Spatial Distribution Characteristics of Internal Load and Analysis of Impact on Designing Air-conditioning Load in Office Building

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ABSTRACT

By the daily experience and professional research, we found that the value of internal load is random. Thus, a difficulty arises when designing air-conditioning system, calculating the building load and sizing the equipment. After a survey in an office building, we found the characteristics of internal load distribution can be defined by a distribution function. Since cooling load is not sure in the designing phase, over sizing air-conditioning equipment has been a common practice in order to ensure occupants comfort. In the investigation, it has been analyzed the detailed characteristics of internal load and this paper will propose a new design method based on the distribution characteristics observed.

KEYWORDS

Air-conditioning, Internal load, Distribution characteristics, Building load, Design method

1 INTRODUCTION

In recent years, with China's economic growth, improvement of living standards and consequently a higher demand for energy services have led to an increasing focus on internal comfort and air-conditioning system which is the major equipment in buildings. So air-conditioning system has taken a significant role in commercial building across China, and is representing a growing share in the energy consumption of those buildings.

In order to response China's policy on energy-saving and emission abatement, it seems that appropriate measures have to be taken as soon as possible on the planning, design, construction and operation phases of buildings. Each phases of the building life cycle has its own characteristics and its own energy-saving potential, the methods aiming at characteristics of each phases are obviously different.

In the early design stage of commercial buildings (offices, shopping malls, etc.), the regional function (such as offices, meeting rooms, pantries, shops, public areas) is not decided and even if it is decided but it may not follow the plan when used. It is uncertain for the air-conditioning design because of project changing quickly and uncertainty of occupant load, lighting power load, equipment power load. So in order to insure the capacity of air-conditioning is enough, it leads to calculation of building load with higher internal load than most actual status and then the capacity is oversized. This design method can ensure the equipment capacity is sufficient but often result in high initial cost and operation problem.

In the research of building load characteristics, most of the research focused on the impact of building envelope and Climate change on building load [1, 2, 3]. Thus, researchers assumed the internal load including occupant load and electrical load remaining unchanged. However, by the investigation in office building, it found that both internal occupant density and measured electrical load density have significant difference. Therefore, not only the external disturbance changes quickly but also the internal load have random characteristics on time and space. In the indoor research, it often focused on the randomness of the indoor temperature, humidity and air quality, and the optimized air-conditioning system control mode on the randomness [4]. As a contrast, it rarely studied on the office building internal load and its characteristics even the impact on air-conditioning designing. The researches concentrated on energy consumption just about the energy-saving and energy consumption one year total [5, 6]. They didn't care the peak load, internal heat gain and the randomness.

In allusion to the lack of research on office building internal load characteristics, this article investigated the distribution characteristics (mean value, dispersion degree). These characteristics have different effects on chiller and end-equipment loads and capacities. This article proposed a new and reasonable methodology to calculate load and size.

In order to ensure the values of the actual office building internal load and its distribution characteristics, requires a lot of real research data to support and presents a reasonable method to design air-conditioning system.

2 METHOD

In order to acquire reliable and sound internal load data, a research was carried out in an office building group in Hong Kong and occupant load, electrical equipment (including lighting) load was measured. The kind of function zone in office buildings is various, such as offices, meeting rooms, corridors, toilets, computer rooms and so on, the function zone except toilet isn't decided in the early stage of construction but decided afterwards by users. However, it's certain that office room plays a major role in office building and if the office load characteristics are clear, and then the effect of other rooms can be ignored for the whole building. The computer room which has the largest load has often a dedicated air-conditioning system, it is not accounted for the central air-conditioning system.

We were not allowed to count people working in the office. Instead, the investigation was based on office ichnographies and we counted working positions and area (rental area, including meeting room, Pantry). The methodology based on ichnographies has been assumed as a good description of the reality and no deviation in the real results has to be accounted. Electrical equipment load density comes from electrical power measurement and rental area.

