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The Impact of Occupancy Energy Use Behaviour of High-Rise Dwellings In Southeast China

Wuxia Zhang[1*], John Calautit[1], Neveen Hamaza[2]

[1] Department of Architecture and Built Environment,
University of Nottingham, UK
e–mail: wuxia.zhang@nottingham.ac.uk (Corresponding Author), john.calautit1@nottingham.ac.uk
[2] School of Architecture, Planning and Landscape,
Newcastle University, UK
e–mail: neveen.hamza@ncl.ac.uk

ABSTRACT

Reducing building energy use and the associated greenhouse gas emissions is becoming increasingly important. Since occupants' behaviour has significant impacts on building energy performance and occupant comfort, and it varies with an individual's age, sex, background, and other personal factors, it is important to understand the critical links between people's lifestyles and energy consumption. Most studies of the relationship between occupancy behaviour and energy consumption focus on public buildings like office buildings and commercial buildings. Research for dwellings is limited since the information is difficult to collect, and detailed knowledge of individual homes is needed. This paper conducted a detailed survey to gain information on thermal satisfaction levels, occupancy equipment ownership and their using patterns of 112 urban households who lived in a typical booming city in southeast China. Based on the collected data, an energy simulation software program was used to investigate the main factors of occupancy behaviour, which affect energy consumption. The results lead to the internal gains profiles and window-opening profiles, which reflect the lifestyle in the target area who lived in an urban high-rise building. The simulation of typical households indicated that occupancy behaviour only occupied a small scale compared to equipment but still significant to improve.

Keywords: Occupancy Behaviour; Building Energy Consumption; Southeast China; Urban High-Rise Dwelling

1. INTRODUCTION AND LITERATURE REVIEW

The rapid development of the Chinese economy and the high concentration of urban populations results in increases in the number of urban residential buildings and corresponding energy consumption. China has promised to reach the peak of its total carbon dioxide (CO_2) emissions around 2030 and become carbon neutral by 2060. In China, the new building area has added to 60 billion square meters since economic reform in the 1980s [2], and another 40 billion square meters will be built by 2025 [3]. 25% of the urban built-up land area contribute to residential land [4], and the floor area ratio in residential buildings increase from 2007 to 2016 especially in the south and central China [5], which means massive people from rural area move to urban high-rise buildings in these areas in recent years. Such changes can severely influence the residential building sector with more energy demand and more carbon emissions [6].

Many researchers studied the influence of urban-rural differences on occupancy behaviour. One study found that energy requirements of subdivisions are higher nearer the city centre[7], another study showed that the largest carbon footprints were in either the inner city or rural areas [8]. The relationship between occupants' age and the dwelling energy consumption is not clear. Some studies found a negative correlation between householder age and energy consumption [9], some found no significant association [10], while others found the relationship is positive [11].

Since the diversity of urban households has been so large, some families' energy consumption could be ten times higher than that of the lowest energy consuming

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families [12]. The changing housing conditions for these new urban occupants will lead to different behaviour, leading to an energy consumption variation. However, most studies of building energy use and consumption focus on public buildings like offices and commercial buildings, since the information of residents' life patterns are hard to collect due to the privacy issue and it is not easy to gather large enough samples in the same age, sex, background, and other factors.

To get more information on the main factors and promote suitable energy efficiency technologies and policies, the researcher conducted detailed surveys and simulations of an example of an urban residential high-rise building in southeast China located in a typical area of urbanisation. The survey participants are residents who live in the southeast city in China, and their behaviour in buildings was collected, which represent the lifestyle of residents in this area. The base case is simulated without the occupancy profile, and the case study uses the survey result as input in software to simulate the energy consumption in the selected building.

The aim and objectives of this study are as follow:

1) Literature review and statistical data are used to provide data for calculation and comprehensive validation of real energy consumption.
2) Survey and investigation, which provide data for calculation, comparison and analysis. It includes:

Individual survey on household energy consumption in the target area, in which internal gains in the household are the main part of the questionnaire. It provides a good estimation for energy consumption in urban households in southeast China. The data concerns occupancy activities will be categorised into occupancy profiles in IES<VE>.

