



# *An Air Zonal Model for Predicting Air Flow, Temperature Distribution and Humidity Distribution in Buildings*

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## **ABSTRACT**

The design of air-conditioning systems for energy saver buildings relies on fast and accurate methods able to predict the details of the indoor environment. In this paper, it is shown that the air zonal method is able to quickly assess the indoor environment quality. The zonal method is based on energy and mass balance equations in macroscopic volumes. Zonal models use a coarse grid and balance equations, state equations, hydrostatic pressure drop equations and power law equations. The aim of this paper is to study the simulation of temperature and humidity distributions through a large horizontal opening in a room with mixed ventilation by means of air zonal method and the results are compared to Computational Fluid Dynamics (CFD) calculations and experimental data. It has been shown that for the simple rectangular geometries, the air zonal method gives reasonably an accurate air temperature and humidity results in engineering applications even for the whole year.

## **KEYWORDS**

Air Zonal Model, Simulation, Temperature Distribution, Humidity, Horizontal Opening.

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## 1- INTRODUCTION

Prediction of an indoor environment is very important for the analysis of energy consumption and indoor air quality. It is well known that there exist temperature and moisture variations in different zones of a room. The temperature and moisture of the occupied zone, where the occupants stay, are usually different from that of the discharge zone of the conditioning air.

The basic idea of zoning is to divide the room air volume into several air zones, each zone is assumed to be perfectly mixed with the uniform temperature or pollutant concentration. The zonal method is based on heat and mass balance in macroscopic volumes.

The key purpose and aim of this paper is to develop an air zonal model which is less time consuming than other methods such as CFD and experiment and its algorithm is simpler than that of CFD. In addition, and most importantly, its results are quite acceptable for engineering purposes.

In this paper, the air flow distribution in the geometry of references [2, 3] has been predicted using the air zonal method. For this purpose, at first, this geometry has been divided into several macro elements (zones) and after that, balance equations have been applied in each zone. Finally, the temperature and humidity distributions of this work have been compared to the numerical results and experimental data of references [2, 3]. This comparison shows good agreement among these results.

## 2- AIR ZONAL METHOD

Zonal modeling introduces more dynamics into the prediction of mean flows compared to the nodal models. In this report, a "zonal" model is considered to use a Cartesian grid to subdivide the room air into control volumes in the horizontal direction as well as the vertical. In zonal modeling, equations are formulated that attempt to account for how flow rates might change based on temperature differences, length scales, and initial momentum. Each control volume in the grid, or cell, is used to formulate the balanced equations. Some of the cells are associated with a special driving mechanism because walls, jets or plumes directly affect them. These are termed special cells. Special cells have flow laws associated with them which are generally simple correlations chosen or generated by the model developers so that model predictions match experiments. Special cell laws can be drawn from the general engineering literature correlations and analytical fluid mechanics and recast in a suitable form.

For horizontal faces with vertical flow, the pressure term must account for the hydrostatic pressure difference and the mass flux term is calculated using [1]:

$$\dot{m}_{i,j} = \varepsilon_{i,j} \sqrt{2\rho_i} C_d A_{i,j} \left[ p_i - p_j - \frac{1}{2} (\rho_i g h_i + \rho_j g h_j) \right]^{0.5} \quad (1)$$

where  $p$  and  $A$  are pressure of each zone and cross sectional area between two adjacent zones, respectively.  $\dot{m}$  is mass flow rate between adjacent zones and  $\varepsilon$  is a parameter which is dependent to flow direction. In

addition,  $C_d$  and  $\rho$  are, respectively, discharge coefficient and density of air in each element that fluid goes from this element to its adjacent element. If the flow direction is from element  $i$  to element  $j$ ,  $\varepsilon_{i,j}$  is positive and  $\rho = \rho_i$ . Otherwise,  $\varepsilon_{i,j}$  is negative and  $\rho = \rho_j$ .

In addition to the mass and energy conservation equations, the equation of hydrostatic pressure and the relationship between speed and pressure, the law of ideal gas must be used to get the density in this model:

$$\rho_i = \frac{P_i}{RT_i} \quad (2)$$

where  $T$  is temperature of each zone and  $R$  is gas constant.

In this model, heat transfer and mass transfer are based on evaporation and condensation theories. Due to the fact that in some areas there are moisture absorption and excretion mechanisms, in addition to the mass conservation equation of air, the mass conservation equation of water must also be used:

$$\sum_{j=1}^n \dot{m}_w + \dot{m}_{w,source} = 0 \quad (3)$$

To simulate relative humidity of air using air zonal method, the following equations must also be used [4]:

$$\rho_{ma} = \rho_a + \rho_w \quad (4)$$

$$P_{ma} = (\rho_a R_a + \rho_w R_w) T_{ma} \quad (5)$$

## 3- CASE STUDY

Figure 1 shows the two-story test-hut built. This two-story building is consist of one room in each floor with the size of 3.62×2.44×2.43 m. A gate with the size of 1.19×0.19×0.22 m connected these two rooms and had an area of 12.3% of total area of the floor of the upper room. This gate provides air flow between the two rooms. In addition, there were other three gates. One of them was set in the upper floor with the size of 96.5×21.8 mm for entering air with flow rate equal to 6.93 gr/s into the building. The others were set in the lower floor for conducting air out of the building. The inlet air temperature was 17.9 °C.

