B-53.3-3: Evaluation of Thermal Environmental Load from the Buildings

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1 Introduction

The reduction of urban heat island phenomena is specified in the principle of Japanese government as a countermeasure for the global warming problem. Air temperature of Tokyo has risen as 1.7℃ in summer since last century. This climatic change may be a match for 34 billion yen as a negative effect on the seasonal electricity charges, mainly for air conditioners summed up in the metropolitan area. In Japan, power supply facilities are mainly designed out of consideration for the peak in summer time. Then, the reduction of heat island phenomena is important for the reduction of peak demand of electric power.

2 Research Objectives

Fig. 1 shows thermal mechanism related to heat island phenomena. Thermal effect of building is related to each of all allows in the figure. Then, thermal modeling of buildings is needed for the evaluation of heat island phenomena, in a form of thermal load in the urban atmosphere. This research aims to develop a numerical tool for the evaluation of heat released from buildings and air conditioning systems considering interactive relation between urban structures and atmospheres, and to quantify the exhaust heat of buildings as a thermal load in the urban atmosphere. The abstract of research results ever year is shown in Table 1.

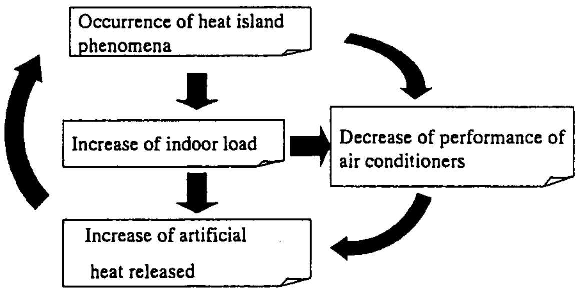

Fig.1 Thermal vicious circle in urban areas[1)]

Table 1. The abstract of research results ever year

Results in the 1997 year	Results in the 1998 year	Results in the 1999 year
Air conditioning systems were classified using database of SHASE and performance data of air conditioners were gathered	Computational program of thermal load from buildings was developed and some case studies under different weather conditions were examined	Interactive relation between urban structure and atmosphere was analyzed to obtain the quantitative data of energy-saving effect by reduction of urban heat island phenomena

3 Research Method

3.1 Classification of Air Conditioning Systems

State of air conditioning systems in Tokyo was surveyed using the 826 cases in the database on air conditioning equipment arranged by SHASE[2]. Air conditioning systems of several uses and scales were selected as shown in Table 2. A consistent tendency was recognized in control system that individual type was for small scale and central control for large one.

Table 2. Air conditioning systems of various scales and uses of the buildings

use	scale	system
Office	low-rise(1～5F)	air-cooled heat pump (multi system)
	medium-rise(6～10F)	air-cooled heat pump (multi system)
	high-rise(11F～)	absorption refrigerator
Shop	low-rise(1～5F)	air-cooled heat pump (multi system)
	medium-rise(6～10F)	absorption refrigerator
Hotel	medium-rise(6～10F)	absorption refrigerator
Condominium	medium-rise(6～10F)	air conditioner (room type)
	high-rise(11F～)	air conditioner (room type)

3.2 Performance Data of Air Conditioners

Performance data were collected for the evaluation of cooling energy of buildings. COP (coefficient of performance) data of air-cooled heat pump system was shown in Fig. 2. As air temperature rose, the values of COP decreased, and it had the peak in low values of partial load. For the computational use, the COP data were arranged by the functions of temperatures and partial loads.

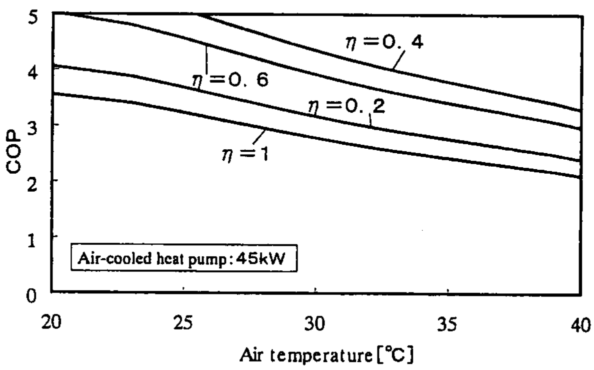

Fig.2 Performance of air-cooled heat pump

3.3 Process of Generation of Exhaust Heat from Air Conditioning System

The numerical tool of thermal load, MICRO-PEAK 1987, was used for the calculation of cooling load. Energy for cooling was derived from the characteristics of air conditioning system to dispose cooling load. Exhaust heat from air conditioning system was evaluated as the summation of cooling load, ventilation load and energy for cooling. The process of generation of exhaust heat from air conditioning system was shown in Fig.3.

