Transactions of Tianjin University
Vol. 9 No. 4 Dec. 2003

Cooling Load Distribution of Large Space Building

CHEN Hong-bing(陈红兵)[1], TU Guang-bei(涂光备)[1], YANG Jie(杨 洁)[1], Chan K T[2]
(1. School of Environmental Science and Technology, Tianjin University, Tianjin 300072, China;
2. Department of Building Services Engineering, Hong Kong Polytechnic University, Hong Kong, China)

Abstract: The cooling and heating load distribution of large area air-conditioned room such as "open" offices, shopping malls and waiting rooms is usually assumed to be even in air conditioning system design. However, it is not the case in reality, and a low efficient air conditioning system results from this assumption. A simulation and analysis of the cooling load distribution of an office building in Hong Kong with TRANSYS software is provided in this paper. A typical office is divided into 13 zones for simulation, including external zone, medial zone and internal zone in the north, the south, the east and the west respectively and a central zone, instead of 4 directional zone. The result shows there is much cooling load difference between each zone, and more attention should be paid to uneven indoor cooling and heating load distribution to further guide the design.

Keywords: zonal temperature distribution; cooling index; internal zone; cooling load distribution
Article ID: 1006-4982(2003)04-0340-05

It is well known that there exists an indoor temperature distribution[1] in building rooms. As the distance to the external wall varies, the temperature is different. However, when we design a heating, ventilation and air conditioning (HVAC) system, the indoor air volume is still modeled as "one point" or "perfectly mixed" until recently. This negligence of indoor temperature distributions is one of the main reasons of the malfunction of the air-conditioning control system, which in turn causes the complaints of the room occupants about indoor thermal comfort. Therefore to have more precise predictions of the indoor thermal comfort, better control of the indoor thermal comfort and the indoor thermal conditions, a detailed and fast model of the dynamic indoor temperature distributions is needed.

So far, computational fluid dynamics (CFD) is the best tool for predicting detailed indoor temperature distributions. But it is too time-consuming and its cost is not effective. Furthermore, a detailed model of the indoor temperature distributions like CFD is really not necessary since people are not sensitive to minor temperature changes (e.g., < 0.5 ℃). Therefore, people have been trying to find a zonal model for the indoor temperature responses in the past years[2-4]. The basic idea of the zonal model is to divide the room air volume into several air zones, each of which is assumed to be perfectly-mixed and is assigned one temperature. In addition, an assumption of no mass and heat exchanges between two adjacent air zones is made for the simulation.

Here a simulation of a "large space" building divided into 13 zones on the basis of its structure and function with TRANSYS software is conducted.

1 Simulation and analysis

1.1 Model description

One floor of an office building in Hong Kong with the length of 20 m, the width of 20 m and the height of 3.6 m is simulated. Fig. 1 shows the structure of the glazed envelope[5]. The opaque sector is made up of

1) Concrete wall, 0.24 m;
2) Insulation, 0.1m;
3) Metal sheet, 0.000 5 m;
4) Air gap ;
5) Spandrel glass, 0.008 m.

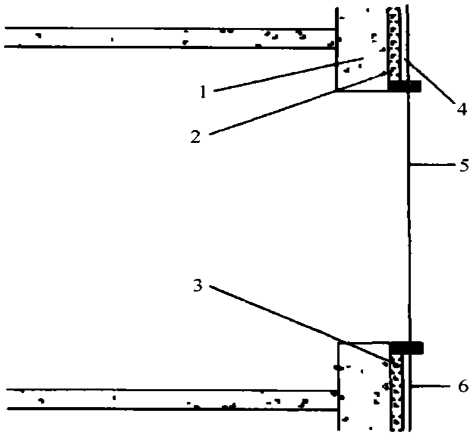
The U-value of the opaque sector is 0.337 W/(m^2·K). The transparent sector, accounting for 36% of the external wall, is vision glass with a thickness of 0.008 m and U-value of 5.8 W/(m^2·K).

