Three-Dimensional Nonsteady Coupled Analysis of Thermal Environment and Energy Systems in Urban Area

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Three-dimensional nonsteady coupled analysis of the local thermal environment and air-conditioning loads was carried out in a local city. First we conducted a survey of the actual condition of electric power consumption and cooling heat load for each building. The survey period was from January to December 2008. Electric power consumption and cooling heat load were estimated based on the hourly data of BEMS and the district heating and cooling system in the city. Meteorological condition, electric power consumption at the buildings, land surface, building construction and location were databased for numerical simulation. Surface temperatures of the buildings and the ground were determined by calculating the shadow area and conducting mutual radiation analysis of short and long waves while considering view factors. The cooling heat loads were also calculated for each building based on the heat value entering the room from outside and on the internal loads. The calculation results reproduced the observed daily behavior of cooling heat loads with excellent accuracy.

Keywords: Heat island, low-carbon city, radiation, heat storage, air-conditioning load

1. Introduction

Recently, countermeasures against the urban heat island (UHI) effect, such as reduction of anthropogenic heat release and enhancement of urban ventilation, have become increasingly important in Tokyo. The evaluation of urban ventilation requires the construction of a high-resolution computational fluid dynamics (CFD) system, which takes account of complex urban morphology. The morphological complexity arises from multiscale geometry consisting of buildings, forests, and rivers superimposed on varying topography. Given this morphological background, we have been developing a high-resolution CFD system and have performed simulations of wind and air temperature fields in the 23 special wards of Tokyo using a horizontal grid spacing of 5 m[1]. It is necessary to accurately handle the heat transfer phenomenon of buildings or the ground prior to fluid analysis of an urban area. In 2010, we developed a calculation method that grasps the surface temperature of a city in a three-dimensional nonsteady manner. We conducted a shadow calculation and mutual radiation analysis of short- and long-waves considering the geometrical factor, and finally determined the surface temperatures of buildings and the ground. In addition, we calculated the cooling heat loads for each building from the heat value that entered the room and from the internal load.

2. Subject of Analysis

A bird's eye view of the subject of the analysis is shown in Fig. 1. Three-dimensional nonsteady analysis was conducted for an area in which the cooling load was to be analyzed (370 m x 480 m) (herein the AC load analysis area) considering the buildings' mutual radiation impact and heat stored in building walls, etc.. A surrounding area (670 m x 780 m) was set around the AC load analysis area so as to incorporate the impact of shade formed by the surrounding buildings on the AC load analysis area in the calculation. The distribution of sky view factors is shown in Fig. 2. It is suggested that control of nocturnal radiation from the concentration of buildings effectively reduces the occurrence of "tropical nights." The sky view factor of the ground decreases near the buildings, and it is indicated that resultant heat storage occurs locally and eventually contributes to an increase in night-time surface temperatures.

3. Calculation Method

The distribution of surface temperatures on urban surfaces is calculated by three-dimensional nonsteady analysis under the

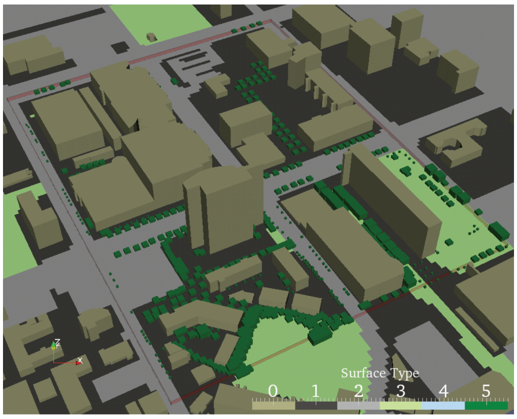

Fig. 1 Bird's eye view of the analysis area
Land use signs: 0 - building; 1 - building site; 2 - asphalt; 3 - grass field; 4 - water surface; and 5 - trees.

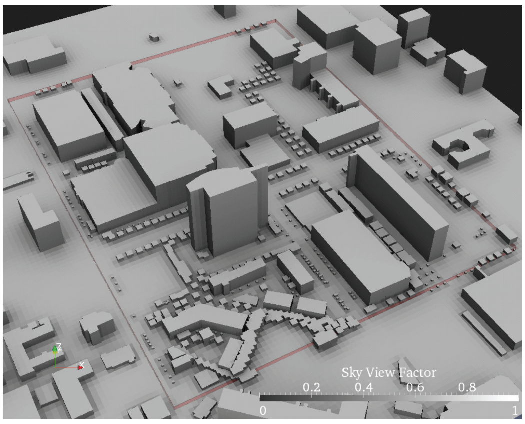

Fig. 2 Distribution of sky view factors
Laterally subdivided by 5 m mesh for ground and buildings and 1 m mesh for trees.

meteorological conditions of the summer of 2008. Value of the transmission heat that enters the room through rooftop slabs and walls is calculated at the same time. There are measured data for the electric power consumption of buildings for the same period, and the cooling heat loads occurring in this period as a result of the addition of the electric power consumption and the transmission heat values. Since the cooling heat loads may be calculated from the time data for the amount of cold heat supplied from the district cooling system to the building, the measured data and calculated data can now be compared.

