Springer Geography

Shinsuke Kato
Kyosuke Hiyama

Ventila

Cities

Springer Geography

For further volumes:
http://www.springer.com/series/10180

Shinsuke Kato • Kyosuke Hiyama
Editors

Ventilating Cities

Air-flow Criteria for Healthy and Comfortable Urban Living

Springer

Editors
Shinsuke Kato
Institute of Industrial Science
The University of Tokyo
4-6-1, Komaba, Meguro-ku
Tokyo 1538505, Japan
kato@iis.u-tokyo.ac.jp

Kyosuke Hiyama
Institute of Industrial Science
The University of Tokyo
4-6-1, Komaba, Meguro-ku
Tokyo 1538505, Japan
hiyama@iis.u-tokyo.ac.jp

ISBN 978-94-007-2770-0 e-ISBN 978-94-007-2771-7
DOI 10.1007/978-94-007-2771-7
Springer Dordrecht Heidelberg London New York

Library of Congress Control Number: 2011943356

Cover design: © Spectral-Design – Fotolia.com

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Most of the population on the earth lives in urban areas. Blocks of buildings in urban areas form windbreaks and reduce wind speeds compared with bare regions. Thus, most of the people in the world live in environments with artificially weakened wind. In their living environments, anthropogenic heat and contaminant is also generated with certain extent by human activities. During the summer, dense urban areas thereby suffer from the urban heat island phenomenon, an urban climate problem.

Wind is a stochastic phenomenon that is mainly driven by atmospheric Rossby waves. The direction of wind varies with passing high or low atmospheric pressure fronts, and the wind stream is not steady, with up and down streams changing frequently. Few books consider the environmental concerns related to wind, especially concerning the weakened wind in urban areas. It is somewhat difficult for civil engineers and civil engineering students studying urban built environments to comprehend the characteristics of urban wind, especially its ventilating characteristics. This book provides the latest knowledge related to urban wind at the pedestrian height from the ground in details.

To create new integrated knowledge for sustainable urban regeneration, the Center for Sustainable Urban Regeneration (cSUR), The University of Tokyo, was established. The center coordinates international research alliances and collaboratively engages with common issues of sustainable urban regeneration. This book presents one of the achievements of the new integrated approach toward sustainable urban regeneration.

Tokyo, Japan | Shinsuke Kato

Contents

Contributors

Zhen Bu Mott MacDonald (Shanghai, China), Unit 2601, 398 Caoxi Bei Road, Xuhui District, Shanghai, 200030, China

Hiroshi Hayami Environmental Science Research Laboratory, Central Research Institute of Electric Power Industry, 1646 Abiko, Abiko-shi, Chiba 2701194, Japan

Kyosuke Hiyama Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 1538505, Japan

Tomomi Hoshiko Graduate School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 1138656, Japan

Hong Huang Center for Public Safety Research, Department of Engineering Physics, Tsinghua University, Beijing 100084, China

Shinsuke Kato Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 1538505, Japan

Yoichi Kawamoto School of Engineering, The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku Tokyo 1138656, Japan

Mai V. Khiem Applied Climate Division, Vietnam Institute of Meteorology, Hydrology and Environment, 23/62 Nguyen Chi Thanh, Ha Noi, Viet Nam

Mahmoud Farghaly Bady Mohammed Faculty of Engineering, Assiut University, Assiut 271516, Egypt

Fumiyuki Nakajima Environmental Science Center, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 1110033, Japan

Keisuke Nakao Faculty of Engineering, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 1538505, Japan

Ryozo Ooka Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku Tokyo 1538505, Japan

Tassanee Prueksasit Faculty of Science, Chulalongkorn University, Phayathai Road, Pathumwan, Bangkok 10330, Thailand

Hom Bahadur Rijal Department of Environmental & Information Studies, Tokyo City University, 3-3-1 Ushikubo-nishi, Tsuzuki-ku, Yokohama 224-8551, Japan

Kazuo Yamamoto Environmental Science Center, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 1110033, Japan

Hiroshi Yoshikado Graduate School of Science and Engineering, Saitama University, 255, Shimo-Okubo, Sakura-ku Saitama-shi Saitama 3388570, Japan

Chapter 1
Introduction

Shinsuke Kato and Kyosuke Hiyama

Keywords Wind environment • Low wind • Urban environment • Criteria • Ventilation performance

1.1 Measurement and Evaluation of the Ventilation Through and Over Urban Blocks

What is the ideal wind environment in urban areas for people to live healthy and comfortable lives? What is required to realize such wind environments in urban areas? These simple questions cannot be answered easily.