The natural infiltration is set to be 1 h^{-1} during the occupation time from 8:00 am to 18:00 pm and 0.25 h^{-1} during the non-occupation time. The HVAC system working during the occupation time has been simulated to maintain the internal temperature at 24 ℃ and the rela-

* Accepted date: 2003-05-30.
CHEN Hong-bing, born in 1977, male, doctorate student.
E-mail: hbhit@sohu.com

© 1994-2012 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

tive humidity at 50% for every zone. Five working days and no consideration of heat gains of indoor service, human beings and artificial lighting are involved in the simulation.



1—Concrete wall; 2—Insulation; 3—Metal sheet;
4—Air gap; 5—Vision glass; 6—Spandrel glass.

Fig. 1 Structure of glazed envelope

Generally speaking, a building is divided into several parts according to different directions. Here for this model with a large space, we divide it into 4 zones (zones N, E, S and W) and one central zone (zone C), and every zone of each direction is further divided into external zone (zones 1, 4, 7 and 10), medial zone (zones 2, 5, 8 and 11) and internal zone (zones 3, 6, 9 and 12).

As we all know, the more zones a building is divided into, the more accurate the result will be, but accordingly the longer the time will be consumed. Here 13 zones are involved in the simulation. The zone distribution is shown in Fig. 2.

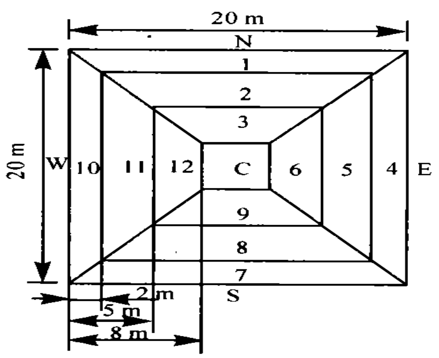


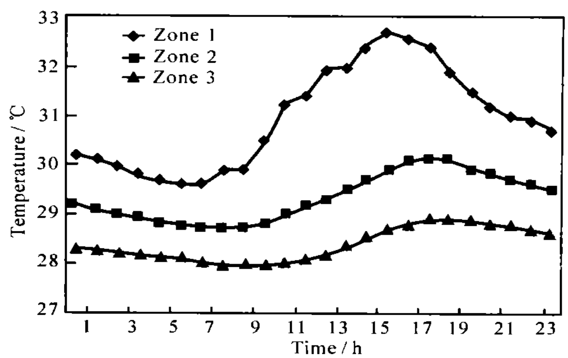
Fig. 2 Zone distribution

1.2 Analysis and discussion

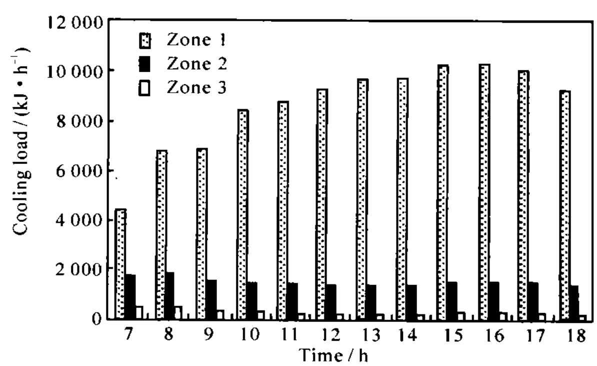
1.2.1 Summer

The average temperature of each zone can be worked out on the basis of the dynamic outside temperature and the solar radiation with the assumption that the average temperature is equal to the zonal center temperature, and the temperature variation is continuous.

Fig. 3(a) shows the temperature comparison of the zones in the north without HVAC system operation. From Fig. 3(a) we can see that the closer the zone is to the external wall, the higher the zonal temperature will be. The daily average temperatures of zones 1, 2 and 3 are 31 ℃, 29.3 ℃ and 28.4 ℃ respectively. And the maximum temperatures of zones 1, 2 and 3 are 34.2 ℃, occurred at 17:00 pm; 32.5 ℃, occurred at 18:00 pm and 30.9 ℃, occurred at 19:00 pm. The maximum temperature difference among these zones is 4 ℃, occurred between zone 1 and zone 3 at 16:00 pm. Fig. 3(b) shows the cooling load comparison of zones in the north with HVAC system operation. The daily average cooling load from 7:00 am to 18:00 pm of zones 1, 2 and 3 are 8 603 kJ/h, 1 454 kJ/h and 273 kJ/h respectively, and their cooling load indexes are 66 W/m^2, 10 W/m^2 and 4 W/m^2. It is obvious that great difference in zonal temperature and cooling load exists among those zones.



