Air Flow Distribution in the Sales Area of a Supermarket

Xiumu Fang Professor | Chuanliang Song Doctoral Candidate | Jianing Zhao Professor | Zhaojun Wang Associate professor

School of Municipal and Environmental Eng. Harbin Institute of technology

Harbin P. R. China, 150090

fxm490@163.com

Abstract: Many kinds of goods are displayed in a supermarket, which have their own particularities. The consumer flow rate is great and the type of shelved goods varies significantly, thereby influencing the objects that generate heat, and the demands of air temperature, air velocity and humidity in different zones. The results of a study of a sales area of a supermarket in Harbin are presented in this paper, including air temperature, air velocity and humidity. According to the assessment index of air flow distribution (EDT, ADPI, temperature efficiency, energy coefficient of utilization, coefficient of ununiformity and so on), the experimental data were analyzed. The rationality of airflow distribution was then evaluated. Suggestions for air conditioning system design are also presented in this paper.

Key words: EDT, Energy coefficient of utilization, coefficient of ununiformity

1 INTRODUCTION

Since the first supermarket has been established in She kou of Shenzhen city in 1984, supermarkets developed rapidly in China. Belonging to commercial buildings, supermarkets have their own characters which were different from conventional marketplace. The difference in construction and function had made the criterion of air supplied temperature and velocity been different individually. In this paper, the testing results of temperature, velocity and humidity in some supermarket sales area located in Harbin will be introduced, and provides reference for the air conditioning design of umbrella supermarket.

2 SUPERMARKET SUMMARY

The supermarket located in the downtown area of the city proper. The parts tested were the first and the second floors, total area was 24000 m^2. Its story height was 4.5m, with ductwork locating at 3.5m above floor. With full air central air-conditioning system, shutter lateral supply air distribution and upper exhaust. Air conditioner series were set by layer, eight in the first floor, and seven in the second. There were four types of shelves, 1.1m, 1.8m, 2.0m and 2.5m height. Guarding against theft, there is no windows in supermarket, except for two skylights. According to the system layout, the whole sales area in the second floor was separated for six districts and the fourth districts should been focused on, for the reasons that the situation of district five was similar to that of district four.

3 TEST METHODS AND THE TEST PARAMETERS

There are many key indexes affected the thermal comfort[1], economical efficiency and air distribution in sales area, such as air velocity, pollutant discharge potential, degree of temperature and velocity uniformity, the degree of energy utilization and so on. For the purpose of evaluating the air conditioning in the supermarket, in this testing, air supplied velocity, temperature and humidity in the sales area were tested and analyzed.

In the sales area, the survey points were laid among the shelves, also where the customers moved about. There were 1196 survey points[2] had been set totally, which were over floor 0.1m, 1.1m, 1.7m and 2.5m separately, and three parameters such as air

temperature, air velocity, and humidity were tested. Air quantity of inlet and outlet of air conditioner and temperature were tested in the equipment room, air flow velocity in ducts were tested in every air port. The test points were showing as Fig.2.

Air temperature, humidity, air velocity and temperature of inlets and outlets were tested with INDOOR CLIMATE ANALYZER. Air flow velocity of inlets and outlets , and the air flow velocity of air conditioner were tested with HEAT BALL ANEMOMETER, and the testing results were calibrated, according to the gross air quantity and result tested in air port.

