Study of Effects of Building Layout on Carbon Dioxide Emissions

Hinako Motohashi*, Masayuki Oguro*, Hitoshi Fukao*

*Technology Center, Taisei Corporation, Japan (344-1,Nase-cho, Totsuka-ku, Yokohama 245-0051, Japan)

Abstract

The effects of building layout, thermal insulation, and types of exhaust heat from buildings on energy conservation and the outdoor environment are studied numerically by incorporating the coupling effects of exhaust heat from various air-conditioning systems. The amount of exhaust heat strongly depends on the conditions of the outdoor environment. Hence, a computational procedure has been developed to properly evaluate ambient condition-dependent exhaust heat in terms of outdoor air properties and materials of street blocks. When there are open spaces in street blocks, exhaust heat is found to increase by 10% compared to a reference case without open spaces. However, exhaust heat decreases to a level of a favorable outdoor thermal environment if buildings are thermally well insulated.

Key words coupling effects of air-conditioning heat exhaust, heat island phenomenon, open spaces

1. INTRODUCTION

There is growing concern about heat island phenomena in Japanese cities, in addition to the global warming effects. An increasing number of heat stroke patients have also been reported. In heat island analysis, the conventional approach is to specify constant exhaust heat according to the building size and energy usage patterns only. However, it has been well recognized that the amount of exhaust heat depends also on the conditions of the outdoor environment.

In the present research work, we have developed a computer program enabling to calculate ambient condition-dependent exhaust heat in terms of outdoor air properties and materials of street blocks. Using the numerical procedure, the effects of street patterns, degrees of thermal insulation, types of exhaust heat and planting on energy conservation and outdoor thermal environment are investigated.

2. ANALYSIS OF THE OUTDOOR THERMAL ENVIRONMENT CAUSED BY THE COUPLING EFFECTS OF EXHAUST HEAT FROM AIR-CONDITIONING SYSTEMS

2.1. Outline of the Analysis

A street block has been constructed based on an existing urban area in Tokyo, to which analysis on the thermal environment and air quality during daytime in summer is performed by generating solar radiation, exhaust heat from automobiles, and pollutants simulating exhaust gases from road vehicles. Different street patterns are considered by varying arrangements of open spaces that are present over the entire urban area. From the results of average wind speed, temperature, humidity, MRT, SET* and pollutant concentration in pedestrian spaces, assessment is made of effective energy conservation and a favorable outdoor thermal environment.

2.2. Analysis Model

Figure 1(1) shows the analysis model, which represents a virtual urban area encompassing a square field of about 1.7km long. Buildings surrounded by narrow streets are grouped together. The capacity of street block is taken to be 1100% and vacant spaces are assumed to occupy 50% of the entire street block. Figure 1(2) depicts an area selected as a representative street block. It is almost centrally located in the urban area and feels little effect from the model boundaries. To calculate outdoor air load, evaluations are made at air cells in the immediate vicinity of buildings (the first cells from building walls) under the assumption that outdoor air near buildings is introduced into building interior.

2.3. Computational Cases

Computational cases are summarized in Table 1. The effects of open spaces, thermal insulation, exhaust heat, planting and water retaining pavements are studied.

2.4. Conditions of Computation

Computational conditions, solar radiation heat transfer and physical properties of each components are provided in Table 2. A Tokyo region is considered. Daytime weather conditions correspond to those at noon during summer time when the thermal environment is most severe.
2.5. Analytical Approach

Load of solar radiation and heat transfer into buildings is known from results of solar radiation analysis. Outdoor air load is obtained from computed enthalpy of air in the vicinity of a building to be taken inside through CFD analysis. Exhaust heat from air-conditioning systems is calculated under an assumed COP by summing the load data and inner load of the building. The whole procedure is repeated several times in the coupled analysis.

3. RESULTS OF THE COMPUTATION AND DISCUSSION

Figure 2 shows exhaust heat generated by air-conditioning (per gross floor area, without inner heat load) at a representative block. Average temperature, SET*, wind speed, MRT, Humidity ratio and concentration at 1.5m above the ground level in pedestrian spaces are presented in figures 3 through 5 (Note 6). Also shown in figures 6 and 7 are average humidity ratios of air coming into buildings through air-conditioning systems.

3.1. Effects of Open Spaces (Case A vs. Case B)

From figure 2, it is seen that exhaust heat of air-conditioning systems for Case B (with open space) increases by about 10% compared to that in Case A (without open space). This is because, in Case B, a slightly reduced outdoor air load resulting from a temperature drop at air intakes of buildings is offset by increased shortwave solar
radiation load due to appearance of areas newly exposed to sunshine caused by an overall increase in distance between buildings. MRT in Fig. 4 also increases in Case B, indicating farther penetration of sunshine between building spaces. Contrary, the presence of open spaces serves to improve outdoor ventilation by increasing wind speed and reducing pollutant concentration. (see Figs. 3, 4 & 5)

Furthermore, in Case B, although wind speed at the center of the main street increases, SET* deteriorates as a result of rising MRT in the sunlit pedestrian spaces.

