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Thermal and Airflow Network Models for Computer Simulation and Measurement in Building Multi-zone Systems

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Summary

The present paper describes the author's two models of heat transfer and airflow in buildings for the purpose of prediction, or for the measurement of air quality or energy consumption. The former is a general spatial discretized model of not only contaminant but also of heat transfer systems called the Thermal Network. This model has a common framework for the finite element model, the finite difference model and the control volume model. The author has developed both computer simulation and optimization methods for the design, a system identification method for the measurement and an optimum control method by using this model in the state space approach of the system theory. The latter model of Airflow Network has a simple and general structure and is expected to be a comprehensive model including the computational fluid dynamic model.

Introduction

In Japan, forced convection heating and cooling is quite common and is subject to the peculiarity that temperature and contaminants are rather mixed and uniform in a single chamber. However even in the case of supplying air using a duct system, a lower flow rate for some zones may be possible due to the unexpected flow resistance change or the stack effect for the entire building. Therefore, it is necessary to consider that ventilation efficiency is useful not only in a single chamber but also in a multi-chamber system. In this way, the macroscopic model of the coupled multi-zone system is also as important as the microscopic model that displays the state in a single chamber, thus the unified and broad scope is necessary for the airflow models.

The phenomenon of contaminant transfer and dispersion depend upon airflows, and airflows themselves have interaction with the building's heat transfer because of the stack effect. In this context, the prediction, measurement, and control methods of airflows inside buildings should preferably have a good common framework which is standardized and systematized for the compatibility and interchangeability of model data, the saving of resources and software, and efficiency in practice.

The contaminant transfer system can use a mathematical model which is similar to the temperature transfer system so that the contaminant transfer system can be modeled using the author's thermal network. The inter-zonal airflows can be modeled by the airflow network. However, the various thermal or airflow networks and these solutions are now proposed, so the author would like to state the characteristics of the author's model.

Standardizing model of transfer system as spatial discreting idealization

The governing partial differential equation, as a distributed parameter system for transfer phenomenon, is essentially the same even if it belongs to a heat transfer system or a contaminant dispersion system. A finite element model and a spatial finite difference model exist as spatially discretized and approximated models of this equation.

On the other hand, there is also a practical spatial discretization method of modeling available called control volume method in which the spatial domain as an object of calculation is divided into the volumes by the engineering decision, and concerning these volumes, the conservation law of mass or energy are formulated.

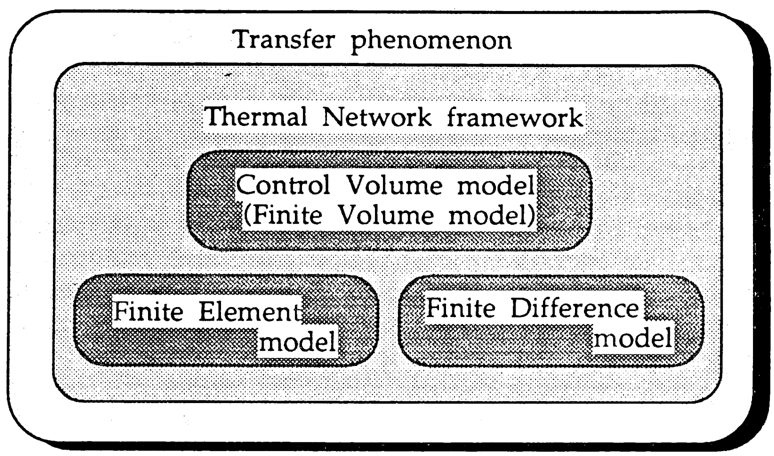

Figure 1 Common framework of spatial discretization models

The author's thermal network (1) started from the aforementioned control volume method of spatial discretization. The final state equation is formulated by the "perfectly connected nodal equations " composed of system parameters of generalized conductance and capacity. The generalized conductance expresses all transfer types such as convection or conduction, further the nodal equations which do not depend on spatial dimensions, describe the general N-dimension. Therefore, this equation is quite flexible in application for the objects of calculation, and they can be modeled freely.

