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The Energy-related Impacts of Social Factors of Rural Houses in Southwest China

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Abstract

Background: In the last 30 years, the average energy consumption of one person has risen from 80 kgce to 204 kgce in Chinese rural areas. Considering rural areas in China occupy over a half of China's population, the study on energy usage of rural houses is crucial to the development of building energy efficiency of China. Researchers have conducted many studies on this situation, and the climate and technology are mainly considered in these studies. However, in recent years, great changes have taken place in terms of social factors of rural areas in China, for example, rural migration to the cities and gender imbalance. Some changes may lead the rural occupants to a high-carbon life-style.
Objectives: This research exploits the data collected from rural houses in southwest China and aims to establish which factors relate to occupant social aspects, and to what extent affects energy-related characteristics in rural houses. We hypothesize, in rural houses, that the energy efficient design strategies are not only related to climatic and building envelope physical characteristics but also may be derived with the particular considerations on social factors.
Methods: 50 houses in Tongzi rural area of Chongqing city were selected as the samples. In this paper, the social factors lie in three folds in this research, occupants' demographics, life patterns, and behaviors. The energy-related characteristics embrace three aspects: thermal comfort, predicted energy consumption, and heating methods. Measurements on energy usage and environmental performance were conducted for each house. Also, we used semi-structured interviews on social factors for each family. The process of life patterns was observed by the researchers. In addition, statistics from the local government were used. The variables in this research are investigated by linear regression, one-way ANOVA, and contingency analysis.
Results: This study shows the female group preferred to warmer thermal conditions and spent 33% more hours in kitchens which consume over 50% total building energy in rural houses. The group with more hours per day spent outside reported the lower level at the indoor operative temperature, compared with the group with more indoor hours (P-value is 0.042). In addition, two basic heating choices in winter were adopted by rural occupants: charcoal braziers (28.6%) and indoor sun exposure (71.4%). Also, the use of charcoal braziers compromised with aging.

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Conclusion: Although the climate and the building physical characteristics are crucial to building energy consumption and indoor environmental performance, this paper demonstrated that some social factors related to residents can affect the energy-related components, especially in the free running rural houses.

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"Keywords: Rural houses; Field measurements; Social factors; Energy ;"

1. Introduction

In China, the building energy consumption shares about 30-40% of the total national energy [1]. Based on the climatic zones classification of China's building energy standards [2], the Hot Summer and Cold Winter Zone plays a special role due to its energy and social features. On one hand, the building energy consumption in this zone occupies about 45% of the whole country building energy use [3]. On the other hand, this climate zone owns nearly 50% provinces and more than 40% of population, which results in much higher population density than other climatic zones; meanwhile, the cities in this climate zone contributes around 48% GDP of China with more rapid economy growth compared with other zones [4].

Fig. 1. Chinese Climate Zones, Image Source: Lin [2]

Moreover, because rural buildings in China are related to about 60% of the whole building area, rural buildings account for over 67% of total building final energy consumption [5, 6]. Facing this fact, Chinese Ministry of Housing and Urban-Rural Development has already set a series of plans to promote energy efficient strategies for rural buildings, such as certain energy-saving materials implementation [7]. However, in recent years, great changes have taken place in the rural areas in China. For example, rural migration to the cities, development of running water and accessible transportation, gender imbalance, and social network pressures. In the rural areas of Chongqing which are selected as our research site, the average number of rural household members drops from 3.49 of the year 2003 to 2.72 of the year 2010, the number of owning air-conditioners per 100 households increases from 0.39 of the 2003 to 14.56 of the year 2010, and the sex-ratio of male to female decreases around 6% from the year 2003 to 2010 [8]. Because of male labour migration from rural to cities, according to 2010 population data, in our selected city Chongqing, there were around 14.5% aged persons (>65) living in the rural areas but this number was only 8.3% in 2001[8]. These social changes may affect rural houses' energy usage and environmental performance. Further, some indirect factors related to these changes, such as occupant life patterns, behaviours, and energy source choices, also have possible influences on building performance of rural houses.

Regarding the roles of socioeconomic and behavioural aspects of occupants in the energy consumption area, numerous studies have been conducted in worldwide. For example, Levy et al.[9] studied the correlations of occupants health levels and envelope insulation; Kitou and Horvath [10] analysed the effects of teleworking on building energy usage; Steemers and Yun [11] explored the roles of occupant for building energy consumption based on the Residential Energy Consumption Survey (RECS) by the US Department of Energy.