The information accessed by personal interviews, which concerns lifestyle patterns and internal gains profiles of occupants who live in selected dwellings.

Modelling and simulation. Simulation, by the software IES<VE>, of energy use of each end-usages in buildings, which provides comprehensive explanations for case buildings in a microscopic perspective. The simulation results will be converted into EXCEL and comparisons with each other will be conducted regarding the percentage of thermal comfort and energy consumption.

2. METHODOLOGY

2.1 Case study selection

In China, the proportion of newly constructed high-rise towers and plate buildings have increased rapidly, especially in the major cities after 2000[13]. In the meanwhile, the first building energy code in China was announced as part of basic national policy in 2009 when lots of buildings have finished, especially in big cities[14]. It led to many buildings in China constructed after 2000 to be considered not energy efficient or of good quality. For this research, using Fuzhou city, which is a major city in southeast China as an example, the population is around 7.7 million in 2018 and 5.4 million of which live in the urban area[15]. A high-rise residential building built in 2006 is selected for this study as a representative example of buildings built in the rapid construction time in China. The detailed building envelops elements will be discussed in later chapters.

According to the Köppen-Geiger climate classification, Southeast China is located in a humid subtropical climate zone which is a zone of climate featured by hot and humid summers where tropical air masses dominate, and mild winters[16]. In this climate zone, usually, space cooling is needed in summer and no heating in winter.

Fig 1 The location of the selected representative dwelling in Fuzhou, China[1].

The selected case study is a high-rise residential building located in Fuzhou, one of the main cities in southeast China (Fig 1). In this study, Fuzhou city is treated as representative urban areas and the surrounding countryside as representative suburb areas. The building was built in 2006 and had 11 floors which representing the typical building envelope in major cities during Chinese urbanisation. The apartment is around $100m^2$, which is a typical size of a household according to the survey.

In this study, relevant archival information regarding the selected dwelling was collected (Fig 2). The acquired data included architectural drawings of the

Fig 2 The elevation and planning of the studied high rise residential building (source: from the author of this research).

building, project specifications, materials, quantities, and pictures used to evaluate in the following analysis and as inputs for software simulation. The material and thickness were accessed from building archival files (Table 1). In some cases, hypothetical assumptions could be made to apply various strategies in software IESVE, which will be the main tool to simulate the energy consumption in this research. The building has no insolation layer, which is the common case in southern China. This could lead to more heating/cooling energy and time, which will be discussed in later chapters.

Building Elements	Description	Thickness (mm)	U-value(W/m²K)
External Wall	Concrete Wall with No Insulation	240	1.74
Internal Wall	Brick Wall with No Insulation	100	1.37
Roof	Flat Roof with No Insulation	240	0.98
Floor	Timber Floor on Concrete Layer	200	0.54

Table 1 The U-Value and Description of Building Envelop Elements

2.2 Questionnaire survey

An online questionnaire was carried out to map lifestyles and related occupancy patterns in southeast China, which included a set of structured questions that target occupants living in high-rise buildings in southeast China. The questionnaire was developed in English and translated to Chinese, and the author of this paper controlled the translations. It did not involve disclosing personal information nor included delicate subjects that may affect the occupant on a psychological level. Invitations to participate in the survey are sent to acquaintances who lived in high-rise dwellings in the target climate area and their acquaintance to explore it. The questionnaire is set to find a representative view of the southeast Chinese housing stock on the following parameters: dwelling size, dwelling age, ownership conditions, geographical location and the heating/cooling set in the dwelling. The invitation consisted of a letter inviting the occupant to log on to a website with a user-specific code and fill in the questionnaire. All the information collected via questionnaires is only used for this study's aims, and all records will be destroyed within one year.