Many factors that determine the wind environment in urban areas are natural phenomena that are beyond the power of human intervention. That is, they cannot be controlled by humans easily. When considering the safety of constructions against strong wind, the possibility of controlling the wind strength is never considered. At most, the structures are designed with a factor of safety from a stochastic point of view by predicting the strength of the wind stochastically. In other words, the countermeasures taken against strong wind are extremely passive. However, the circumstances change when the wind is sufficiently strong not only to damage the constructions but also to affect daily living. The wind strength is controlled to an extent by windbreaks and/or windbreak fences to provide a wind environment acceptable to pedestrians and residents. The building-induced winds that occur due to high buildings should be controlled by the building shape and/or windbreak fences to a status acceptable to pedestrians and residents.

S. Kato (✉) • K. Hiyama
Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba, Meguro-ku, Tokyo 1538505, Japan
e-mail: kato@iis.u-tokyo.ac.jp; hiyama@iis.u-tokyo.ac.jp

S. Kato and K. Hiyama (eds.), *Ventilating Cities: Air-flow Criteria for Healthy and Comfortable Urban Living*, Springer Geography,
DOI 10.1007/978-94-007-2771-7_1, © Springer Science+Business Media B.V. 2012

Weaker wind is also a concern. The wind in urban areas is expected to dilute pollutants and transport them away from the area and exhaust heat produced within the city so that these factors do not affect daily living. The wind has a corresponding body-cooling ability if the ambient temperature is lower than the body temperature. It effectively cools the human body and buildings that receive heat from solar radiation. What is the status of wind required to protect daily living? What kind of device is needed to ensure wind that is effective to protect people from pollutants and exhaust heat? What can prevent the benefits of useful wind? The researchers in wind engineering continue to discuss these questions in terms of "low wind environments in urban areas." However, because the damage and disadvantages of insufficient wind are not as clear as wind damage caused by strong winds, this topic has been treated lightly. The countermeasure to low wind seems to not have an answer that has achieved social consensus.

The concentration of buildings in urban areas degrades ventilation as well as the effects of dilution/transportation of pollutants and heat exhaust. Currently, the building coverage and floor area ratio, which indicate building density, are restricted to a limited amount to avoid extreme concentration. Open areas such as parks and roads are also used to control the building density. As a result, the degradation of ventilation in urban areas is prevented to a certain degree. However, the relationship between the building density and ventilation level and the influence of poor ventilation that affects daily living are not sufficiently clear as to be explained quantitatively.

In this book, the argument will be developed with those questions and problems as starting points. First, the following information will be provided through a case study: the contribution of a low wind environment to improve the living environment in urban areas, the risk in living environments when a low wind environment is lost, and the measurement and concept of a minimum standard regarding the low wind environment required to provide healthy and comfortable life in the city. To discuss this low wind environment, evaluation methods are required to quantitatively explain the building density and the relationship between urban geometry and ventilation level. Therefore, disregarding the influence of regionality, a globally applicable evaluation method will be proposed.

1.2 Outline of Chapters

This book is divided into two sections.

Part I is entitled "Wind Environment and Urban Environment." It consists of four chapters, Chaps. 2, 3, 4, and 5. Here, the benefit of a low wind environment, such as the effect of sea breeze in reducing the heat island phenomenon, and the improvement in the thermal comfort of the human body with cool breeze will be introduced. This chapter also introduces the possible risk when the low wind environment is insufficient, a health damage risk assessment due to the transport of exhaust emissions, and the evaluation of ventilation performance against a sudden diffusion of hazardous material, such as biological or chemical terrorism. They will be explained in detail through a case study performed by computer simulation and/or survey investigation.

Part II is entitled “Criteria for Assessing Breeze Environment.” It consists of two chapters, Chaps. 6 and 7. This part introduces the concept required to realize the wind environment, which enables a healthy and comfortable life. To secure healthy and comfortable living conditions, it is important to define the minimum wind conditions required. Then the regulation required to include this wind environment in city planning must be discussed. In this case, “specific safety guidelines” that make a certain level of performance obligatory as performance target are considered important. A method to quantitatively evaluate the wind environment is required when defining specific safety guidelines. This part includes the authors’ ideas regarding the definition of a wind environment to secure healthy and comfortable living conditions, the quantitative evaluation method of such a wind environment, and the regulation concept to reflect the wind environment in city planning.

