Building and Environment 71 (2014) 259–274

Contents lists available at ScienceDirect

Building and Environment

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

Developing a weather responsive internal shading system for atrium spaces of a commercial building in tropical climates

Fan Wang [a,*], Kittitach Pichatwatana [a], Sue Roaf [a], Lihuan Zhao [b], Zhichao Zhu [a], Jingyan Li [b]

[a] The School of the Built Environment, Heriot-Watt University, Riccarton, Edinburgh EH14 4AS, Scotland, UK
[b] The School of Architecture, South China University of Technology, 381 Wushan Rd, Guangzhou 510641, PR China

ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form
1 October 2013
Accepted 3 October 2013

Keywords:
Atrium building
Buffer zone
Retractable shading system
Thermal comfort
Lighting quality
Cost analysis

ABSTRACT

In response to the non-trivial problem of overheating in glass roofed buildings in low latitudes a study was undertaken to reduce discomfort and high energy consumption in a large atrium building in China. This paper reports on the development of a shading system designed for that building as a remedial solution to reduce temperatures while maintaining adequate levels of natural lighting in the atrium spaces of a large multifunctional commercial building. The effects of the shading system on both the physical indoor environment and its economic implications were analysed using implemented models. Calibrated with the data measured in the building during the hottest season, summer, the models were used to test both thermal and lighting performance of two shading arrangements: high and low level blinds in both open and covered modes on typical overcast days and clear days in summer and winter respectively. Also tested were two types of fabric used for the blinds.

The performance of these tested cases was assessed for solar gain, cooling loads, internal surface temperatures, air temperatures and operative temperatures of both ground floor and surrounding walkways on various levels within the atrium, the major circulation areas. The results reveal that the high level shading, with blinds fixed close to the glazed roof are generally less effective in the provision of thermal and lighting conditions of the atrium, than the low level shading, where blinds are fixed 3–5 m below the glazed roof to form a ventilated void. The financial benefits of these remedial solutions were also assessed using standard economic analysis methods to provide recommendations on their costs and payback periods.

1. Introduction

In recent years, highly glazed spaces have proliferated in commercial buildings [1]. Various forms of atria are used for offices and hotels whilst glazed pedestrian concourses are widely used in malls [2]. Their popularity is due partly to the benefits of natural light penetrating deep into the central communal spaces of buildings. Such forms of glazed building originated in colder regions where the thermal buffers they create at night and the passive solar gain they collect during the day are useful. It has become a common feature that an atrium, often over many stories in the centre of a large tall building creating a large, bright and charming communal space [3]. However, the use of this form has also become popular in other regions, including the hotter countries of Asia (Fig. 1) where they are less climatically appropriate, and yet increasingly commonly found.

Their 'visual' impacts, brightness and openness, can be easily seen at the early design stage even without modelling. Harder to visualise and foresee, and thus too often overlooked, are their thermal effects, overheating risks and high life time costs of operating their cooling system in hot climates [4]. Operational costs only emerge after the building is occupied. High heat gain through the glass results in large, expensive and maintenance intensive mechanical systems with high running costs. The poor thermal performance in such buildings may also necessitate remedial improvements to lower running costs and increase comfort after a couple of years of occupancy [5].

Whilst allowing the natural light to enter, a glazed roof also results in excessive solar heat gain in summer and heat loss in winter. Although the heat gathered at the top of the atrium, especially in the summer could enhance the buoyancy and encourage natural ventilation, it can easily lead to discomfort, particularly on high level balconies, and even overheating in adjacent occupied zones. These problems are exacerbated due to the high solar altitude and ambient temperatures in the tropical climates, where indoor temperatures can exceed outdoor ambient temperatures in

* Corresponding author. Tel.: +44 131 451 4636; fax: +44 131 451 3161.
E-mail address: fan.wang@hw.ac.uk (F. Wang).