The coefficients in the whole equation of the finite element model are compatible to the system parameters of this author's state equation model. Therefore, it is possible to connect different types of spatial discretized models in the framework of the mathematical model which is based on the author's thermal network. The saving of resources will be expected through the common use of solvers, and it will also benefit from the standardization. Axley has also proposed a model (2) aims at a mixed idealization, with the method of similar to the finite element, and seems to be complicated.

Unified and systematic approach

Engineering techniques related to building heat transfer, ventilation, and contaminant transfer are considered to be roughly classified into design, measurement, and control. The author's thermal network model is the basic model which includes those techniques in a view of state space method. Although the design is a kind of optimization act which can primarily be accomplished in the human brain, some mathematical optimizations can be substituted to a certain extent by the use of computer. A computer simulation which predicts the physical phenomenon is the elemental tool that plays the basic role in these optimizations.

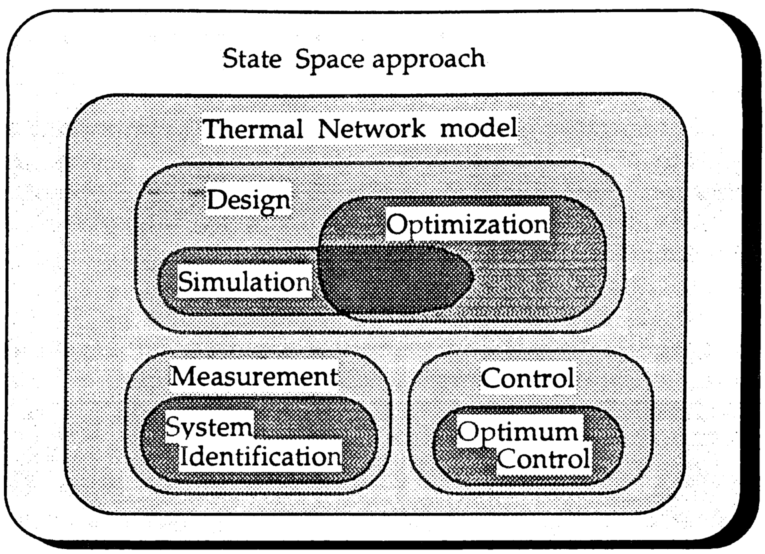

Figure 2 Unified and systematic approach

In most cases the measurement can be considered as a sort of system identification. For instance in the measurement of length, the ruler can be considered as the system identification model. In this way the author's thermal network model for the tracer gas transfer in a multi-zone system can be compared with this measurement ruler. The author's system parameter identification theory on the thermal network model, which is deduced from the principle of the least squares, realized the multi-chamber airflow measurement system (3)as an application.

As the author's thermal network is represented in a state equation, it can directly put the modern control theory into practice. The author has already shown the theory that optimizes the state and energy supplies in the heating and ventilation system formulated in the quadratic evaluating function using the multi-variable least squares method.

Inclusive and comprehensive model for airflows inside buildings

In the building engineering field, there are many phenomena to be considered in multi-storey and chamber systems, such as the stack effect. Therefore not only microscopic model of computational fluid dynamics which is applied to the single space in its utmost capability, but also the macroscopic airflow network model calculating inter-zonal airflows is necessary for the practical use.

The constituent elements of the author's airflows network model are only zone and flow path, but they can be assembled to express any complex building airflow system including mechanical ventilation installations with air ducts. The flow path model does not classify various types of openings and air ducts, because the pre-processor should do this job.

This author's model has a simple and minimum data structure of one dimensional vectors, and doesn't have a complicated description of network connection e.g. graph theory. The most important routine for flow rate balances is made brief and plain by using "indirect addressing for nodal number".

Thus, the calculation program is quite simple. The author's solving method belongs to the pressure assuming method and he has clearly shown the oscillation mechanism when you try to solve a set of non-linear simultaneous equations for the nodal pressures by the ordinary Newton-Raphson Method and he has proposed the modified method.

