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The role of occupant behavior in low carbon oriented residential community planning: A case study in Qingdao

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ABSTRACT

When planning a residential community, an important factor–occupant behavior–is often omitted. Previous research suggested that the age of occupants may significantly affect the dwelling time and use of air conditioners, thus should be considered during low carbon oriented residential community planning. In this study, an energy related occupant behavior survey recently conducted in Qingdao city is presented. Through this survey, the thermal preference, dwelling time, and air conditioners usage behavior of three different family structures (young couple family, old couple family, and couple with parents family) are analyzed. These information, together with urban planning parameters (floor area ratio, building coverage ratio, aspect ratio, etc.) are then fed into energy simulation models, to investigate the role of occupant behavior in low carbon oriented residential community planning. The results show that the energy demand of old couple family is more affected by community planning. Aspect ratio is more important than height in terms of space cooling and heating demand. The optimal aspect ratio strongly depends on the type of occupants and HVAC system. In general, aged occupants need more heating energy, thus are better located in buildings with lower aspect ratio. Communities with district heating system and decentralized cooling system need lower aspect ratio than that with other types of HVAC systems. The results have important implications to low carbon oriented residential community planning.

1. Introduction

Residential buildings occupy a significant portion of global energy usage. An efficient way to alleviate global warming and improve environmental sustainability is to enhance the residential building energy efficiency.

In general, it is believed that building energy consumption is affected by four factors: occupant behaviour, building geometry and envelope properties, urban planning, and building energy systems [1]. During the past, while the role building geometry, envelope properties, and energy systems in energy consumption have been heavily studied [2–5], the impact of occupant behaviour and urban geometry were studied with much less rigor. Nevertheless, as the impacts of urban geometry parameters are of interest to urban planners, some studied have already been undertaken.

Ko recently conducted a literature review to identify key planning parameters related with the energy performance of residential communities, and concluded that building density, exposed building surface area, and tree planting are the three most important parameters [6]. Besides, the effect of mutual shading due to the layout arrangement of buildings was emphasized in the study of Pisello [7]. Stromann-Andersen & Sattrup showed that the geometry of an urban canyon can increase the energy consumption of office buildings by 30% and that of residential buildings by 19% [8]. Along this line, Taleghani et al. compared three types of block typologies (single, linear, courtyard) in the Netherlands, and concluded that courtyard block is the most energy efficient form [9]. It is summarized by Sanaieian that, urban geometry affects building energy consumption mainly through three mechanisms: (1) change the solar accessibility of buildings; (2) change the thermal environment and ventilation around buildings; and (3) change the heat transfer process between buildings and its surrounding climate [10].

The above studies have undoubtedly shown that, building layout and geometry affect the space cooling and heating demands, thus should be taken care when designing residential communities with high energy performance. However, what is missing in these studies is the interrelationship between urban geometry and occupant behaviour, which could significantly change the optimal urban geometry. A study of the US residential energy use by Steemers et al. found that occupant behavior affects the energy consumption significantly in summertime, and occupant behavior can accounts for

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Table 1
Information of the surveyed estates.

Names	Real Estate Typology	Construction year	Floor Area Ratio	Green Area ratio	Average monthly family income (RMB/m)	Neighborhood
Lushang	Super Block	2013	5.2	30%	7870	Zhuhai Rd.
Hai'er	Super Block	2006	1.6	40%	8704	Fushan hou
Lihai	Small grid	2003	1.15	45%	6972	Fushan hou
Haiqing	Small grid	1999	3	35%	8093	Zhuhai Rd.

Fig. 1. Location of the surveyed real estates.

47% of the variation in cooling energy while building explains less than 10% [11].