4. Calculation Results

The distribution of surface temperatures measured at 16:00 on August 3, 2008 is shown in Fig. 3. Surface temperatures vary depending on the shade, ground surface coverage, and the direction of the building wall. The shade distribution at the same

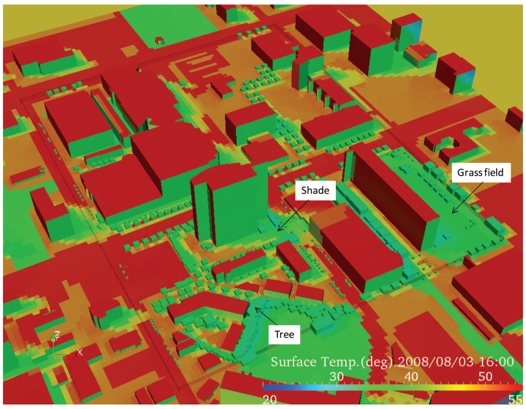

Fig. 3 Surface temperature distribution (16:00, August 3, 2008).

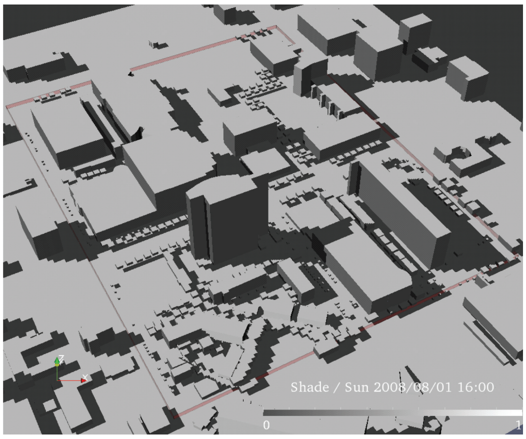

Fig. 4 Shade distribution (16:00, August 3, 2008).

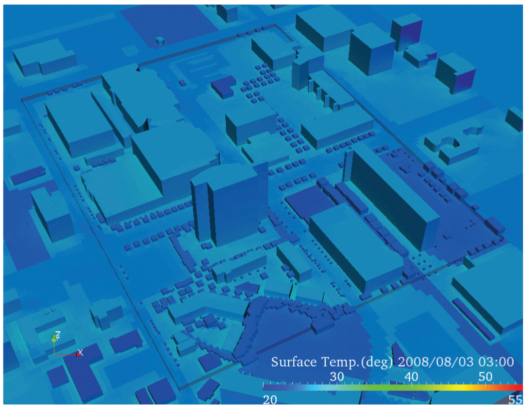

Fig. 5 Surface temperature distribution (3:00, August 3, 2008).

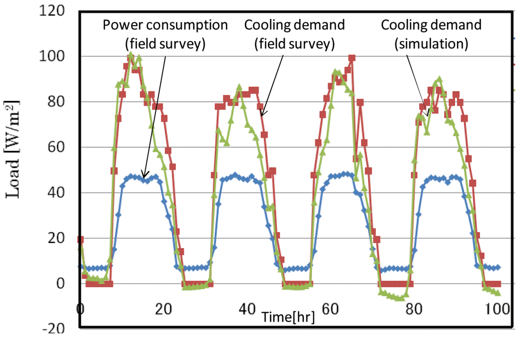

Fig. 6 Calculation results of air-conditioning load (a few days in the summer period of 2008).

time is shown in Fig. 4. The surface temperature distribution at 3 o'clock is shown in Fig. 5. The impact of heat storage differs depending on the type of building construction (RC or wooden), and hence surface temperatures differ from place to place. The temperature of the green area remains relatively lower all through the day. There are a few places observed where elevated road surface temperatures are maintained because of the relationship between the heat storage in the daytime and the sky view factor. Figure 6 compares the calculated values of cooling heat loads of a commercial facility in the analysis area with the field observation values. There is a close agreement in the daily behavior trends which were calculated and observed.

5. Summary

The three-dimensional nonsteady coupled analysis method for local thermal environment and cooling heat loads, which was developed in our research, is expected to contribute to the clarification of the dynamic state of wide-area local heat circulation when coupled with nonsteady CFD analysis. At the same time, the method is capable of quantifying the air-conditioning load reduction effects achieved by choosing the appropriate building surface finishes and conducting greening of buildings.

References

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地域熱環境と空調負荷の3次元非定常連成解析

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地方都市を対象にして地域熱環境と空調負荷の3次元非定常連成解析を実施した。まず各建物で消費される電力と空調負荷の実態調査を実施した。調査期間は2008年1月～12月、電力はBEMSデータを利用し、空調負荷は地域熱供給時刻データから推定した。次に、空調負荷解析領域（370m × 480m)、放射袖領域（670m × 780m）における建物配置、土地被覆等を基に、調査期間の気象条件下の空調負荷を地域レベルで算出した。時刻毎に日陰計算を行い、形態係数を考慮して短波、長波の相互放射解析を実施することにより、建物および地面の表面温度を決定した。さらに、室内へ流入する熱量と内部負荷から空調負荷を建物毎に算出した。数値計算結果は、観測による空調負荷の日挙動を良く再現した。

キーワード: ヒートアイランド, 低炭素都市, 放射, 蓄熱, 空調負荷