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THE STUDY OF INDOOR AIR ENVIRONMENT IN A PARTITIONED RESIDENTIAL BUILDING

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ABSTRACT

This paper describes the measured and calculated results of air humidity and profiles of tracer gas in a residential apartment in Taipei city, Taiwan. A complete multizone indoor air quality model was used to evaluate the test results. The concentration of CO_2 were employed to investigate the indoor pollutant transport. Also, the indoor air humidity was studied in order to evaluate the indoor moisture effects on human. The data from the measurements were used as simulation input data for the calculation of indoor air flow rates and pollutant concentrations. The results of comparisons between measurement and simulation values of indoor air humidities and CO_2 concentrations using the simulated model are reasonable.

INTRODUCTION

Single-zone modelling of indoor air quality can fairly account for most air quality evaluations in single-zone buildings [1]. However, such models cannot truly assess air quality in most buildings since they have distinct interior partitioning on their volumes. Therefore, it is very important to study the technology of control and simulation of multizonal indoor air quality. Basically, the multizonal air quality model is developed from multi-chamber theory of air infiltration [2], which used the multiply trace gas method to observe the air infiltration from each individual room and connect each individual space by one-way passage. It is assumed that all the airflow rates within a multizone space shall remain mass balance. Yashino et al. [3] studied the effect of thermal insulation, airtightness, and the space-heating patterns on multizone residential thermal environment and heat load by computer simulation. It was found that improvement of the thermal insulation level for the envelope is the most effective for a room temperature rise in rooms without heating and energy saving for space heating. In order to get a quick estimate of the nonisothermal behavior of a room with heating or ventilating systems, a short review of zonal model was presented [4]. From the existing comparisons with CFD codes or real-scale experiments in this paper, it shows that most of the time the zonal models are able to predict, with reasonable accuracy, airflow rates and heat transfers within a room. Due to the different characteristics of connections (e.g. window, door, and doorway), Walton [5] presented an airflow network model which simulated the interaction between zones of a multizone space by mathematical formulations. Coupled airflow and thermal analysis methods, the temperature distribution of each zone can be estimated precisely [6]. Using the same technology to integrate the airflow with the humidity model, the dynamic individual zones air humidity behavior were obtained [7].

In order to ensure the human health, ASHRAE standard 62-1989 recommend 15 cfm per person to control occupant odors and ensure that the concentration of carbon dioxide will not exceed 1000 ppm. Carbon dioxide exhaled by occupants must be diluted to achieve desirable comfort as well as to reduce odors and avoid serious health hazards. As the concentration load increases, the amount of outdoor air needed to dilute occupant-generated carbon dioxide increases. In recent year, the use of trace gas method or airflow network model to predict the indoor air quality based on concentration has been well investigated and is in the increase [8-12]. However, no a general total model which can examine the four important parameters at the same time is found so far and all the above models study only one or two indoor air quality parameters, such as airflow coupled thermal analysis, airflow coupled humidity model, or concentration analysis coupled airflow. For a complete indoor environment control aspect, all the necessary parameters which can effect the indoor climate shall be considered. Therefore, a multizonal total indoor air quality model which can simultaneously analyze the airflow, temperature, humidity, and concentration is required for investigating the problems of indoor environment.

SIMULATION MODEL DESCRIPTION

The airflow model is based upon the idea that there is a simple nonlinear relationship between the flow through an opening and the relative air pressure difference across it, and that a building can be considered to be composed of a large number of rooms which are connected by openings to each other and to the outside [13]. This is a network of rooms (nodes) and openings (connections) which is conceptually similar to the air handling system network where the connections are the ductwork and the nodes are the ductwork junctions [14]. An airflow network model studied in this paper consists basically of a set of nodes connected by airflow elements. The nodes may represent rooms, connection points in ductwork, or the ambient environment. Conservation of mass for the flows into and out of each node leads to a set of simultaneous nonlinear equations which are solved iteratively for the airflows of each node.

