5th International Conference on Air Distribution in Rooms

Yokohama, JAPAN   July 17 - 19, 1996

Vol. 2

ROOMVENT '96

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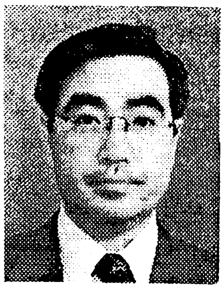

Error Analysis and Verification of Multi-chamber Airflow Measurement

Hiroyasu Okuyama
Senior Researcher,Dr.Eng.
Institute of Technology
Shimizu Corporation
Tokyo Japan

Yoshiaki Nagashima,Kenji Tsuji
Chief
Technical Research Institute
National House Industrial Co.Ltd.
Echigun Shiga Pref. Japan

Akira Hatanaka
Department of Mechanical and Electrical Engineering
Kume Sekkei Co.Ltd.
Tokyo Japan

ABSTRACT

The multi-chamber airflow measurement method is currently an interesting research theme from the theoretical standpoint of multivariable input/output and optimal systems. The author has deduced a theory for system parameter identification based on the thermal network model, and also developed a multi-chamber airflow measurement system as an application. The present paper describes the laboratory verification experiment and the error analysis of the field measurement conducted in an apartment house. This paper also investigates the effect of nonnegative constraints in the system identification, the length of the identification calculation period and the effect of dividing zones onto the precision. The result shows that the Root Mean Square provides a useful index for the error analysis also shows that the nonnegative least squares method is more precise.

KEY WORDS

thermal network model, interzonal airflow, least squares method, system identification, root mean square

INTRODUCTION

A method of multi-chamber airflow measurement is characterized by the advantage that not only airflow between space in a building and an outdoor atmosphere but also inter-chamber airflow can be determined. The present airflow measurement method deals with a single room. Although this method requires gas uniformity inside the building, actual buildings with multi-zonal space structures often disturb this assumption. This difficulty results in a higher error. Moreover, the present method is accompanied by the functional defect that the passage of airflow cannot be understood. For example, the airflow passage is such that air comes into the first story and leaves the building from the second story. Since the first author devised a theory for identifying system parameters in a thermal network (1984), developing a multi-chamber airflow measurement system is one application. Furthermore, experiments of verification(1990) and improvements of the theory and hardware(1992) were carried out. This paper describes the simple two chamber verification experiment in a laboratory and the field measurements investigating how errors are changed depending on system identification.

LABORATORY TEST

A two-chamber model is such that a square space of $12.96m^2$ is divided by a partition into two parts. The model is located in an artificial climate room in the technical research institute of the second authors' company. A cylindrical duct with a length of 600 mm and an inside diameter of 106 mm was used for mutual ventilation between chambers and between the inner space and the outdoor atmosphere. The duct is provided with a small-sized fan at the inlet. Airflow velocity in it was measured using a hot wire anemometer to determine an airflow rate. Equipment in which carbon dioxide gas was used as the tracer gas was developed for verification. Figure 1 illustrates the equipment. The equipment intermittently injects carbon dioxide gas to create changes in gas concentration and measure those changes and changes in the flow rate of the gas injection. Processing measured data using a system parameter identification computer program, SPID, for a thermal network enables estimation of airflow rates including an inter-chamber airflow rate in the two-chamber model. Estimated airflow rates were compared with airflow rates decided from measured airflow velocity.

RESULTS OF VERIFICATION

Figures 3 and 4 illustrate changes in measured gas concentration and the flow rate of the gas injection. In the laboratory test, gas was released into each chamber for five minutes in one cycle of 30 minutes. Values measured for 30 minutes were used for system identification. Table 1 covering data compares the estimated airflow rate with the measured airflow rate. The maximum difference of about 20 percent between both airflow rates is found. This difference has resulted from a reduction in errors through some trial tests and verification. Those errors originate in:

[1] nonuniformity of gas concentration in chambers;
[2] natural airflow through such invisible clearances as baseboards and spiral grooves;
[3] excessive airflow rate produced by the small-sized fan;
[4] shortcut circulation of airflow in the chamber;
[5] errors of the gas analyzer and the flowmeter; and
[6] errors of the data processing system.