The research result shows that the internal load presents distribution characteristic and can be fitted to a normal distribution function. The whole building load is the sum of every floor, and distribution characteristic of whole building concentrates in a smaller range (e.g. smaller variance). The different distribution characteristic of whole building and single floor means that different methodologies to size chillers and end-equipments are needed.

3 CASE ANALYSIS

Through the research of office internal load, we got 46 samples and arranged in accordance with internal load as follow:

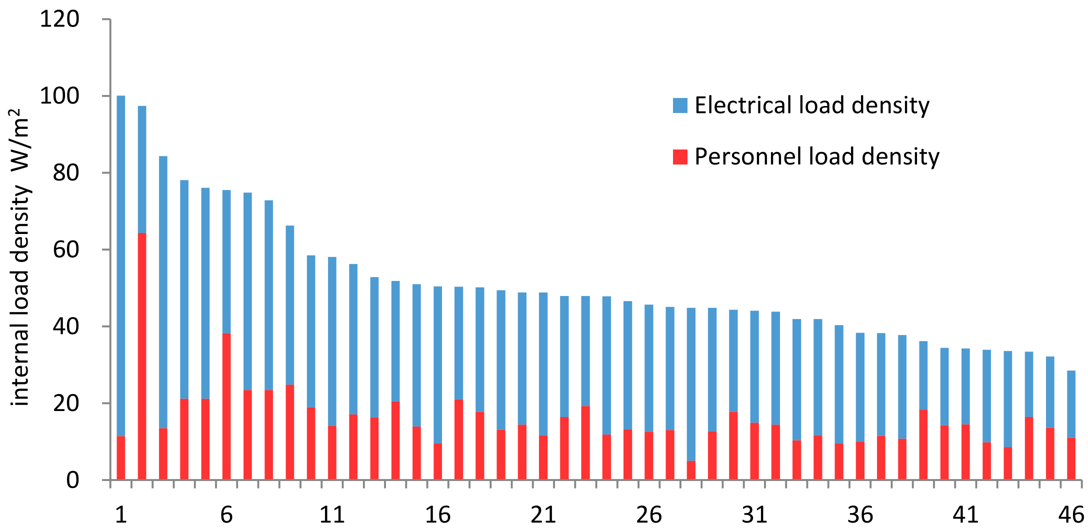

Figure 1 *Investigated Office Internal Load Distribution*

Mean value internal load is 51W/m^2, maximum is 100 W/m^2, minimum is 29 W/m^2. It's obvious that the maximum largely deviates from the mean value. In order to be statistically meaningful, data has been processed and the extreme figures rejected. This has been done as follows:

$$\text{upper limit} = Q_1 - 1.5(Q_3 - Q_1)$$
$$\text{lower limit} = Q_3 + 1.5(Q_3 - Q_1)$$

Q_1 is a 25% point of the quartile, Q_3 is 75% point of quartile.

Calculation result is as follow:

Table 1 *Results of internal load research*

Meaning	Mark	Occupant load density	Electrical equipment load density	Internal load density
		W/m^2	W/m^2	W/m^2
Minimum	Q_0	5.0	17.0	28.5
Quartile 0.25	Q_1	11.7	28.4	40.7
Quartile 0.50	Q_2	14.2	32.2	47.9
Quartile 0.75	Q_3	18.2	38.7	55.4
Maximum	Q_4	64.4	88.7	100.1
Lower limit		1.88	12.88	18.65
Upper limit		27.96	54.21	77.44

After eliminating the data beyond threshold value, the three types of samples remaining data amount is 44, 42 and 42. As the amount decreases little, it fits for statistic.

As normal distribution is often used to describe natural distribution, use normal distribution describing above samples.

Normal distribution density function: $f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$, also called bell-shaped curve.

Being μ the mean value or expectation and σ the standard deviation or variance. Another function is the so-called cumulative distribution function (CDF), however, cannot be drawn by elementary function.