The multizone numerical model of airflow, temperature, humidity and contaminant concentration used in this study was developed as an analytial tool for evaluation the total indoor air quality of a build environment. The complete calculation model is divided into four parts. The first part is a thermal model to calculate the temperature distribution of internal rooms. The second part is an airflow model that calculates multizone airflow rates by Newton-Raphson method. The third one is a humidity model. The last part is a carbon dioxide concentration model. Chung [15] described the multizone model in detail and the model has been validated against measured data from full-scale tests conducted in an environmental control building. The room temperatures are first calculated by the thermal model using initial values of airflow rates, room characteristics, and weather data. The thermal balance equations for steady in a multizone building are given below.

$$[X]_{nxn}[T]_{nx1} = [B]_{nx1} \qquad (1)$$

where the X and B terms are ($AU+c_p dm$)/dt for different zones. Second, using the calculated room temperatures and weather data, the new multizone airflow rates and infiltrations are also calculated. After that the concentration and humidity distributions of each rooms can be calculated using known airflow rates, schedule of daily life, and weather data. The equations of the conservation of humidity and concentration in room k are expressed as followed differential equations.

Humidity balance equation:

$$[\frac{dH_i}{dt}] = [A]\ [H_i] + [M_g] - [M_r] \qquad (2)$$

where the H_i is the humidity ratio of zone i, the M_g is the moisture generated volume and M_r is the moisture removal volume.

Concentration balance equation:

$$[\frac{dC_i}{dt}] = [A]\ [C_i] + [P_g] - [P_r] \qquad (3)$$

where the C_i is the pollutant concentration ratio of zone i, the P_g is the pollutant generated volume and P_r is the pollutant removal volume.

MEASUREMENTS IN A RESIDENTIAL SPACE

The field measurement was carried in a residential apartment for 24 hours in a spring day. The measured plan is shown in Figure 1 and the detail dimensions are listed in Table 1. The Auto-Successive Method (ASM) is used for evaluating air quality through monitoring carbon monoxide, carbon dioxide and PM_{10} for a 24-hour period. For each test two points or three points are simultaneously picked for the measurements, one or two points in the indoors and one in the balcony, measuring height is chosen the breathing zone [16].

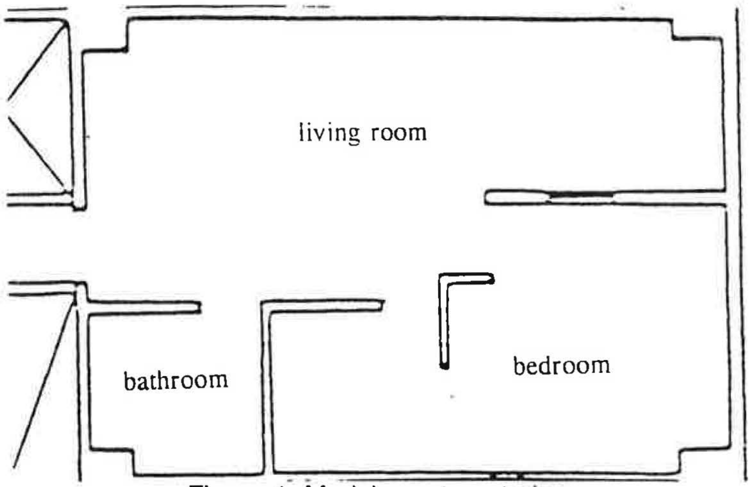

Figure 1. Model apartment plan

Table 1. Detail dimensions for measured apartment

	living room	bedroom	kitchen
measured area (m^2)	16	14.5	5.5
measured volume (m^3)	38.6	41.2	14.7
total measured opening area (m^2)	—	8.3	—
ventilation way	nature ventilation	nature ventilation	nature ventilation

RESULTS AND DISCUSSION

The results of measurement are presented in Figure 2. The outside CO_2 level is about 300 to 400 ppm. The CO_2 level of living room is about 400 to 500 ppm. The CO_2 level is about average after 8:00 PM because the occupants' activity. However, the CO_2 level is still within the normal range. The CO_2 level of bedroom is higher than that of living room. Most CO_2 levels are above 600 ppm and the maximum values is about 700 ppm.

