Building and Environment 82 (2014) 215–227

Contents lists available at ScienceDirect

Building and Environment

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

Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: A Chinese vernacular house case

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A R T I C L E I N F O

Article history:
Received 14 June 2014
Received in revised form
6 August 2014
Accepted 17 August 2014
Available online 27 August 2014

Keywords:
Building microclimate
Summer thermal comfort
Adaptive thermal comfort
Free-running building
Diverse spaces
Chinese vernacular house

A B S T R A C T

In this paper, the authors first clarify the definition of building microclimate in free-running buildings and the relationship with summer thermal comfort. Next, field measurements were conducted to investigate the microclimate in a Chinese traditional vernacular house. Subsequently, the results of measurements were compared with a dynamic thermal and a CFD simulation in order to determine the building microclimate and thermal comfort of the present vernacular house over the period of an entire summer. The field measurements show the present Chinese vernacular house has its own independent building microclimate in summer, which is in accordance with the main character of microclimate in terms of different distributions of solar gain, air temperature and wind velocity in different spaces. The simulation results of the vernacular house could be matched well with the field measurements. According to the simulations, at night, a comfortable temperature could be obtained throughout most of the summer period whereas in the daytime the operative temperature was higher than the comfortable temperature for one-third of the summer period. Wind velocity in the semi-outdoor and outdoor spaces however, improves the thermal comfort significantly. The thermal comfort environment can thus not only change in time but also in space. This example of the vernacular building shows that it is possible to create comfortable conditions for the inhabitants when not only the indoor climate is taken into account but the whole building microclimate as defined in this paper. This paper also shows that the simulations can predict the building microclimate.

1. Introduction

In recent years, researchers, environmentalists and architects have become increasingly interested in the thermal performance of buildings in summer. This interest is mainly directed at the two main aspects, energy consumption and thermal comfort. Rising standards of living, the globalization of modern architecture, urban heat islands and global climate change, together with the affordability of air conditioning, have caused the energy demand for cooling to increase dramatically. Studies have shown that refrigeration and air conditioning are responsible for about 15% of the total electricity consumption in the world [1]. On the other hand, the thermal comfort in modern buildings, whether free-running or air-conditioned, tends to be poor. Inferior architectural design can make it impossible to utilize passive cooling approaches for thermal comfort in summer, while the constant use of air conditioning leads to uncomfortable conditions due to the bad indoor environmental quality.

Climatic features can significantly influence the performance of the built environment in terms of thermal comfort and energy consumption. When spatial scale is considered, the climate can be subdivided into macro-scale, meso-scale, local scale and micro-scale [2]. There is no strict boundary between the different scales. For urban planning and architectural design, local climate and microclimate are the main focus.

Bioclimatic design is an approach based on local climate. These methods result in buildings that respond to the climatic conditions of their environment, are able to modify them and thus contribute to resource conservation with maximum comfort [3]. The design of the built environment can modify the climate on different scales, especially the microclimate scale. Hence, in bioclimatic building design in which passive approaches are applied, it is crucial to first analyse the local climate and microclimate to which the building is

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http://dx.doi.org/10.1016/j.buildenv.2014.08.022
0360-1323/

exposed and to explore how the microclimate can be modified and improved to ensure a good building performance.

Neither the horizontal extent nor the vertical thickness of the air layer of the microclimate is rigidly defined, although several millimetres to 1 km is often employed [2]. Within a particular region, deviations in the climate are experienced from place to place within a few kilometres distance, forming a small-scale pattern of climate, called the microclimate [4]. With respect to urban and building design, neighbourhood, urban canyon, building block, building and indoor space are all part of the microclimate spatial scale. In the microclimate, the distribution of air temperature, relative humidity, solar radiation and wind characteristics are the principal elements determining the physical character of the microclimate.

A literature review revealed that the majority of previous studies have focused on the urban microclimate in relation to the urban scale, i.e., neighbourhoods, urban canyons and building blocks. Some researchers have conducted field studies on the thermal environment, assessing aspects such as air temperature distribution and wind characteristics in the urban microclimate (urban canyon and streets) [5–7]. Others have examined the effect of geometry and orientation on urban and street canyon [8–11]. Still other researchers have studied the thermal comfort of outdoor and semi-outdoor environments in the urban microclimate [12–15]. Studies have also been carried out to investigate how to use passive approaches to improve the thermal comfort of outdoor spaces [16–19]. On the other hand, large number of studies focused on indoor climate. Few studies focused on the microclimate at the single building scale.

