Research on Ventilation Computing System for Multi-area Network Model

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***Abstract*—The problem of indoor air quality is a complicated issue involving many fields. In recent years, it has attracted the attention of a large number of researchers, especially the multi-area ventilation air volume and concentration of pollutants are among the core issues. According to the characteristics of each ventilation path, the setting of pollution information and the corresponding boundary conditions, the air volume of each different ventilation path and the concentration of pollutants in each area can be calculated. Using this principle to build a ventilation computing system for multi-area network model, the user can quickly build a model based on the actual physical scene, and the software automatically calculates and derives the calculation results to meet the needs of engineering applications for the rapid design of multi-area models and ventilation volume calculations.**

Keywords- Air quality; multi-area network; ventilation volume prediction

I. INTRODUCTION

The problem of indoor air quality is a complex issue in many fields, mainly including regional ventilation volume calculation and pollutant concentration calculation. In an indoor space, many partitions are divided into different layers by partitions. Ventilation ducts, door gaps, and other ventilations are interconnected between the various areas, and the correlations between pollutants can be calculated. Through the mathematical model of multi-area network ventilation and the determination of the characteristics of the ventilation path, a specific functional relationship is expressed, and the ventilation characteristics are determined by inputting the constant coefficient values in the function relationship.

This paper builds a mathematical model based on the actual content of a multi-area network and uses this as a basis for a computing system. Based on this principle, it further develops a multi-area network ventilation software to realize input integration, simplify parameter definition, and model typification. The requirements make it possible for users to build models based on actual physical scenes and quickly derive calculation results based on input boundary conditions to meet the requirements for rapid design in engineering applications.

A. Multi-area network mathematical model construction principle

The calculation models of the simulated ventilation process mainly include empirical formula models, multi-area models, and unit models. These models are all simplified to different degrees according to actual physical phenomena. The most common ventilation models are multi-area models. The multi-area model is derived from a single-area model. The multi-area model divides each room into one unit and the unit model will have one. The room is divided into sub-units so that the physical parameters in the room can be defined in more detail. The construction of a multi-area network mathematical model involves many basic models. The details are as follows.

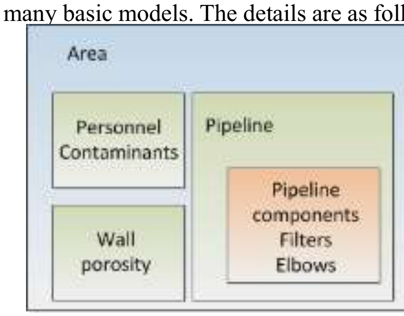

Figure 1 Multi-area network model relationships

B. Multi-zone ventilation model construction

The flow in the multi-zone model is related to the air pressure and temperature of the two zones. Define the air channel e between the area i and the area j. The mass flow rate of air flowing through is , and the flow direction of the area j to i is positive. The opposite direction is negative. The equation for the node where a mass flow channel is located is:

$$F_{ji} = f(P_j - P_i) \tag{1}$$

The air quality calculation is based on the ideal gas state equation.

$$m_i = \rho_i V_i = \frac{P_i V_i}{RT_i} \tag{2}$$

For transient calculations, the mass conservation equation can be calculated by.

$$\frac{\partial m_i}{\partial t} = \rho_i \frac{\partial V_i}{\partial t} + V_i \frac{\partial \rho_i}{\partial t} = \sum_j F_{ji} + F_i \tag{3}$$

$$\frac{\partial m_i}{\partial t} \approx \frac{1}{\nabla t}[(\frac{P_i V_i}{RT_i})_t - (m_i)_{t-\nabla t}] \tag{4}$$

Where m_i is the air mass in zone i; F_{ji} is the flow between zone j and i, positive value means that air flows from zone j to i.The calculation of the dynamic pressure difference of the inter-area channel flow is calculated using the Bernoulli equation.

$$\Delta P = (P_1 + \frac{\rho V_1^2}{2}) - (P_2 + \frac{\rho V_2^2}{2}) + \rho g(z_1 - z_2) \tag{5}$$

Each area needs to set parameters such as pressure, temperature (calculated density and viscosity) and height. The area height value is used to determine the stack effect pressure. If the air in the room is at a constant temperature,

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the hydrostatic equation can be used to relate the pressure difference across the inter-area channel to the bottom of the channel and the elevation of the area. The pressure conditions are recalculated and may increase the wind pressure of the building envelope.

$$\Delta P = P_j - P_i + P_s \tag{6}$$

Where P_i and P_j represent the pressures of the regions i and j, respectively, and P_s represents the pressure difference due to air density and height.