The wind speed remain 0.05 m/sec in bedroom and 0.2 to 0.3 m/sec for outside. The higher wind speed was found at 6:00 AM and 9:00 AM; the value is 0.55 m/sec. The wind speed of living room is about 0.2 to 0.3 m/sec.

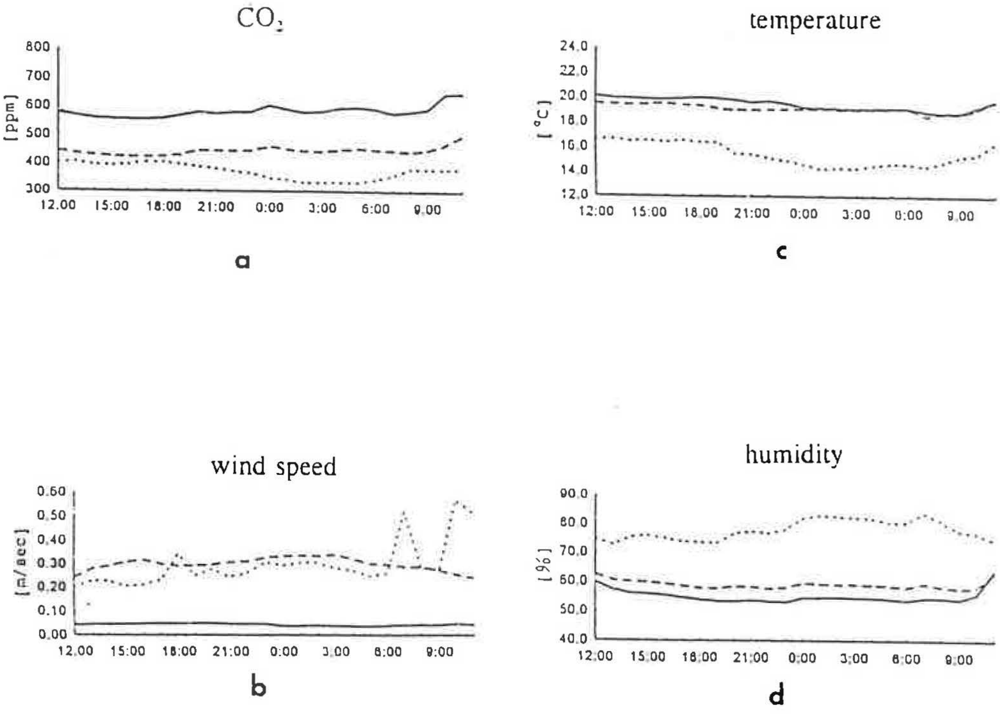

Figure 2. Measured results (a)CO_2 (b)wind speed (c)temperature and (d)humidity ratio

The temperature of living room and bedroom is about 20 C. No significant fluctuation is found. The outside temperatures keep between 15 to 17 C. The highest temperature was found near noon.

The humidity ratio of bedroom and living room is about 55 to 60 %. Due to the raining effects, the measured values were higher than usual. The outside humidity ration fell between 73 to 84 %.

In order to evaluate the prediction ability of the multizone model used in this paper, a comparison of measured and predicted data was undertaken. The humidity ratio and CO_2 concentration are adopted for comparison, as shown in Figure 3 and Figure 4. In Figure 3, the CO_2 concentration levels of bedroom are higher than living room because the windows of bedroom are closed for a long time. The deviation between computer simulation and measured data is 2.9 % approximately. The comparison of measured and predicted results for humidity ratio are reasonable. The deviation is 12.9 % approximately. The humidity ratio of living room is higher than that of bedroom. This is because the high moisture outside air (raining day) flowed into living room through door and window but the windows and door of bedroom are closed.