In this paper, the authors first clarify the definition of building microclimate in free-running buildings and define the building microclimate in terms of building spatial features, thermo-physical features and the relationship with summer thermal comfort. Next, the authors discuss the field measurements conducted to investigate the microclimate in a Chinese traditional vernacular house. This house is free-running, comprises of a number of different spaces and is situated in a hot and humid summer climate region of China. Subsequently, the results of measurements were compared with a dynamic thermal and a CFD simulation in order to determine the microclimate and thermal comfort of the typical Chinese vernacular house over the period of an entire summer. The authors expect their findings to contribute to more comfortable and more energy-efficient buildings using bioclimatic design in hot and humid summer climates.

2. Building microclimate and thermal comfort

In this section, the authors clarify the definition of building microclimate, as used in this paper. The authors also attempt to clarify the relationship between building microclimate and summer thermal comfort in the free-running buildings.

2.1. Building microclimate

As mentioned above, the term microclimate in urban planning and urban design always refers to the climate connected with a group of buildings in the urban fabric or to the climate around a single building. But, within a particular building, a small-scale pattern of "building microclimate" is found, which is different from the microclimate related to the urban fabric scale. In this paper, "building microclimate" refers to one type of microclimate, involving the indoor space and the spaces around the indoor spaces of a particular building. It is the extension of the indoor climate. The building microclimate is mainly defined by the spatial and the thermo-physical properties.

The spatial characteristics of a building microclimate regard the following aspects (Fig. 1):

- The spatial scale is smaller than the urban fabric. It rarely covers an area more than several hundred metres wide, but is bigger than an indoor space alone. It is limited to one particular building, whether a small house or a big stadium.
- The spaces in a building microclimate are connected for particular building functions in one building. The spaces are connected either directly or by building components such as walls, roofs and beams. Sometimes, the area of an urban canyon or building block is similar in size to one big single building. However, urban canyons and building blocks lack continuous spaces for particular building functions. Architectural decisions are typically made at the building scale, thus effect the building microclimate.
- The existence of diverse types of spaces is another important feature of the building microclimate, distinguishing it from a single indoor climate. Indoor space, semi-outdoor space and outdoor space are the main spatial types in a building microclimate. Hence corridors, semi-outdoor rooms, courtyards, patios and atria play a very important role in the spatial design to obtain a good building microclimate.
- The boundary between the different spaces should be adaptive and switchable. For example the openable windows and doors in the boundaries always are adaptive. This applies especially to the boundary between the indoor space and the semi-outdoor space and outdoor space. As a result, the spaces can be mutually adjusted as needed.

At the building microclimate scale, the thermo-physical properties are as follows:

- The average air temperature and humidity in the building microclimate are influenced by the local climate. However, air temperature and humidity distribution vary in the different spatial types. In summer, normally, the indoor temperature of the free-running buildings is lower than the semi-outdoor and outdoor temperature during the daytime; at night, the situation is reversed. The humidity follows the air temperature changes.
- The influence of the local climate on the solar radiation in the microclimate is relatively small, but is significantly influenced by the design of the building components.
- The wind velocity distribution is significantly different in different spaces. Generally, the wind velocity in the semi-outdoor and outdoor space is higher than in indoor spaces. The wind velocity and direction are influenced by the local wind environment, the organization of building spaces and the envelope design.

2.2. Thermal comfort in a building microclimate

In the building microclimate identified above, the spatial features and thermal properties of the building microclimate are interactive, just as in the urban space, where urban form, landscape and used material influence the urban microclimate. Similarly, the building microclimate is significantly influenced by building form, spatial organization, vegetation and landscape in building and construction materials. The essence of architectural bioclimatic design is to understand the local climate and utilize appropriate design strategies for building form generation and material selection, in order to create or modify the building microclimate required for a comfortable living environment. Building form, solar control and natural ventilation are the main