

## Study on Emporium Airflow Optimization in View of Cooling Load Distribution Indoor

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### **Abstract**

*Large load and high energy consumption is the characteristics of air-conditioning in shopping malls. For most of these shopping malls which are in excessively high energy consumption were accompanied by unreasonable airflow forms. This work measured the lighting and body cooling load at three shopping malls, analyzed lighting and body cooling load on the different floors, different lighting area, then compared the measured value and the design manual recommended values, According to the results of analysis, recommended values is wrong. A personalized airflow forms is proposed according to the actual personnel distribution of the shopping mall; the plan of ceiling exhaust is proposed according lighting heat dissipation, the ventilation efficiency of air conditioning systems proved be significantly increased after the improvements of airflow form, it provide an effective reference to design air conditioning system for these types of shopping malls.*

### **1. Introduction**

In recent years, with the economic development and people's living standards improve, we are seeing an ever increasing number of large emporiums. Emporium, has the characteristics of large construction area, high passenger flow density and a variety of lighting and appliance. Thus, central air conditioning systems are mostly used to control the mall temperature and humidity. Meanwhile, large shopping malls generally run more than 12 hours a day, basically no holidays throughout the year. Therefore, compared with other types of public buildings, high power density unit area and large total annual energy consumption demonstrate that large shopping malls have enormous energy saving potential<sup>[1]</sup>. Research show that SOHO, shopping malls, hotels and other large public buildings have a total area of less than 5% of the total area of urban construction, but the annual energy consumption per unit area is as high as 100 ~ 300kWh / (m<sup>2</sup> • a), and the total power consumption accounts for more than 30% of the total energy consumption. Building energy consumption accounts for 12% ~14% of the civil building's total energy consumption, which is more than 10 times of residential building<sup>[2]</sup>

Studies have shown that, the air conditioning system's energy efficiency is generally not high enough in these emporiums<sup>[3]</sup>, because of the characteristics of indoor load distribution did not fully consider when designed the air conditioning system, supply and return air have been arranged unreasonable, thus the lower ventilation efficiency.

In this paper, air conditioning loading characteristics in the three large-scale comprehensive emporiums have been depth tested and researched. The density and distribution of lighting and body cooling load in emporium is been investigated, and proposed air distribution solutions for the above features, which can effectively improve the efficiency of air conditioning and ventilation in emporium, reduce air conditioning energy consumption.

## 2. The Object of Study Introduction

The surveyed emporiums are located in commercial focus area in the urban, which are comprehensive retail businesses, business area were 35,000 square meters, 42,000 square meters, 43,000 square meters, and sales in good condition. The specific introduction is shown in Fig1、 Fig2 and table 1.



Emporium A



Emporium B



Emporium C

**Fig 1. The Surveyed Emporiums**

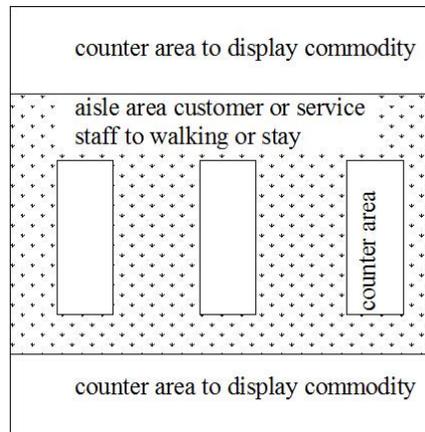
**Tab1. Introduction About Three Malls**

Serial number of mall	Building area (m <sup>2</sup> )	Total numbers of layer	Functional Description
A	35000	4	The 1 floor: cosmetic jeweler shoes The 2and 3 floor: women's dress The 4 floor: Menswear
B	42000	5	The 1 floor: cosmetic jew0ellery shoes The 2and 3 floor: women's dress The 4 floor: Menswear The 5 floor: general merchandise
C	43000	5	The 1 floor: cosmetic jeweler shoes The 2and 3 floor: women's dress The 4 floor: Menswear The 5 floor: Sportswear

The three shopping centers are all installed full air conditioning system; airflow organization is top-supply and top-return air by diffuser, which evenly arranged.

To facilitate the analysis and description for the distribution of lighting and body cooling load inside the mall, according to the characteristics of the internal arrangement inside the mall, business area will be divided into two parts, one is counter area, the main

function of it is to display commodity, which area accounted for about 60% - 70% of the business area; the other is aisle area, the main function is to provide customer or service staff to walking or stay, which area accounted for about 30% - 40% of the business area, as is shown in Fig2.