A rather high error occurred despite the simple model consisting of the minimum number of chambers. In the future, the measuring equipment and the building model will be improved.

OVERVIEW OF MULTI-CHAMBER AIRFLOW MEASUREMENT SYSTEM

For field measurement, a hardware system was developed using a commercially available gas monitor, a multi-point gas doser, and a multi-point air sampler. Figure 2 illustrates the hardware system. In addition, a program to control the hardware system was developed by the authors themselves. The airflow measurement system enters tracer gas intermittently to each chamber to create sufficient changes in gas concentrations and measures the gas inflow rate and gas concentrations. The system parameter identification program,SPID, for a thermal network model processes measured data and estimates the multi-chamber airflow rates. This program can also estimate the effective mixing chamber volumes.

FIELD MEASUREMENT

Field measurement was carried out in an apartment located in the suburbs of Tokyo. The apartment consists of 11 stories. A 3LDK home on the fifth story having an area of 73.4 square meters was used for field measurement. The veranda in the living room faces southeast. Two identification models were introduced: one for comparatively fine zoning and the other for coarse zoning. In the fine model, a number of (1) stands for an room facing northeast, (2) for an room facing northwest, (3) for a living/dining room, (4) for a washroom, (5) for an entrance hall, (6) for a kitchen, (7) for a Japanese-style room, (8) for a bathroom, (9) for a toilet room, and (10) for an outdoor atmosphere. In the coarse model, a number of (1) stands for the room facing northeast, (2) for the room facing northwest, (3) for the living/dining room, the kitchen and the Japanese-style room, (4) for the washroom and the bathroom, (5) for the entrance hall and the toilet room, and (6) the outdoor atmosphere. Ten gas dosing tubes and ten air sampling tubes were installed according to the fine model. The state in which partitions, sliding doors, doors, and curtains are closed according to the fine model is called a finely partitive state. On the other hand, the state in which those partitions are opened according to the coarse model is referred to as a coarsely partitive state. Despite the coarsely partitive state, therefore, the fine model can be used for system identification. One or two gas mixing fans with a diameter of about 10 cm were installed in each room. One cycle of gas releasing and air sampling schedule was 100 minutes. In this cycle, gas was released for six to nine minutes for each zone according to the room volume. This gas releasing schedule was continued for several to 24 hours unless conditions of partitioning or ventilation were changed. The measurement system was run in the period from the evening on September 4, 1995 to the morning on September 8. The finely partitive state was set up in the periods from 16:38 on September 5 to 9:40 on September 6 and from 13:10 to 15:10 on September 7. In the time zones other than those periods, the coarsely partitive state was set up. In the period from 13:05 to 14:58 on September 5, the bathroom and the toilet room were mechanically ventilated with the ventilator in the kitchen turned off. In the period from 14:58 to 16:38 on September 5, the kitchen was mechanically ventilated in medium flow rate with the bathroom and the toilet room turned off. In the period from 10:20 on September 7 onward, the bathroom, the toilet room, and the kitchen were mechanically ventilated(medium flow rate). In the other periods, those rooms were subjected only to natural airflow. For about one hour from around 9:00 on each day except September 5, the windows were opened for air replacement.

ERROR ANALYSIS METHOD

The system identification theory also covers error analysis(1984). The error analysis concept sets out a rule of error propagation from equational residuals to identification parameters. But, this study was predicated on a simpler, intuitive method. The method is such that a computerized simulation model for gas flow is created by airflow rates identified by the system. The model is given measured changes in gas flow, and ambient gas concentration. The RMS (Root Mean Square) value of differences between calculated and measured changes in gas concentration in each room was adopted as judgment criteria.

ERROR INVESTIGATION

The degree of errors was examined because of possible effects of ULS (usual least squares) and NLS (nonnegative least squares) concerning airflow rates, and of differences resulting from the length of an identification period and from the fine and coarse system identification models. For the actual state accompanied by more error factors, it has turned out that fewer errors occur under application of NLS. See Table 2. Figure 5 compares above-mentioned two gas concentrations. This comparison shows that the calculated gas concentration changes based on the airflow model obtained from NLS do not deviate significantly from measured values in comparison with that from ULS. Moreover, if the airflow rates are constant, a longer identification period will provide fewer errors. However that the airflow rates are changing in actual situation, the optimum period must be determined. As shown in Table 2, a period of about two hours leads to the minimum error in this case. The optimum period becomes longer with an increase in the number of airflow rates to be identified, depending on the set problem. Figures 6 and 7 compare the nine-room model with the five-room model to determine effects of the zoning fineness of the models. This comparison tells that both the models provide nearly the same results in the airflow rate between the whole home and the outdoor atmosphere. If the space were not partitioned off actually, the identification model that sets no partition would provide higher accuracy. For reference, Figure 8 shows the result in mechanical ventilation condition.

