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A Multi-Zone HVAC System for a Typical Building for MATLAB/SIMULINK Platform

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Abstract

Matlab/Simulink is known in a large number of fields as a powerful and modern simulation tool. In the field of building and HVAC simulation its use is also increasing. However, it is still believed to be a tool for small applications due to its graphical structure and not to fit well for the simulation of multi-zone buildings. This paper presents the development of a new multi-zone building model for Matlab/Simulink platform.

Keywords: *HVAC system, Multi-Zone, PM factor, IAQ factor*

1. Introduction

The particulate matters effect on human health has been extensively examined in large amounts of epidemiological studies. In the past studies PM has usually been measured as the mass of PM whose diameter is smaller than 10μm (PM10) [1, 2]. More recently, the health significance of fine PM smaller than 2.5μm (PM2.5) has been reported in several studies, because exposure to PM2.5 can increase the risks of suffering from lung cancer, heart disease and gene aberrance [3-5]. On the other hand, people generally spend most of their lifetime in rooms [6]. And as the public acknowledgement, building envelop does not support enough safeguard to prevent the fine PM entering the rooms [7]. Therefore it is crucial to make clear how to evaluate the indoor PM concentration level quantitatively. In the past two decades, a large number of IAQ models with various degrees of complexity and applicability have been developed. The choice between an existing model and the design of a new model for a specific purpose is usually a compromise among the details of the model, input requirements, simulation times and program complexity. For example, by Dockery [8], Kulmala [9], Weschler [10] and Yang [11], Single-zone particle mass balance models with a limited number of mechanisms included were simplest for application. Multi-zone models, with more enhanced features, were established and verified by measuring the concentration of rooms [12-14]. The models above attempted to assess the effects of ventilations, air filtration, surface deposition, and coagulation. However, there are only few studies discussing the relationships of inner zones of multi-zone by experimental methods [15]. In this study, a particle dynamic model is presented to predict multi-zone indoor PM concentration, to analyze the relationship of pollutant level among inner zones', and to develop efficient natural ventilation patterns in residential building as well.

2. Single Zone HVAC Model

The system modeled in this study is simply referred to as HVAC system while it benefits from both VAV and VWF capabilities, serving a single thermal zone, as shown in Figure 1 [1]. Initially, fresh air enters the system and mixes with 75% of the return air, while the remaining air is exhausted. Then, mixed air passes through the heat exchanger where it is conditioned according to desired set-point. Next, the conditioned supply air is delivered to the thermal zone by a draw-through fan. Supply air satisfies the thermal loads. The system controller simultaneously varies fa and fw according to load changes, so that the desired set-points in temperature and RH, as control variables, are maintained. Considering the ratio of volumetric flow rate of outside air to the supply air as $f_{a,0}/fa = 0.25$, the differential equations formulated based on energy and mass balances for the system of Figure 1 are given by [13]:

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$$\frac{dW_3}{dt} = \frac{W_2 - W_3}{V_z} + \frac{M_z}{\rho_a V_z} \tag{1}$$

$$\frac{dT_2}{dt} = \frac{(T_3 - T_2) f_a}{V_{he}} + \frac{0.25(T_o - T_3) f_a}{V_{he}} - \frac{h_w\,(0.25W_o + 0.75W_3 - W_2) f_a}{C_{pa} V_{he}} - \frac{\rho}{\rho} \tag{2}$$

$$\frac{dT_3}{dt} = \frac{(T_2 - T_3)\,f_a}{V_z} - \frac{h_{fg}(W_2 - W_3)\,f_a}{C_{pa} V_z} + \frac{(Q_z - h_{fg} M_z)}{\rho V_z C_{pa}} \tag{3}$$

The variables are defined in the nomenclature. Equation (1)–(3) describe the transient mass and energy balances for the air entering and leaving the thermal zone.

Table 1. Nomenclature

f_a	volumetric flow rate of air (m3/s)	T_2	Temperature of supply air
f_w	volumetric flow rate of water (m3/s)	T_3	Temperature of thermal zone
h_w	enthalpy of water (kJ/kg)	C_{pa}	specific heat of air (kJ/kg _C)
h_{fg}	enthalpy of water vapor (kJ/kg)	V_{he}	Volume of heat exchanger
M_z	moisture load of thermal zone (kg/s)	W_2	humidity ratio of supply air (kg/kg)
Q_z	thermal load (kJ/s)	W_3	humidity ratio of thermal zone (kg/kg)
V_z	Volume of thermal zone (m3)	W_o	relative humidity of outdoor
ρ	density (kg/m3)	Φr	relative humidity

