Influence of Shelves on Air Temperature and Velocity in a Supermarket

Chuanliang Song Doctoral Candidate

Xiumu Fang Professor

Yufei Tan Professor

School of Municipal and Environmental Eng. Harbin Institute of technology
Harbin P. R. China, 150090
Songcl1979@163.com

Abstract: In the sales area of a supermarket, the airflow pattern is different from the general marketplace due to its particularity in shelf layout and system zones. When something generates heat, the influence on velocity fields and temperature fields will be great. According to the analysis of measurement results of a supermarket in Harbin, factors such as relative position of supply and return air inlets, height of shelves and objects with heat generating capabilities influence the velocity fields and temperature fields. As a result of this analysis, we give some suggestions for design of air conditioning systems that consider the position of fixed supply and return air inlets, goods' shelf layout and the area system design with heat-generating objects.

Key words: sales area, air flow distribution, ADPI, nonuniformity coefficient

1. INTRODUCE

That airflow distribution in supermarket sales area is very complicated for its large space, various goods and heavy customer flowing. Conventional design focuses on the characters of department store and always ignores particularity of supermarket, and induce uncomfortable somewhere in the sales area. Now, supermarket comes to play more and more important roles in people's social lives. And that sales turnover depends to a great extent upon the indoor thermal comfort. Analysis of factors affecting the air flow distribution has special significant. Combined with the PHOENICS model has been validated, this paper will study the factors effects according to the experiment results[1]. The study will spread with the character of heat source and the outlay of goods shelves.

In the paper, the sales area in the second floor of a supermarket located in Harbin with the area of 590 m^2 and the height of 4.5m was analyzed. All-air central air conditioning systems were used in the supermarket, and grille diffuser with upper outlet on the opposite side was used for the terminal. There are four outlets, six air return grilles, and 150 air supplied inlets arranged on the ductworks which are at the height of 3.5m above the floors. The paper has separated the whole sales area for five districts by the air conditioning systems. In district 1, commodities such as CD, books, PC, TV and so on were showing. In district 2, commodities such as washers, humidifiers, cutters, stationary and dish wares were showing. Furniture, fitness apparatus, cases and toys were placed in district 3; costumes, shoes and cats were placed in district 4 and district 5. In the first district, there are two TV sets showing walls, which generate heat continuously. Survey points were set over floor 0.1m, 1.1m, 1.7m and 2.5m separately. In the sales area, the survey points were laid among the shelves, also where the customers move about. Velocity in air inlet was tested, too.

2. ANALYTIC METHOD

This research combines experiment and simulation, makes use of software -PHOENICS to analyze airflow distribution in the sales area. According to the second reference, hypothesis was made as follows[2].

1) Air-conditional body load were uniform distributed;

2) Air condition lighting load were uniform distributed.

3) Exterior-protected construction was frictionless lamina;

4) The surfaces of shelves were Thermal-Insulating Materials, and all goods and

shelves were taken as solid core.

5) Ductworks were taken as blocks with solid core.