(a) Comparison of temperature

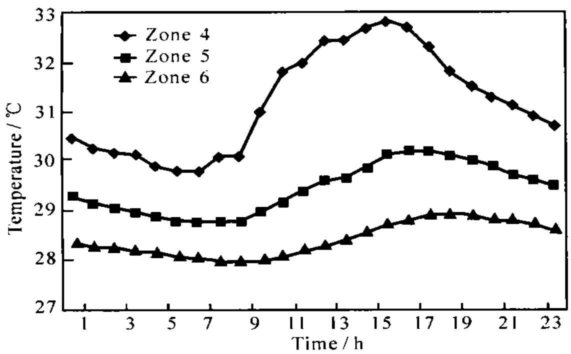


(b) Comparison of cooling load

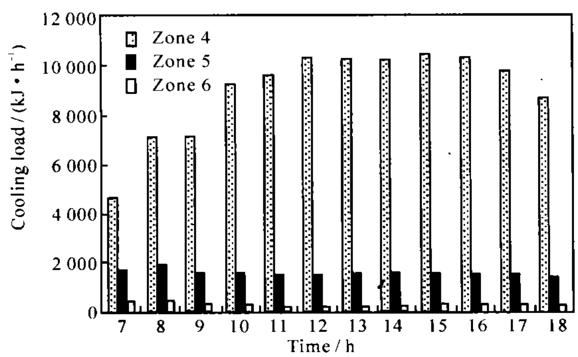
Fig. 3 Comparisons of temperature and cooling load of northern zones in summer

© 1994-2012 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

Fig. 4(a) shows the temperature comparison of zones in the east without HVAC system operation. The daily average temperatures of zones 4, 5 and 6 are 31.2 ℃, 29.5 ℃ and 28.4 ℃ respectively. And the maximum temperatures of zones 4, 5 and 6 are 34 ℃, occurred at 17:00 pm; 32.3 ℃, occurred at 17:00 pm and 30.7 ℃, occurred at 18:00 pm. The maximum temperature difference among these zones is 4.1 ℃, occurred between zone 4 and zone 6 at 13:00 pm. Fig. 4(b) shows the cooling load comparison of zones in the east with HVAC system operation. The daily average cooling load from 7:00 am to 18:00 pm of zones 4, 5 and 6 are 8 930 kJ/h, 1500 kJ/h and 278 kJ/h respectively, and their cooling load indexes are 69 W/m^2, 11 W/m^2 and 4 W/m^2.