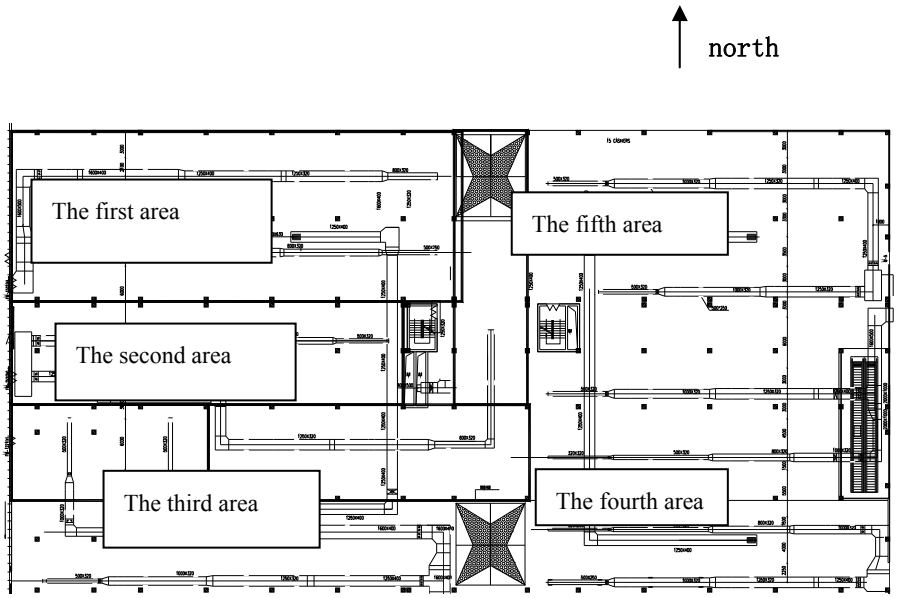


Fig.1 The system in sales area

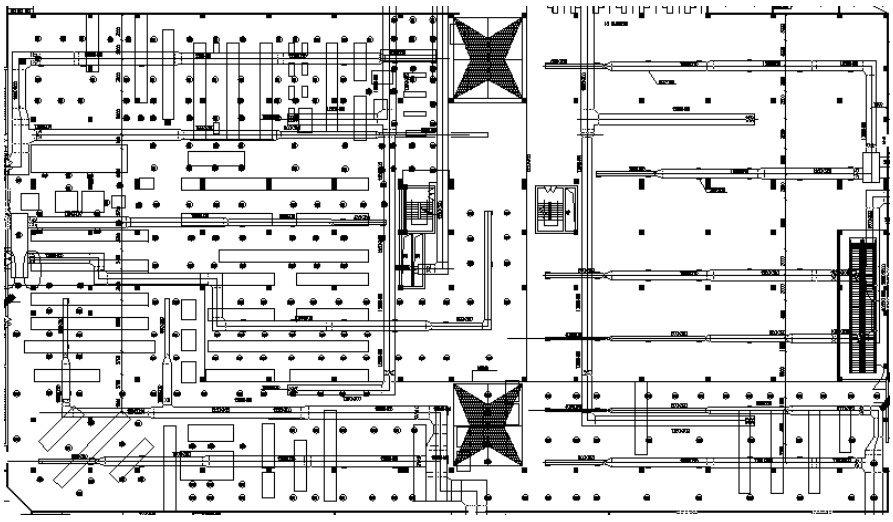


Fig.2 Goods shelves and testing points distribution

Test point goods shelves

Tab.1 Property list of indoor climate analyzer

detector	measured range	precision accuracy	response time
Air temperature	-20~50℃	5~40℃ ±0.2℃	catastrophe 50%：20s
Surface temperature	-20~100℃	5~40℃ ±0.5℃	50%：2s
Humidity	t_a - t_d<25℃	t_a-t_d<10℃ ±0.5℃	Normal：1min
Air flow velocity	0.05~1.0m/s	±5% ±0.05m/s	90%：0.2s

4. THE EVALUATION OF AIR DISTRIBUTION

In order to evaluate the index of thermal comfort, economical efficiency and air distribution of air condition system in sales area, EDT (Effective Draft Temperature), Energy coefficient of utilization, temperature and velocity coefficient of ununiformity，ADPI (Air Diffusion Performance Index) were introduced, except temperature grads and humidity relative.

4.1The Characteristic Index of Draft Sensation & Air Distribution

Peoples are always dissatisfied in air conditioning room by the draft sensation. Draft sensation is caused by the function of air temperature and velocity (Assume that the humidity and radiation temperature are constant.)[3], induce to uncomfortableness. By experimental data, ASHRAE has deducts EDT (Effective Draft Temperature), which has been the acceptance and rejection criteria of draft sensation. Defined as follow:

$$EDT = (t_x - t_m) - 7.8(v_x - 0.15) \qquad (1)$$

In the formula t_x，t_m— The temperature some place indoor and mean temperature, ℃；v_x— The velocity some place indoor, m/s.

