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A simple dynamic model of cooling coil unit

Guang-Yu Jin [a,*], Wen-Jian Cai [a], Yao-Wen Wang [a], Ye Yao [b]

[a] *School of Electrical and Electronic Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798, Singapore*
[b] *Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai 200330, PR China*

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Abstract

In this paper, a dynamic cooling coil unit (CCU) model is developed by extending the CCU engineering model and by combining the model with the mass and energy balance equations. Commissioning information is then used to estimate, at most, six model parameters by a nonlinear on line identification method. Unlike other existing dynamic CCU models for control and optimization, this modeling method is relatively simple and exactly captures the nonlinear characteristics over a wide operating range of the CCU without requiring geometric specifications, which is very convenient in real time engineering control practice. Experiments on a centralized heating, ventilation and air conditioning (HVAC) pilot plant are conducted to show that the method is robust and gives an accurate match to real performance over the wide range of operating conditions. This method is expected to work well for real time control of an operating HVAC system. Even more, the modeling methodology can also be extended to other heat exchangers.

Keywords: Heating; Ventilation and air conditioning system; Cooling coil unit; Air handling unit; Engineering model; Mass and energy balance; Dynamic modeling; Experiments

1. Introduction

The cooling coil unit (CCU), as shown in Fig. 1, is the basic equipment in an air handling unit (AHU) of heating, ventilating and air conditioning (HAVC) systems. The CCU plays an essential role [2,3] to transfer the cooling load from the air loop to the chilled water loop by forcing the air to flow over the coil and into the space to be conditioned. The performance of the coils, which is embodied through their heat transfer characteristics, directly influences the performance of the HVAC system. Therefore, accurate predication of the CCU performance under transient conditions is required for the optimized control strategies of the entire HVAC system [4,5].

Various approaches have been suggested, and these can generally be placed in two categories: finite difference models and lumped parameter models. The finite difference approach results in a large number of equations that are suitable only for numerical simulation. For this approach, Myers et al. [6] and Kabelac [7] used

* Corresponding author. Tel.: +65 6790 6538; fax: +65 6793 3318.
E-mail address: jing0002@ntu.edu.sg (G.-Y. Jin).

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Nomenclature

A	area of flow (m^2)
C	specific heat (J/kg °C)
F	film coefficient (W/m^2 °C)
Q	cooling load (W)
R	heat resistance (°C/W)
T	temperature (°C)
V	volume (m^3)
a, b	parameters
c_{1-6}	parameters
h	enthalpy of moist air (J/kg)
$\dot{m}$	mass flow rate (kg/s)
p	pressure (kPa)
q	heat exchange quantity of element (W)
u	velocity of mass flow (m/s)
τ	a certain time interval (s)
ρ	density of flow (kg/m^3)

Subscripts

a	air
chw	chilled water
i	inlet or on-coil
o	outlet or off-coil
tube	tube
ma	moist air
wb	wet bulb
total	sum of variables

the governing differential equations to study the dynamic response of a CCU by assuming that one fluid had an infinite capacitance. Gartner and Daane [8] found transfer function relations for the different coil parameters. Bocanegra [9] and Khan [10] developed a model to analyze the performance of a counter flow cooling and dehumidification coil. Quite recently, Yao [11] presented a rigorous analysis of the effect of perturbations of the relevant parameters on the thermal quality of a CCU under different initial conditions. The obstacles for these models being applied in industry applications are that the modeling methodologies require comprehensive information on the structure of the CCU and the physical properties of the fluids, such as fin and tube thickness, diameter and spacing, which often may not be available from the manufacturers' catalog. Another drawback is that they require large computational effort and potentially cause numerical instabilities.

The lumped parameter approach results in fewer equations but frequently ignores some dynamics due to the complex heat exchanger behavior. Specifically, the entire CCU dynamics is often modeled as a single system, which ignores the important dynamics associated with the moving boundary between the wet surface region and the dry surface region. Lebrun et al. [12] derived a first order differential equation on the basis of an energy balance to represent the dynamics of a coil with lumped thermal mass. This approach has been used by several authors for simulation purpose and occasionally for control analysis purposes [13]. Extending this approach, Bi et al. [14] presented a lumped parameter empirical model using a robust identification method and applied the modeling method to HVAC control loop auto-tuning [15].

Recently, Wang and Hibara [16] presented a distinct method (called the equivalent dry bulb temperature method) to simplify the calculation in each region. This approach was improved by Wang et al.'s [1] work. They showed that the complex heat and mass transfer characteristics of the CCU could be further simplified, and their proposed model still predicts the system correctly. In this paper, we will extend the previous work [1]