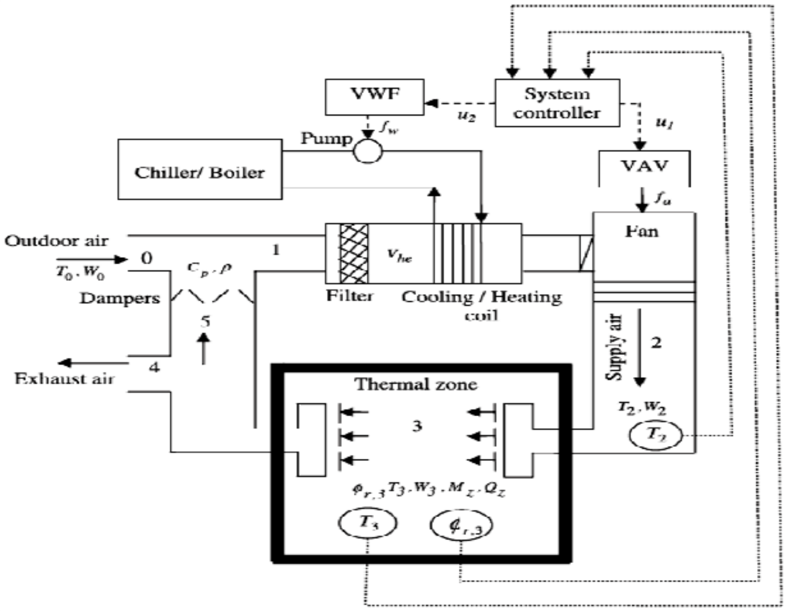

Figure 1. HVAC System Schematic and Control Block Diagram [1]

3. Multi-zone Model

Figure 2 illustrates the basic features of the multi-zone model. This model consists of three zones. Every zone has one window. Specifications of zones are shown in Figure 2. In Figure 3 HVAC system that used for multi-zone is shown.

For mathematical modeling of this multi-zone system we have used from single zone model that are described in previous section. Equation (4), (5), and (6) show the differential equations formulated based on energy and mass balances for the system of Figure 2 and Figure 3.

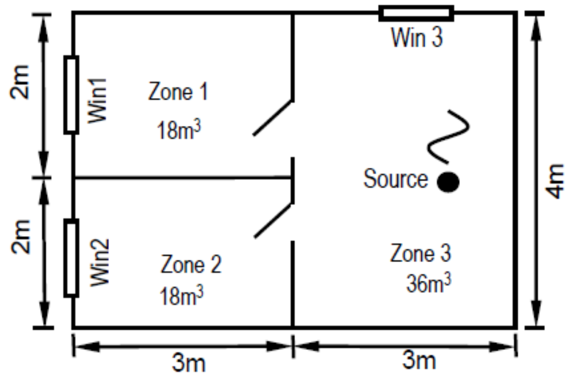

Figure 2. Schematic of Multi-zone Model

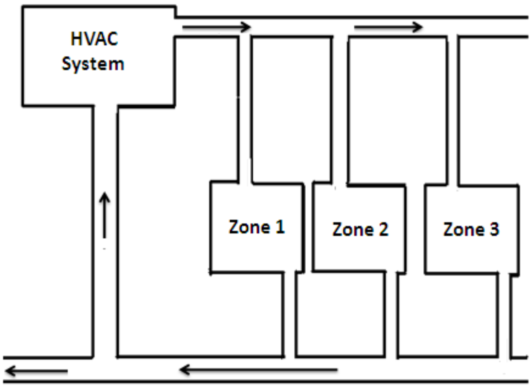

Figure 3. Multi-zone with HVAC System Configuration

$$\begin{cases} \frac{dT_2}{dt} = \frac{(T_{3(z1)} - T_2) f_a}{V_{he}} + \frac{0.25(T_o - T_{3(z1)}) f_a}{V_{he}} \\ \quad - \frac{h_w (0.25W_o + 0.75W_{3(z1)} - W_2) f_a}{C_{pa} V_{he}} - \frac{\rho\Delta}{\rho C} \\ \frac{dT_2}{dt} = \frac{(T_{3(z2)} - T_2) f_a}{V_{he}} + \frac{0.25(T_o - T_{3(z2)}) f_a}{V_{he}} \\ \quad - \frac{h_w (0.25W_o + 0.75W_{3(z2)} - W_2) f_a}{C_{pa} V_{he}} - \frac{\rho\Delta}{\rho C} \\ \frac{dT_2}{dt} = \frac{(T_{3(z3)} - T_2) f_a}{V_{he}} + \frac{0.25(T_o - T_{3(z3)}) f_a}{V_{he}} \\ \quad - \frac{h_w (0.25W_o + 0.75W_{3(z3)} - W_2) f_a}{C_{pa} V_{he}} - \frac{\rho\Delta}{\rho C} \end{cases} \tag{4}$$