1.2.1 Part I: Wind Environment and Urban Environment

Part I Chap. 2 is entitled “Sea Breeze Blowing into Urban Areas: Mitigation of the Urban Heat Island Phenomenon.” In recent years, various sorts of degradation in city environments have been discussed due to sudden urbanization. One of the problems that have gained attention is “heat islands,” which means that the ambient temperature in the urban area is increased compared to the surrounding rural areas. As a solution to this problem, a countermeasure to take in the cold air generated in green land and waterscapes within or close to the city has been suggested. Among them, the utilization of the sea is particularly promising because it can generate a large amount of cold air. Maritime transportation plays a huge role in city development. Therefore, many of the large cities in the world are located in areas next to large bodies of water. About half of the global population lives within 100 km of a coastline, which is another reason that using sea breeze to cool cities is expected to have a great benefit. In this chapter, a case study intended for Tokyo, which was chosen among megacities that show the heat island phenomenon, will be introduced. Using computer simulations, the effect of sea breeze was quantitatively evaluated by considering the influence of city planning, including land use, on the sea breeze utilization. According to this case study, the change in land use between 1976 and 1997 caused a temperature rise of 0.86°C in the city area. It also delayed the sea breeze arrival to an inland area (about 30 km from the coastline) by approximately 20 min. The thoughts regarding the countermeasures for the heat island phenomenon and the evaluation method of the cooling effect in the city area using wind will be introduced through this case study.

Part I Chap. 3 is entitled “Thermal Adaptation Outdoors and the Effect of Wind on Thermal Comfort.” Temperature, humidity, radiation, and airflow, collectively, the wind environment, are listed as external factors that affect the warm-cold sense of the human body. In contrast to the indoors, where the environment can be controlled, these factors are influenced greatly by changes in the natural environment outdoors. On the subject of indoor environments, the thermal comfort index to determine the goal value of air-conditioning is proposed with the assumption that the indoors can be controlled to an ideal thermal environment. On the other hand, outdoors, the main focus is on revealing how humans feel under variable natural environments. However, because of the adaptability of humans to the surrounding environment, the amenity level varies with region. This chapter explains the research on outdoor amenity based on the environmental adaptability of humans and regionality. In addition, information on the concept of an outdoor thermal environment in each region will be provided. The outdoor thermal environment is not uniform. It is influenced by region, especially the average temperature in each season. For example, a temperature lower than the ideal value determined by examining thermal balance is regarded as comfortable in cold areas, but a temperature higher than the ideal value is regarded as comfortable in hot areas. The wind environment is also influenced strongly by regionality. High wind velocity causes discomfort in cold areas, but in hot areas, it improves comfort. The outdoor wind environment depends on the city shape. Therefore, the wind environment is the only factor that is controllable to some extent in natural environments. This chapter gives important knowledge when examining the wind environment of a city and the amenity of outdoor environments.

Part I Chap. 4 is entitled “Health Risk of Exposure to Vehicular Emissions in Wind-Stagnant Street Canyons.” The air pollution problem has existed throughout the ages. For example, the air pollution caused by industrial exhaust has led to serious harm, and therefore, many studies were performed. As a result, various data were obtained regarding risk evaluation. However, the air pollution problem has been diversified in recent years. First, the transportation mechanism of exhaust from chimneys, such as industrial exhaust, is different than that of pollutants generated near the ground. When the pollutant occurs near the ground, the transportation is obstructed by the surrounding structures. The pollutant becomes stagnant in the street canyon and increases the health risk. With an insufficient wind environment, the risk can become extremely high. Therefore, the consideration of the wind environment and city characteristics is very important when evaluating risk. Understanding the health risk, including the reaction speed of each material, is an important issue because the risk evaluation target materials are also diversifying. This chapter introduces the risk evaluation result of PAHs based on in situ measurements. Among the automobile air pollutant problems intensifying in Asia, PAHs have an insufficient health risk evaluation. Through this case study, the idea of risk assessment in urban areas will be explained.