It requires large number of samples in order to achieve a probability density function which has not been feasible in the present investigation. However, it has been possible to generate a cumulative distribution function that needs fewer samples and it is suitable in this case.

Characteristic value of three type load is as follow:

Table 2 *Calculative characteristic value*

	Occupant load density	Electrical equipment load density	Internal load density
	W/m^2	W/m^2	W/m^2
Mean value μ	14.74	31.84	47.61
Standard deviation σ	4.38	7.95	11.77

Real cumulative distribution curve and regression normal cumulative distribution curve is presented in the following graphic:

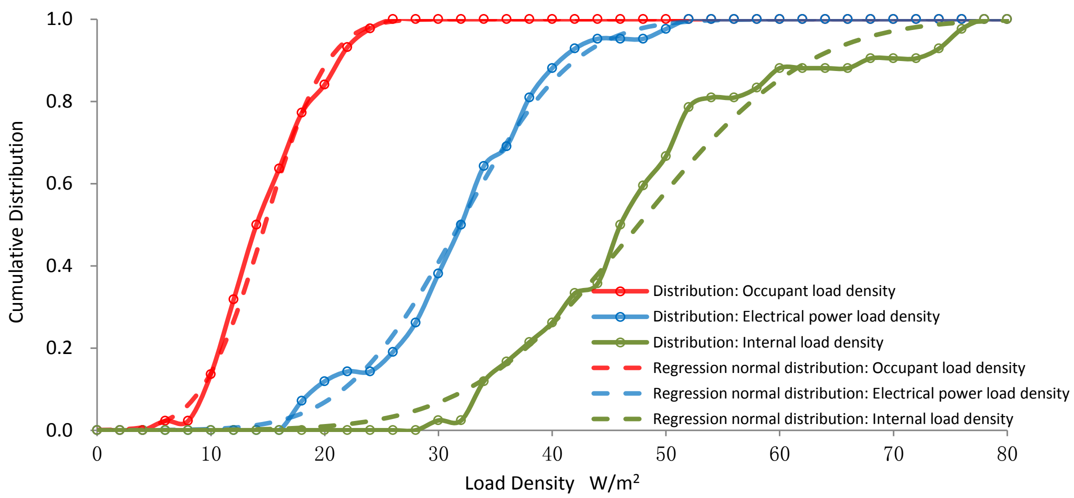

Figure 2 *Distributions of Internal Load and Regression Normal Distribution*

The regression results of occupant load density and electrical load density is acceptable and the regression results of internal load density has larger distinguish from real distribution. The standard deviation of occupant, electrical, internal load successive increases and the samples distribution increasingly fragmented. Standard deviation represents the degree of dispersion of investigated data or distribution.

4 IMPACT OF DISTRIBUTION CHARACTERISTIC BUILDING LOAD AND ROOM LOAD

Above part summarized the distribution characteristic of internal load. The characteristic is for single office. For the whole building, larger the building is and more office rooms it possesses, more concentrated the internal load is.

For example, a office building has n storeys, each storey internal load obeys normal distribution $X_i \sim N(\mu, \sigma)$, i=1, 2 …… n, Y is mean value of all storeys, $Y = (X_1 + X_2 + ... + X_i + ... + X_n)/n$, then Y also obeys normal distribution, mean value doesn't change and standard deviation becomes $\sigma/\sqrt{n}$. As $Y \sim N(\mu, \sigma/\sqrt{n})$, the whole building internal load becomes more concentrated. Assuming building has 20 storeys, each storey obeys $X \sim N(48,12)$, the cumulative distribution curve of single floor and mean building is as follow:

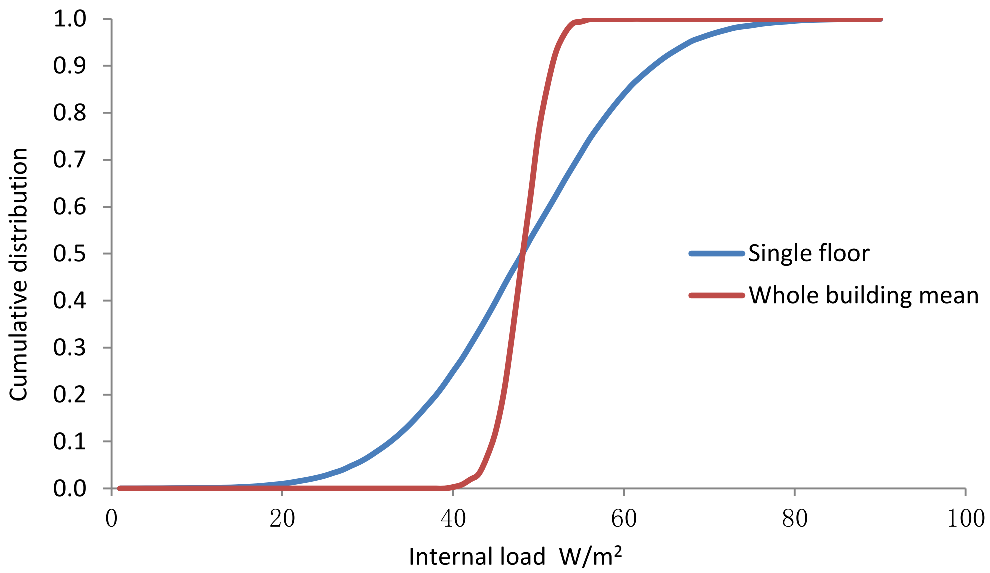

Figure 3 *Distribution Characteristic of Single and Whole Building Mean*

Under the same assurance rate (e.g. 95%), distinguish of internal load between single floor and whole building is obvious, are 67.7W/m^2 and 52.4 W/m^2, the difference reaches 23%. According to the normal distribution character, any normal distribution function can converts to standard normal distribution with mean value and standard deviation. Thus calculate the independent variable (internal load) under some assurance rate, the process is as follows:

1) $X \sim N(\mu, \sigma)$;

2) $U = (X - \mu)/\sigma \sim N(0,1)$;

3) As assurance rate of standard normal distribution is 0.95 or 0.99, $U_{0.95} = 1.64$, $U_{0.99} = 2.33$;

4) $X_{0.95} = \sigma U_{0.95} + \mu = 1.64\sigma + \mu$, $X_{0.99} = \sigma U_{0.99} + \mu = 2.33\sigma + \mu$.

The work to get the actual office internal load reliable distribution characteristic (mean value, standard deviation) requires a lot of research data is a long-term and arduous task. Then using the distribution characteristic calculates internal load density which used to calculates building load and room load. At the present stage of lacking large amount of research data, can use the distribution characteristic above which $\mu = 48W/m^2$, $\sigma = 12W/m^2$. End equipment internal load is $X_{end} = \sigma U + \mu$, and chiller internal load is $X_{chiller} = \sigma U/\sqrt{n} + \mu$, U depends on assurance rate and standard normal distribution, n is storey number.

Internal load which is used to calculate chiller capacity gradually decreases as the storey increases because of $1/\sqrt{n}$. The figure below shows the chiller internal load and end equipment internal load as different amount of floors:

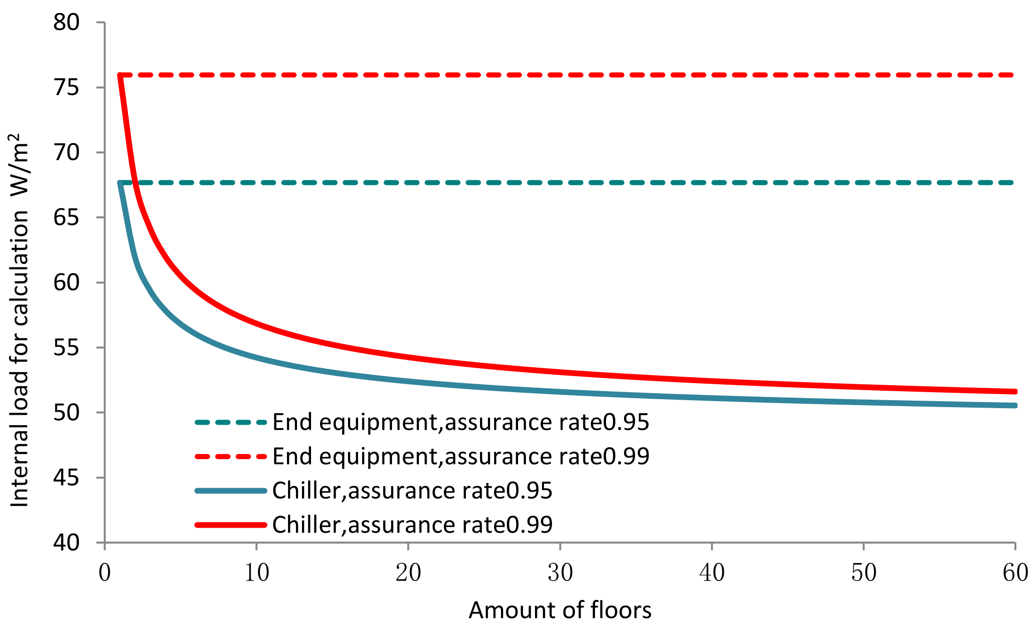

Figure 4 *Chiller Internal Load and End Equipment Internal Load with Different Amount of Floors*

When the assurance rate changes from 0.95 to 0.99, though it's tiny, but end equipment internal load increases 8.3W/m^2, about 10%. As amount of floor is less than 20, chiller internal load decreases significantly with the amount, but as amount of floor is more than 20, decreasing trend slows.

Through the above analysis, the sensitive factor of end equipment internal load is assurance rate, the sensitive factor of chiller internal load is area of construction (or amount of floors). This is why chiller capacity is often oversized but end equipment capacity is often not enough. As the assurance rate is low, individual room capacity is not enough. When choosing the chiller capacity, impact of floor amount was not considered in and it leaded to chiller capacity oversize. When designing air-condition system, assurance rate and amount of floors should be considered in to save as much as possible on the initial cost based on meeting cooling need.

5 BUILDING SIMULATION

Now let's analyze the contribution of internal load to the building load which also including envelope load and fresh air load. Establish an office building in software DeST. The building has 20 storeys office and loads of occupant, lighting and other electrical equipment account for 1/3 of the floor internal load. Now design 5 kinds of condition, distribution characteristics are as follow:

Table 3 *Distribution characteristics of conditions*

Characteristic value	Unit	Reality	Centralized	Decentralized	Minimum	Maximum
Mean value	W/m^2	48	48	48	23.3	72.7
Standard deviation	W/m^2	12	8	16	-	-

The first three conditions internal load show a distribution and the last two conditions internal load remain unchanged. The cumulative distribution functions are as follow:

