Sustainable Cities and Society 19 (2015) 414–420

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Impacts of disaster mitigation/prevention urban structure models on future urban thermal environment

Satoru Iizuka[a,*], Yingli Xuan[a], Yumi Kondo[b]

[a] Department of Environmental Engineering and Architecture, Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan
[b] Obayashi Corporation, Tokyo, Japan

ARTICLE INFO

Article history:
Received 7 March 2015
Received in revised form 28 June 2015
Accepted 30 June 2015
Available online 18 July 2015

Keywords:
Urban thermal environment
Future projection
Weather Research and Forecasting (WRF) model
Urban structure
Disaster mitigation/prevention
Tsunami damage
Strong motion damage
Ground liquefaction damage

ABSTRACT

The possibility of a huge earthquake and the following disasters, such as tsunami and ground liquefaction, in the near future has been pointed out in the third largest metropolitan area (Nagoya metropolitan area) in Japan. In the region including the Nagoya metropolitan area, a huge earthquake of magnitude 8 class has occurred every 100–150 years. The last huge earthquake in the region happened in 1944. Therefore, the viewpoint of disaster mitigation/prevention against an expected huge earthquake is crucial for future urban planning in the Nagoya metropolitan area. On the other hand, the population in the Nagoya metropolitan area is expected to decrease in the future. Such a decrease in population usually leads to a reduction of the urban area. In this study, three disaster mitigation/prevention urban structure models were designed for future urban planning of the 2050s (the target period in which about 100 years will have passed since the last huge earthquake) in the Nagoya metropolitan area considering a reduction in the urban area according to a projected decrease in population. Subsequently, the impacts of the introduction of the three disaster mitigation/prevention models, i.e., (1) a tsunami damage mitigation/prevention model, (2) a strong motion damage mitigation/prevention model, and (3) a ground liquefaction damage mitigation/prevention model, on the future (the 2050s) thermal environment were quantitatively investigated using a regional atmospheric model, the Weather Research and Forecasting (WRF) model. Moreover, an urban structure model that combined the three disaster mitigation/prevention models was constructed, and the effect of the combined model on the future thermal environment was also evaluated.

1. Introduction

Many observational and numerical studies on urban heat islands and their countermeasures have been conducted (e.g., Wong & Yu, 2005; Kanda, 2007; Kusaka, 2008; Miao et al., 2009; Masson et al., 2013; Barlow, Halios, Lane, & Wood, 2015). Nagoya, which is located in the central part of Japan, is the third largest metropolitan area in Japan, and problems associated with urban heat islands are very serious in the metropolitan area. The increase in the annual mean air temperature in Nagoya for the last 100 years has been 2.9 °C (Japan Meteorological Agency, 2014), and a further increase will likely occur in the future. However, not only in the Nagoya metropolitan area but also in other big cities, few have focused on future projections of urban thermal environments.

In our previous studies (e.g., Iizuka, Kinbara, Kusaka, Hara, & Akimoto, 2009; Iizuka et al., 2011), future projections of thermal and wind environments in the summers of the 2030s, 2050s, 2070s, and 2090s in the Nagoya metropolitan area were conducted using a regional atmospheric model, the Weather Research and Forecasting (WRF) model (Skamarock et al., 2008), combined with the pseudo global warming method proposed by Kimura & Kitoh (2007). For the future projections, however, only the effect of future global warming was considered.

In this study, future projections of the thermal environment in the summer (August) of the 2050s were carried out by introducing several urban structure models in the Nagoya metropolitan area in addition to the effect of future global warming, and their impacts on the thermal environment were quantitatively investigated using the WRF model. In the region including the Nagoya metropolitan area, a huge earthquake of magnitude 8 class has occurred every 100–150 years. The last huge earthquake in the region happened in 1944. The 2050s is the period in which about 100 years will have passed since the last huge earthquake. (However, note that it is very difficult to predict when the next huge earthquake will happen.) In addition, Nagoya City (2008) formulated a future urban planning strategy aiming toward 2050. Considering the above things,

* Corresponding author. Tel.: +81 52 789 3751.
E-mail address: s.iizuka@nagoya-u.jp (S. Iizuka).

http://dx.doi.org/10.1016/j.scs.2015.06.008

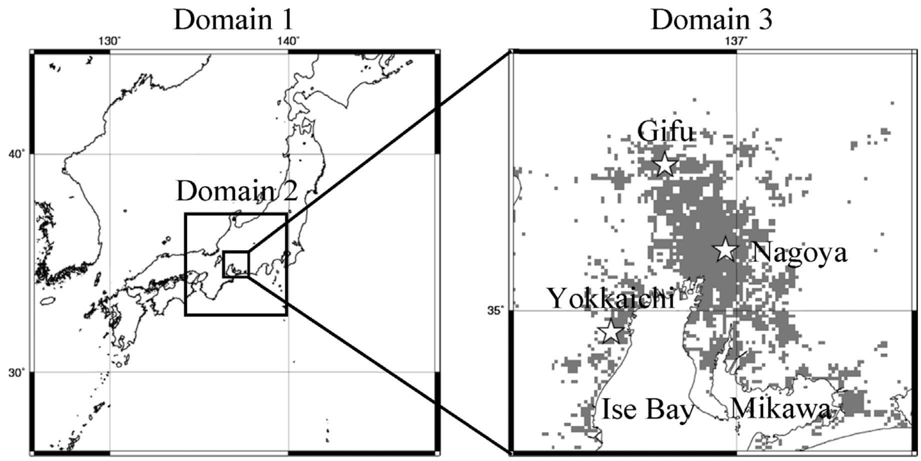

Fig. 1. Computational domains (Gray in Domain 3: Present status of the urban area).