The pressure difference between the channels is calculated using the above principle. The air flow calculated from the pressure difference is mainly an exponential power model. The following formula is used to calculate the gap or small opening flow.

$$F = C(\Delta P)^n \tag{7}$$

For large orifices use the orifice equation to calculate.

$$Q = C_d A \sqrt{\frac{2\Delta P}{\rho}} \tag{8}$$

Where n is the flow index; C_d is the flow coefficient; A is the orifice area. In theory, the flow index is generally between 0.5 and 1. For a large opening close to 0.5, for a slit opening its value is close to 0.65.

C. Personnel exposure model construction

Personnel in the building have the ability to simulate. Simulate occupant movement throughout the building, allowing occupants to leave the building and determine the exposure of each resident's contaminants. Residents can also generate pollutants in buildings, so people can be simulated as a mobile source of pollution. Personnel exposure is achieved by integrating the concentration of pollutants in the area where the person is located over a period of time.

$$E = \int_{t_1}^{t_2} C(t)dt \tag{9}$$

D. Pollutant Model Construction

1) Pollutant Discharge Source Model

For pollutants in the area, the amount of pollutants emitted and the removal efficien.cy can be set. There are mainly the following models.

(1) Constant coefficient model

The constant coefficient model is calculated using the following equation.

$$S_a(t) = G_a - R_a C_a(t) \tag{10}$$

Among them, S_a is the emission intensity of pollutant a, G_a is the production amount of pollutant, and R_a is the removal coefficient of pollutant. For the purification equipment in the room, G=0, R=f•e, where f is the flow rate through the purifier and e is the single filtration efficiency of the purification equipment.

(2) Cutoff concentration model

For volatile organic compounds, the source equation is sometimes expressed in the following form.

$$S_a(t) = G_a(1\text{-}\frac{C_a(t)}{C_{cutoff}}) \tag{11}$$

Where C_{cutoff} is the cut-off concentration, dispersal of contaminants is interrupted when the concentration reaches this value.

(3) Attenuation source model

Another source-strong equation for volatile organic compounds is decaying exponentially, with the following expression.

$$S_a(t) = G_a e^{-t/t_e} \tag{12}$$

Where t_e is the decay time constant and t is the elapsed time from the start of release.

(4) Boundary layer diffusion control model

$$S_a(t) = h \cdot \rho \cdot A(C_i - \frac{C_s}{k}) \tag{13}$$

Where h is the average membrane mass transfer coefficient; k is the Henry's adsorption constant; C_i is the concentration of pollutants in the air; C_s is the concentration of pollutants in the adsorbent

2) Pollutant propagation model

The theoretical basis for pollutant transmission analysis is that each component in the control area observes the law of conservation of mass. The volume of each control area refers to the volume of air in a single room, or a part of a room, or a room linked to another room.

In many cases, when the concentration of a component is very low, it is considered that it has no influence on the air concentration, and therefore the component concentration can be regarded as a tracer concentration. When only pollutants are traced in the example, the physical properties of the dry air will be considered as the parameters of the air properties added to the calculation. Establish a mass conservation equation for the component α of the control region i.

$$\begin{aligned} \frac{dm_i^a}{dt} &= \sum\nolimits_j F_{j-i}(1-\eta_j^a)C_j^a + G_i^a - \\ &\sum\nolimits_j F_{i-j}C_i^a - R_i^a C_i^a \end{aligned} \tag{14}$$

Where $F_{j\text{-}i}$ denotes the mass flow rate of the control zone j to i, η_j^a denotes the filtration efficiency of the component a through the flow channel, G_i^a denotes the component generation rate, and R_i^a denotes the component loss rate.

For transient conditions, the mass balance equation for component a in control region i can be expressed as.

$$\begin{aligned} \rho_i V_i C_i^a \big|_{t+\Delta t} &\approx \rho_i V_i C_i^a \big|_t + \Delta t \bullet [\sum\nolimits_j F_{j-i}(1-\eta_j^a)C_j^a \\ &+ G_i^a - \sum\nolimits_j F_{i-j}C_i^a - R_i^a C_i^a]_{t+\Delta t} \end{aligned} \tag{15}$$

E. Filter model construction

In the simulation of pollutants, a mathematical relationship is used to define the filter. A filter consists of two parts, the filter itself, which is associated with a specific component (path or pipe segment), and filter elements that can be associated with one or more filters. The filter element provides the physical properties of the filter and the mathematical relationship that describes the filter behavior during the simulation.