SUMMARY

Concerning the verification experiment, further improvement for measurement devices and experimental installations are expected. A potential method for accuracy examining is to create a forecasting model based on the identified airflows and calculating changes in gas concentration under an actual driving condition. The model enables examination of the RMS (root mean square) of differences between forecast and measured values. As various errors occur actually, so the method of least squares under application of nonnegative constraints provides relatively better accuracy.

ACKNOWLEDGMENT

The field measurement was made possible by Dr. Y. Takebayashi and Dr. M. Suzuki of Shimizu Corporation. Special thanks to Mr. Y. Ohnishi for his artistic works.

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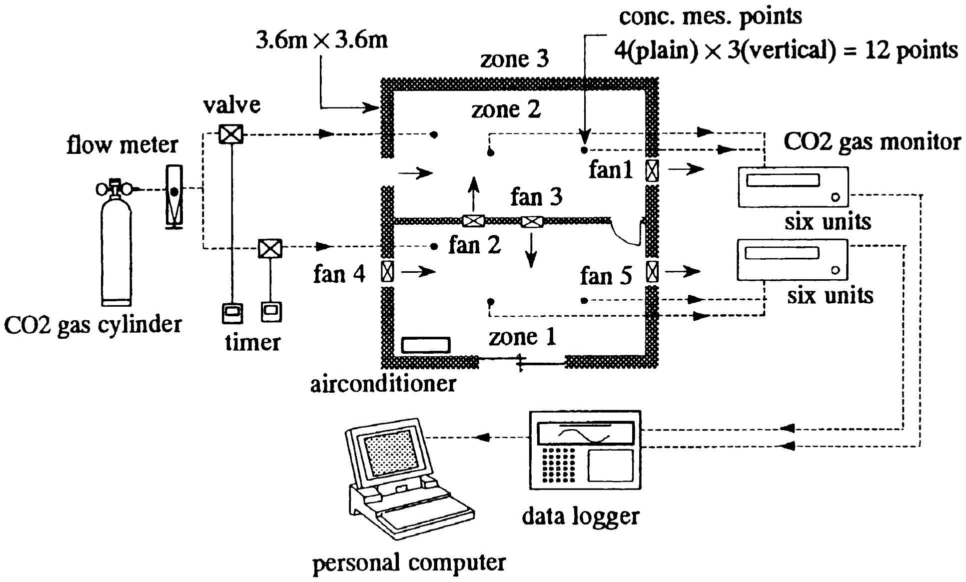