the 2050s was selected as the target period in this study. We also consider that it is possible to utilize what we learn from this study when improving the future city planning strategy.

The future urban structure models were designed from the viewpoint of disaster mitigation/prevention against the huge earthquake expected in the near future. (1) A tsunami damage mitigation/prevention model, (2) a strong motion damage mitigation/prevention model, (3) a ground liquefaction damage mitigation/prevention model, and (4) a combined model of the above three disaster mitigation/prevention models were introduced for the future projections. As a comparison, the present land use model was also applied. In the disaster mitigation/prevention models (except the combined model), a 20% reduction of the urban area was considered in accordance with a projected decrease in population. The projected decrease in population was assumed based on a report by the National Institute of Population and Social Security Research, Japan (2008). According to the report, the population of Nagoya in 2010 was 2.23 million, and the population in 2030 and 2035 was projected to be 2.11 million and 2.05 million, respectively. The decreasing rate from 2030 to 2035 was 2.85%. By assuming the same decreasing rate in the further future, the population in the 2050s is estimated to be 1.79–1.88 million; therefore, the decrease ratio from 2010 (present) to the 2050s (targeted future) is 15.6–19.9%. As some other cities in the Nagoya metropolitan area have larger decrease ratios, finally, a 20% population reduction in the urban area was assumed in this study.

2. Outline of simulations

2.1. Computational domains and grid layout

Three nested computational domains were used, as shown in Fig. 1. The smallest domain (Domain 3), covering 120 km × 120 km, was the main computational domain (Nagoya metropolitan area). The sizes of the domains and the number of grid points are given in Table 1. The horizontal grid resolutions of Domains 1–3 were 25 km, 5 km, and 1 km, respectively.

Table 1
Computational domains and grid layout.

	Size (km)	Grid points	Horizontal grid size (km)
Domain 1	1975 × 1975 × 21	79 × 79 × 34	25
Domain 2	500 × 500 × 21	100 × 100 × 34	5
Domain 3	120 × 120 × 21	120 × 120 × 34	1

Table 2
Urban parameters used in the urban canopy model.

	Cases 1–3	Case 4
Average height of buildings [m]	9.0	11.6
Building coverage ratio [–]	0.23	0.23
Vegetation coverage ratio [–]	0.25	0.25
Roughness length for roof/wall/road [m]	0.005	0.005
Albedo for roof/wall/road [–]	0.1	0.1
Emissivity for roof/wall/road [–]	0.97	0.97
Volumetric heat capacity for roof/wall/road [J/m^3 K]	2.1×10^6	2.1×10^6
Thermal conductivity for roof/wall/road [W/m K]	1.68	1.68
Daily maximum anthropogenic heat release [W/m^2]	50.0	64.5

2.2. Numerical model and conditions

The WRF modeling system, version 3.0.1.1, with the ARW dynamic solver (Skamarock et al., 2008) was used for the future (August in the 2050s) projections of the thermal environment in the Nagoya metropolitan area. For the turbulence model (planetary boundary layer scheme), we used the Mellor–Yamada–Janjic model. The Noah-LSM was used for the land surface model, and the urban canopy model proposed by Kusaka, Kondo, Kikegawa, & Kimura (2001) was applied in urban areas. In this study, the urban parameters in the urban canopy model are given in Table 2. The values of the average height of buildings and the building coverage ratio were set based on a survey of building uses by Nagoya City in 2006. The daily maximum anthropogenic heat release was assumed to be 50 W/m^2, and the diurnal variation of the heat release rate shown in Fig. 2 was considered. These conditions were the same

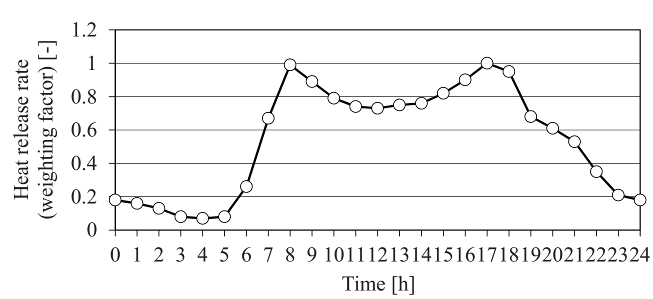

Fig. 2. Diurnal variation of the anthropogenic heat release rate.