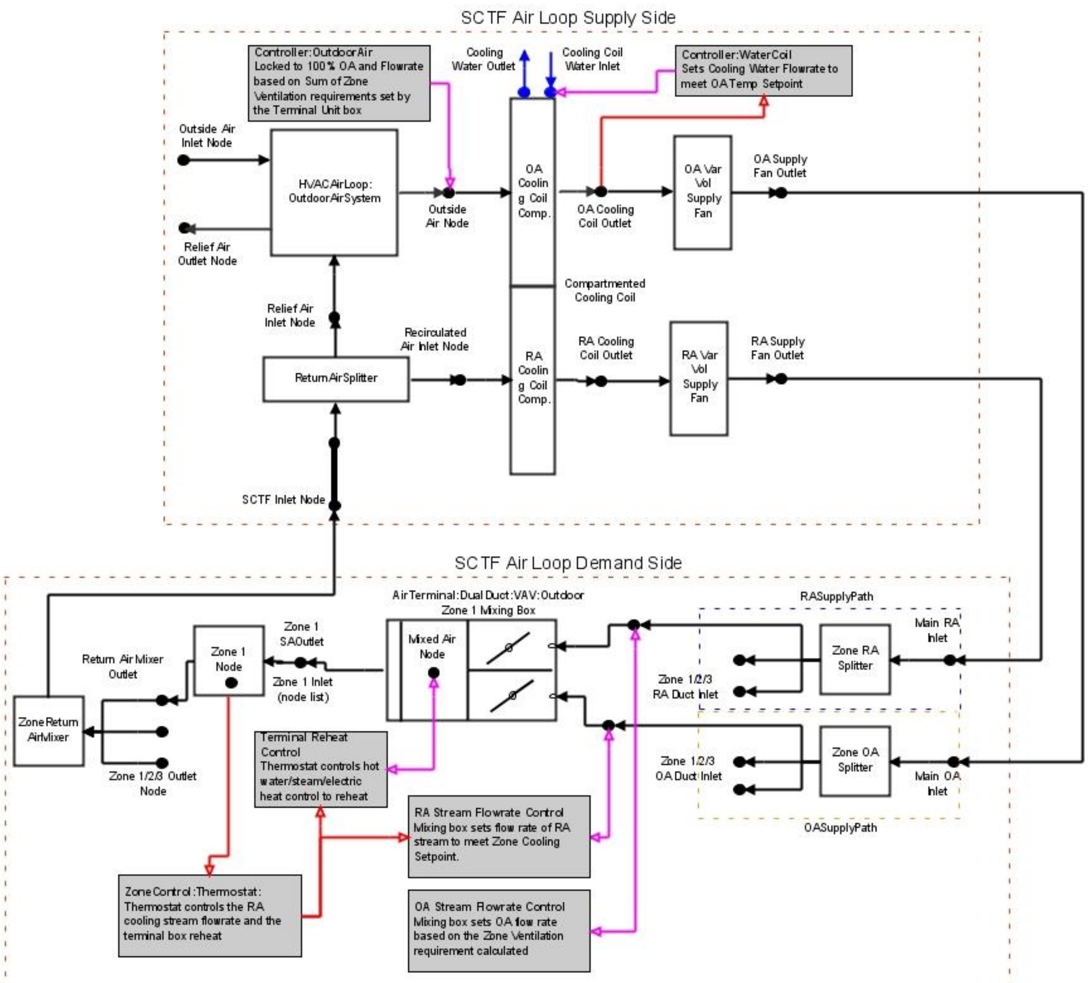

Figure 2 SCTF Components and Controller Diagram

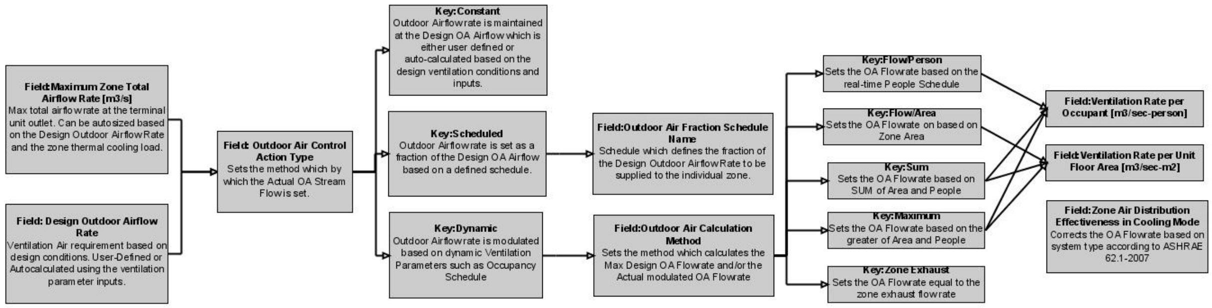

Figure 3 Dual Duct Outdoor Air Terminal Unit

The new dual duct air terminal unit is designed to first size the system based on the maximum combined airflow of the two streams using zone thermal load calculations and ventilation requirements defined at the zone level. The outdoor air control action type and calculation method are then specified by the user. These choices stipulate how the terminal unit will set the outdoor airflow at each timestep. A basic overview of the calculation procedure that will occur in this new terminal unit is seen in Figure 3.