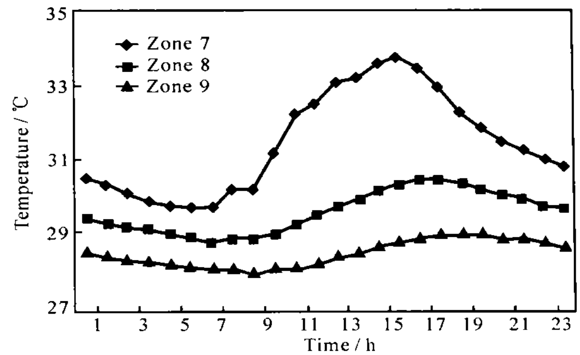
(a) Comparison of temperature



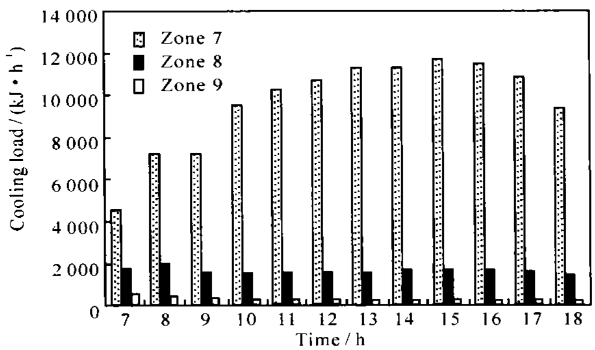
(b) Comparison of cooling load

Fig. 4 Comparisons of temperature and cooling load of eastern zones in summer

Fig. 5(a) shows the temperature comparison of zones in the south without HVAC system operation. The daily average temperatures of zones 7, 8 and 9 are 31.5 ℃, 29.6 ℃ and 28.5 ℃ respectively. And the maximum temperatures of zones 7, 8 and 9 are 33.9 ℃, occurred at 17:00 pm; 32.3 ℃, occurred at 18:00 pm and 30.8 ℃, occurred at 19:00 pm. The maximum temperature difference among these zones is 5 ℃, occurred between zone 7 and zone 9 at 16:00 pm. Fig. 5(b) shows the cooling load comparison of zones in the south with HVAC system operation. The daily average cooling load from 7:00 am to 18:00 pm of zones 7, 8 and 9 are 9 624 kJ/h, 1 588 kJ/h and 289 kJ/h respectively, and their cooling load indexes are 74 W/m^2, 11 W/m^2 and 4 W/m^2.



(a) Comparison of temperature



(b) Comparison of cooling load

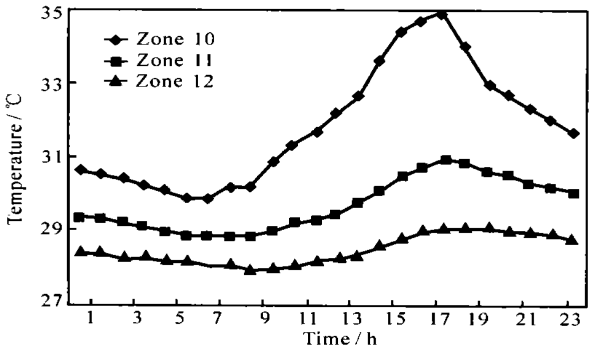
Fig. 5 Comparisons of temperature and cooling load of southern zones in summer

Fig. 6(a) shows the temperature comparison of zones in the west without HVAC system operation. The daily average temperatures of zones 10, 11 and 12 are 31.8 ℃, 29.7 ℃ and 28.5 ℃ respectively. And the maximum temperatures of zones 10, 11 and 12 are 36.4 ℃, occurred at 18:00 pm; 33.7 ℃, occurred at 19:00 pm and 31.3 ℃, occurred at 19:00 pm. The maximum temperature difference among these zones is 5.8 ℃, occurred between zone 10 and zone 12 at 18:00 pm. Fig. 6(b) shows the cooling load comparison of zones in the

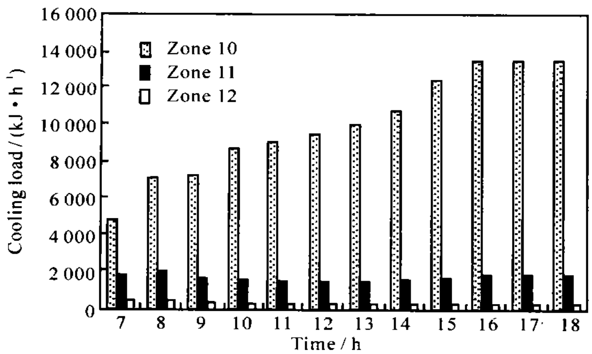
© 1994-2012 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

west with HVAC system operation. The daily average cooling load from 7: 00 am to 18: 00 pm of zones 7, 8 and 9 are 10 019 kJ/ h, 1 643 kJ/ h and 295 kJ/ h respectively, and their cooling load indexes are 77 W/ m^2, 12 W/ m^2 and 4 W/ m^2.