Figure 1 Laboratory verification experiment

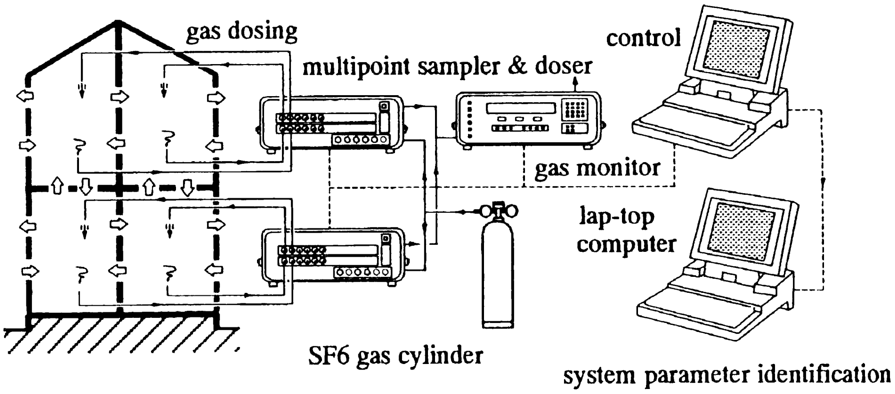

Figure 2 Multi-chamber airflow field measurement system

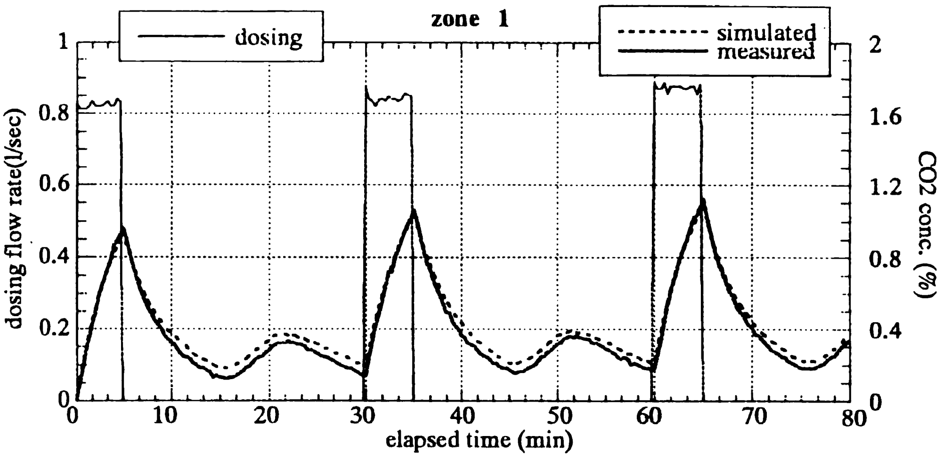

Figure 3 CO2 concentration and dosing flow rate in zone 1

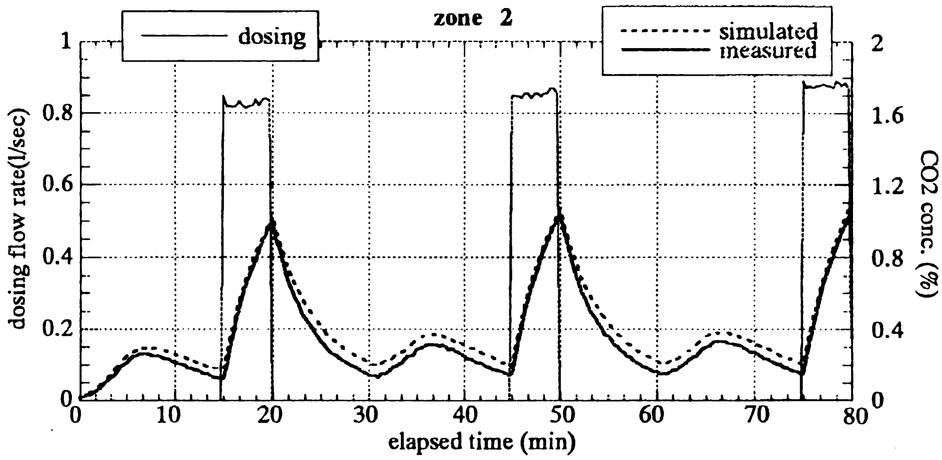

Figure 4 CO2 concentration and dosing flow rate in zone 2

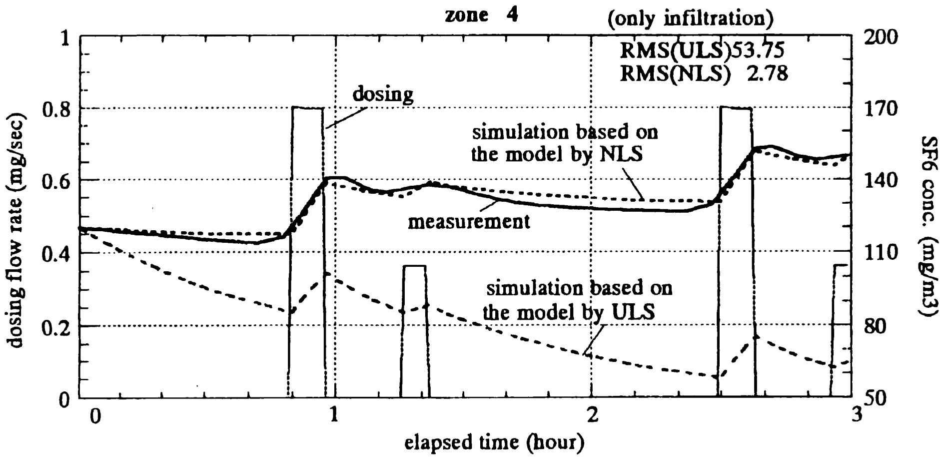

Figure 5 Measured and simulated SF6 gas concentration in zone 4

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AIR CHANGE RATE IN EACH ZONE (1/Hour), AIRFLOW(m3/Hour):
 1:   .475,    2:   .518,    3:  9.757,    4:  2.509,    5:  2.304,
 6: 30.253,    7:  4.271,    8:   .018,    9:  7.961,   10:   .031,