**Fig 2. The Interior Layout Schematic**

### 3. Test Methods and Content

#### 3.1 Test Method

This work aims to study on the space distribution of indoor cooling load in design conditions, instead of dynamic cooling load changes. On the basis of checking local meteorological data over the years, we selected a Saturday in air conditioning running typical season to test.

This will ensure the consistency of outdoor weather conditions and design conditions on the test day, but also ensure the measured shopping malls is in relative peak of passenger flow, that meets the most unfavorable conditions of air conditioning cooling load calculation. The test included the parameters of indoor temperature and humidity, personnel number and distribution of indoor, indoor lighting load and distribution. Among those, the measurement of personnel number and distribution is through visiting monitoring images from various parts of the shopping malls, the measurement of indoor lighting load and distribution are completed by looking at the mall lighting design drawings, and compare the various parts of the actual situation lighting arrangement. After the measurement is completed, day cooling load should be calculated hourly by load factor method, by taking the maximum value of the cooling load as the analysis target.

#### 3.2 Indoor and Outdoor Air Parameters in Shopping Malls

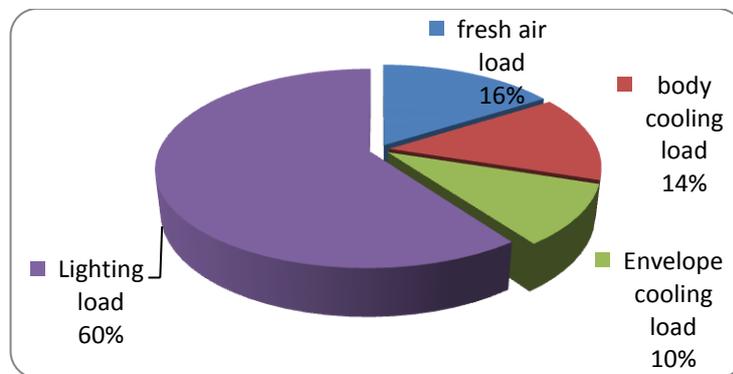
The basis conditions for determining the air conditioning load is indoor temperature and humidity parameters of buildings and outdoor weather conditions, the indoor and outdoor parameters obtained by measured is shown in Tab.2.

**Tab.2 Outdoor Air Parameters during the Survey Days**

Dry bulb temperature	Wet bulb temperature	Outdoor average wind speed
31.6°C	25.4°C	3.1m/s
Tab.2 Air conditioning design parameters during the survey day		
Dry bulb temperature	Relative humidity	Fresh air
27°C	60%	12m <sup>3</sup> /p.h

### 3.3 The Maximum of Moment Cooling Load Constitution during the Test day

Air conditioning load in shopping malls generally consists of room load and fresh air load. The room load can be divided into internal load including the body, lighting, equipment load and external load including each envelope cooling load. After testing, the constitution of daily average air conditioning load at the time for maximum value in the three shopping malls is shown in Fig.3. (Parameters required for the calculation load such as building envelope thermal parameters, numbers of personnel and lighting power are all obtained from measurement.)



**Fig.3 The Composition of the Air Conditioning Load in Shopping Mall**

As we know, a similar study proposed personnel load and fresh air load is the largest proportion in the total load <sup>[2]</sup>. But through the actual measurement, for the three emporiums, the total load, lighting load proportion accounted for 60%, second is personnel and the fresh air load for 30%, the remaining 10% belong to. envelope load.

In view of the fact that the cooling load, this paper will focus on the analysis of the characteristics of lighting and personnel load and the optimization of air distribution

## 4. The Characteristics of Interior Building Lighting and Body Cooling Load

### 4.1 Density and Distribution of Lighting Cooling Load

According to the characteristics of the lamp arrangement, lighting in mall can be divided into local lighting which located above the counter and overall lighting which evenly distributed across the top of the mall space. The three malls mainly rely on artificial lighting indoor, so lighting load has a high density, and the distribution showing extremely uneven features in horizontal and vertical.

(1) Because of the large presence of local lighting facilities in counter area, after summarized with the overall lighting, the lighting load density in the three mall is  $45.1\text{W}/\text{m}^2$ ,  $52.3\text{W}/\text{m}^2$ ,  $59.6\text{W}/\text{m}^2$ . But in the personnel area there is only overall lighting, whose load density is only  $14.1\text{W}/\text{m}^2$ ,  $15.4\text{W}/\text{m}^2$  and  $16.9\text{W}/\text{m}^2$ .

(2) Since most of the lighting is mounted in ceiling, a larger portion of the lighting heat would get into the closed chandeliers first, and then heat the ceiling before get into the interior space by convection. That is, the air temperature inside the mall ceiling is significantly higher than the air temperature inside the operating space. The air temperature inside the ceiling of the three mall is  $31.5^\circ\text{C}$ ,  $31.7^\circ\text{C}$ ,  $32.1^\circ\text{C}$ , which temperature is  $4^\circ\text{C}$  -  $5^\circ\text{C}$  higher than the work space.