For office[4,5], when EDT vary from -1.7～1℃，v_x＜0.35m/s, most people feel comfortable, below the low limited , chilled draft sensation will occur. EDT is used for judging whether the draft sensation will occur. For whole work area, the evaluate index is called ADPI (Air Diffusion Performance Index), which defined as: the percentage of the position satisfied in the area. For exist room, ADPI can be got by the temperature and velocities of those survey station. When designs the air flow pattern, CFD can be used for forecast, or consult the data offered by literature and handbooks related.

Velocity coefficient of ununiformity, K_V and temperature coefficient of ununiformity K_T have been introduced here, as the evaluate index of air flow pattern.

$$K_v = \frac{1}{v_{ave}} \sqrt{\frac{\sum_{i=1}^{n} (v_{ave} - v_i)^2}{n-1}} \qquad (3)$$

In which,

$$v_{ave} = \frac{\sum_{i=1}^{n} v_i}{n} \qquad (4)$$

n —Sum of sample points

v_i —Velocity of a point in work area

v_{ave} —Arithmetic mean of velocity

The evener the velocities are, the smaller temperature coefficient of ununiformity would be, otherwise will be bigger.

As follow:

$$K_T = \frac{1}{T_{ave}} \sqrt{\frac{\sum_{i=1}^{n} (T_{ave} - T_i)^2}{n-1}} \qquad (5)$$

in which,

$$T_{ave} = \frac{\sum_{i=1}^{n} T_i}{n} \qquad (6)$$

n —Sum of sample points

T_i —Temperature of a position in work area

T_{ave} —Arithmetic mean of temperature

The evener the temperatures are, the smaller temperature coefficient of ununiformity would be, otherwise will be bigger.

4.2 Energy Coefficient of Utilization

Energy coefficient of utilizationγ_T:

$$\gamma_T = \frac{(T_{out} - T_{in})}{(T_o - T_{in})} \quad (7)$$

In which

T_{in}, T_{out} —Air supplied temperature and air exhausted temperature, respectively.

T_o —The temperature designed in work area

γ_T >1.0 means that air exhaust temperature was higher than that of indoor air, that was economical efficiency; γ_T =1.0 means that air exhaust temperature was equal to that of indoor air, air supplied reached to the temperature indoor air after heat exchanging and absorbing part of afterheat; economical efficiency was poor whenγ_T <1.0.

5. DATA AND ANALYSIS OF THE EXPERIMENT

5.1 Temperature Grads & Effective Draft Temperature

In the second floor, the temperature grads were small, because the big space had made the heat air and cold air mixed evenly, as the follow Fig.3, It is obviously that the temperature in height of 1.7m is the maximum, and the air near floor mixed with fresh and cool air supplied by inlet was heated to rise up. The air would be cooled down until reach to the height in the range from 1.1m to 1.7m. Temperature of the place 2.5m above floor was nearly equal to the near floor; the minimum temperature was the level of floor. It may be the cause that there was little heat source and the hot air rising. As far as the local area temperature be concerned, the area where TV sets placed was the hottest area, and temperature range from 25.5 to 28 Centigrade. The same as the area at the entrance, range from 25.4 to 26.4, where there the sunlight from the skylight. The other areas such as books, tapes, cutter and fitness apparatus were cool a bit. Though the area showing clothes were installed many lamps, where was not so hot for the low temperature air supplied.

EDT in most part of the sales area was range from -1.7 to 1 centigrade, which fits the needed. Combined with the statistical result of data with survey points layouts, EDT situation should be studied according to the function area.

Air diffusion performance index in the whole area shows as Tab.3.

For whole area, ADPI is 84.7%, which satisfy the design requirement. The minimum value occurs at the 0.1m height, the maximum value occurs at the 1.1m height, and the value decrease with the rising of height. It may be caused by the shelves position. So，the position and direction should be considered thoroughly when put them in the sales area.

