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A review on energy conscious designs of building façades in hot and humid climates: Lessons for (and from) Kuala Lumpur and Darwin

Edward Halawa[a], Amirhosein Ghaffarianhoseini[b,c,*], Ali Ghaffarianhoseini[d], Jeremy Trombley[a], Norhaslina Hassan[c], Mirza Baig[a], Safiah Yusmah Yusoff[c], Muhammad Azzam Ismail[e]

[a] Centre for Renewable Energy, Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Australia
[b] Faculty of Engineering and Architectural Science, Ryerson University, Toronto, Canada
[c] Department of Geography, Faculty of Arts and Social Sciences, University of Malaya (UM), Kuala Lumpur, Malaysia
[d] Department of Built Environment Engineering, School of Engineering, Computer and Mathematical Sciences, Auckland University of Technology, Auckland, New Zealand
[e] Department of Architecture, Faculty of Built Environment, University of Malaya (UM), Kuala Lumpur, Malaysia

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ABSTRACT

Emerging environmental threats originating from rapid urbanization and the associated energy shortages, negative impacts of climate change, and sick building syndromes have led to government sectors and various construction-based professional bodies recognizing the need for developing effective sustainable building design strategies. As a result, growing interest in the development of effective solutions for enhancement of the sustainable energy performance of buildings has been observed in recent years. Along this line, building envelopes that separate the indoor from the outdoor environments, and in particular building façades, play a substantial role for energy saving in buildings. Nevertheless, this study argues that there is a lack of a systematic and comprehensive analysis of the available literature regarding the energy and thermal performance of building façades based on the various possible design and technical configurations, especially in hot and humid climates. Important decisions should be made by architects and engineers during the early design stages of buildings with viewpoints to the ultimate impacts of building physics on the overall energy performance and indoor comfort conditions of buildings. With such a research gap in existing literature, in these early stages many key façade attributes may be overlooked. Hence, this study attempts to develop a state-of-the-art analysis of the existing literature about the circumstances of optimizing the performance of building façades, particularly in hot and humid climates. Likewise, the study extracts practical lessons learned from AEC industry and demonstrates the current status of utilizing energy efficient building façades in recent construction developments in Malaysia (Kuala Lumpur) and Australia (Darwin). Finally, the study draws attention to the emerging innovative solutions for the design of building façades towards improving the energy efficiency of building sector and contributing to the sustainable development of cities.

1. Introduction

The building envelope, and particularly the façade, has a large impact on the thermal and visual comfort of occupants as well as the energy demand of a building. Much of the focus of building façade design has been for the temperate climates of Europe and the United States but the requirements are much different for hot and humid climates where to date research has been scarce. Under the Köppen climate classifications, climates of Kuala Lumpur (Af, tropical rainforest) and Darwin (Aw, tropical savannah) are classified as tropical experiencing warm temperatures throughout the year and have high humidity and rainfall for at least part of the year. As the population of these cities continue to grow and more buildings - residential and commercial - are constructed, the energy demand for cooling of occupied spaces will continue to rise. The impacts of building façade design in hot and humid climates have not been properly understood. This paper presents the state-of-the art review of the energy performance of the building façades in hot and humid tropics and identifies

Abbreviations: AEC, Architecture, Engineering and Construction; DCC, Darwin Convention Centre; DSF, Double Skin Façade; ETICS, external thermal insulation composing systems; GBI, Green Building Index; IEA, International Energy Agency; KLSP, Kuala Lumpur Structure Plan; PCMs, phase change materials; PV, photovoltaic; SGHC, solar heat gain coefficient; VDSF, ventilated double skin façades; WWR, window to wall ratio

* Corresponding author at: Faculty of Engineering and Architectural Science, Ryerson University, Toronto, Canada.
E-mail address: amirhosein.ghaffaria@ryerson.ca (A. Ghaffarianhoseini).

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lessons learnt from the existing research and practices for the cities of Kuala Lumpur (Malaysia) and Darwin (Australia).

2. Rapid urbanization and the need for sustainability: the case of Kuala Lumpur and Darwin

Urbanization has been occurring rapidly in the last century. The world's urban population increased from 30% in 1950 to 54% in 2014 [1]. and the rate is expected to increase over the next few decades [2], with two thirds of the world's population living in urban areas by 2050 [1]. Industrialization, mobility, technology, population and economic growth are known key contributors to rapid urbanization [3]. Although urbanization has brought positive impacts such as establishment of new settlements and towns [4], economic progress, industrial development, modern transportation systems, increased consumerism and globalization [5], its negative impacts are equally significant. Studies have long established the direct relationship between urbanization, economic growth, energy consumption and CO_2 emissions, with population density having a stronger impact on CO_2 emissions [6–10]. Supporting half of human population on less than 2% of the earth's surface, urban areas amass 80% of economic output, consume between 60% and 80% of energy, and emit approximately 75% of CO_2, making them key to tackling climate crises [11,12]. An inevitable and key phenomenon in the process of economic development, urbanization intensifies human socio-economic capital and activities, as well as energy consumption in cities. Significant savings can be achieved by reducing energy use in key components of cities – buildings, transport, and industry – as they consume 35%, 30%, and 31% of the total final energy, respectively, and are important sources of CO_2 emissions [13]. Furthermore, high density compact cities, with mixed-use urban form, are believed to be more resource-efficient than sprawl development [14].