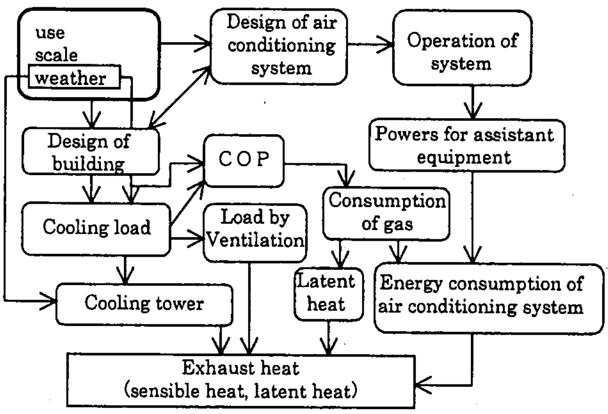

Fig.3 Process of generation of exhaust heat from air conditioning system

3.4 Modeling of Cooling Tower

From the conditions of quantity of water, ventilation amount of cooling tower and weather data, temperatures of cooling tower at entrance and exit were estimated considering hourly change of cooling load. Heat and mass transfer model was adopted for the calculation of temperature distribution in the cooling towers to obtain the breakdown of sensible and latent heat released in the atmosphere.

3.5 Analytical Method of Simple Building

Standard weather data, HASP was used for the calculation of simple building. Three days were selected for the calculation (August in TOKYO, day of lowest temperature, day of average temperature and day of highest temperature). Office building of RC type (floor area: 8,000m^2) was shown in Fig. 4. Hourly pattern of indoor heat generation and the construction of walls and roofs were established for the analysis.

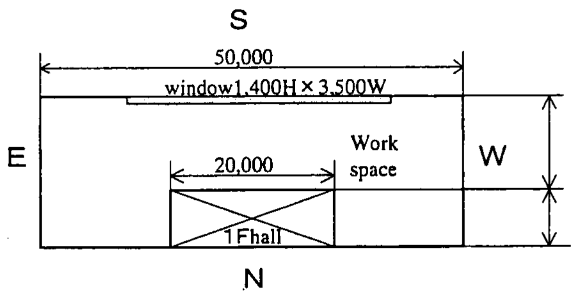

Fig.4 Office building (floor area: 8,000m^2)

Two types of air conditioning systems, air-cooled heat pumps and absorption refrigerators were analyzed. Heat source devices, air handling units of fresh air and ventilation devices for work rooms and machine rooms were equipped, and cooling towers, pumps of cooling water and pumps of hot-cool water were established in the case of absorption refrigerators.

3.6 Analytical Method of Urban Canopy[5]

Simple building model was extended to the model of urban canopy including some buildings. Fig. 5 showed the abstract of urban canopy model coupled with air conditioning systems. Furthermore, urban canopy model was coupled with the atmospheric turbulent model. Atmospheric turbulent model was for the computation of the wind field, air temperature and humidity, and a k- ε type used widely in the environmental engineering. The ensemble-spatial averaged three-dimensional Reynolds equations, equation of continuity, turbulent kinetic energy (k-equation) and turbulent energy dissipation equation (ε -equation) were solved together with equations of heat and moisture transfer in the air. Inside the urban canopy layer, effects of buildings and other urban structures on the momentum transfer were modeled by introducing a form