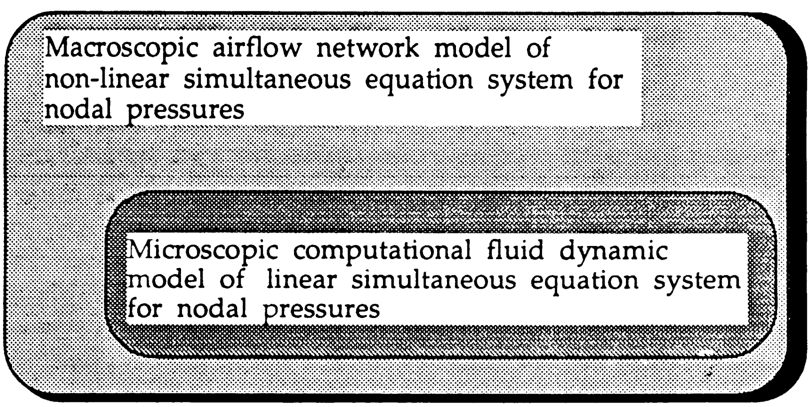

Figure 3 Inclusive and comprehensive airflow model in buildings

As for the macro and the micro models, both have good points and bad points. We need a unified model which will compensate for each of the bad points. The micro model can be regarded as a set of linear simultaneous equations concerning pressure. Thus the set of the non-linear simultaneous equation system of macro model will include it. In the airflow network solving process, the Jacobian matrix, which is composed of numerical derivatives by pressure, is fully inverted. However for the large equation system including the microscopic model, the inversion of the full size Jacobian matrix will be a time consuming calculation. Therefore some pseudo-inversion must be devised, for example the total inversion is approximately formed by the weak coupling of the subdivided and inverted matrices.

The author believes that the vertical temperature distribution in a large space can be predicted practically if the thermal plume flow path is introduced into his macro model, and now he is carrying out the numerical experiment on this idea.

Thermal and airflows network simulation program "NETS"

The author developed the computer program NETS to simulate non-steady or steady state with the coupled system in the three, previously mentioned networks of the thermal, airflow, and the gas transfer. The computer simulation is based on the standard hourly meteorological data for one year provided by SHASE of Japan, and also on the arbitrary artificial driving conditions. The incremental interval can be from one minute, to a maximum of one hour. Of course, it can also calculate a temporal variation of the air quality in the long term, in addition to the thermal load or the performance of passive solar houses.

For the time integration of the state equation, besides the practical implicit finite time difference, the author's analytical method by the spectral resolution on the basis of eigenvalue analysis can be applied. Furthermore the author's economizing method can be used which approximately synthesizes the state transition matrix from subdivided state equations.

The time schedule of gas or heat production is changeable, and these conditions can be adjusted through the feedback of gas concentration, temperature or the pressures state, as well. NETS also takes into account Mode Change which means the structural change of the calculation model. Mode Change is achieved by schedule or by the state feedback control. The examples of Mode Change are regulating the airflow resistance damper, control of the revolution of the fan or the opening and closing of doors and windows. To consider the driving, feedback control and mode change for every day, the Daily Patterns are defined for these changes, and these patterns constituting a period for arbitrary days are necessary. A simulation is carried out by this periodic schedule.

There is another multi-zone airflow calculation program COMIS, the result of combined international efforts (4). In the author's opinion this kind of models can be evaluated on the three points of "simplicity and universality of the model", "stability and efficiency of the solution" and "arrangements for model parameters". NETS may be insufficient in this third item, as compared with COMIS, but this could be considered as a problem of pre-processor. This encourages the development of the interactive graphic modeling pre-processor "NETSGEN" which will provide a more user-friendly interface for NETS, and also for the other models with same data structure.

Multi-chamber airflows measurement system

The author's measurement system has been recently improved (5) by introducing the non-negative constraints. This system can also identify the effective mixing volume of rooms as system parameters, so that it may be possible to measure the ventilation efficiency. Other researchers of the method are frequently using multiple tracer gas which seems to be both complicated and of limited use. Given the possibility of errors, statistical methods are recommended rather than deterministic methods. The author's present measurement system is the second generation. The author thinks that further improvement in practicality and accuracy can be realized by the decentrallized measurement system in which a small gas concentration analyzer and a gas releasing device are placed in each room.

Concluding Remarks

Simplicity and generality are necessary for the mathematical model of the computer calculation. Therefore, the author's research tendency, which aims not at analysis but at a universal rule, promises to be useful for the development of his thermal and airflow network models. These models are a sort of view of the relevant field. It would be a pleasure for the author if his view provides you with a simple modeling method for the phenomena in our field.

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