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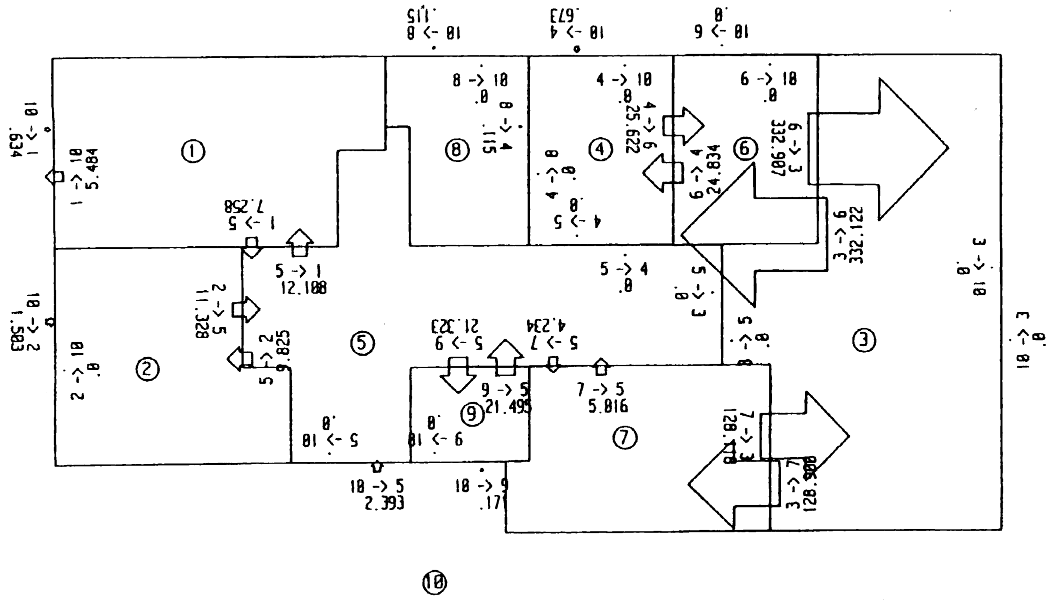

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MEASUREMENT DATA FILE NAME FOR THE IDENTIFICATION:SIZB0906.D01
STARTING TIME =1995- 9- 7, 0: 0 PERIOD OF TIME = 180(min)
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Figure 6 Airflow rates in fine model (fans off)

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AIR CHANGE RATE IN EACH ZONE (1/Hour), AIRFLOW(m3/Hour):
 1:   .520,    2:   .508,    3:   .184,    4:  1.226,    5:  1.401,
 6:   .032,
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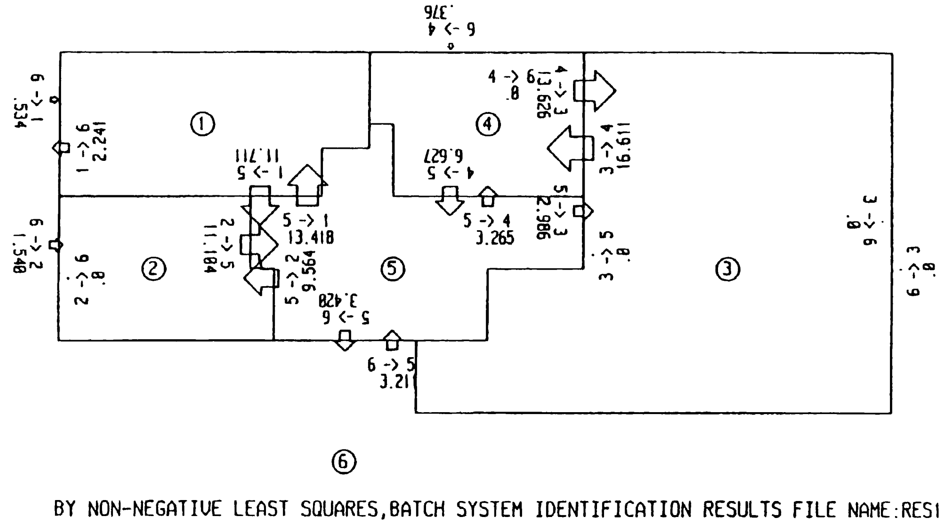