There were 340 test points in the first district, EDT of the test points mostly were in the ranges of -1.7 to 1 centigrade (Fig.4).

Tab.2 Mean temperature in four horizontal level.

Height of test point(m)	0.1	1.1	1.7	2.5
Mean temperature ℃	25.33	25.39	26.32	25.35
Overall average temperature（t_m）		25.60		

Tab.3 The ADPI value in four horizontal levels

Height（m）	0.1	1.1	1.7	2.5	Whole area
ADPI	0.834	0.881	0.856	0.849	0.847

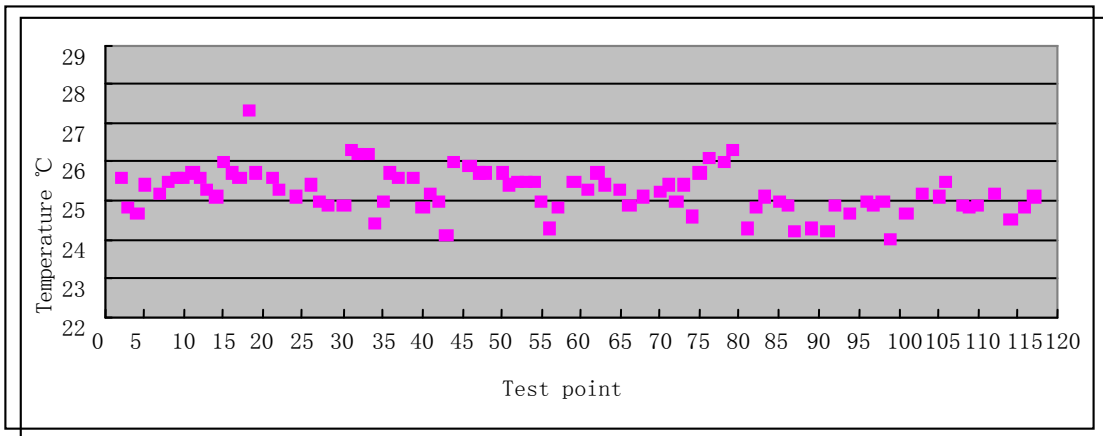
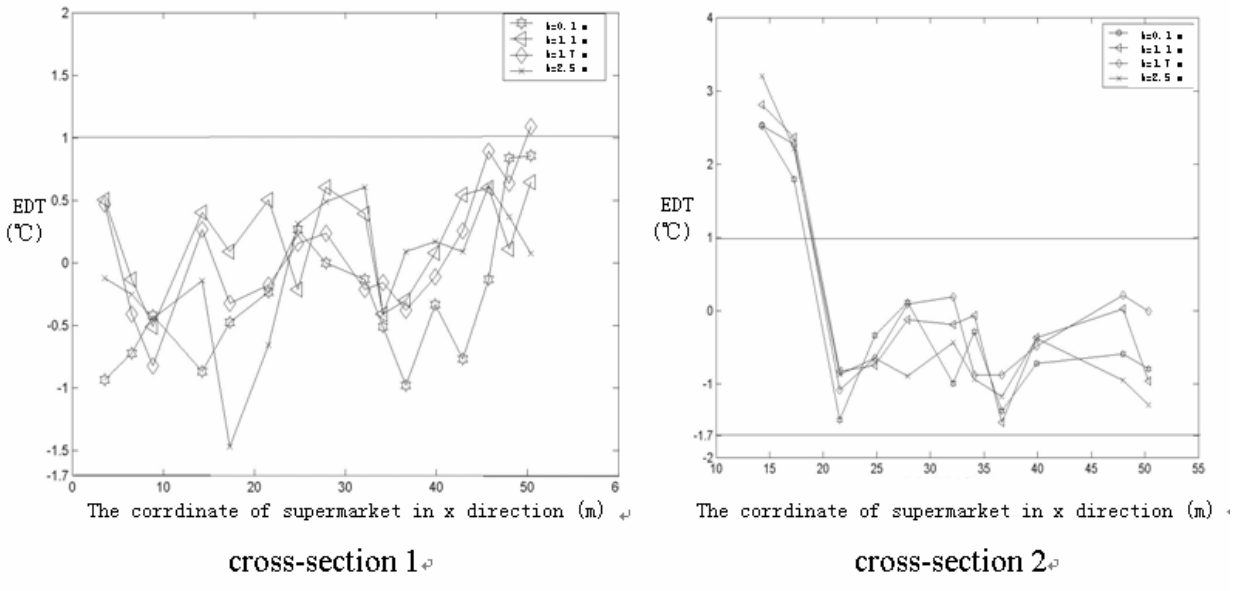
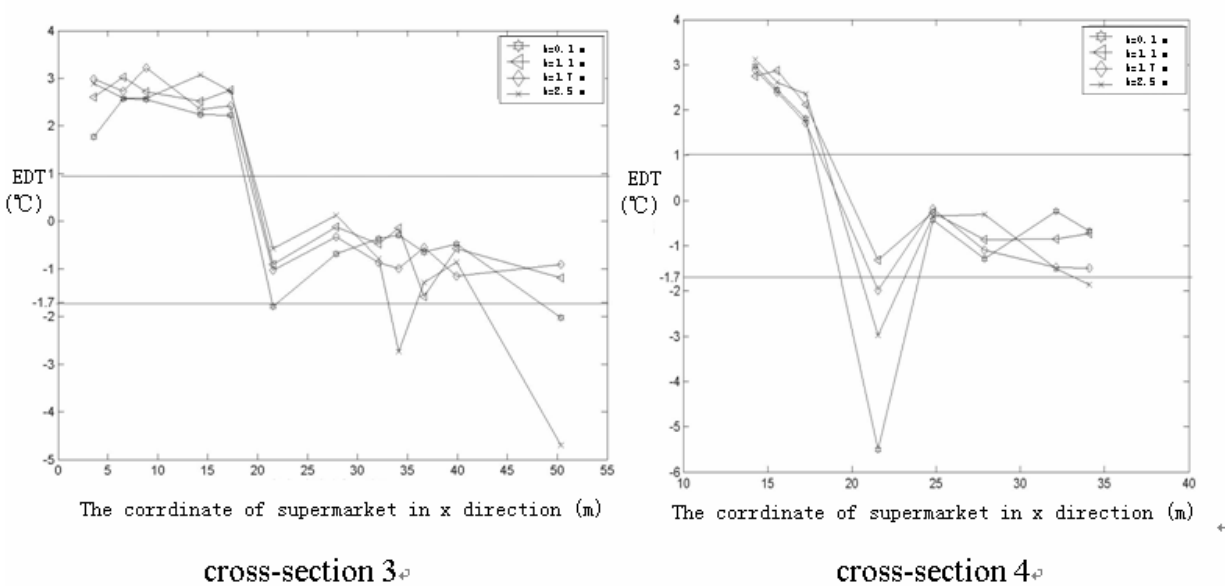