## 4.2 Personnel Cooling Load Density and Distribution

Shopping mall, as a person-intensive place, the number of personnel is directly related to the amount of the indoor heat and the volume of fresh air, the personnel distribution of air-conditioned rooms will cause a significant impact on heat distribution that is body loading cannot be ignored. In the current technical measures, the recommended values of personnel density in shopping mall are shown in Table 3.

**Table 3 Recommended Values of Personnel Density<sup>[4]</sup>**

Room Name	Personnel index(m <sup>2</sup> /person)	area	Personnel density(person/m <sup>2</sup> )
General store business hall	3		0.33
Boutique shopping	4		0.25

After the test, we found a large difference between the measured data and the recommended values in manuals about the density of personnel load, and the distribution also reflects certain regularity. We can find that:

(1) Personnel density is much less than the recommended value. The measured data is peak values of passenger flow, for the three malls, the maximum data of personnel density in a whole day is only 0.12 person/m<sup>2</sup>, 0.13 person/m<sup>2</sup>, 0.15 person/m<sup>2</sup>, it not more than half the recommended value in manual. The main reason is most of the internal field area had been occupied by counter and commodity, the remainder area for passage way is lesser. Therefore, it looks crowded, however, the total number of people is not too much ; furthermore , more and more shopping malls appear, with the improvement of the shopping environment, personnel density of shopping mall is decrease.

(2) Personnel distribution varies with goods species in shopping mall. The survey results shown that jewelry, cosmetics and woman dress have high personnel density, the values of the three shopping malls were 0.21 person/m<sup>2</sup>, 0.25person/m<sup>2</sup>, 0.29 person/m<sup>2</sup>. However, the same values for men's fashion in the same three shopping are 0.10 person/m<sup>2</sup>, 0.11 person/m<sup>2</sup>, 0.13 person/m<sup>2</sup>.

(3)More customer concentrated in the aisle, where personnel density reached 0.50 person /m<sup>2</sup>, 0.55 person /m<sup>2</sup>, 0.59 person /m<sup>2</sup>.

## 5. Air Flow Optimization for Indoor Load Distribution Characteristics

The pros and cons of airflow distribution have significant impact on ensuring indoor air environment and reducing air conditioning energy consumption of the buildings. Airflow impact on indoor air environment, which can be represent as the ventilation efficiency of the system  $E_c$  , the steady-state expression is:

$$E_c = \frac{c_e - c_s}{c_i - c_s} \quad (1)$$

In formula 1:  $E_c$  the ventilation efficiency of the system

$c_i$  The average concentration of pollutants in the work area

$c_e$  Concentration of pollutants in exhausted air

$c_s$  Concentration of pollutants in supplied air.

Ventilation efficiency is an index, which represent the ability of ventilation system to exclude contaminants, the main factors that affect the index is both the location of the air inlet, outlet and the location of contamination sources and its dissemination characteristics.

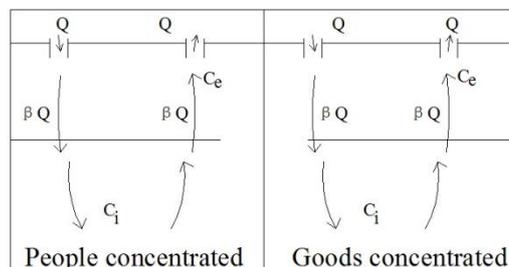
In the three shopping mall, air distribution forms is up-outlet and up-return air by diffuser, which evenly arranged, as shown in Figure 4. The Internal area no matter for the crowded aisle or for commodity display is the area burden by a pair of outlet and return air. The interior space is assumed to be divided into two parts, upper and lower. Supply air flux is expressed as  $Q$ , secondary circulation air flux is  $\beta Q$ , and  $\beta$  is mixing coefficient, which is the ratio of secondary circulation air flux and primary one.

Studies have shown that, for this evenly arranged up-outlet and up-return air pattern, the ventilation efficiency of the system in workspace is relatively low [5]. However, because of the limitation of condition, for the relatively efficient way airflow such as lower blow and lateral blow, it is difficult to apply in such a large space in the mall [6]. Then, on the premise of the same basic ways of up-outlet and up-return air, how to improve the efficiency of ventilation as much as possible? Obviously, whether it is evenly arranged or inside and outside arranged, the characteristics of the internal load in mall did not fully be considered, especially for the distribution of personnel and lighting cooling load.