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Figure 7 Airflow rates in coarse model (fans off)

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AIR CHANGE RATE IN EACH ZONE (1/Hour), AIRFLOW(m3/Hour):
 1:  2.488,    2:  2.944,    3:  5.840,    4:  7.918,    5: 10.464,
 6: 32.672,    7:  5.338,    8:  1.022,    9:  0.000,   10:  1.627,
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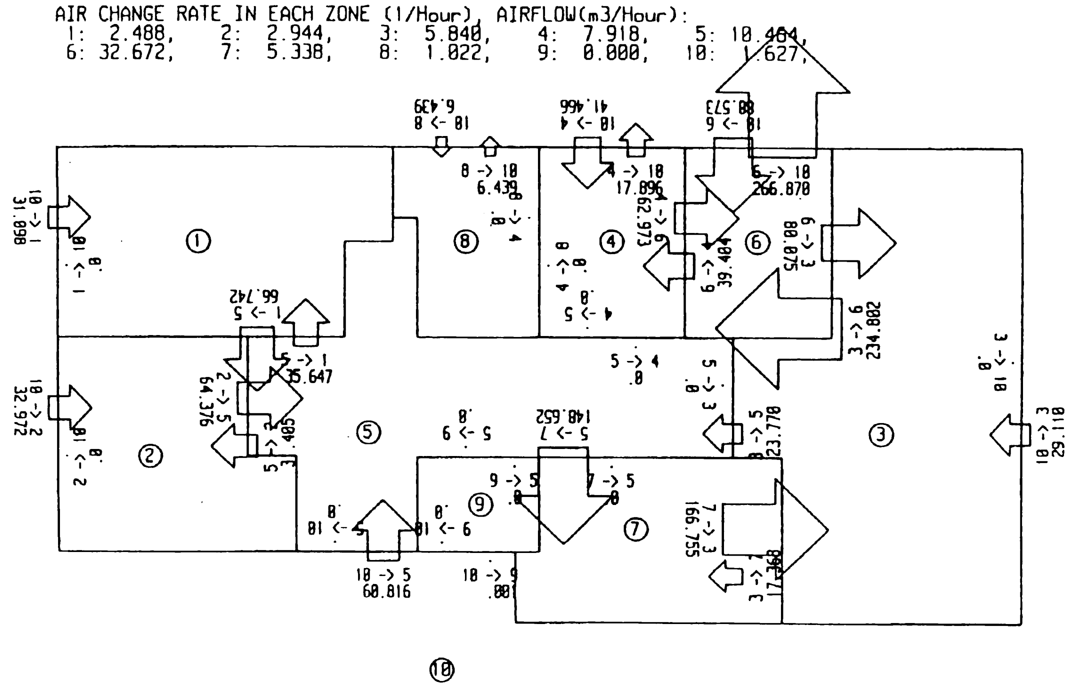

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Figure 8 Airflow rates in fine model (fans on)

Table 1 Verification results

Airflow (m3/hour)	measured	estimated	estimated / measured (%)
1 → 2	111	90	81
2 → 1	117	114	97
1 → 3	115	136	118
3 → 1	131	112	85
3 → 2	130	157	120
2 → 3	113	133	118

Table 2 RMS Error Analysis

period(min) / method	240	180	120	100
Usual Least Squares	43.01	38.95	29.98	21.70
Non-negative Least Squares	1.86	1.33	**1.11**	1.14