Simulation of the Compartmented Cooling Coil

The unique nature of the compartmented cooling coil poses several challenges with regards to simulation as compared to a conventional cooling coil. Previous research has identified several of these differences (Maheswaran et. al., 2006):

- Different off coil conditions are delivered by the coil and and different heat transfer rates exist for the two different air streams
- The geometry and characteristics such as fin spacing, water tube lengths, materials, face area, etc. across the two compartments can vary according to the load requirements
- The coil is to be controlled using the off-coil conditions of one of the air streams which results in float in the off-coil conditions of the other air stream

These issues were the main motivation for a series of experiments conducted on a set of compartmented cooling coils in previous research in order to determine the fundamental heat and mass transfer coefficients and boundary conditions with the goal of formulating a mathematical model (Maheswaran et. al., 2006). The resultant fundamental forward model that was developed was based on variable heat transfer coefficient calculations as a function of the coil fin surface temperature. While this model is deemed appropriate for advanced coil simulation and selection, it is not suitable for hourly energy simulation programs due to long computation time and its need for inputs and coil characteristics not available within the EnergyPlus environment.

For the purposes of simulation in EnergyPlus, the empirical data collected from the SCTF prototype experiments and case studies is being used to develop an equation fit model to predict the performance of a compartmented coil for the purpose hourly simulation in EnergyPlus. Development of this equation fit model uses the methodology for water-to-air and water-to-water heat pump coil models within EnergyPlus as a guideline. These models, developed by Tang (2005), use the manufacturer's data to create a set of nondimensional governing equations or curves to predict the performance of a heat pump in heating and cooling mode.

For the compartmented cooling coil, the data derived from the prototype is used to create a similar set of governing equations and methodology for calculation of the performance coefficients. A key consideration in the development of these equations is the nature of the model parameters. A diagram of the compartmented cooling coil in Figure 4 illustrates the different input and output parameters.

The governing equations for the SCTF system will be based on the ratio of part load cooling performance compared to the reference capacity. They will be a funtion of various input parameters from each air stream. The basis of these functions is seen in equations (1) through (4).

$$\frac{Q_{tot,OA}}{Q_{tot,OA,ref}} = f\left(\frac{T_{wb,OA,in}}{T_{wb,OA,in,ref}}, \frac{\dot{m}_{OA}}{\dot{m}_{OA,ref}}, \frac{T_{w,in}}{T_{w,in,ref}}\right) \quad (1)$$

$$\frac{Q_{sens,OA}}{Q_{sens,OA,ref}} = f\left(\frac{T_{db,OA,in}}{T_{db,OA,in,ref}}, \frac{T_{wb,OA,in}}{T_{wb,OA,in,ref}}, \frac{\dot{m}_{OA}}{\dot{m}_{OA,ref}}, \frac{T_{w,in}}{T_{w,in,ref}}\right) \quad (2)$$

$$\frac{Q_{tot,RA}}{Q_{tot,RA,ref}} = f\left(\frac{T_{wb,RA,in}}{T_{wb,RA,in,ref}}, \frac{\dot{m}_{RA}}{\dot{m}_{RA,ref}}, \frac{T_{w,in}}{T_{w,in,ref}}\right) \quad (3)$$

$$\frac{Q_{sens,RA}}{Q_{sens,RA,ref}} = f\left(\frac{T_{db,RA,in}}{T_{db,RA,in,ref}}, \frac{T_{wb,RA,in}}{T_{wb,RA,in,ref}}, \frac{\dot{m}_{RA}}{\dot{m}_{RA,ref}}, \frac{T_{w,in}}{T_{w,in,ref}}\right) \quad (4)$$

Each of the inputs in the governing equations will be multiplied by an equation fit coefficient which is calculated from the coil performance data using the Generalized Least Squares Method. The ratio of capacity will then be used to predict the performance of the coil at part load conditions and calculate the water and air leaving temperatures.