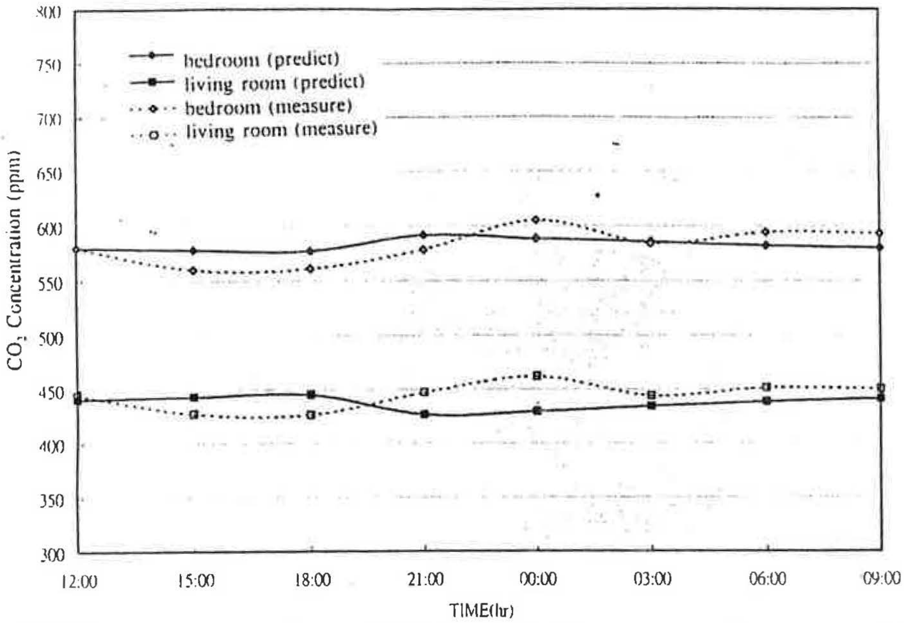

Figure 3. The comparison of CO_2 between measured results and predicted results.

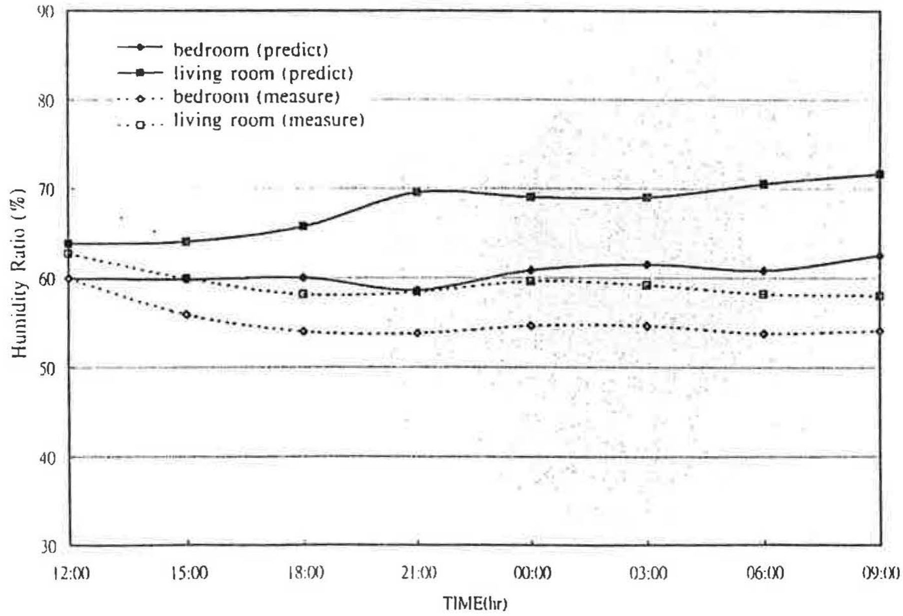

Figure 4. The comparison of humidity ratio between measured results and predicted results.

CONCLUSIONS

In this study, the air environment of a real residential building is investigated by both numerical analysis and model validation. The study parameters include air temperature, air velocity, relative humidity and CO_2 concentration.

The partitioned numerical model of airflow, temperature, humidity and contaminant concentration used in this study was developed as an analytical tool for evaluation the total indoor air quality of a build environment. The complete calculation model is divided into four parts. The first part is a thermal model to calculate the temperature distribution of internal rooms. The second part is an airflow model that calculates multizone airflow rates by Newton-Raphson method. The third one is a humidity model. The last part is a carbon dioxide concentration model.

An experimental program will conduct to validate the model accuracy. The preliminary results show that comparison the measured data with simulated data, the average deviations are 2.9 % for CO_2 and 12.9 % for relative humidity.

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