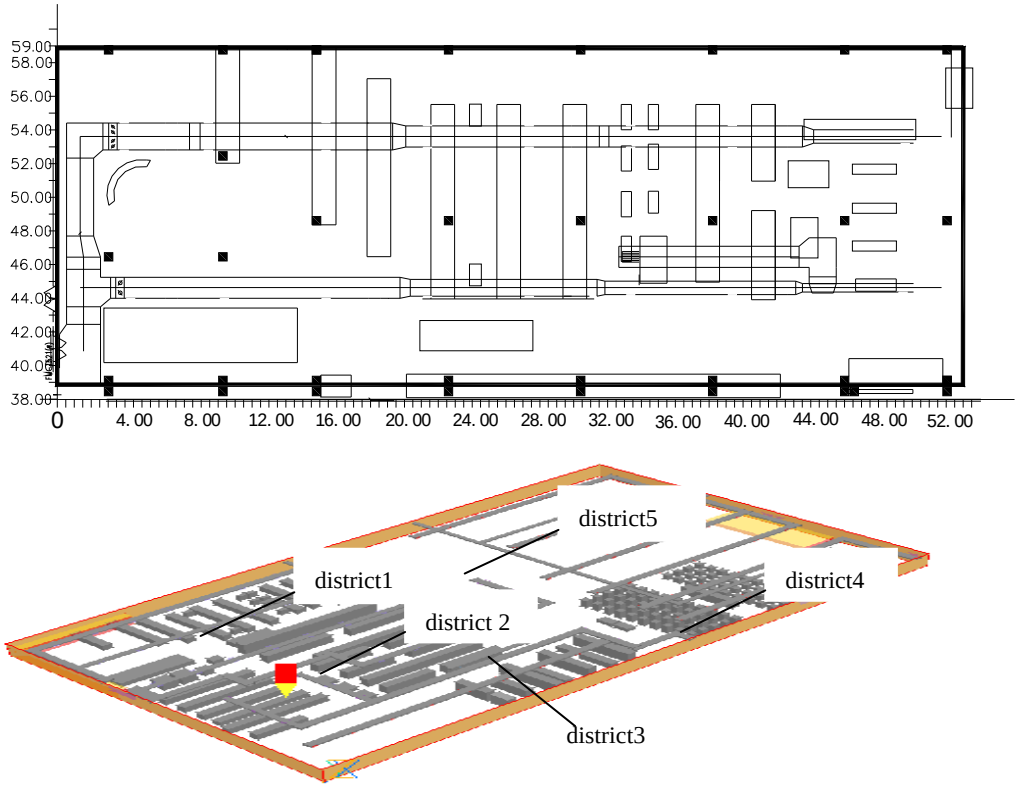


Fig.1 district 1and goods shelves distribution in sales area of the second floor

In the paper, owing to the large number of grids ,capacity and computational speed of the computer, auto-convergence methods weren't very well. At the beginning of calculations, default value of relaxation factors were used, and adjust the values step by step according to the reference [3], during the computation process. The parameters used were the testing data of inlets and outlets. Total Air Volume of the air-conditioning system was 39.103 m^3/s; recycle outlet volume was 29.228 m^3/s; fresh air volume was 9.875m^3/s and 26% of total air volume of the whole system. When the customer flows was 0.365 person/m^2 [3], the value 15.85m^3/h per person of fresh air volume was used. Cool load of TV sets shelves NO.1 was 6000W, NO.2 was 8500W.

3. SIMULATION RESULTS AND ANALYSIS

3.1Evaluation of the air flow distribution in the sales area

The goods shelves in the area researched range from the height of 1.4m to 2.5m, and they direct towards different directions what have affect the air flow distribution separately. From the analysis of various data between simulation and experiment concerned, the deviation of simulation was found to be acceptance and its results was creditable.

The paper will evaluate whether the temperature field and velocity field present met demands, then analyze how the goods and shelves were affecting the air flow distribution in the sales area, as follows

There are some key evaluating indicators such as ADPI (air diffusion performance index), K_T& K_v (temperature and velocity nonuniformity coefficient) and r_T (coefficient of utilization of energy) which should been used to analyze the air flow distribution in the sales area. It was shown in Tab.1 to Tab.3

The simulation results in Tab.1 accord with experiment, and the index in whole area was above 84.7%, satisfy the requirement of conventional design. ADPI at the 1.1m height was the highest, and decreased with height increase what attribute to the shelves blocked to air flow. How to layout the goods shelves should be considered.