2.3 Building simulation to predict occupants' behaviour

In this study, prototype models have been created in IES<VE>(Virtual Environment by Integrated Environmental Solutions) Version 2016. Models of the selected buildings will be constructed within VE using the "Model IT" module, which can then be analysed in various ways. With a module called "Radiance" that looks at the viability of day-lighting, a module called "MacroFlo" that investigates the effectiveness of natural

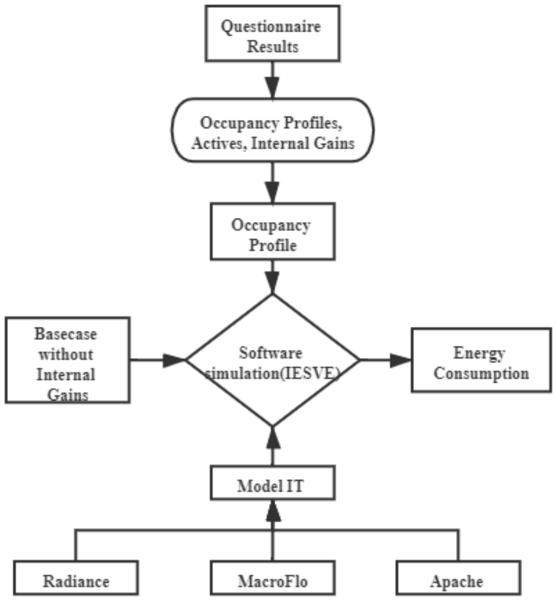

Fig 3 The workflow of the simulation in this study

ventilation, and thermal analysis module the "MarcroFlo", which provides an either steady-state or dynamic analysis of energy consumption and indoor thermal conditions[17]. The workflow of this work is presented in Fig 3.

The results of the simulation were considered as a realistic approximation for the actual buildings. The software is a product of the compound nature of the building as a system, the sophisticated mathematics and variables of the simulation and the fact that the results are dependable on data inputs. The data in this study were configured via the questionnaire analysis included occupancy profiles, actives, internal gains. The physical characteristics of studied buildings, both fabric and façade, were approximated in the building model.

3. RESULTS AND DISCUSSION

3.1 Questionnaire results

71% of responders in the survey own their house, 15% rent their house, and 14% share their dwelling with others. The dwelling size of most responders are between 50 m^2 to 100 m^2, and there are 2 or 3 bedrooms in their households. As for the number of people in a household, there are usually three or four people in one household, which reflects the typical family size of two parents and one child in China. However, with the new China's more than one child policy, the trend of family size will have a big possibility to change[33].
From the survey result, most people stay at home in the evening and night on weekdays and all weekends (Fig 4).

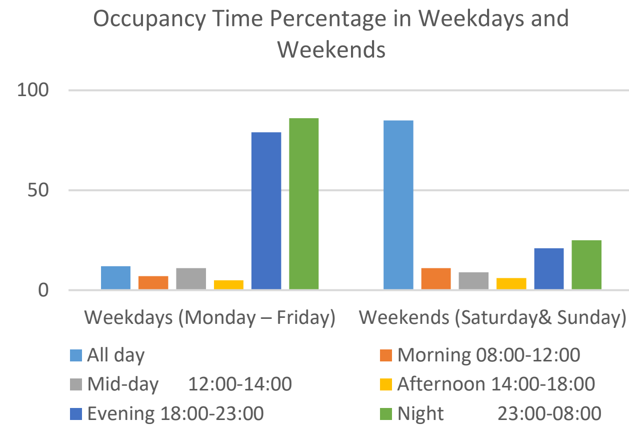

Fig 4 The distribution of occupancy time on weekdays and weekends

3.2 Simulation model study

In this study, the simulation ran in IES<VE> divided into a base case with no HVAC or internal gains profiles and a case study that used occupancy profiles conducted from the survey before. Research and occupancy profiles based on questionnaire analysis and building archives obtained all construction material, details, doors, and windows. The external air temperature and climate information were obtained as the city "Fuzhou" in IES<VE>. The simulation data is chosen from Jan 1 to Dec 12 in 2016, which present the whole year for the full picture of the energy consumption. MoHURD divided China into five major climate zones for residential buildings based on the average outdoor air temperatures of the coldest and hottest months[18]. The case study city located in hot summer and warm winter climate zone, which in design criteria GB 50189-2005[19] and JGJ 75-2012[20], indoor air temperature of 26 °C is the comfortable temperature specified for residential buildings under air-conditioned conditions and 18.0°C to 30.0 °C is the operative temperature. The operative temperature is used as an index temperature for comfort where the air velocities are low. The operative temperature takes both room air temperature and the mean radiant temperature into consideration. However, the simulation software does not use operative temperature, which refers to dry resultant temperature.

