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RESEARCH ARTICLE

Parametric study on the performance of green residential buildings in China

Xi Wang[a,*], Hasim Altan[b], Jian Kang[a]

[a]*School of Architecture, University of Sheffield, Western Bank, Sheffield S10 2TN, United Kingdom*
[b]*Faculty of Engineering and IT, The British University in Dubai, DIAC, Dubai, UAE*

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Abstract
The parametric study of the indoor environment of green buildings focuses on the quantitative and qualitative improvement of residential building construction in China and the achievement of indoor thermal comfort at a low level of energy use. This study examines the effect of the adaptive thermal comfort of indoor environment control in hot summer and cold winter (HSCW) zones. This work is based on a field study of the regional thermal assessment of two typical cases, the results of which are compared with simulated results of various scenarios of "energy efficiency" strategy and "healthy housing" environmental control. First, the simulated results show that the adaptive thermal comfort of indoor environment control is actually balanced in terms of occupancy, comfort, and energy efficiency. Second, adaptive thermal comfort control can save more energy for heating or cooling than other current healthy housing environmental controls in China's HSCW zone. Moreover, a large proportion of energy use is based on the subjective thermal comfort demand of occupants in any building type. Third, the building shape coefficient cannot dominate energy savings. The ratio of the superficial area of a building to the actual indoor floor area has a significant positive correlation with and affects the efficiency of building thermal performance.

1. Introduction

Chinese urbanization has undergone more than three decades of "reform and opening" (Gu et al., 2012). The country's economic development has stimulated significant growth in rural areas, the physical size, population, and new residential building construction of which have increase.

*Corresponding author. Tel.: +44 114 222 0375; fax: +44 114 22 0315.
E-mail address: rexarch@gmail.com (X. Wang).
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China's national development strategy of "green building" was announced in the special planning outline of the country's 12th Five-Year Plan (Wu and Xu, 2013; Ye et al., 2013). This green building strategy has two main development targets in new building construction: to produce a comfortable building environment and to encourage the efficient use of energy through energy conservation techniques. The most important design strategy of a residential building has previously focused on energy efficiency, and the building criterion of JGJ134-2010 (MHURD-PRC, 2010) usually provided the design standard for indoor environmental design or the guideline for building operation. The key guidelines contained in the document "The Technical Essential for Construction of Healthy Housing" published in 2004 (CNERCHS-PRC, 2004) clearly defined the norm of comfort in indoor environmental designs. However, such a green building strategy soon moved beyond economic efficiency and also considered the comfort and well-being of local occupants. Knowledge of user perception and satisfaction in green buildings remains lacking (Gou et al., 2013). Gou presented a huge difference in satisfaction and comfort in among different green buildings. They further recommended the need to balance the personal comfort of occupants and sustainable levels of energy use.

A green building is defined as one that is energy- and resource-efficient to sustain the life cycle of its operations while being conducive to the health and comfort of its occupants. Green buildings may be considered as a small-scale "ecological footprint" with the following characteristics or effects: minimal energy use; minimal requirement for water, material, and energy resources throughout its life cycle; conducive to occupant health productivity; and minimal waste, pollution, or environmental degradation (Gabay et al., 2014). In other words, a green building is characterized by a sustainable design that meets the needs of present users without compromising the ability of future generations to meet their own needs (Roufechaei et al., 2014). The green building revolution has proven to be a significant and irreversible event in the building sector and a change that has improved building environments in urban areas and global environments (USEPA, 2009;USGBC, 2009). The intensive study on 40 green projects and hundreds of existing reviews developed by Lawrence Berkeley Laboratory and Capital E Group (Kats et al., 2003) show that the cost of occupant comfort, productivity, and health are larger than those spent on construction and operation. The U.S. Green Building Council launched a survey to present a sustainable building design and identify how such a design can positively affect human living; this survey eventually became a significant study on green buildings (Heerwagen, 2000; Reeder, 2010; Sighn et al., 2010). Two large-scale studies were also launched by the Center for Built Environment of the University of California, Berkeley in North America (Abbazadeh et al., 2006; Brager and Baker, 2008; Leaman and Bordass, 2007) and by Building Uses Studies Ltd. in the UK (Leaman and Bordass, 2007). These two studies highlighted the limitations of green building performance and occupant comfort and satisfaction (Fu 2002a, 2002b). Moreover, the indoor environments of "green buildings" became an extension of research on sustainable design, which focused only on natural impact while disregarding occupancy issues. Only a few relevant parametric studies have focused on the indoor thermal environment of green residential buildings in China with consideration of their thermal comfort and energy efficiency. Regional occupant thermal cognition is becoming increasingly important in building designs that follow the "people first" concept.

A cursory review of the literature shows that two different approaches are employed to define thermal comfort, namely, the heat-balance and adaptive approaches (Djongyang et al., 2010). The steady-state heat-balance model of thermal comfort is premised on the deterministic logic of physics-physiology-subjective thermal sensation from climate chamber studies. The adaptive approach differs from the theory of stable thermal transfer; consistent conditions of measurement are impossible in field studies under this approach. This method holds that people achieve thermal comfort by flexibly adapting to the overload in the thermal environment to which they are exposed; this idea is also called the "experiential realism" of determining thermal comfort, which in turn promotes the "real" participation of actual occupants (Schiavon and Melikov, 2008). Adaptation is a complex process that determines the negative effects of "adaptive feedback" (Yao, 1997). The logic of the adaptive *PMV* (*aPMV*) model developed by Yao holds that the full operational details of human adaptation are complicated and can even be partially unknown because such details are based on an individual's own physiological, psychological, and behavioral adjustment (Yao et al., 2009). These complicated processes of the "black box" are based on the concept of cybernetics, which considers the influence of social, economic, cultural backgrounds and of the previous thermal experience on behavioral adaptations. The adaptive thermal comfort approach has been used in the environmental assessment of classrooms (Yao et al., 2010), offices (Bouden and Ghrab, 2005; Liu et al., 2012), free-running buildings (Nicol, 2008; Nicol and Humphreys, 2002), and air-conditioned buildings (Mui and Chan, 2003). Some studies that employ adaptive thermal comfort have been specifically conducted in the context of Indian apartments (Indraganti, 2010; Singh et al., 2011). Only very few studies employ this approach in investigating residential buildings with a mixed mode of natural ventilation (NV) and split air-conditioners (SAC) in China. Residential buildings are usually controlled by a mixed mode of ventilation. NV provides fresh air and cools down the indoor air temperature when the environment is uncomfortably warm, but it results in an unwanted waste of energy (Liu et al., 2012; Yin et al., 2010). Therefore, NV significantly affects the balance of indoor thermal comfort and energy efficiency.

This study investigates whether the adaptive thermal comfort approach can effectively achieve indoor thermal comfort while saving energy. A parametric simulation is conducted on the basis of data input from field study results. Through the results of the estimations, the actual subjective thermal sensation in local residential buildings is discussed. In particular, we discuss the issue of whether the adaptive thermal comfort approach, including thermal comfort perception and energy performance, improves "green buildings" in a parametric design. This study also extends the investigation on building performance, which used to be defined solely by the "building shape coefficient."