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A review on natural ventilation applications through building façade components and ventilation openings in tropical climates

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ABSTRACT

Energy consumption in the building sector is a major concern, especially in tropical climates where high temperatures and humidity force occupants to use electro-mechanical ventilation. Passive design strategies, in particular the application of natural ventilation, are one of the main techniques to moderate temperatures in buildings. Furthermore, many studies have shown reduced operating costs, better thermal comfort and indoor air quality, to be some of the advantages of the application of natural ventilation in buildings. Although existing studies support the efficiency of natural ventilation, the efficiency and practicability of architectural elements to maximise ventilation in buildings remains problematic. This study reviews studies on natural ventilation with other passive design strategies in tropical climates in order to support the argument for the application of natural ventilation in tropical climates. Through a review of studies on the operation of natural ventilation in buildings, it also identifies the most effective architectural elements and techniques in building façades and ventilation openings. The results indicate that ventilation shafts, window-to-wall ratio and building orientation should be applied in future construction. This study also identifies some further specific elements that are worth further investigation, including the shape of louvered windows, different forms of apertures and vernacular elements.

Contents

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1. Introduction

The high demand for building construction nowadays as a result of population increases has become a primary concern of scholars in developing countries. The availability of modern housing as a new type of construction in urban contexts has helped to meet the demand from the huge number of migrants who want to live in fast-growing cities. Although this strategy has mitigated some issues in overpopulated cities, responding to overheated indoor air temperatures in the primary stages of building design has proved a complicated challenge. As a result, most residents in modern housing rely on electro-mechanical ventilation to achieve acceptable and tolerable indoor temperatures in their units. As a consequence, the amount of energy required for cooling and heating buildings has grown to 6.7% of the total world energy consumption, with air-conditioners consuming a major part of this [1,2]. This percentage may be even higher in tropical climates, where high temperatures and humidity intensify air-conditioner usage. According to the World Business Council for Sustainable Development (WBCSD) report [3] of 2008, buildings account for 40% of the world's energy use and produce substantially more carbon emissions than the transportation sector, in order to achieve thermal comfort (cooling or heating) inside units. For instance, the carbon emissions and energy consumption of an air-conditioned house are 67% and 66%, respectively which is higher than a naturally ventilated house. This is why the WBCSD has called for the building sector to achieve greater energy efficiency through a combination of public policies, technological innovation, informed customer choices and innovative design.

In fact, scholars have expressed specific concern about the need to conserve energy in the construction and building sector to reduce air pollution and counteract global warming. Earlier studies have shown that passive cooling systems could reduce world energy requirements by 2.35% [2]. The term 'passive cooling' was coined to describe buildings architecturally designed to be responsive to local climatic conditions, creating comfortable and sustainable indoor conditions by natural means [4]. Another definition by Cook [5] describes passive cooling as any building design technique that not only prevents outdoor heat coming in, but also transfers indoor heat out to a natural heat sink.

Following extensive studies, innovatively designed natural ventilation systems have been applied in buildings in the tropics in an attempt to reduce the use of electro-mechanical ventilation [6–11]. However, the efficiency of natural ventilation in reducing the cooling load in tropical climates is highly dependent on a number of factors such as the outdoor micro-climate, the nature of the terrain, innovative techniques and the design of building elements and so on. This study reviews the literature on the underlying scientific bases for operation of natural ventilation and the related installation of architectural elements in buildings to better understand what elements and techniques are most effective in increasing indoor air velocity in tropical climates. Furthermore, in line with findings of previous studies, this study recommends certain architectural elements and strategies for natural ventilation which are worth testing.

2. Natural ventilation efficiency and precedence in tropical buildings

Studies by Kubota et al. [12–14] cite a reduction in energy consumption and greenhouse gas emissions as some of the advantages of using natural ventilation in the built environment. It further states that using natural ventilation in buildings increases the degree of thermal comfort in both indoor and outdoor environments. Another study regarding the use of fresh air in buildings suggests that naturally ventilated buildings offer greater occupant control and higher levels of environmental quality than electro-mechanically ventilated buildings [15]. A further, comparative study of natural and electro-mechanical ventilation indicates that up to 18% savings in health costs could be achieved by regularly using natural ventilation in mixed mode systems [16]. A study of office buildings by Fisk [17] reveals that the incidence of sick building syndrome could be reduced by greater use of fresh air, saving US$10 to 30 billion in the USA. This concept can similarly be applied to residential buildings such as apartment blocks with higher indoor air quality and a better thermal comfort being achieved through fresh natural ventilation [18]. Taking all these studies together, the overall advantages of applying natural ventilation in buildings can be summarised as follows:

- Reduced operation costs
- Increase the degree of thermal comfort
- Better air quality

Moreover, natural ventilation as a passive cooling strategy in buildings seems to offer significant advantages over other artificial cooling techniques [19], including other passive design techniques in tropical climates.

Studies on radiation cooling by Givoni [20,21] for example confirmed that this strategy does not work well in a hot and humid climate. The lack of temperature fluctuation between day and night, high humidity and cloud cover in the sky are all variables which reduce the rate of heat transfer and, also trap heat inside the building, causing uncomfortable thermal conditions. By the same token, high levels of humidity reduce the efficiency of the evaporation cooling technique. Wu and Yellott [22] point out that evaporation cooling works effectively when the tangible heat in the air stream is exchanged for the latent heat of water droplets or wet surfaces. However, in tropical regions there is a need to remove moisture from the indoor environment, where it otherwise condenses in the air or even onto surfaces, and then to apply air velocity (drafts) from outdoor in order to achieve effective evaporation.

Based on above climate characteristic, it could be argued that natural ventilation is the best technique to achieve comfortable indoor temperatures and humidity levels inside buildings. However, for this technique to achieve maximum efficiency, strategies that avoid heat are also needed. In other words, natural ventilation can enhance cooling significantly, but only where attention has been paid in the primary stages of building design to minimising heat absorption from the surrounding environment. Table 1 shows some relevant heat avoidance techniques as complementary strategies to achieve effective natural ventilation [4,23–31].

3. Natural ventilation operations and principles in buildings and its application through architectural elements

3.1. Natural ventilation operations and basic principles in buildings

Air movement is the key requirement in the overall ventilation process when integrating and designing building façade, building form, apertures and building orientation [32]. In addition, a study by Chen [33] indicates that temperature, humidity, air flow patterns and air velocity are key factors to consider when collecting, measuring and evaluating data on indoor temperatures and inside air flow quality. Moreover, outdoor air velocities can also affect indoor air movements and temperatures as a result of differences in air pressure applied through building façades by the appropriate location of openings and passive design strategies [34].