The results obtained indicate that, from a viewpoint of energy conservation, it is important to place open spaces for securing wind streets and, at the same time, improve thermal insulation and blocking of sunshine of buildings. Concerning the outdoor thermal environment, generation of shading is crucial for sustaining a low MRT.

3.2. Effects of Shading and Thermal Insulation (Case B vs. Case C)

The lowest emission of exhaust occurs in Case C, which is 15% less than that in Case B. Formation of sun shades and better thermal insulation of buildings are thought to suppress solar radiation load to the buildings. Note that in Case C, SET* is higher by 0.4°C and MRT increases. (see Figs. 3 & 4) This is due to the fact that better thermal insulation raises surface temperatures of the buildings and that a higher reflection rate for shortwave radiation increases reflection from the surroundings by hanging brightly colored blinds for better shading properties. Based on the above results, suppressing reflection by planting and eaves, for example, and/or increasing reflection within an unhararmful range to the human body is important as a means of blocking sunshine near the ground for achieving a favorable outdoor environment.
3.3. Effects of Exhaust Heat Types from Air-Conditioning Systems (Case B vs. Case D)

Case D, in which exhaust heat from air-conditioning systems consists of 90% latent heat and 10% sensible heat, is shown to attain lower air temperatures both in the pedestrian spaces and at the air intakes of the buildings compared to that in Case B (100% sensible heat) (see Figs. 3 & 6). The air temperature drop is due to lower sensible heat and, therefore, types of exhaust heat are thought to cause significant differences. While humidity ratio and concentration of air coming into the buildings are seen to increase (Fig. 7), the lower air temperature slightly reduces heat transmission and exhaust heat. Outdoor SET* is degrading with falling wind speed. Exhaust latent heat cuts sensible heat from street blocks, thereby reducing mixing of outdoor air (Fig. 6).

From the results shown, heat discharge by latent heat is highly effective for reducing air temperatures as long as sufficient ventilation with high wind speed is maintained.

3.4. Effects of Planting and Water Retaining Pavements (Case B vs. Case E)

In case E, to which planting and water retaining pavements are applied, shortwave solar radiation and heat transmission are reduced compared to those in Case B. Planting and water retaining pavements act to cut heat reflection from buildings. As to the outdoor environment, comparing the results among the cases with open spaces, SET* is the lowest and air temperature drops by about 1°C (Fig. 3). Furthermore, MRT is also lower roughly by 8°C compared to that in Case B (Fig. 4). Although wind speed falls somewhat, no discernible difference is seen in pollutant concentrations (Figs. 5 & 7).

It is demonstrated that planting and water retaining pavements can generate the most favorable outdoor environment by reducing heat exhaust.

3.5. Effects on CO₂ Emission

Estimation of CO₂ emission from air-conditioning systems is made by calculating back power consumption at a COP of 3 and multiplying the basic unit of CO₂ emissions. Comparing to the baseline result (Case A) of CO₂ emission from a representative street block, it is found to increases by 1.07 (ton/hour) in Case B, while it decreases by 1.71 (ton/hour) in Case C. As to Cases D and E, CO₂ emission increases by 0.94 and 0.79 (ton/hour), respectively.

4. CONCLUSIONS

(1) We have performed analysis on the outdoor thermal environment in the summer by incorporating the coupling effects of exhaust heat by air-conditioning.
(2) From a viewpoint of energy conservation, it is important to place open spaces for securing wind streets for ventilation and improve properties of blocking sunshine and thermal insulation of the buildings.
(3) Although blocking sunshine and better insulation are effective for suppressing heat exhaust by air-conditioning, care should be taken to prevent reflection near the ground from a standpoint of the outdoor thermal environment.
(4) Discharging heat by latent heat works to lower air temperature as long as sufficient ventilation is maintained.
(5) Planting and water retaining pavements act to cut exhaust heat by air-conditioning and sustain a favorable outdoor environment.

Notes

1) The computational field includes buffer regions near a street block
2) Computational meshes have been reduced to such an extent that they would not significantly affect computational results through comparison with solutions obtained using finer meshes.
3) Values of k and ε are set with reference to an estimation formula for turbulence intensity provided by a guideline for building loads published by the Architectural Institute of Japan.
4) Set as the average wind speed during a period between 10:00 and 16:00 (daytime) on sunny days in July and August 2002 measured at the Otemachi Observatory, Tokyo, of the Japan Meteorological Agency.
5) Z₀ is determined by sustaining a 1/4-law profile.
6) Note only open spaces are considered here, without taking into account open areas in pedestrian walks.
7) CO₂ emission factor of 0.339 (kg/kWh) Reference 3), Also, load may be overestimated from actual values due to steady-state assumption.

References

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