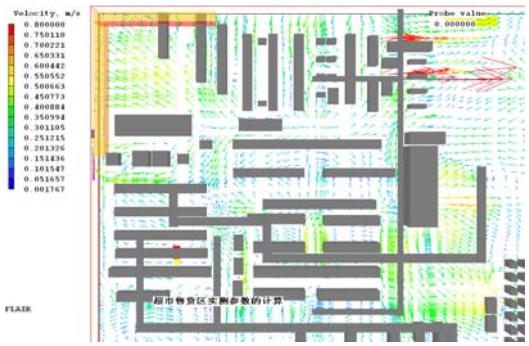


Fig.2 Air velocity distribution at 0.1m height

Fig.3 Air velocity distribution at 0.4m height

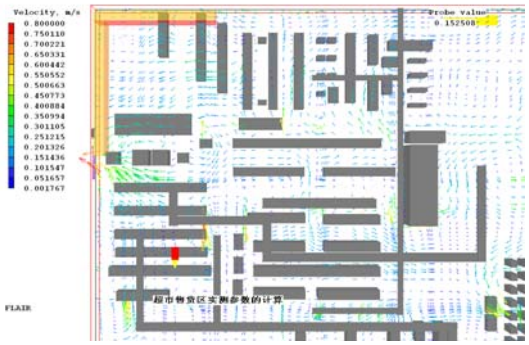


Fig.4 Air velocity distribution at 1.7m height

Fig.5 Air velocity distribution at 2.5m height

In Tab.2, the simulation results was a bit poor than the experiment for the absent consider of disturbing by custom flow and clearance of shelves which would made the air distribution evenly.

In another hands, temperature fields was more evenness than velocity fields, and velocity fields in the height of 1.7m and 1.1m was even and steady than other fields。All of the appearances above will be analyzed detailed in the next parts of the paper.

By calculation of experiment data, coefficient of utilization could be get, present as Tab.3.It was obviously that the positions or the air supplied parameters of inlets and outlets wasn't in reason, in district 1and 2. While the 3rd and 4th districts have a economical energy use, for there is no complicated shelves distribution and many heat source. So, those factors should been considerate in future design.

Tab.1 Air distribution index in four levels

height（m）	0.1	1.1	1.7	2.5	Whole area
ADPI（test）	0.834	0.881	0.856	0.849	0.847
ADPI（simulation）	0.853	0.88	0.874	0.865	0.860

Tab.2 Contrast between experiment and simulation in air distribution evenness

Sort	parameter	0.1m	1.1m	1.7m	2.5m	Whole area
Experiment	K_T	0.037	0.037	0.038	0.038	0.0376
Results	Kv	0.428	0.365	0.363	0.478	0.4113
Simulation	K_T	0.066	0.383	0.036	0.041	0.047
Results	Kv	0.869	0.498	0.546	0.539	0.631

Tab.3 Contrast between experiment and simulation in coefficient of utilization of energy

r_T	District 1	District 2	District 3	District 4
Experiment Results	0.85	0.87	1.01	0.99
Simulation Results	0.92	0.99	1	1.05

3.2 Effect of goods shelves and heat sources on air flow distribution.

The direction of shelves placed whether paralleled or crossed with air supplied direction should form different air distribution near by, showing as Fig.2 to Fig.7. The effect of goods shelves on air flow mainly consists of the two aspects: firstly, they block the air flow below the shelves; secondly, they make the velocity of air flow changed when the air flow through them with different gap. As far as the evenness is concerned, the way that shelves were placed paralleled with air supplied direction should be more favorable. In order to further contract and analyze the effect, two areas in the 3rd district were selected and studied, as follow fig.8.

An air-conditioning system was distributed in those areas, and there are shelves with different direction in the district, the data tested was selected and calculated. In fig.8, there are some shelves placed crossed with air supplied direction in area A, and 104 measuring points were extracted. There are some shelves placed paralleled with air supplied direction in area B, and 48 measuring points were extracted. The nonuniformity coefficient was presented as follow tab.4

Though there are errors unavoidable, combined with Fig.6 and 7, it was found that the direction of shelves placed had great effect on the evenness of air flow distribution.