Part I Chap. 5 is entitled “Pollutant Transport in Dense Urban Areas.” To prevent health damage due to air pollution, the first step is to identify the source of a pollutant and reduce its generation. The conventional air pollution countermeasures generally follow this idea because the air pollution and health damage due to industrial exhaust appeared with industrialization. However, in recent years, risk management not only for the industrial air pollution but also for the sudden pollution, such as gas tank leaks or diffusion of hazardous material due to BC terrorism, is required. These accidental, sudden emissions are difficult to control with the conventional method. Therefore, as a second best solution, the method to send fresh air to the source of pollution to dilute it and “ventilate” it appropriately is considered to be effective. In this case, it is required to accurately predict whether wind will transport and dilute the pollution. When considering the pollution from industrial exhaust, the pollutant exits from the chimney projecting from the city block. Hence, the building density has no effect on diffusion. The transportation and diffusion simply depend on the ambient air. In addition, because an examination of the long-term exposure is required when evaluating health risk, the consideration of the average value was sufficient for pollutant concentration. However, when the pollutant occurs within the urban area, such as with BC terrorism and automobile exhaust gas, the diffusion is influenced greatly by the building shapes. The increase in the number of voids, where the air become stagnant and so does the pollutant, in the urban area due to rapid urbanization also complicates the pollutant diffusion problem. To consider the health risk of short-term exposure, it must be determined whether the concentration exceeded the threshold amount, even for an instant, that causes a health problem by predicting the concentration fluctuation. In this chapter, the conventional pollutant diffusion model targeting industrial exhaust will be explained first. In addition, the information including the characteristics of the concentration fluctuation regarding the pollutant diffusion in the actual city will be given. The information was obtained through a case study performed by wind tunnel tests using the model of actual urban areas (Tokyo). When the source of the pollutant and the observation point were close, a high concentration material transportation was observed through the path created by the buildings. In addition, the properties of diffusion, such as the occurrence of a vortex due to the buildings, will be explained. A vortex plays a huge role in pollutant diffusion in the vertical direction. It is clearly stated that the difference in the positional relationship between the occurrence point and observation point (e.g., the distance or urban shape of the transportation path) is a characteristic of its concentration fluctuation. The information was given to predict the diffusion.

1.2.2 Part II: Criteria for Assessing Breeze Environment

Part II Chap. 6 is entitled “Legal Regulations for Urban Ventilation.” People wish to have a healthy and comfortable life, and they have a right to do so. However, when everyone insists on their maximum rights, the right of their neighbors can be violated. This insistence of rights can often escalate into a conflict. To solve this problem and secure the best living environment for the whole urban area, it is important to protect everyone’s rights with appropriate legal regulations.

This chapter gives an overview of existing legal regulations regarding the wind environment necessary for a healthy and comfortable life. However, an existing countermeasure against air pollution focuses on the source control, not on the examination of the city shape to promote ventilation. Hence, legal regulation that is approved based on sufficient examination of the relationship between the city shape and ventilation performance does not exist at the present moment. Therefore, based on the method of examining the city shape by defining specific safety guidelines, the authors reviewed the ideas of precursors regarding ventilation and developed the concept of legal regulation to secure better ventilation.

Part II Chap. 7 is entitled "New Criteria for Assessing the Local Wind Environment at the Pedestrian Level and the Applications." This chapter proposes the concept of the minimum standard and the measurement method of ventilation required for a healthy and comfortable life:

1. Ventilation requires continuous airflow. Therefore, it is rational to evaluate it in the continuous region (the simplest is a spatial average) and not as a value at a point.
2. Because the wind is a stochastic phenomenon, the ventilation should be evaluated as a statistical value over a certain period of time, such as spring, summer, fall, and winter or yearly. Determining the probability of days that fulfill the required wind environment is better for human recognition than evaluating the average rates of a period.
3. Kinetic energy is used an index to improve thermal comfort because a scalar quantity is more convenient in indicating the strength of wind than a vector quantity.
4. The kinetic energy that indicates wind strength does not directly express the ability to discharge pollutants or exhaust heat. Therefore, the ventilation efficiency index, which indicates the transportation efficiency of pollutants and exhaust heat by wind, is used as an index to express discharging ability.

Based on these concepts, the quantification of an average kinetic energy in the target area for comfort is proposed. For health (safety), the quantification of ventilation performance using the ventilation efficiency index is also proposed. This minimum standard value for kinetic energy is 0.05 m^2/s^2, and value for a purging flow rate (PFR) is above 60 times/h. This kinetic energy is defined by the kinetic energy of the wind that people acknowledge as cool (0.3 m/s). The PFR is 10 times faster than that required to rapidly clear the pollutants when they occur indoor (6 times/h). By clearing the tenfold amount, it is thought that clean ambient air is obtained at all times, even when rapidly ventilating indoors. Then a stochastic expression using these minimum standard values is proposed. For example, the following methods are listed as options:

1. There is more than 1 day in a week where the probability that the kinetic energy of wind has a cooling effect on the human body, meaning that the kinetic energy exceeds 0.05 m^2/s^2.

2. There are more than 6 days in a week where the probability that safety can be expected because wind reduces the health risk, meaning that PFR is 60 times/h in a week.

This chapter contains an example to evaluate this method in detail through the case study using street canyons and a concentrated city. An enrichment of the understanding of the evaluation method and its procedure is the aim of this chapter.

