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Transformation of industrial planning in Singapore: Study on the microclimatic condition of different industrial estates

Steve Kardinal Jusuf [a, *], Nyuk Hien Wong [b], Zhi Ying Wong [b], Erna Tan [b]

[a] NUS Environmental Research Institute, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore
[b] Department of Building, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore

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ABSTRACT

Despite the progression and variation of Singapore industrial developments over time, present literature have yet to examine the changes in the urban morphology of local industrial estates and consequently, their impact on the microclimate.

The paper discusses the microclimatic condition and urban morphology in four different industrial developments developed by JTC in Singapore, constructed in different decades, and categorized into Business Park development (BPD) and B2 development (B2).

Comparisons of urban morphology and microclimatic condition among the different estates were analysed. In general, it is found that, compared to B2, BPD has a lower mean SVF value, more extensive greenery, higher building height and building mass, a significantly larger proportion of greenery but lesser pavements and building area, and lower building density. There is a decreasing trend in the mean ambient air temperature observed along with the transformation of industrial developments over time. B2 has higher mean air temperature than BPD at all times of the day. B2 has lower diurnal temperature range than BPD which infers that BPD is generally more effective in reducing the heat island intensity.

Finally, critical morphology parameters on ambient temperatures in industrial estates were identified. Within the 50 m radius, critical parameters with significant influence on the minimum temperature (T_{min}) and the average temperature (T_{avg}) values are the green plot ratio (GnPR), the total tree leaf area (TREE) and the percentage of greenery area (GREEN), whereas the critical parameters with significant influence on the maximum temperature (T_{max}) are SVF, GnPR, TREE and GREEN.

1. Introduction

The management of urban growth is a key to the spatial distribution and variability, which in turn affects the environmental quality. Differences in land-use, surface characteristics, urban morphology and atmospheric conditions give rise to variations in the thermal environment within an urban area [2–7]. The impact of land use including commercial, residential, agricultural, industrial uses has been extensively researched using remote-sensing technology in United States, China and Germany [8–11]. More importantly, several overseas studies and Singapore have found that regions associated with industrial activities tend to exhibit higher temperatures than the surroundings [12].

Yu [13] noted that Singapore economy has witnessed a rapid expansion of industrial developments since independence in 1965. According to Han [14], approximately 7000 ha of industrial land and 4 million m^2 of ready built factor space have been developed in the last 36 years. The industrial sector is found to be the largest consumer of electricity constituting 40.2% of the nationwide electricity consumption in 2011 [15]. Currently, the industrial sector takes up 18% of the total land mass and is projected to increase to 20% by 2050 [16]. With the overall supply of industrial spaces set to grow, these trends underline the value of examining the transformation of existing industrial estates to help negate the adverse microclimatic effects for future developments.

Despite the variations in forms and functionalities, Peddle [17] defines industrial estates as a large tract of land, subdivided and developed for use of several firms, distinguished by sharable infrastructure and close proximity, bounded by the restrictions on the lot sizes, access and utilities.

Established in 1968, the Jurong Town Corporation (JTC) is a statutory board in charge of the planning, development, leasing and

* Corresponding author. Tel.: +65 65164691.
E-mail addresses: stevekj@nus.edu.sg, stevekardinaljusuf@gmail.com (S.K. Jusuf).

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Nomenclature

JTC	Jurong Town Council
BPD	Business Park development
B2	B2 development
SVF	sky view factor
T_{min}	minimum temperature
T_{avg}	average temperature
T_{max}	maximum temperature
GnPR	Green Plot Ratio within 50 m radius area
TREE	total tree leaf area within 50 m radius area
GREEN	percentage of greenery area within 50 m radius area
IP21	Industrial Land Plan for 21st Century
LTA	Land Transport Authority
GIS	Geographic Information System
BDG	percentage of building footprint area within 50 m radius area
PAVE	percentage of pavement area within 50 m radius area
HBDG	average height to building area ratio
WALL	total wall surface area
AvgHT	average building height
TURF	turf area within 50 m radius area
TotalGreen	total green area within 50 m radius area
DTR	diurnal temperature range
Gross floor area	all covered floor areas of a building, except otherwise exempted, and uncovered areas for commercial uses [1]
Gross plot ratio	the ratio of the gross floor area of a building(s) to its site area [1]

management of Singapore industrial estates. With control over 80% of the total industrial land, JTC is the largest industrial landlord and is responsible for the implementation of industrial land use policies to meet the changing and diverse needs of businesses [18].