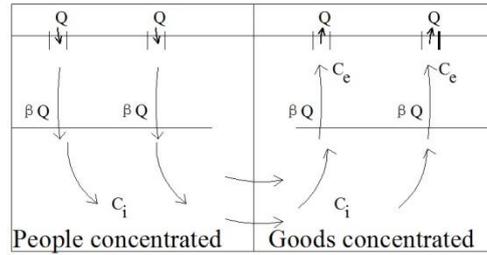
Based on the above analysis, the distribution of lighting and personnel load is not uniform in the mall space, but took on certain regularity with the internal arrangement of the mall. In the horizontal direction, person concentrated in the passageway, but in the counters area there are also more lighting; In the vertical direction, the heat from the lighting installed on ceiling make the air temperature inside the ceiling much higher than the temperature of the work area, that is to say, a large part of the lighting heat exist in the ceiling. After understanding these laws, we can analyze how to adjust the airflow programs to improve energy efficiency of air conditioning systems.

### 5.1 Adjustment of the Outlet and Return air Location

According to the characteristics of the lighting and personnel load distribution, uniform air supply (Fig 4) is changed for personalized supplying air. Increase the number of outlet for personnel relatively concentrated region, and increase the number of return air and exhaust ports for counters area more lighting but few persons, as shown in Fig 5. This would increase air volume for personnel concentrated region, also played a mobile guide of indoor air from personnel area to counters area.

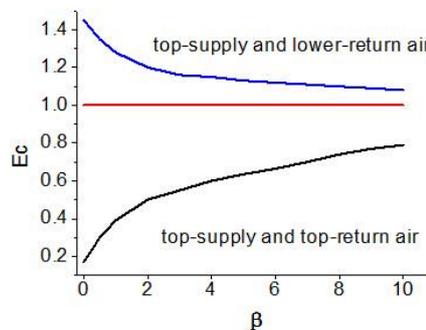


**Fig4. Indoor Air Distribution Diagram of Supply, Return Air Evenly Arranged**



**Fig5. Indoor Air Distribution Diagram of Improved Location of Supply, Return Air**

Because the air conditioning supply, return air were rearranged according to the layout inside the mall, supply air is the main way in the personnel region, to exhaust the air in the commodity region. There formed a transverse air flow between the personnel region and the commodity region, that is to say, after the supply air blowing through the personnel region then blowing transverse through the commodity region, last to leave the room through return air inlet above the commodity region. Thus, if the personnel region is analysis separately, where airflow is no longer a top-supply and top-return air, but become a top-supply and lower-return air, in [6] and [7], the two patterns had been theoretical analyzed, and their ventilation efficiency curves had given in Fig 5, under the same value of  $\beta$ , top-supply and top-return air's ventilation efficiency is much lower than top-supply and lower-return air. Such as, when  $\beta = 2$ , the two ventilation efficiency is 0.58 and 1.1. Evidently, the adjusted system ventilation efficiency greatly improved.



**Fig6. Indoor Air Distribution Diagram of Improved Return Air Arrangement**

### 5.2 Exclude High-temperature Air Inside the Ceiling

Based on the measured, The air temperature inside the ceiling of three shopping malls is 4 °C -5 °C higher than the average temperature of the work area, it indicates that much of lighting heat still exist inside the ceiling. If exclude the heat inside the ceiling, and keep it away from work area, it has obvious significance on reducing the energy consumption of the air conditioning system. According to this feature, the shopping mall whose indoor thermal environment satisfaction is worst in three malls has been reformed. Specific programs to set up a number of air vents in the ceiling, the high-temperature gas is directly removed to the outdoors through the air conditioning exhaust system, to ensure that the air inside the ceiling is not in too high negative pressure, ventilation holes are made in the ceiling around the lighting, so that the indoor's air can flow into the ceiling under the differential pressure. That exhaust from the ceiling instead of the original exhaust approach from business space. Without changing the ratio of original mall fresh air and exhaust, either the lighting load or the air conditioning energy consumption are all reduced. By measurement after reform, without changing the output of refrigerator, the

temperature of ceiling and open space decreased by 3.5 °C and 1.2 °C, achieved a significant effect in energy savings.

## 6. Conclusions

(1) There is a big difference between the value of many shopping mall actual cooling load constitute and recommended value in design manuals, interior lighting, body cooling load are not evenly distributed in shopping mall, but reflects a certain regularity with the internal arrangement of the mall.

(2) After fully considered lighting, personnel distribution characteristics, personalized arrangement of delivery, return air can improve the ventilation efficiency and reduce air conditioning energy consumption

(3) To drain away the lighting heat inside the ceiling by using exhaust air in shopping mall, can effectively reduce the cooling load.

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