Fig.4 Nonuniformity coefficient of area A and B

parameters	A	B	Contrast percentage
K_T	0.017082	0.009583	43.9%
Kv	0.434748	0.314526	27.66%

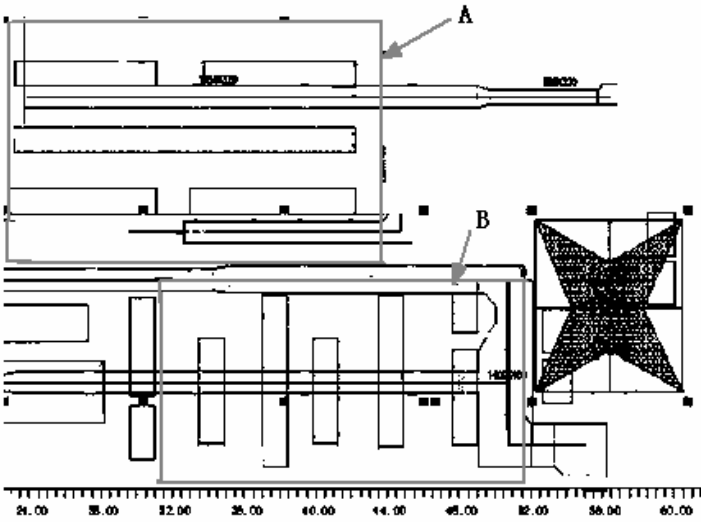


Fig.8 The areas studied of the effect of different direction on air flow distribution

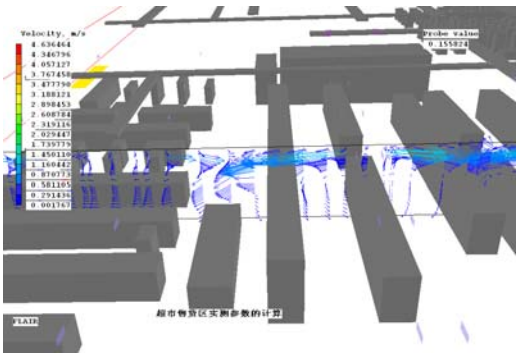


Fig.6 the effect of shelves with different direction on velocity field

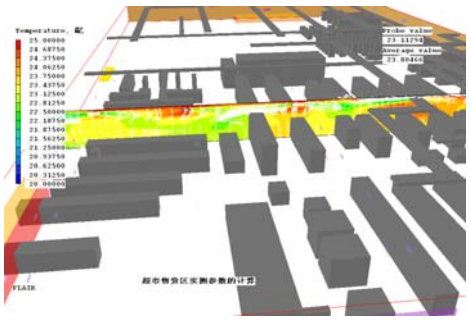


Fig.7 the effect of shelves with different on temperature field

The velocity field and temperature field situation near the TV sets shelves and below the ductworks were showing in follow fig.8 and fig.9. In the region air was heated by the TV set wall and float close to the wall then form eddy and get out by outlet. The air flow made upper space temperature of the area increased, while that of the bottom of the space was affect little, showing as follow figs. In work area (within the height of 2m from ground), air flow supplied jets and decays to the wall, then forms back flow, what make the temperature below ductworks will higher than nearby.

Combine with simulation, the analysis of air flow distribution in supermarket area showing that air supplied couldn't reach the region below ductworks. So, the facility dispersing heat and source of pollution shouldn't placed below the ducts work. Shelves should been placed fitting the direction of air flows; More inlets and outlets should been designed near the TV set shelves, for the heat and polluted air exchanging.

4. CONCLUSION

1) The direction of goods shelves placed has great effect on the temperature and velocity distribution. The way that the direction of goods shelves were placed crossed with air flow supplied will spoil the evenness of indoor air temperature and velocity. This paper suggests that the way of shelves placed should been adjust without affecting commercial profit.

2) The fresh air was difficult to reach the below of ductworks and take the excess heat and contaminants away, when the grille diffuser with upper outlet on the opposite side was used for the terminal. So this paper suggests that the source of heat or contaminants should be placed avoiding there.