Fig.3 Temperature distribution at the heights of 1.7m

There were 47 points beyond the range, and 41 of them exist hot draft problems, 6 points of them exist cold draft problem. In the 41 points with hot draft problem, there were 8 points caused by the blockage of air supply inlet, and the others were distributed in the TV set showing area. Which indicates that the air supplied currently couldn't take the heat generated by TV sets away. The six points with cold draft problem were near the place where two inlets facing and blew each other, which leads to the air supplied flow too much.

There were 344 test points in the first district, EDT of the test points mostly were in the ranges of -1.7 to 1 centigrade (Fig.5).There were 3 points beyond the range(9% of total sum),that there no heat source and two series inlet facing supply air, and the points located between goods shelves(2.5m).





cross-section 3 cross-section 4

Fig.4 EDT distribution in district 1

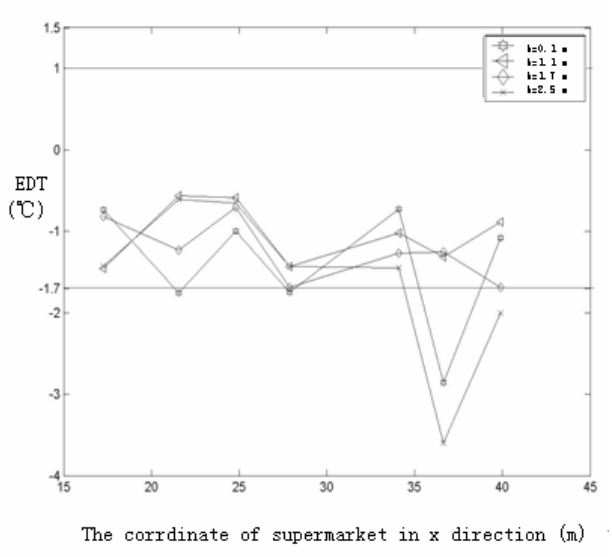


Fig. 5 EDT distribution in district 2

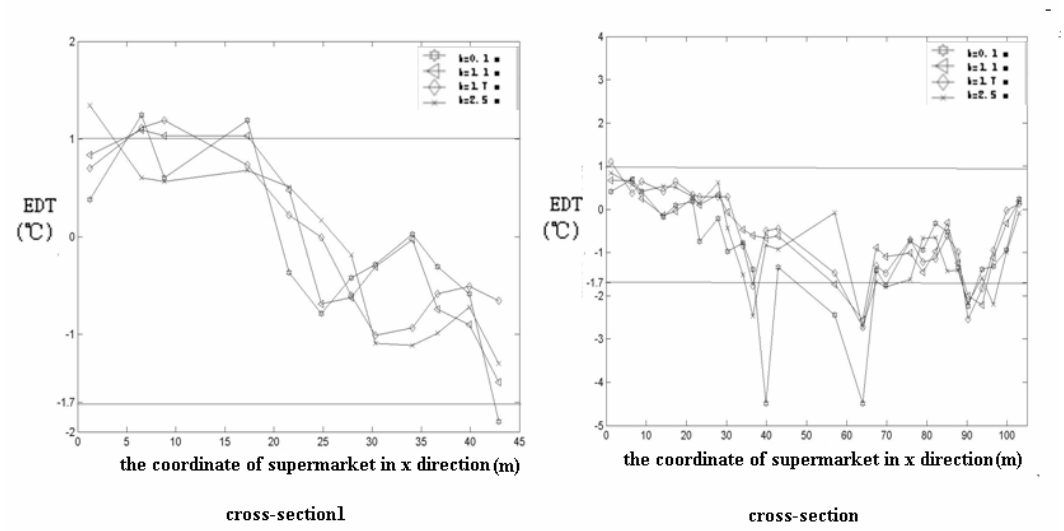


Fig. 6 EDT distribution in district 3

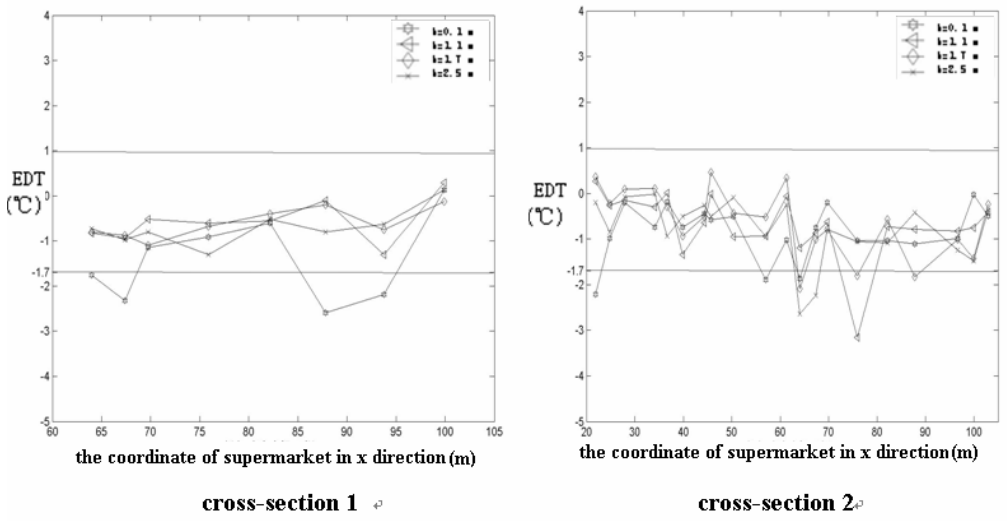


Fig. 7 EDT distribution in district 4

There were 384 test points in the first district, EDT of the test points mostly were in the ranges of -1.7 to 1 centigrade (Fig.6).There were 24 points beyond the range(6.3% of total sum),8 of them have the hot draft problems, for the drag components install there, air quantity wasn't enough. The other points with cold draft problem was located between goods shelves (2.5m) and two series inlets blow .

There were 128 test points in the first district, EDT of the test points mostly were in the ranges of -1.7 to 1 centigrade (Fig.7).There were 12 points beyond the range(9.4% of total sum),4 of them at the height of 0.1m. There were 8 of the 12 points have the cold draft problems for the backset maybe. The others were caused by high air velocity.

5.2 Temperature Coefficient of Uniformity and Velocity Coefficient of Uniformity

It can be seen that the temperature distribution was uniform; as well the velocity was not very uniform. It was greater than that of the height of 1.1m and 1.7m for 0.1m height's velocity coefficient of ununiformity, while the value was closed for the middle horizontal plane, and the value is highest at the height of 2.5m. The situations were attributed to the shelves layouts and customers' moving, as well as the function area.

The present paper has filter the data in the four horizontal levels, then calculate and analysis; obtain the coefficient of uniformity as follows tab.3