As shown in figure 1, a baseboard heater was set in each room that in this paper, only the bottom heat source is used. In addition, the moisture source was complex to be modeled because water dripped into the steel pot above the hotplate and evaporated immediately when it hit the hot steel pot. The measured power consumption of the hotplate was 150 W, with approximately 65 W that corresponds to latent heat involved in the evaporation process of the dripping water. Thus, the sensible heat specified for the hotplate is 85 W. The top cylindrical plate of the hotplate is modeled as a heat source. The steel pot is modeled as a block with a small fan that represents the hole through which vapor left the pot. The fan generates a constant mass rate of water steam at 100 °C [2].

The walls were modeled having zero-thickness and the surface temperature of the walls in both rooms was assumed to be constant. So that, for the lower room, the surface temperatures of the floor, the ceiling, the north wall and the south wall were 19.6, 23.2, 22.2 and 20.2 °C respectively. For the upper room, the surface temperatures of the floor, the ceiling, the north wall and the south wall were 17.9, 17.8, 17 and 17.1 °C, respectively. Precise geometric and thermal characteristics of the building are available in references [2, 3].

#### 4- AIR ZONAL RESULTS

Figures 2 and 3 show the comparisons between the simulated moisture and temperature profiles and the corresponding measurement. The overall performance of the zonal model to predict the moisture and temperature along line A2 is good, which is essential to properly model the indoor air and moisture transport through the horizontal opening. Comparisons between the measured and computed air temperatures along line A2 show that the zonal model results and the trends of the predicted and measured temperature profiles are agree well with each other. Comparisons of the simulated and measured moisture and temperatures are made along the vertical height at seven locations. It can be seen that the zonal model provides very good predictions of moisture in values and trends for most of data points. In most of the measurement points, the differences between the computed and measured moisture are within the uncertainty measurement (0.9 g/kg).

#### 5- CONCLUSIONS

In this paper, it has been shown how a zonal model can be used to calculate air temperature and moisture distribution for single-and multi-room configurations, especially for engineering purposes.

Computational Fluid Dynamics (CFD) has been used as a powerful tool for predicting the detailed indoor environmental conditions. However, it is too time consuming and costly for studying the performances of building ventilation systems, especially for the whole year performance analysis. On the other hand, relatively simple models, namely zonal models, provide an alternative and inexpensive approach for engineering design.

Conventional zonal models can estimate airflows and heat and contaminant transports rapidly with low requirements regarding input data. This was especially appropriate when the computers were slow and expensive.

#### 6- REFERENCES

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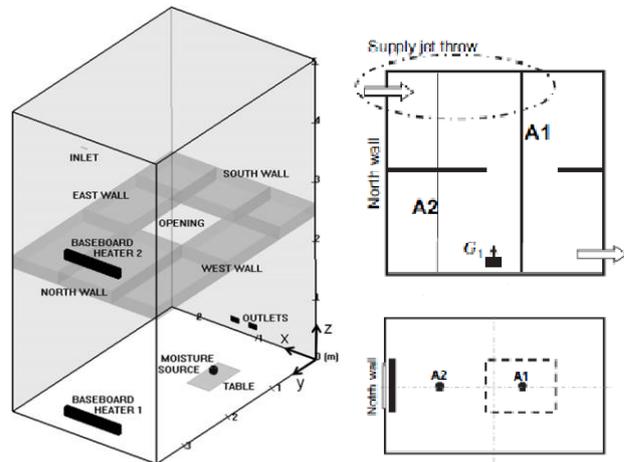


FIGURE 1: THE GEOMETRY OF THE BUILDING [2, 3].

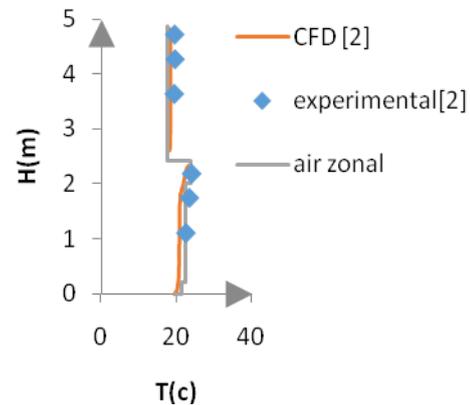


FIGURE 2: COMPARISON OF TEMPERATURE DISTRIBUTIONS ALONG LINE A2.

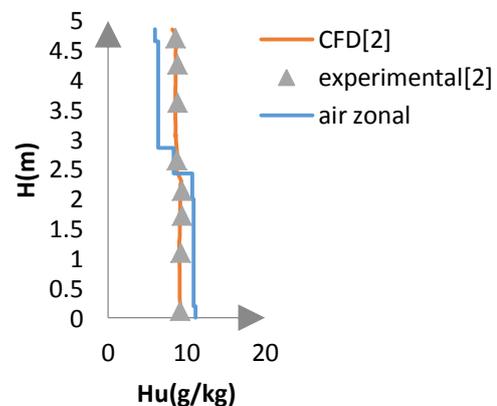


FIGURE 3: COMPARISON OF MOISTURE DISTRIBUTIONS ALONG LINE A2.