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An evolutionary approach to single-sided ventilated façade design

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Abstract

A significant portion of the carbon and greenhouse gas emissions of residential buildings in Australia is associated with energy consumption for comfort and health. This study aims to reduce the carbon emissions of residential buildings by optimizing façade design. Targeting to minimize thermal loads, mechanical ventilation will be substituted by natural ventilation, meanwhile indoor environments and appropriate visual comfort will be improved. An evolutionary approach based on a Genetic Algorithm (GA) is developed to determine a set of optimal solutions of façade design for the performance targets of ventilation efficiency, energy consumption, and visual comfort. The proposed approach comprises: an evolutionary process model; the genetic representation of single-sided façade design; genetic operation methods; and fitness functions of multi-objective performance targets as well as Pareto evaluations. The process model enables mapping of façade design options and performance targets to evolve over time. Ventilation, energy and comfort analysis of single-sided ventilation are conducted for the evaluation of the resulting performance of façade design. The expected research outcomes will improve low carbon façade design of residential buildings while reducing cooling and heating costs for the construction industry and the consumer.

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Keywords: Single-sided ventilation; façade design; genetic algorithm (GA); energy efficiency; ventilation efficiency; thermal comfort; visual comfort; multi-criteria assessment; genetic representation

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1. Introduction

Nearly 40 percent of the residential energy use in Australia is attributed to heating, ventilation and air conditioning (HVAC) systems that aim at creating a better indoor environment and maintaining health and productivity for the occupants. The huge amount of energy consumed, and the associated greenhouse gas emissions lead to the conclusion that a more sustainable approach, using renewable energy sources, is needed to provide an acceptable indoor environment in residential buildings. This suggests the need for a natural ventilation solution as an answer to decreasing unsustainable energy use and greenhouse gas emissions [1].

The efficiency of natural ventilation in providing a pleasant indoor environment and decreasing energy consumption depends on the ventilation type, commonly: single-sided ventilation (SSV) and cross ventilation (Fig.1). Although cross ventilation is known to be more efficient, single sided ventilated buildings are the most prevalent design type in metropolitan cities. Unlike cross ventilation, wind turbulence strongly affects airflow through an opening in SSV [2]. Since this parameter is unstable, evaluating the airflow needed to provide a pleasant indoor environment is complicated, and an unsatisfactory indoor environment is more likely to happen in an SSV building.

The performance of wind-driven SSV is mostly a function of facade treatments such as vertical and/or horizontal protrusions, window type, area, location and size. All possible permutations of these parameters will create a large design space and therefore to reach an optimum combination may be costly.

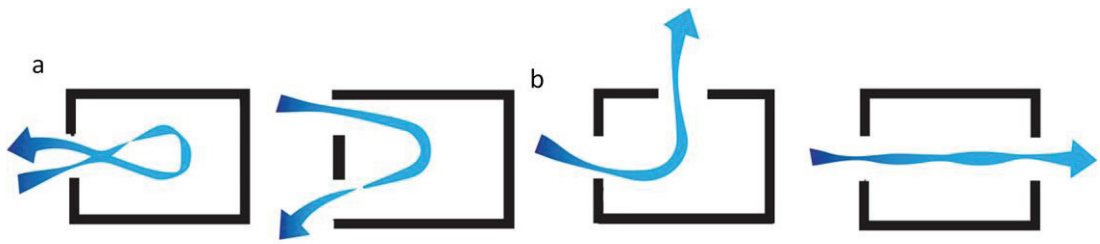

Fig.1. (a) single-sided ventilation and cross ventilation; (b) cross ventilation

Evolutionary optimization approaches have been proven previously to be effective in resolving design and building-related problems. Such approaches are capable of handling an extremely large number of variables and potential solutions in a huge design space and they can produce unexpected optimal results [3]. The Genetic Algorithm (GA) has been introduced as one of the most powerful evolutionary optimization approaches to study natural ventilation problems [4, 5]. In a GA optimization of SSV, the vast design space of façades and their design variables can be explored and successful sets can be evolved to the next generation to ultimately converge to solutions within an acceptable range of performance targets.

In addition to ventilation efficiency, a practical SSV solution needs to satisfy objective targets of energy consumption and visual comfort. An optimum facade design for maximizing natural ventilation (very large openings as an extreme example) may satisfy natural ventilation efficiency while conflicting with visual comfort.

GA has also been a successful tool for multi-objective optimization problems. Some studies dealt with the optimization of the building envelope construction type and insulation level for walls, roofs and floors [6, 7]. A more thorough research was conducted by Magnier et al. [8] to help in the design process of low-energy buildings. The authors selected the window to wall ratio (WWR) as the single variable representing the envelope. Adding this to variables representing the HVAC system, they found the best solutions for thermal comfort and energy use based on a GA process. Caldas et al. [9] also used a GA-based process to look for optimized design solutions in terms of daylighting, heating and cooling performance. They addressed limited variables relating to windows (placement and sizing of the windows) in an office building. In addition Tuhus-Dubrow et al. [10] developed and applied a simulation tool to optimize building shape and envelope features. Wall and roof construction, foundation types,