Tab.4 Temperature coefficient of ununiformity and Velocity coefficient of uniformity

Height of Test point (m)	0.1	1.1	1.7	2.5	Average of coefficient of ununiformity in the area
Velocity coefficient of ununiformity K_v	0.428	0.365	0.363	0.478	0.0376
Temperature coefficient of ununiformity K_T	0.037	0.037	0.038	0.038	0.4113

5.

3 Energy Coefficient of Utilization

Through disposal and calculation, the Energy coefficient of utilization was obtained. The first area was γ_T=0.92,the second was γ_T=0.99,the third was γ_T=1, the fourth was γ_T=1.05.

5.4 Humidity

The data shows the humidity was reducing gradually from the entrance to inside, range from 58% to 40%.

6. CONCLUDING

1)There were 1013 points of 1196 test points' EDT value which had met the demands, in the range of -1.7 to 1 centigrade. The percentage reaches to 84.7%. The others was beyond the range acceptable which account to 15.3%.

2) There were 49 points with hot draft problem which caused by deficiency air supplied. And there 33 points of them were in the district of TV set showing area, which problem caused by the heat generating of electrical household appliance.

3) There were 37 points with cold draft problem which caused by excessive air supplied or the effect on air flow by high goods shelves.

4) As far as velocity coefficient of ununiformity been concerned, the values at the low height was high, for customers ambulant; the values at the middle height were closed and the upper‘s value is the highest for the air supplied jet. As far as temperature been concerned, the values were evenly for the four heights in sales area which were caused by the customers moving. So, the way with full air central air-conditioning system, shutter lateral supply air distribution and upper exhaust was in reason.

5) It should be considered when supermarket was designed, that the effecting on air flow distribution of different height goods shelves, position, and the property of the goods should been considered and then to configurate system properly and confirm air quantity.

REFERENCES:

[1] Lichun Du. Feng Pei Numerical Simulation of the Airflow in Air Conditioning Room Refrigeration & Air-condition Vol.1.2004

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

[3] Zhihong Cai, Longjun Cai, Feng Zhejuan. Large Supermarket design of HVAC Refrigeration Technology 2002.3,p28-p30

[4]Yimin Du, Zezhi Liang, Similarities and differences in air conditioning design between large and medium supermarket and department stores. Building energy & environment, 2003.2,P45-P46

[5] ASHRAE Standard 55-92. Thermal EnvironmentalComfort Conditions for Human Occupancy. ASHRAE. Inc