Recently, with the increasing demand to fill the gap between buildings simulation and actual building energy consumption, understanding how occupants act at various conditions (time, temperature, solar radiation, etc.) is urgently needed [12]. For this purpose, onsite measurement is becoming a popular approach. Methods such as CO_2 density, camera, motion detectors have been developed to monitor occupancy presence and behavior [13]. For example, to understand how occupants use AC units in summer and winter, Schweiker & Shukuya monitored 39 single occupant rooms in a foreign student dormitory in Tokyo. While the temperature, humidity, and window opening are detected using wireless sensors, the usage of AC units is determined by comparing indoor and outdoor absolute humidity [14]. Their research suggested that both outdoor temperature and individual background significantly affect the usage of AC units.

Compared with onsite measurement, questionnaire survey approach has the advantage of fastness and low cost. By asking the respondents to fill out a survey form, information of interest can be quickly collected. With this approach, Fan surveyed 3446 households in the greater Sydney region in Australia, and found that the number of occupants has the largest impact on household energy consumption [15]. Chen et al. surveyed a number of families in Hangzhou city (642 families in winter, and 838 families in summer), and showed that occupant age is a strong influential factor to energy consumption, and the household characteristics and occupant behaviour together could explain up to 28.8% of the energy use variation [16]. Furthermore, Lin & Deng surveyed the AC unit usage behavior of 554 Hong Kong residents, and found that more than 80% residents kept AC units on for more than 5 h at night [17].

Apparently, both urban geometry and occupant behavior affect building energy consumption to some extent. However, by far the contribution of these two factors to energy consumption in real settings has been studied by few. Therefore, the research presented in this paper intends to: (1) understand how residents in Qingdao city use AC units in summer; (2) evaluate the implication of occupant behavior on optimal community layout planning. To achieve these, a systematic research methodology is designed as following. First, the dwelling time and thermal preferences of various family structures (young couple, old couple, young couple with parents) are collected with questionnaire survey approach, due to its fastness, low cost, as well as to avoid privacy issues; second, simulation models are established for all of the surveyed real estates, which are then calibrated based on monthly electricity consumption data; third, parametric analysis based on the developed models is then conducted to identify the optimal community planning parameters; finally, the influence of family structure on energy consumption and optimal planning parameters is analyzed.

The content of this paper is as follows. First, the procedure and results of the questionnaire survey are introduced; second, the energy modelling method and model validation process is presented; third, the parametric analysis framework as well as the results are described; finally, conclusion remarks are given.

2. Occupant Behavior (OB) Survey

2.1. Survey procedures

To collect information regarding household characteristics and energy related occupant behavior in residential buildings, a one-week long survey was conducted in Qingdao city, Shandong Province (from July 1st to July 7th, 2015).

The first step was to choose the survey samples. To allow the variable of urban geometry to be compared, four housing estates were selected: Lushang, Hai'er Eastern Town, Lihai Garden, and Haiqing Garden. These estates are mainly distributed in two neighborhoods: Zhuhai Rd. neighbourhood and Fushan Hou neighbourhood (Fig. 1). A detailed information of these estates is shown in Table 1. While Lushang and Hai'er are high rise apartments constructed within 10 years, Lihai and Haiqing are middle rise apartments constructed 10 years ago. An exterior view of the four real estates is shown in Fig. 2.

Secondly, in each estate, around 100 survey questionnaires were distributed to its residents through the local residential committee, which were then collected again by the residential committee and sent back. The questionnaire includes mainly three types of questions: household characteristics, occupant preferences, and energy usage. A list of questions in each category is shown in Table 2. The survey results are presented in the following section.

Table 2
List of survey questions in the questionnaire.

Household characteristics	Q1: Number of residents in the family Q2: Type of family structure (couple, single, couple with kids, etc.) Q3: Family income Q4: House area Q5: Number of air conditioner and nominal power
Occupant behaviour in space cooling	Q6: Type of summer cooling (air conditioner or fan) Q7: Air conditioner usage behavior (always on, turn off when away, turn off at night, etc.) Q8: Summer indoor temperature setpoint (below 26 °C, between 26 °C and 28 °C, above 28 °C)
Energy usage	Q9: Electricity utility in spring/autumn, summer, and winter Q10: Natural gas utility