Synthesized Analyses of Meso-Micro and Indoor Climates
- Evaluation on the Spatial Distribution of Wind Potential inside a City for Reducing the Cooling Load of Residential Buildings by means of Cross-ventilation -

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ABSTRACT: A new simulation system that integrates the simulation methods for analyzing mesoscale and microscale outdoor climates, indoor climate and cooling load of buildings was developed. The influence of regional characteristics of local climates inside a city on the performance of cross-ventilation in residential houses was numerically investigated using the simulation system developed in this study.

KEYWORDS: Passive Cooling, Cross-Ventilation, Indoor Climate, Microscale Climate, Mesoscale Climate, Regional Characteristics

1 INTRODUCTION
This study aims to evaluate the natural potential of outdoor climate for improving the indoor climate and reducing the energy consumption for space cooling of buildings by utilizing passive cooling methods, such as cross-ventilation, solar shading by trees etc. Since the passive cooling effects are strongly affected by the spatial distributions of airflow, air temperature and radiative heat transports around buildings, the microclimate around buildings should be accurately predicted. For this purpose, a new simulation system was developed to integrate the simulation methods for analyzing mesoscale and microscale outdoor climates, indoor climate and cooling load of buildings. The influence of regional characteristics of local climates inside Sendai city of Japan on the performance of cross-ventilation in residential houses was numerically investigated using the simulation system developed in this study[Note 1].

2 SYNTHESIZED ANALYSES OF MESO-MICRO AND INDOOR CLIMATES
In the prediction of the indoor thermal environment and the heat load, meteorological data of each city obtained from weather station are usually utilized as meteorological conditions. However, there exist considerable differences in the local climate of each region inside a city [1] (cf. Fig.1). Thus, it is necessary to consider the regional characteristics of meteorological conditions inside a city in order to improve the prediction accuracy.
2.1 Outline of Synthesized Analyses

Fig. 2 illustrates the flowchart of the new developed simulation system. The simulation procedure consists of three phases as follows:

Phase 1: The regional characteristics of meteorological conditions in the city are firstly quantified by the numerical analysis of mesoscale climate [1].

Phase 2: Microclimate around buildings is analyzed by CFD and radiation computations [2, 3]. Here, the results of Phase 1 are employed as the boundary conditions.

Phase 3: The cooling load is calculated, using the values of incoming solar radiation onto the building walls under the shade of trees obtained by the radiation computation and the cross-ventilation rates predicted by CFD computation as boundary conditions, by the transient energy system simulation tool “TRNSYS” [4].

2.2 Evaluation of air change rates

The air change rate, as input data for TRNSYS, is calculated using normalized air change rate $Q^*$ and representative wind velocity $V_0$. $Q^*$ values are calculated by CFD simulations under eight wind directions. Here, it is assumed that the buoyancy effect is negligible and the $Q^*$ values would not vary according to the changes of wind velocity and air temperature, so that $Q^*$ values could be treated as only the function of wind direction and ground roughness of the surrounding areas. The representative wind velocity at the height of 60m is given from the result of mesoscale analysis. The wind velocity $V_0$ at the height of the opening at inflow boundary is calculated by assuming the logarithmic law velocity profile containing the roughness length $z_0$. Here, the $z_0$ value in each region is set based on the land-use data.

In this study, $Q^*$ is defined as follows,

$$Q^*_{(w_d, z_0)} = Q_{CFD} \cdot (A \cdot V_0)$$

Then, $Q(t)$ is evaluated using the following relation.

$$Q(t) = Q^*_{(w_d, z_0)} \cdot A \cdot V_0(t)$$

where, $Q^*$ ($w_d, z_0$) = Normalized air change rate[-] (Wd: wind direction, z_d: roughness length),

$Q_{CFD}$ = Air change rate given form CFD simulation [m$^3$/s], $A$ = Opening area [m$^2$],

$V_0$ = Representative wind velocity [m/s] (Wind velocity at the height of the opening on inflow boundary),

$Q(t)$ = Air change rate at time t [m$^3$/s],

$V_0(t)$ = $V_0$ value at time t [m/s] (i.e. the wind velocity which is corrected, from the result of mesoscale simulation at the height of 60m, to at the opening height).