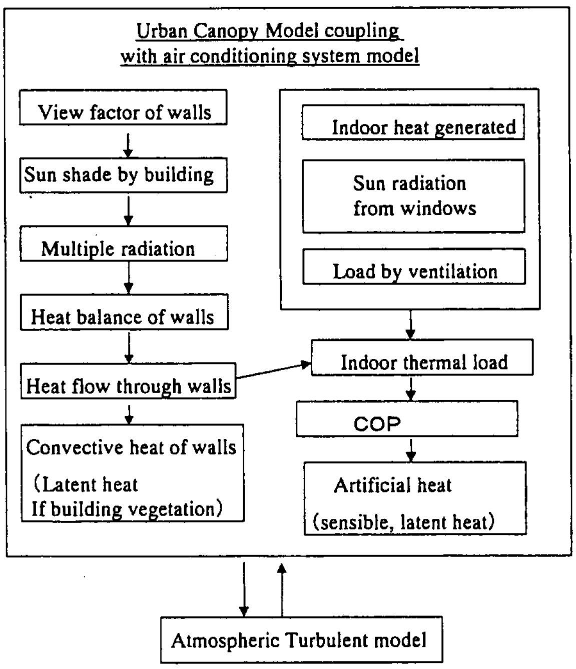

Fig.5 urban canopy model coupled with air conditioning systems drag force, and volumes of them were accounted for by a spatial averaging procedure. The values of the coefficient for eddy viscosity evaluation C_μ and turbulent Prandtl number P_{rt} were defined as the atmospheric stability function as same as the Level 2.5 model[6].

4 Result

4.1 Results of simple building

Fig. 6 showed numerical result of air-cooled heat pump system. The amount of energy consumption and the values of system-COP were different each day. Energy consumption increased as air temperatures went up. The values of system-COP decreased in the daytime except for the day of lowest air temperature. As for the case of absorption refrigerator, energy consumption extremely increased because city gas was directly stoked and system-COP values were almost constant. Analysis of cooling tower suggested that latent heat was dominant to dispose total heat, and the ratios of sensible heat to total heat were 8.5%-13.3% in the day of average air temperature.

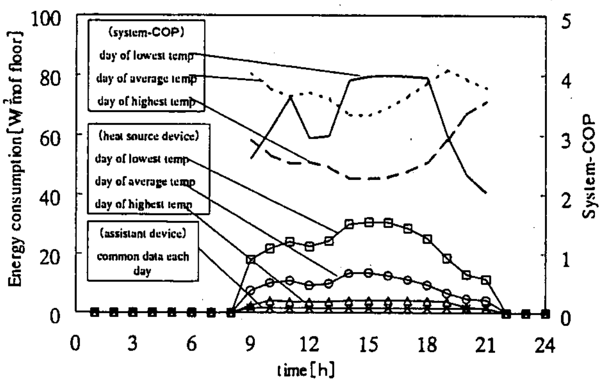

Fig.6 Numerical result of simple building (Air-cooled heat pump system)

4.2 Results of urban canopy model

Urban canopy model was analyzed in the case of uniform district in which all buildings were 16 m height, 16 m width and the building ratios were 0.5. Numerical results showed the increase of air temperatures in the daytime induced the increase of energy for cooling. The COP values decreased in the daytime as same as the result of simple model.

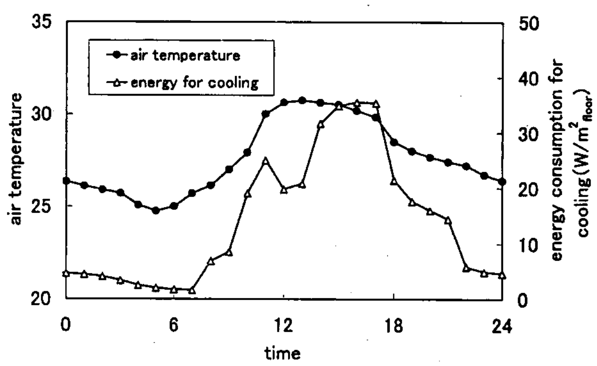

Fig.7 Numerical result of urban canopy model (Air-cooled heat pump system)

5 Discussion

The relation between air temperature and energy for cooling, system-COP derived from the simple building model was displayed in Fig. 8. Energy consumption of the system using air-cooled heat pomp increased rapidly by the increase of cooling load in the region above 25-degree C in air temperature, in