$$\begin{cases} \frac{dT_{3(z1)}}{dt} = \frac{(T_2 - T_{3(z1)}) f_a}{V_{z1}} - \frac{h_{fg} (W_2 - W_{3(z1)}) f_a}{C_{pa} V_{z1}} + \frac{(Q_{z1} - h_{fg} M}{\rho V_{z1} C_{pa}} \\ \frac{dT_{3(z2)}}{dt} = \frac{(T_2 - T_{3(z2)}) f_a}{V_{z2}} - \frac{h_{fg} (W_2 - W_{3(z2)}) f_a}{C_{pa} V_{z2}} + \frac{(Q_{z2} - h_{fg} M}{\rho V_{z2} C_{p}} \\ \frac{dT_{3(z3)}}{dt} = \frac{(T_2 - T_{3(z3)}) f_a}{V_{z3}} - \frac{h_{fg} (W_2 - W_{3(z3)}) f_a}{C_{pa} V_{z3}} + \frac{(Q_{z3} - h_{fg} M}{\rho V_{z3} C_{pa}} \end{cases} \tag{5}$$

$$\Phi_r (\%) = 5000W_3 - 1.388T_3 + 107 \tag{6}$$

4. Simulation Results

The windows/doors govern indoor air exchange rate and this can be regulated not only by the position but also by the aperture of windows (open factor). Figure 4 shows the profile of air exchange rate by the change of window1's aperture (0~1) under Case A. The AER of zone1 is enhanced by increasing the aperture of window1. While the AER of zone 2 and 3 have the maximum value when the aperture is 0.1, and then keep stable, at 1.6h-1. The AERs of zone2 and zone 3, and the aperture of window1 change independently, respective.

Similarly to the above case, Figure 5 illustrates the more zone 3's air exchange rates are due to the larger window 3 aperture. But zone1 and 2's AER, following each other, have independent relationship with the open factor of window 3.

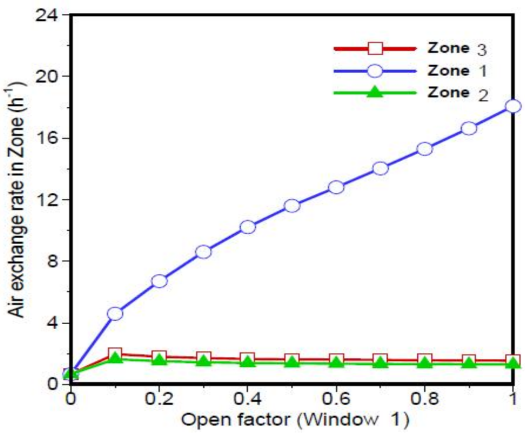

Figure 4. The Air Exchange Rate as a Function of Window 1 Aperture (open factor)

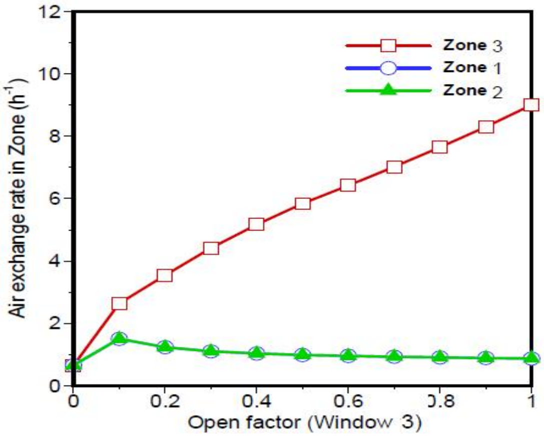

Figure 5. The Air Exchange Rate as a Function of Window 3 Aperture (open factor)

5. Conclusion

The distribution of multi-zone is the familiar mode of residential house and public building. According to the multi zone model, the PM concentration level of any zone in a house can be calculated and predicted. The calculated results show the correlation with pollutant levels of different zones. The parameters of the model, such as air exchange rate, penetration factor, deposition rate and source, have important effects on indoor air quality. Penetration factor, deposition rate and source are assumed as the constants in this research. But the effect of AER, including the position of the windows/doors and windows/doors aperture is mainly focused on. Compared with the cases of controlling the windows/doors of different zones, it is the most effective measure to strengthen the ventilation of the zone with pollutant source (Case C). This measure can not only attenuate the concentration level of this zone, but also prevent the particles from transporting into other zones. On the other hand, the segregation case (Case B) can assure the clean zone out of pollution, but cannot reduce the concentration of polluted zone with source. Window aperture is the other important factor affecting the ventilation rate. Opening the window of a zone can increase this zone's air exchange rate. But there is no obvious influence on the other zones. On the other hand, controlling the aperture of windows/doors can improve the indoor IAQ. Increasing the open factor of window in the polluted zone can improve the IAQ of the zones, and contribute the same effects on the two clean zones. In addition, increasing the window aperture of one of the clean zones can reduce the concentrations of this zone and polluted zone, but other concentrations still keep high. Thus to optimize the position of windows is needed, and the dynamic model is an effective tool for this task.

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