2.3 Evaluation of the Effect of shading by Trees [5]

The effects of solar shading on indoor climate and cooling load were evaluated based on the computations resulting from “TRNSYS” [Note 2].
3 EVALUATION OF CROSS-VENTILATION POTENTIAL IN SENDAI CITY

3.1 Outline of analysis

The influence of regional characteristics of local climates on the performance of cross-ventilation in residential houses was examined based on the simulation system developed in this study. Fig.3 shows the model building used in this study, and Fig.4 illustrates the region, 16.5km in east-west and 15km in north-south, considered in this study. This domain was divided into 130 sub-domains. The cooling loads of the model building shown in Fig. 3 were then evaluated in turn for each of these 130 domains by TRANSYS. Table.2 lists all the cases investigated in this study [Note 3]. Here, the results of numerical analysis of mesoscale climate were utilized as the input data of meteorological conditions for TRNSYS [Note 4]. The simulation was carried out for 6 days. Q(t) was estimated from Eqn. (2) using the results of the numerical analysis of mesoscale climate and CFD [Note 5]. Here, Q* values were selected according to the wind direction and the land-use conditions [Note 6].

3.2 Results

Fig.5 shows the spatial distribution of cooling load integrated over one day in Case1. The cooling load was small in the area near the coast. Fig. 6 compares the spatial distribution of total periods when the cross-ventilation was performed in Cases 3 and 4. The area where the cross-ventilation can be used has extended in Case 4 compared to Case 3 because the upper limit value of SET* was relaxed in this case [Note 3]. Fig. 8 shows the reduction ratio of cooling load which is defined as the ratio of cooling loads in Cases 3 and 4 to the value in Case 1 where air conditioning was performed all day long. The reduction ratio of cooling load was high in the area near the coast, this clearly indicated the effectiveness of cross-ventilation to reduce the energy consumption for space cooling in this area.

4 CONCLUDING REMARKS

(1) A new simulation method, which combined numerical analysis of mesoscale climate, CFD method for microclimate around building, radiation computations,
and heat load calculation using TRNSYS, was developed to evaluate the spatial distribution of passive cooling method effects due to the cross-ventilation.

2) It was found that the effect of cross-ventilation was significantly large in the coastal areas of Sendai. The cooling load could be reduced by 50% ~ 90% in these areas by utilizing, appropriately, the passive cooling effect of cross-ventilation.

NOTE
(1) As shown in Fig.1, Sendai city is located on about 300km North-East of Tokyo and faces the Pacific Ocean. Sendai is the core city of the Tohoku district in Japan and the population of Sendai is around one million.

(2) The “Reduction Ratio of Solar Radiation” is defined as the ratio of solar radiation onto building walls under the influences of the shades of trees and surrounding buildings to the solar radiation under the conditions without the influences of the shades. This ratio was evaluated from the unsteady heat balance analysis based on the results of radiation and conduction computations. The reduction ratios of global solar radiation, direct solar radiation, sky radiation and reflected solar radiation were calculated based on the radiation analyses. Since these reduction ratios change in accordance with the change of solar position, the hourly reduction ratios of one day were calculated [5].

(3) The cooling loads under various conditions were calculated. Case 1 indicates that air conditioning was performed all day, while Case 2 indicates that cross-ventilation was performed all day. Case 3 was the case where air conditioning was performed when SET* values became higher than the upper limit of comfort range (SET*>27°C) in the results of Case 2, and cross-ventilation was performed when air conditioning was not performed. Case 4 was the test case that relaxed the condition of SET* in consideration of the human thermal adaptation.

(4) Numerical analyses of mesoscale climate in and around Sendai city were carried out. Three-stage nested grid was adopted [1]. The Mellor and Yamada 2.5 level model was employed.

(5) The cooling loads of Room 1 on the last day, which was a typical fine day in early August, were compared here.

(6) The computational domain covers an area of 108m(x: west-east direction)×106m(y: north-south direction)×60m(z: vertical direction). This domain was discretized into 48(x)×40(y)×35(z) grids. The revised k-ε model proposed by Durbin was employed. Wind velocity profiles at the inflow boundary were given by the logarithmic law containing the roughness length z0. To consider the difference of vertical velocity profile in each region, the z0 values were classified into three groups as shown in Table.1. Twenty-four values of Q* for eight wind directions and three z0 values were predicted by CFD simulations.

REFERENCES