The following components may contain filters, 1. Air flow passages; 2. Impurities in outdoor air and circulating air streams in air handling systems; 3. Air supply and return systems in air handling systems; 4. Pipeline sections; 5. The end of pipelines

To better represent changes in filter efficiency, cubic spline fitting is used, so when at least three load and filtration efficiency status points are given, the filter efficiency changes for a gaseous filter under different loads can be fitted.

F. Air flow pipe model construction

The piping system consists of pipe sections, connection points, termination points, and forced air components. A pipe segment is a pipe at two connection points, an end point, or both. The main ventilation duct models are the following,

(1) Darcy-Colebrook model

The model uses the Darcy resistance relationship and the Colebrook roughness function

$$\frac{1}{\sqrt{f}} = 1.44 + 2\cdot\log(D/\varepsilon) - 2\cdot\log(1+\frac{9.3}{\mathrm{Re}\cdot\varepsilon/D\cdot\sqrt{f}}) \quad (16)$$

$$F = \sqrt{\frac{2\rho A^2 \Delta P}{fL/D + \sum C_d}} \quad (17)$$

Where e is the roughness, Re is the number of Reynolds, L is the length of the pipe, D is the equivalent diameter of the pipe, and f is the coefficient of friction.

(2) Exponential power model

In this model, the flow coefficient and flow index are directly input, and the flow in the pipeline is also calculated according to the exponential power model in the ventilation model.

(3) Fan performance curve model

This model can build fans based on fan performance curves. A set of pressure rise and flow correspondence data is provided to perform polynomial curve fitting to determine the fan performance.

(4) Constant flow model

Define a constant volume flow or mass flow within the pipe.

II. MULTI-AREA NETWORK VENTILATION SOFTWARE DESIGN

Using the method of multi-area network mathematical model construction, the corresponding ventilation calculation system is developed. The main development modules of the system are as follows, (1) definition of model; (2) database application; (3) model parameter extraction; (4) software Interface development

A. Model definition function

The model definition is based on a two-dimensional drawing board. The drawing board is equipped with an automatic mesh capture capability to directly generate independent areas. After inputting or specifying the location and size, the function area can be directly generated. The attribute definition tool has a corresponding topological relationship. Pipelines, pollutants, personnel, etc. should be defined within the area. Porosity should be defined on the wall surface of the area. Pipe components such as filters should be defined on the pipe as shown in the figure below.

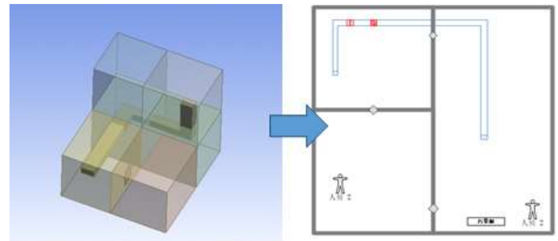

Figure 2 Actual physical model to 2D model

B. Database reference design

In order to respond to the need for rapid design and rapid modeling, the data in the built-in database should be directly referenced in the physical model definition, rather than reading a little bit of data during the modeling process to enter the required data. Database built-in typical data, in the drop-down menu list can be directly selected to refer to the database data.

1) Ventilation path reference

The ventilation path function library mainly contains the air volume-pressure model of a series of components. The corresponding relationships in the function library mainly include the following.

$$F = f(P_1 - P_2) \quad (18)$$

Among them, F, P_1, and P_2 are floating-point numbers, F is the air volume, and P_1 and P_2 are pressure values at both ends of the component. The library contains the common air volume-pressure model that requires user-defined constant coefficients, and also includes the air volume-pressure model under a completely defined typical scenario. For example, the flow characteristics of a typical door closed state or open state when the user selects After the corresponding model, the corresponding data already set in the database is directly called.

2) Reference to the pollutant database

The pollutant database contains the values of the physical parameters of common pollutants. When this type of pollutant is selected, the corresponding pollutant data can be directly referenced. as the picture shows.