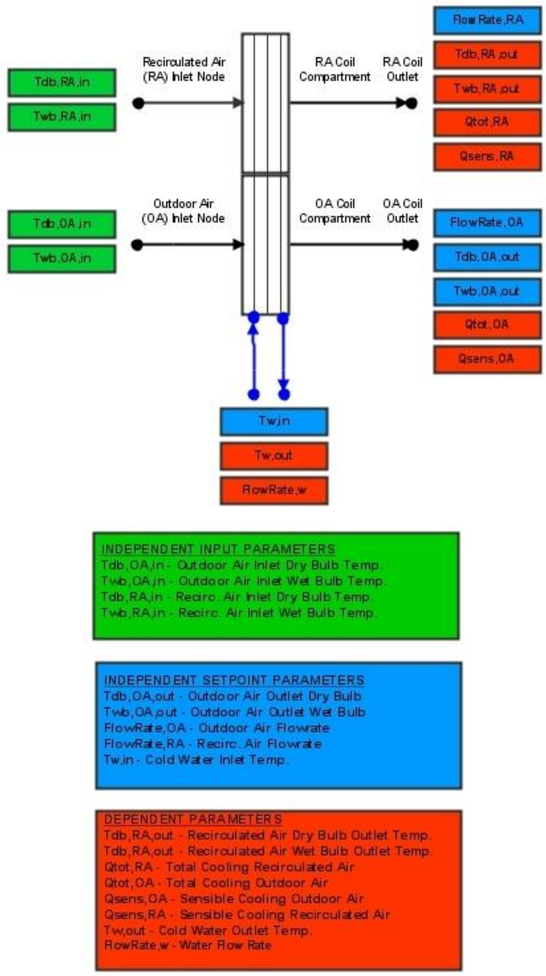

Figure 4 Compartmented Cooling Coil Diagram and Parameters

Figure 5 illustrates the various inputs, reference conditions, capacity coefficients, and outputs in the curve fit compartmented coil model.

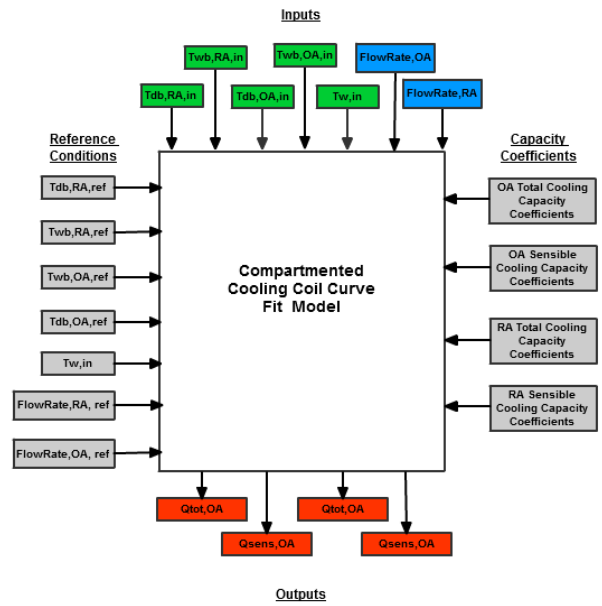

Figure 5 Compartmented Cooling Coil Curve Fit Model Information Flow

FUTURE WORK AND EXPECTED RESULTS

Implementation in EnergyPlus

In order to model the strategies outlined in this study, at least two new objects are to be added to the EnergyPlus source code for the new terminal unit and the compartmented cooling coil. The proposed object AirTerminal:DualDuct:VAV:OutdoorAir is in the process of implementation in the HVACDualDuctSystem.f90 module and a future Coil:Cooling:Water:Compartmented is should be developed to simulate the coil.

Validation of Models

Model validation will occur after implementation in EnergyPlus and include simulation of an existing installed system with actual weather data. The proposed comparative validation data is to be gathered from an installed system at the BCA Academy Net Zero Energy Building (NZEB), a 3,000-sq meter classroom and office building located in Singapore. The NZEB has installed SCTF systems with an extensive sensor and data collection system which can be used to calibrate the model and compare the measured versus predicted performance of the system.

CONCLUSION

This study outlines a conceptual approach towards the implementation of a unique DOAS system type in EnergyPlus. The main issues addressed are the ability to simulate and control unmixed outdoor and recirculated air streams in a dual duct arrangement and predict the energy performance of a compartmented cooling coil. These types of DOAS systems are especially applicable in humid, tropical climates and performance simulation is key in evaluation, design, and implementation of such systems.

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NOMENCLATURE

$\dot{m}_{OA}$: Outdoor Air Stream Mass Flow Rate

$\dot{m}_{RA}$: Recirculated Air Mass Flow Rate

$Q_{tot,OA}$: Total Outdoor Air Cooling Load

$Q_{sens,OA}$: Sensible Outdoor Air Cooling Load

$Q_{tot,OA,ref}$: Rated Total Outdoor Air Cooling Load

$Q_{sens,OA,ref}$: Rated Sensible Outdoor Air Cooling Load

$Q_{tot,RA}$: Total Recirculated Air Cooling Load

$Q_{sens,RA}$: Sensible Recirculated Air Cooling Load

$Q_{tot,RA,ref}$: Total Rated Recirculated Air Cooling Load

$Q_{sens,RA,ref}$: Sensible Rated Recirculated Air Cooling Load

$T_{db,OA,in}$: Outdoor Air Stream Dry bulb Inlet Temp.

$T_{wb,OA,in}$: Outdoor Air Stream Wet bulb Inlet Temp.

$T_{db,RA,in}$: Recirculated Air Stream Dry Bulb Inlet Temp.

$T_{w,in}$: Cooling Water Inlet Temp.

$T_{w,in,ref}$: Rated Cooling Water Inlet Temp.

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