Part I
Wind Environment and Urban Environment

Chapter 2
Sea Breeze Blowing into Urban Areas: Mitigation of the Urban Heat Island Phenomenon

Yoichi Kawamoto, Hiroshi Yoshikado, Ryozo Ooka, Hiroshi Hayami, Hong Huang, and Mai V. Khiem

Abstract Currently, about 50% of the world's population is living in urban areas, and that figure is predicted to continue to increase (United Nations, Department of Economic and Social Affairs Population Division, Population Estimates and Projections Section (2009) World urbanization prospects: the 2009 revision). On the other hand, many cities are facing problems caused by urbanization. The urban heat island phenomenon, one of the urban climate problems, is a typical

Y. Kawamoto (✉)
School of Engineering, The University of Tokyo, 7-3-1, Hongo,
Bunkyo-ku Tokyo 1138656, Japan
e-mail: kwmt@iis.u-tokyo.ac.jp

H. Yoshikado
Graduate School of Science and Engineering, Saitama University, 255, Shimo-Okubo,
Sakura-ku Saitama-shi Saitama 3388570, Japan
e-mail: yosikado@mail.saitama-u.ac.jp

R. Ooka
Institute of Industrial Science, The University of Tokyo, 4-6-1, Komaba,
Meguro-ku Tokyo 1538505, Japan
e-mail: ooka@iis.u-tokyo.ac.jp

H. Hayami
Environmental Science Research Laboratory, Central Research Institute of Electric
Power Industry, 1646 Abiko, Abiko-shi, Chiba 2701194, Japan
e-mail: haya@criepi.denken.or.jp

H. Huang
Center for Public Safety Research, Department of Engineering Physics,
Tsinghua University, Beijing 100084, China
e-mail: hhong@tsinghua.edu.cn

M.V. Khiem
Applied Climate Division, Vietnam Institute of Meteorology, Hydrology and Environment,
23/62 Nguyen Chi Thanh, Ha Noi, Viet Nam
e-mail: khiem@vkttv.edu.vn

S. Kato and K. Hiyama (eds.), *Ventilating Cities: Air-flow Criteria for Healthy and Comfortable Urban Living*, Springer Geography,
DOI 10.1007/978-94-007-2771-7_2,

environmental problem encountered in dense urban areas in summer. The use of the sea breeze to mitigate the urban heat island phenomenon has attracted attention in coastal cities. Some statistics show that about 40% of the world's population lives within 100 km of the coast (World Resources Institute, Fisheries (2007) Population within 100 km of coast). Further investigation of the environment in the urban area near the coast is, therefore, important. In this chapter, Tokyo is targeted for investigation. Tokyo is the Japanese capital, and its surrounding region, the Tokyo metropolitan area, comprises a circular area with a radius of 50 km and a population of over 30 million. Within this area, the sea breeze from Tokyo Bay is an important factor mitigating the air temperature rise in summer. However, ongoing urbanization could be changing not only the mechanism of the energy balance on the urban surface but also the sea breeze system in the region. To clarify the effects of urbanization, a mesoscale meteorological model was adopted for analysis. Simulation results suggest that expansion of the Tokyo metropolitan area from the 1970s to the 1990s has induced a temperature rise near the ground and that the difference is largest in inland areas. Moreover, the time of sea breeze penetration is delayed in suburban areas. These results suggest that the ongoing urbanization process could raise the air temperature and change the sea breeze system in the Tokyo metropolitan area.

Keywords Urban heat island phenomenon • Urban climate • Urban boundary layer • Mesoscale meteorological model • Land use change

2.1 Overview of Urban Heat Island Phenomenon in the Tokyo Metropolitan Area

2.1.1 Overview of Research on Urban Climate and the Urban Heat Island Phenomenon

In the twentieth century, rapid urbanization produced many environmental problems throughout the planet, including air pollution, water pollution, ground pollution, environmental noise, etc. The urban climate problem is a characteristic environmental effect caused by dense urban areas. Above all, the urban heat island (UHI) phenomenon is a typical urban climate problem found in large cities.

The UHI phenomenon was first recognized in the nineteenth century. The earliest urban climate research was conducted by Luke Howard (1772–1864). Howard was an amateur meteorologist and well known for his nomenclature system of clouds. Furthermore, he made an important contribution to the field of urban climate research by being the first person to detect the urban heat island phenomenon and suggest its causes. From 1806 to 1830, Howard measured various meteorological elements, i.e., wind direction, pressure, temperature, precipitation, and so on, outside London. Comparing these recorded data with measurements taken in the center of London by the Royal Society, Howard found