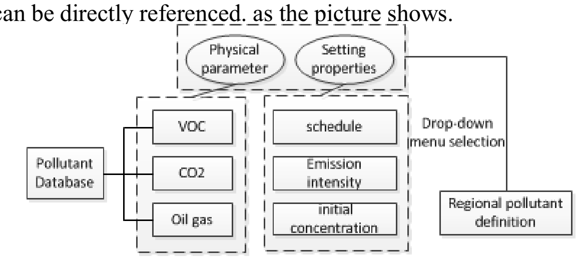

Figure 3 Contaminant database call

3) Staff Activity Database Reference

The law of personnel activity is established to calculate the personnel exposure. For a person, the time they stay in each area directly affects their exposure to contaminants. The schedule is defined in hours and defines the schedule for the day. The way of definition is as shown in the figure.

4) Typical part type database reference

The component type database is a comprehensive database that refers to other databases and default typical values. By using the component type database, users no longer need to define some of the main typical parameters, and they do not need to select other discrete databases, which can greatly speed up The speed of modeling and definition.

During the model establishment process, each corresponding component has a corresponding component type database, ie, after selecting the typical component type in the attribute definition interface of the corresponding component, other parameters no longer need to be defined.

C. Model parameter extraction

After the model is established, the required parameters can be extracted from the model to be calculated. Different model parts need to extract different parameters, and the basic parameters are the same as the attribute definition parameters. Some parameter extraction tables are as follows.

TABLE I Pipeline parameter table

Data name	type of data	Extraction target
Pore number	Shaped number	Pore recognition
height	Floating point	Hot pressure calculation input
Coefficient of pore resistance model	Floating point	Inter-zone ventilation calculation input
schedule	Floating point matrix	Flow coefficient in ventilation calculations

TABLE II Pore parameter table

Data name	type of data	Extraction target
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height	Floating point	Hot pressure calculation input
Coefficient of pore resistance model	Floating point	Inter-zone ventilation calculation input
schedule	Floating point matrix	Flow coefficient in ventilation calculations

TABLE III Staff parameters table

Data name	type of data	Link target
personnel number	Shaped number	Person identification
Staff schedule	Floating point matrix	Links to personnel exposure calculations

D. Software design effect

The software interface mainly includes.

(1) Title bar. The title bar is a square area set at the top of the software graphical user interface. It is mainly used to display the file name.

(2) Menu bar. The menu bar settings are similar to typical Windows programs. Through the selection of the menu bar, the operations that can be performed include: saving and retrieving files, displaying various modes of the project, creating and executing simulations, and accessing online help systems. Some menu items have shortcut keys or shortcut keys for quick access to the corresponding functions.

(3) Toolbar. The toolbar is set under the menu bar and provides convenient shortcuts for some menu items. Some of these toolbar buttons are similar to buttons in other Windows applications. Other buttons are set according to the software usage requirements.

(4) Status bar. The status bar is located under the main drawing area and is used to display the information of active components in the current drawing area, such as the information of the area, the information of the air flow channel, the information of the air treatment system, and so on. For multi-layer models, the current number of layers is also displayed.

The interface effect is shown in the figure below.

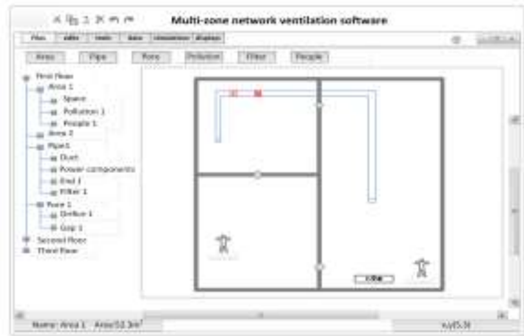

Figure 4 software basic interface

III. CONCLUSION

Ventilation computing system for multi-area network model is based on ventilation mathematical model construction, establishes corresponding functional relationships, determines the ventilation characteristics through constant coefficients in the input function relations, and encapsulates the constructed calculation methods and processes as background knowledge. . During the use of the system, the user can quickly create a two-dimensional calculation model based on the actual physical scene, encapsulate the process that originally required a lot of manual calculations into an automation template, and use the software interface to complete the input, calculation, and output of the information and realize the input modularization. The simplification of parameter definition and the characteristics of the model's typification meet the requirements of rapid design in the project, which greatly improves the design efficiency and shortens the development cycle.

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