Faced with the constraints of limited land, strong physical planning framework and administration are essential to optimize land use in view of various competing uses [13]. To prevent urban sprawl and achieve an orderly distributed land use, boundaries, zoning regulations and maximum plot ratio were set out in the Master Plan. Although the Master Plan has undergone several revisions since its inception in 1960s, the emphasis on environmental management is evident in the detailed planning of industrial areas. Heavy industrial areas are concentrated southwest to the central business district and the remaining areas are located along borders of island, away from the cleaner commercial and residential estates [19].

The emergence of different industrial developments since the inception of Master Plan in 1960s can be categorized into three different time frames.

During the period of 1960s–1970s, ready-built standard factories and light industrial estates were constructed to facilitate the efficient set up of labour-intensive industries. These were typically located in suburban areas and near high density housing estates. Flatted factories, small workshop complexes and landed factories were the predominant forms of industrial infrastructure [20].

During the period of 1970s–1980s, industrial restructuring was necessary to retain global economic competitiveness. The switch to capital and technology intensive industries promoted the growth of high-value industrial businesses, thus the emergence of Science Parks and Business Parks. The high land cost and land scarcity necessitated land intensification. With reclamation, en-bloc redevelopment and higher plot ratios set out in JTC's Industrial Land Plan for 21st Century (IP21), multi-storey premises such as stack up and ramp up factories emerged, raising the plot ratio from 0.5 to 2.5. Specialized clusters also housed and promote knowledge-based activities [19].

During the period of 2000s–2010s, an integrated planning approach was adopted to realize the concept of live-work-play-learn hub, in pursuit of holistic development and sustainability of industrial developments, with an emphasis on environmental quality and aesthetics [20].

Under the Master Plan 2008, the industrial land use is categorized into different zones according to the potential environmental pollution. Lands zoned as Business 1 (B1) and Business 2 (B2) are industrial developments with at least 60% of gross floor area used for light manufacturing or warehousing purposes, leaving a maximum of 40% for ancillary activities such as offices and showrooms [14]. Another category is the Business Parks, set aside for non-pollutive industries and businesses with at least 85% of the total floor area used for its operations. This predominantly includes high-technology, value-added and knowledge-intensive activities [21].

The aim of this study is to evaluate the microclimate with respect to the urban morphological characteristics for the different forms of industrial estates developed by JTC in Singapore.

2. Methodology

2.1. Object of study

The paper is confined to the study of microclimatic condition and urban morphology changes in four different industrial developments constructed in different decades. These include an industrial estate with single-user landed factories, and one estate comprising of a mix of landed and ready-built multiple-users flatted factories, which both are categorized as B2 development. Two different forms of business parks categorized as Business Park Development (BPD), i.e. a pioneer development and an integrated industrial hub are included. They are located at Loyang Industrial Estate (Loyang), Woodlands Industrial Park (Woodlands), International Business Park (IBP) and one-north. The general site locations are highlighted in Fig. 1. All four sites chosen are owned by JTC to minimize hidden factors and allow a common basis for comparison to study the transformation of industrial infrastructure over time.

Background information for the various sites has been obtained from JTC.

Loyang Industrial Estate was developed in 1974–1977. Approximate site study gross floor area (GFA) is 1.16sqkm with gross plot ratio of 2.5. It is located on the eastern of Singapore. This development is categorized as B2 development under Master Plan (2008). Single-storey landed factories were built for aviation industrial centre, manufacturing, repair, overhaul, aviation works and precision parts manufacturing.

Woodlands Industrial Park was developed in 1995–1999. Approximate site study GFA is 1.78sqkm with gross plot ratio of 2.5. It is located on the northern of Singapore. This development is categorized as B2 development under Master Plan (2008). Prototype factories (standalone/semi-detached factories) were built for food production and manufacturing from raw materials, assembly of plants and machinery, and treatment of waste oil/solvents.

IBP was developed in 1992–2009. Approximate site study GFA is 0.37sqkm with gross plot ratio of 1.0–2.5. It is located on the south-