Another design standard of civil buildings GB 50736-2012 [21]provides HVAC design and operation criteria. In this standard, two types of thermal environments were conducted specified for long-occupied air-conditioned spaces. The first category is that air temperature of 24–26 °C, the humidity of 40–60% and airspeed less than 0.25 m/s. the second category is that air temperature of

26–28 °C, humidity less than 70% and airspeed less than 0.3 m/s. These standards above provide criteria only for HVAC system design and operation, and no criteria for architectural design are stated.

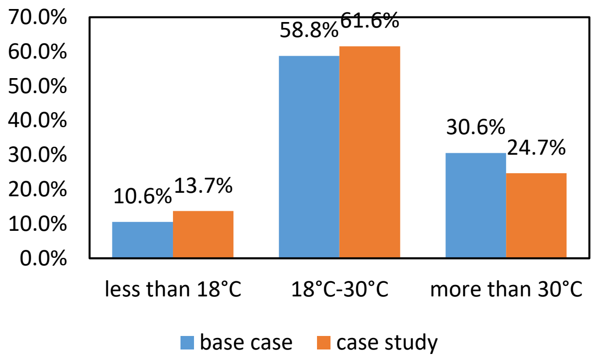

Fig 5 Comparison of the annual indoor temperature inside the comfort zone of base case and case study

According to the survey result, the profile of internal gains and window openings of typical occupants living in the target area are applied to simulation models to compare base case and building standards. The annual indoor temperature inside the comfort zone improved a bit compared to the base case (Fig 5). According to the survey, the thermal comfort is not significantly improved since the air conditioner is only applied in summer and not to all rooms. It is also indicated that the overall thermal comfort in this area is not satisfied, and occupants have to tolerate the uncomfortable environment.

The simulation result shows that the total energy consumption in the household for the whole year is 1624.33 kWh, with the internal gains is 241.02 kWh, and the equipment gain is 1449.54 kWh. The CO2 emissions for the whole building are 5551.84 kg CO2, of which 907.19 kg is the CO2 emissions except equipment. Compared to equipment in the household, internal gains of occupancy behaviour only applied for a small percentage.

In 2017, one research analysed the energy consumption of five climate zone in China and concluded that the constraint value for electricity consumption is 2800kWh in a household for a year [22]. The simulation result of the case study is quite low since other requirements, including a heater in winter and gas are not applied in this case. It is also indicated that in this research, the survey responders tend to tolerate uncomfortable environments rather than use an HVAC system to improve thermal comfort. In general, the occupants in this area lived in relative energy saving live style. The energy loads in the household will be compared with the results in the future to validate.

4. CONCLUSIONS AND FUTURE WORKS

This study investigated the case study of a typical high-rise residential building in southeast China. It is a characteristic example of an urban high-rise building built during the rapid urbanisation in China. Based on the analysis above, the conclusions focus on the effect of occupancy behaviours on energy consumption and CO2 emissions. The relationship between occupancy behaviour and energy consumption is investigated, and the factors affecting it are identified. Finally, a simulation of typical lifestyle patterns is conducted to identify the main factor affecting energy consumption in the building.

The questionnaire results and correlation analysis lead to the internal gains profiles and window-opening profiles, which reflect the lifestyle in the target area who lived in an urban high-rise building. With this information, the quantitative relationship between energy usage behaviour patterns and energy consumption in urban residential buildings was discussed in detail and conducted into simulations. The simulation of typical households indicated that occupancy behaviour only occupied a small scale compared to equipment but still significant to improve.

In the future, with the new “more than one child” policy in China, the family structure and size tend to get bigger than before, the perdition of energy consumption and CO2 emission for the new household in China will increase a lot compared to the typical household now. Also, with the growth of the urban area and population increases in most cities of China, moving to an urban area is going to be a tendency in the future. It will also increase the energy consumption for commuting. From the simulations performed, the trend of energy consumption in the future will increase per household level. Although higher living standards lead to higher energy demand, improvements in energy efficiency, especially of space cooling and appliances, controlled energy consumption will be a need. The large diversity of operating behaviours causes differences in energy consumption, and policymakers and technical engineers should pay attention to this phenomenon.

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