Figs. 7 and 8 show the daily average zonal temperature distribution (isotherm) in summer and winter. We can see that the central temperature is 28. 1 ℃ in summer and 16. 7 ℃ in winter. The denser the isotherm is, the higher the zonal temperature will be. In summer, zonal temperature in the west is higher than that in the north, the east and the south. In winter, zonal temperature in the south is obviously higher than that in other directions. External zonal temperature is higher than that of medial and internal zone both in summer and winter.



(a) Comparison of temperature



(b) Comparison of cooling load

Fig. 6 Comparisons of temperature and cooling load of western zones in summer

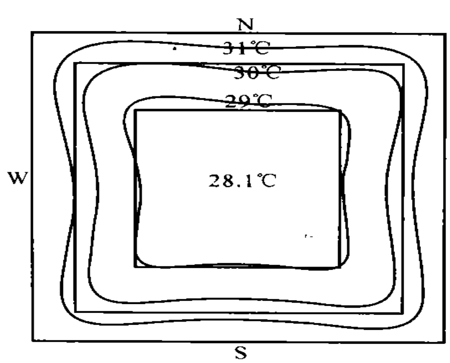


Fig. 7 Zonal temperature distribution in summer

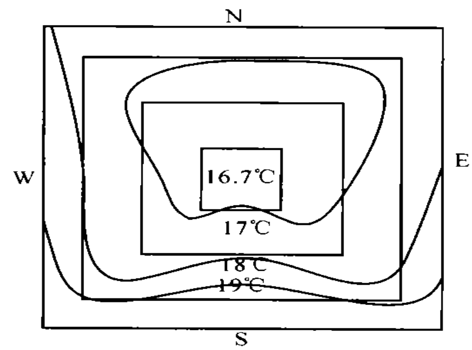


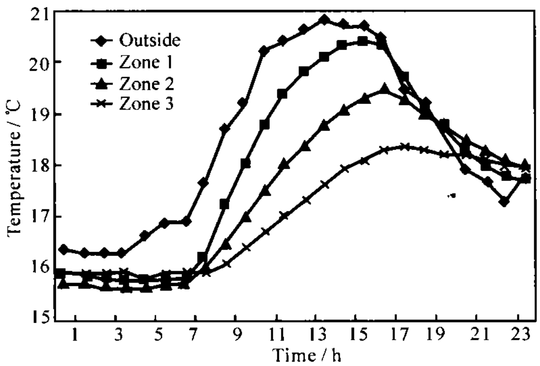
Fig. 8 Zonal temperature distribution in winter

1. 2. 2 Winter

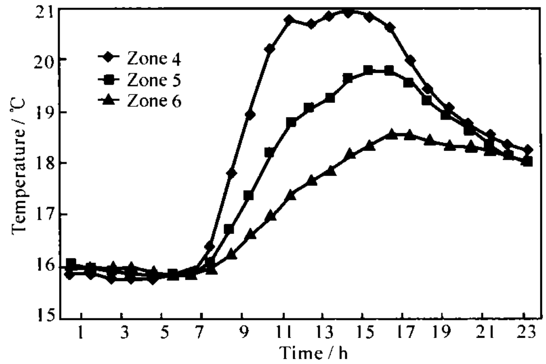
Fig. 9 shows the temperature comparison of zones in different directions in winter without HVAC system operation. For zones in the north, the maximum temperature difference is 1. 9 ℃, occurred between zone 1 and zone 3 at 14: 00 pm. For zones in the east, the maximum temperature difference is 2. 7 ℃, occurred between zone 4 and zone 6 at 12: 00 pm. For zones in the south, the maximum temperature difference is 8. 7 ℃, occurred between zone 7 and zone 9 at 15: 00 pm. For zones in the west, the maximum temperature difference is 4. 4 ℃, occurred between zone 10 and zone 12 at 17: 00 pm. During the non-working time, the external zonal temperature is lower than that of medial and internal zone because of the low outside temperature. In addition, air conditioning is only required for zone 7 and zone 10 sometimes in winter. In this case we can increase the fresh air supply to save energy.