0360-1323/$ – see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.buildenv.2013.10.003

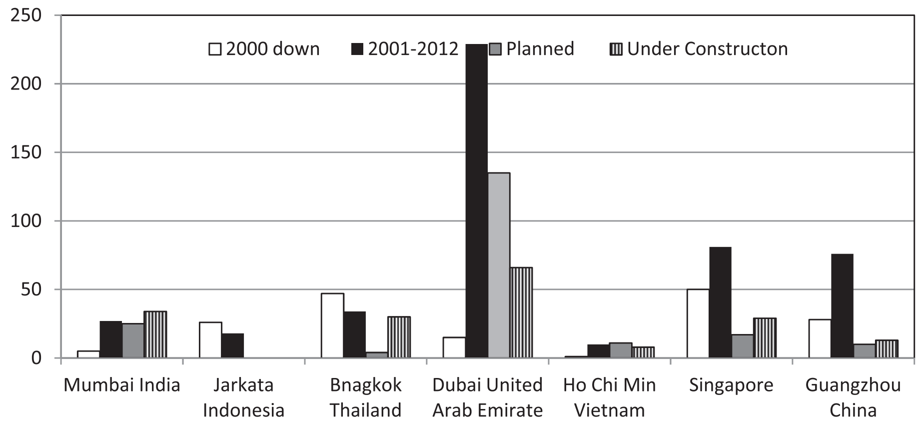

Fig. 1. Gazetteer of Notable large commercial buildings with large atria in hot climate and cold climate countries (Source: http://www.emporis.com/buildings, 2013).

such buildings. The stratification within the upper part of the atrium is intensified and the radiant temperatures of the internal surfaces in the space are enhanced by the direct radiation and convection from the heated air. As the result, the operative temperature inside the atrium leads to thermal discomfort and overheating, particularly in the upper areas [6]. Apart from the fashionable features of glazed atrium roofs and walls, the thermal impacts of the building are further exacerbated by another popular choice, the increasing height of such buildings, can also result in heavy cooling loads and high running costs [7]. These were the problems in a high profile building in Guangzhou, China.

1.1. The building

Built in 2005 as a centre for the textile industry and commence, the building is known as the Guangzhou International Textile City (GITC). With a total floor area of nearly 140,000 m^2 for all floors above the ground level, the building is made of nine rectangular seven storey blocks, which are mainly retail units on the lower four floors and offices on the top three.

The building blocks create four east-west “streets” and two and half north-south streets, which are from 12 to 15 m wide. All are linked and fully open to the outside on the ground level for access of people and commercial vehicles. The streets, together with the junctions, are all covered above their top levels by raised transparent glass canopies forming various atrium spaces. The sides of the atria roofs are all fully open or louvered partially to prevent rain. All these spaces are intended to be airy to suit the tropic climate and open to maximise natural lighting. The central atrium is the largest space with a floor area of 1500 m^2 and height of 35 m (Fig. 2).

Each of the atria is surrounded by walkways (long balconies or side corridors) or concourses over all seven floors providing easy access to the rentable spaces, which were currently occupied by over 4000 brands of textile traders. The design was intended to create a building that facilitates multiple commercial activities related to the textile industry under one roof, from the display of material samples and products to office space and catering, providing a one-stop shop for all, from retailers to individual shoppers, from fashion designers to accessory manufacturers and from fabric dealers to process engineers. At the time of this study, the GITC was used by approximately 30,000–50,000people a day including visitors, tenants and staff members.

1.2. The problems

The atrium spaces, ground floor and balconies, were all naturally ventilated while the surrounding retail units were air-conditioned daily from 0800 h to 2000 h. The total cooling capacity of the plant was 28,000 kW over 120,000 m^2 of floor area (180 W m^{-2}) and was designed according the National Standard for retail units in that specific climate zone. Almost all the doors of these retail units were fully opened by tenants to extend their trading area to the balcony and to attract potential clients passing by. Most of these doors were either unequipped with air curtains or had the device running improperly thus failing to separate the air conditioned indoor space and the naturally ventilated atrium space. This extended space also became cooling burden for the shop and resulted in the higher electricity bills and resulting dissatisfaction.

Many complaints came from the tenants immediately after the first year of operation regarding firstly, the overheating due to solar gain in the atrium spaces (both on the ground floor and balconies), and secondly, despite the high cooling bills, the building still fails to achieve an acceptable temperature: normally about 26 °C in that area.

A preliminary study was carried out during the summer of 2010 over 35 selected air conditioned retail units to represent the whole building and it revealed that over three quarters of the tenants were complaining about overheating in the atrium. The ratio on the higher levels was even worse: all claimed it was “unbearably hot” particularly in balconies [8]. In most of the tests, the air temperature was around 28 °C in afternoons even when the cooling system had been running at full capacity for over 12 h. The high levels of

Fig. 2. The central atrium in the Guangzhou International textile city building.