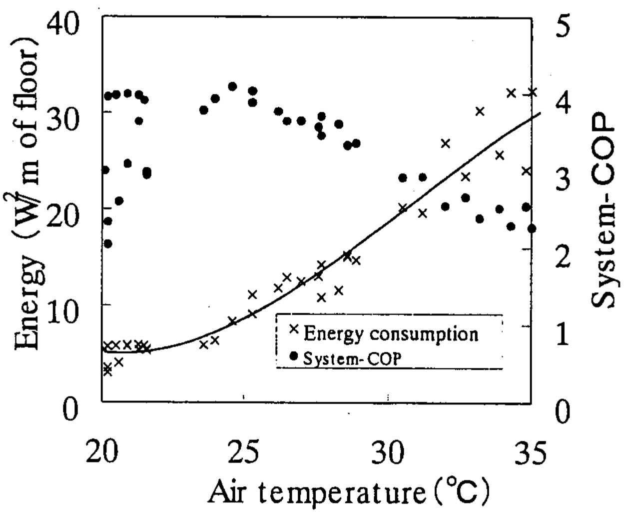

Fig.8 relation between air temperature and energy for cooling, system-COP which the values of COP for the system decrease. This character of air conditioning system may affect the peak demand of electric power in summer time.

Fig. 9 showed several results by urban canopy model. Minimum temperature appeared in the case of forest, and maximum temperature in the case of air-cooled heat pump. The utilization absorption refrigerator reduced air temperatures at 1～4 p.m. by the evaporative cooling effect at cooling towers. As for the roof planting, air temperature decreased in the daytime and night, and energy for cooling was reduced as 14%. In the case of forest, evapotranspiration was very active in the daytime, and amount of thermal storage was very small, then air temperatures were in the low level all day.

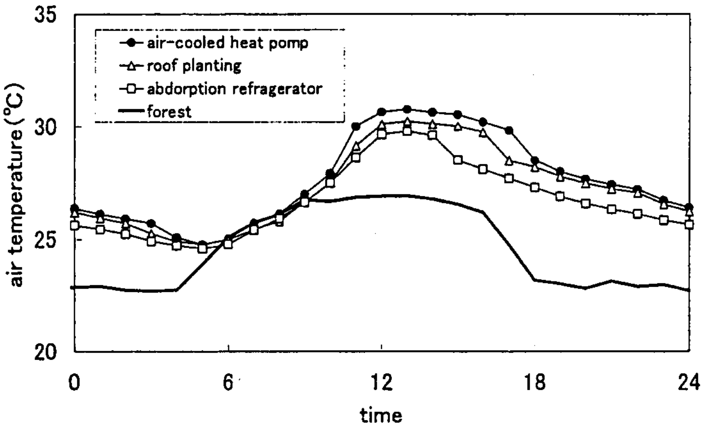

Fig. 9 Air temperatures of several conditions

6 Conclusion

A numerical tool for the evaluation of heat released from buildings and air conditioning systems was developed to analyze the thermal effect of buildings in the interactive relation between urban structures and atmospheres. Some conclusions derived from numerical results are as follows.

1) State of air conditioning systems in Tokyo was surveyed using the database on air conditioning equipment arranged by SHASE, and a consistent tendency was recognized in control system that individual type was for small scale and central control for large one.
2) COP (coefficient of performance) data of heat source devices were collected, and the COP data were arranged by the functions of temperatures and partial loads.
3) The process of generation of exhaust heat from air conditioning system was modeled considering COP of heat source devices, indoor heat generation, operative method of system and the characteristics of cooling tower.
4) Simple building model was extended to the urban canopy model in which the multiple radiation of long wave and short wave, convective heat from building walls and roofs and heat released from air conditioning systems were considered.
5) Atmospheric turbulent model was developed in which effects of buildings and other urban structures were modeled by introducing a form drag force, and parameters were defined as the atmospheric stability function as same as the Level 2.5 model
6) From the analysis of simple building model, energy consumption of the system using air-cooled heat pomp increased rapidly by the increase of cooling load in the region above 25-degree C in air temperature, in which the values of COP for the system decrease. Analysis of cooling tower suggested that latent heat was dominant to dispose total heat, and the ratios of sensible heat to total heat were 8.5%-13.3% in the day of average air temperature.
7) From the analysis of urban canopy model, the increase of air temperatures in the daytime

induced the increase of energy for cooling, and the COP values decreased in the daytime as same as the result of simple model. The utilization absorption refrigerator reduced air temperatures at 1～4 p. m. by the evaporative cooling effect at cooling towers. As for the roof planting, air temperature decreased in the daytime and night, and energy for cooling was reduced as 14%.

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