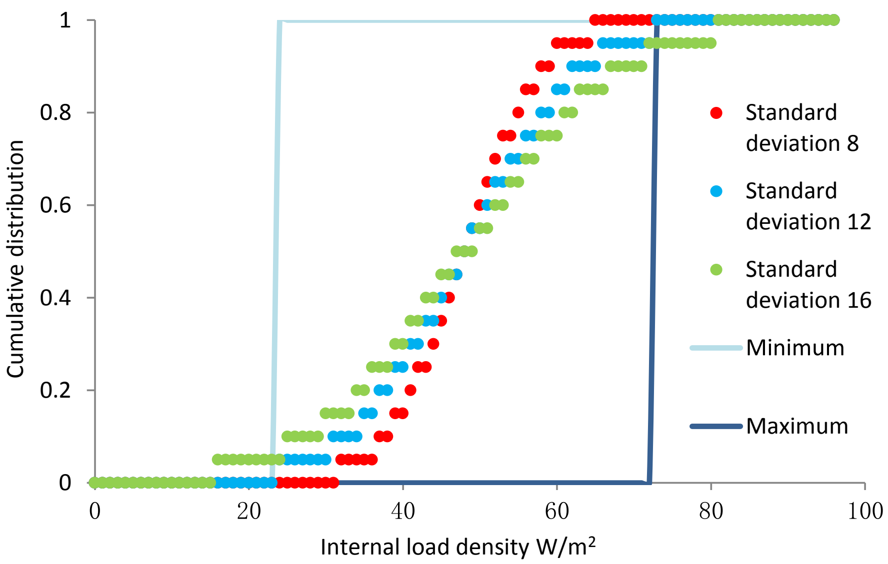

Figure 5 *Distribution of Internal Load in Different Conditons*

Using DeST software to simulate the five conditions, results of every floor total load are as follow:

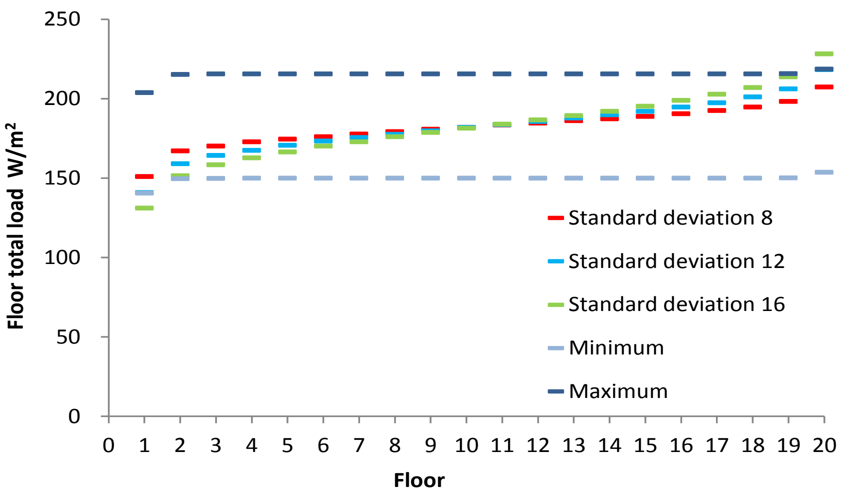

Figure 6 *Every Floor Total Load of 5 Conditions*

The floor total load of the first three conditions show different concentration degrees. The maximums of floor total load are 207W/m^2, 218 W/m^2 and 228 W/m^2 with 10% difference. When designing end equipment, designers often choose the maximum of floor total load to make sure the room comfortable. The mean values of the three conditions are the same. So for the chiller, the difference of the capacities is little.

The last two conditions and the standard condition show the influence of mean value, the building total load of maximum is 1.15 times of that of the actual condition. This is also why chiller capacity is often oversized.

6 CONCLUSIONS

This paper shows that the building internal load has spatial distribution characteristic and could be described by a normal distribution function. The main characteristics are the mean value and standard deviation.

In the early stage of design, mean value and standard deviation of internal load need to be ensured after large research data. In case on data is available, research results in this paper can be used. Then designers must determine the assurance rate of the chiller and end equipment, assurance rate of chiller is often higher than end equipment. Even so, internal load density of chiller is generally lower than end equipment after considering distribution characteristic.

After determining the above parameters and requirements, internal load density for end equipment is up to assurance rate and easy to calculate. Internal load density for chiller is up to assurance rate and amount of floors, and it often lower than end equipment.

Using the described design method can save initial cost and meeting room comfort expectations at the same time, a key factor on the basis of rational design.

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