Urbanization has indeed risen to be among the most important factors impacting sustainability, hence the widespread application of sustainable development ideals in urban and neighborhood planning. In 1987, the World Commission on Environment and Development broadly defined sustainable development as "...development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [15]. Sustainable urban development entails the presence of interdependent and desirable social, economic, and environmental qualities that apply to the past, present, and future functioning of the community [16]. A sustainable city is achieved through innovative design, collaborative management and monitoring. The new planning paradigms such as eco-cities, low-carbon cities, smart cities or zero-energy cities share key characteristics of sustainable urban development: reduced energy use, minimal encroachment on ecological spaces, fewer harmful building materials or more closed-looped waste management systems [17]. Buildings as a prominent infrastructure in the urban landscape provide many opportunities to demonstrate a city's pledge to sustainability. Sustainable building in this context refers to both a structure and processes involved that are environmentally responsible and resource efficient throughout the building life-cycle using ecological principles, social equity, and quality value, and which promotes a sense of sustainable community [18].

As with its counterparts in other developing countries, the rapid rate of urbanization continues to characterize development in Malaysia. Its average urban population growth rate of 2.0% was among the fastest in the East Asian region. In 2010, urbanization rate in Malaysia reached 71%; by 2014 this rate increased to 74% [19]. Kuala Lumpur, which is the capital of the nation, is the most populous and fastest growing metropolitan area with an estimated population of 1.73 million in 2015 [20]. The larger urbanised area officially known as the Greater Kuala Lumpur, meanwhile, is home to an estimated 7 million people [1]. Given the existence of a long-run co-integrating relationship among CO_2 emissions and energy consumption with affluence and population growth [21–23], it is projected that energy consumption and the associated CO_2 emissions will escalate due to its high urbanization rates as development of Kuala Lumpur progresses.

The most spectacular change in the urban landscape of Kuala Lumpur was attributed to the Kuala Lumpur City Centre (KLCC) project which begun in 1992. Dubbed as the "city within a city" and the largest real estate development in the world at the time, it included the world's tallest building, the Petronas Twin Towers [24]. All buildings in the complex which were built and maintained at world class standards have enabled them to command premium values. KLCC is currently the most prominent element and point of reference in the Kuala Lumpur urban landscape where many new and tall buildings are concentrated. The spread of expressways and big-box shopping centers in Kuala Lumpur in the meantime, appeared to follow the trends already observed in the US and elsewhere [25]. While the iconic colonial-era buildings in Kuala Lumpur were mostly designed to use local resources and adapted to the local hot and humid climate, most of the newer buildings which began to be erected throughout the city in the late 1990s and early 2000s used glass shells. They neither paid sufficient attention to the tropical climate nor took appropriate measures to conserve building energy [26].

Since the Rio Summit in 1992, serious efforts to integrate sustainable objectives into urban development plans in Malaysia were evident in the National Urbanization Policy (NUP) (2005) [27] and its corollary National Physical Plan (2009) [28], as well as the lower tier State Structure Plans and Local Plans. In this context, the formulation of the Kuala Lumpur Structure Plan (KLSP 2020), while embodying the goal of the NUP that emphasises a balanced social, economic and physical development within urban areas, incorporates further planning approaches for sustainable urban development that are current and best practiced. These include the maximized use of existing infrastructure through urban regeneration and redevelopment, compact urban form and transit-oriented development. Additionally, the Kuala Lumpur City Hall adopts the various Guidelines prepared by the Federal Department of Town and Country Planning Malaysia as tools to address the objectives and planning requirements for sustainable urban developments. The Guidelines for Green Neighborhood (FDTC 2012) [29] for example, which cover three major design criteria of smart location, neighborhood pattern and design as well as green infrastructure (greenfrastucture), identify buildings that meet the requirements of a green neighborhood as: (i) energy efficient, (ii) use recycled materials for construction, (iii) engage in sustainable building planning and management and (iv) utilize green technology innovations. As the local planning authority, the Kuala Lumpur City Hall takes a voluntary approach to green features in buildings, as no regulations require such features yet in Malaysia.

The integration of sustainable objectives into development plans in Malaysia is corroborated in urban policies, plans and strategies with local planning authorities voluntarily incorporating green features in buildings. While the codes of practice and standards for green building are not mandatory in the country, the Green Building Index (GBI) is frequently used as a rating tool for green buildings and township development. The six criteria of GBI include: (i) energy efficiency, (ii) good quality internal environment, (iii) sustainable building planning and management, (iv) use of recycled materials for construction, (v) water efficiency and (vi) utilize green technology innovations. Increasingly green buildings play an important part in sustainable urban development in Malaysia.

Compared to many developed countries, Australia demonstrates a very high urban population with 89% in 2014 [30] and 65% concentrated in the capital cities [31]. In recent decades, very high immigration into Australia contributed to 60% of the nation's population growth [32]. The Australian population is expected to quickly grow to as much as double the current population by 2050 [33,34]. The large cities in Australia are expected to absorb the bulk of this growth, gaining 72% of the predicted national population growth by 2056, or an