The simulation result in a whole year shows the maximum annually average zonal temperature is 25. 7 ℃ in zone 7, and the minimum value is 23. 1 ℃ in the central zone, zone C, without HVAC system operation. As for the cooling indexes, the maximum value is 381 MJ/ m^2, occurred in zone 7, and the minimum value is 7 MJ/ m^2, occurred in zone C.

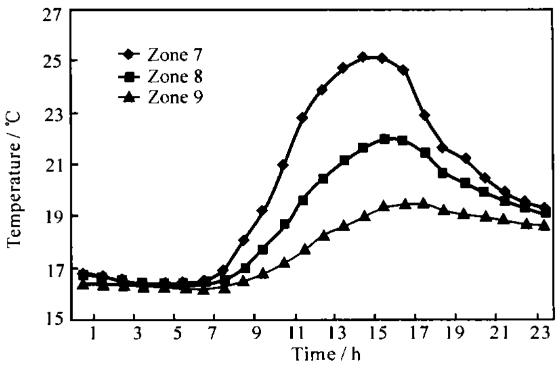
© 1994-2012 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net



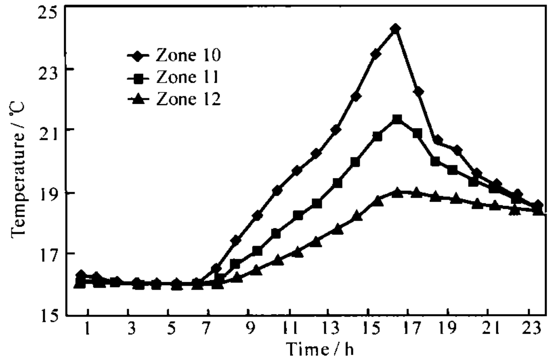
(a) Zones 1, 2 and 3 in the north



(b) Zones 4, 5 and 6 in the east



(c) Zones 7, 8 and 9 in the south



(d) Zones 10, 11 and 12 in the west

Fig. 9 Temperature comparison of zones in winter

2 Conclusions

The study shows the temperature distribution is quite uneven in large space rooms or buildings. Here the building has been divided into many small zones and a simulation has been couducted. The results show the external zonal temperature is higher than that of medial and internal zones. In summer the maximum temperature difference is 5.8 ℃, occurred between zone 10 and zone 12 in the west at 18: 00 pm, and in winter the maximum temperature difference is 8.7 ℃, occurred between zone 7 and zone 9 at 15: 00 pm.

The temperature difference accordingly leads to the cooling difference. In a whole year, the maximum annually average cooling index is 381 MJ/m^2, occurred in zone 7, but the minimum value is only 7 MJ/m^2, oecurred in zone C. Therefore, more attention should be paid to the difference to ensure a reasonable design and effective operation of HVAC system. Meanwhile, it can save energy and improve human comfort.

However, the actual result may be a little different from the simulation because of the assumptions made for the calculation. The simulation accuracy is related to the number of zones a building is divided into. Theoretically speaking, the more zones a building is divided into, the more accurate the result will be, and accordingly the longer the time will be taken.

References

[1] Ren Zhengen, Stewart Joan. Simulating air flow and temperature distribution inside buildings using a modified version of COMIS with sub-zonal divisions [J]. *Energy and Buildings*, 2002 (1472): 1—15.

[2] van der Kooi J, Forch E. Calculation of the cooling load by means of a 'more-air-point-model' [A]. *Proceedings of CLIMA 2000* [C]. Copenhagen, Denmark, 1985, 4: 395—401.

[3] Dalicieux P. Simplified modeling of air movements in a room and its first validation and experiments[A]. *Proceedings of ROOMVENT '92, Air Distribution in Rooms*[C]. Third International Conference, Aalborg, Denmark, 2—4 Sept. 1992, 1: 383—397.

[4] Inard C. Prediction of air temperature distribution in buildings with a zonal model [J]. *Energy Building*, 1996, 24(2): 125—132.

[5] Chan K T, Chow W K. Energy impact of commercial-building envelopes in the sub-tropical climate[J]. *Applied Energy*, 1998 (60): 21—39.

© 1994-2012 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net