3) In the regions near those goods generating heat, it is good for energy exchange, but the contaminants exhaust should be affected that air flow supplied will be hold back by the rising air absorbed heat

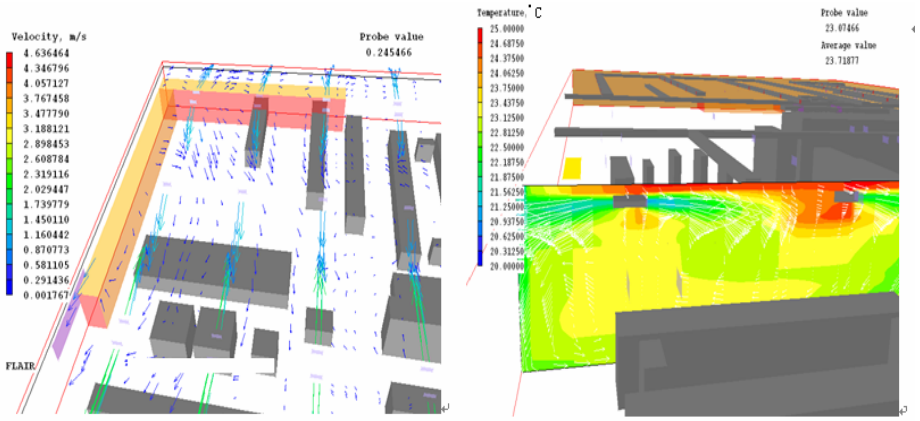
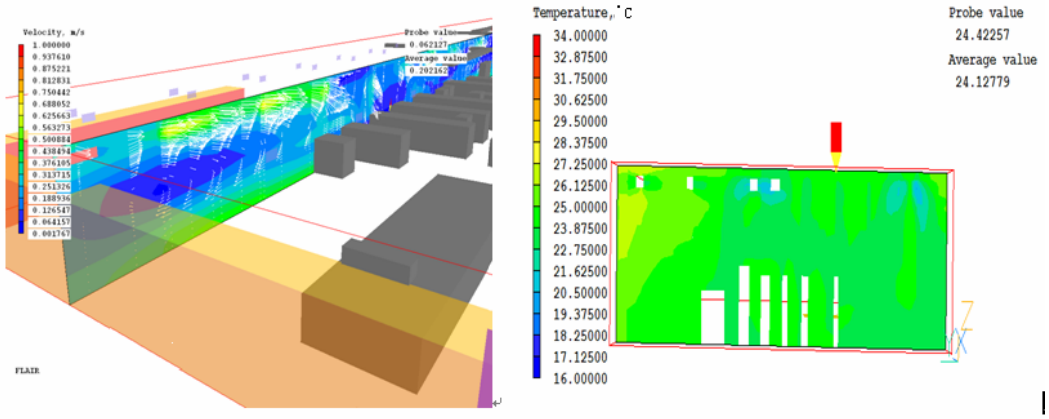


Fig.8 The air flow distribution and temperature field near heat source



Air flow distribution Temperature distribution

Fig.9 The air flow distribution and temperature field near heat source

REFERENCES:

[1] Chuanliang Song Simulation and analysis of air distribution in sales area of supermarket master's paper of HIT 2005

[2] Zhiqiang Zhang. Study on the indoor air thermal environment in the bitter cold region used PHOENICS master's paper of HIT 2002, P25~30

[3] Zhao Jianing, Lixia wu Investigation and analysis of consumer flow rate in a large supermarket, Hv & Ac 2004.Vol 34.No.6

[4]GBJ19—87 HVAC design specification. Peking CHINA PLANNING PRESS. 1989

[5] Lu Yajun. Ma Zuiliang. Zou Pinghua.. HVAC CHINA ARCHITECTRURE & BUILDING PRESS. 2002

[6] ASHRAE Standard 55-92.Thermal Environmental Comfort Conditions for Human Occupancy. ASHRAE. Inc

[7] Zhao Rongyi . Fan Cunyang etc. Air Conditioning.CHINA ARCHITECTRURE & BUILDING PRESS. 1998