This research exploits the data collected from rural houses in Southwest China and aims to establish which factors related to occupant social aspects, and to what extent, affect energy-related characteristics in rural houses. In this paper, the social factors lie in three folds in this research, occupants' demography, life patterns, and behaviours. The energy-related characteristics embrace three aspects: thermal comfort, predicted energy consumption, and heating methods. The variables in this research are investigated by linear regression, one-way ANOVA, and contingency analysis. We hypothesize, in rural houses, that the energy efficient design strategies are not only related to climatic and building envelope physical characteristics but also may be derived with the particular considerations on social factors.

This paper is a part of a funded project entitled *Design Strategies of Chinese Vernacular House in Hot-summer and Cold-winter Climate Zone* by The National Natural Science Foundation of China (NSFC) China which is proposed to explore energy usage and passive design strategies for potential energy savings and indoor comfort for rural houses in the Hot Summer and Cold Winter Zone of China.

2. Methods of data collection

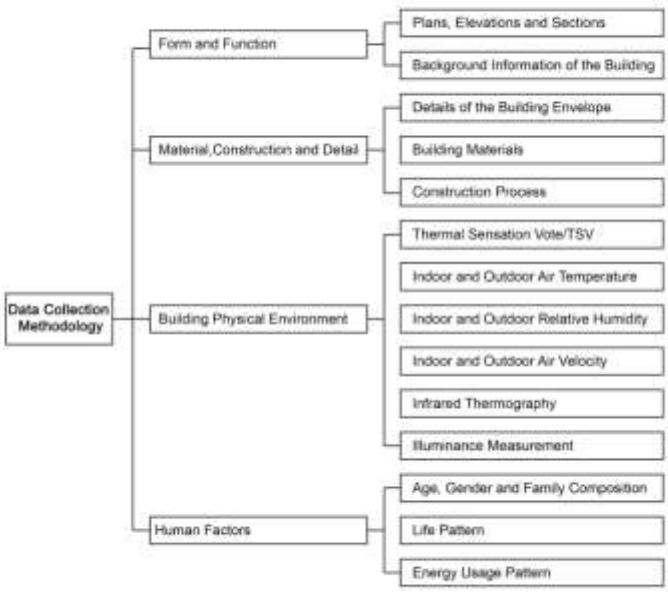


Fig. 2. The framework of data collection methodology

From Aug. 2010 to Feb. 2013, we conducted field measurements and investigation for over 100 rural houses in 4 distinct locations in Southwest China. The methodology of data collection includes four aspects: form/function, materials/construction/detail, building physical environment, and human factors. In order to comprehensively test and review rural houses energy use and environment performance, we combine surveys on social context information and occupants' subjective sensations about indoor environmental quality (via questionnaires, semi-structure interviews, and observation) and field measurements on physical environments (via instruments, see table 1). In addition, statistics from the local government were gathered. The whole process of this field study is shown as the following figure 2.

Particularly, we include the ASHRAE seven point scales for thermal sensation, along with check lists for clothing and activity in the past hour. Additionally, we have questions regarding the subjective rating of sound and illumination levels, air quality, etc.

Table 1: instruments used in measurements on building physical environment performance

Instruments	Model
Thermographic Camera	VarioCAM hr inspect
Thermograph Meter	WZY-1
Hygrothermograph Meter	WSZY-1
PMV and PPD Indices Meter	AM-101PMV-PPD
Light Meter	AEMC CA813
Noise Spectrum Meters	AWA6270B

In respect to potential effects of social factors, the particular collection methods were utilized. First, we add some questionnaire information related to occupants' behavior and daily life patterns. Second, in order to accurately evaluate building physical environmental performance, we carried out a series of continued measurements for each room of four selected houses which vary the building construction types. All measurements were in relation to seven environmental indexes: outside air temperature, inside air temperature, outside relative humidity, inside relative humidity, outside wind velocity, outside illuminance level, and inside lighting level. For instance, in each major room, we put thermometers at the 1.5m height level, and recorded the temperature for each 20 minutes for two periods of Aug. 23-27 in 2011 and Apr. 13-22 in 2012. The following figure 3 shows an example of distribution of test points in a room floor plan. Third, we observed these four houses' occupants behavior related to environmental controls, such as air-conditioner on/off, windows open/close, electric lights on/off, etc.

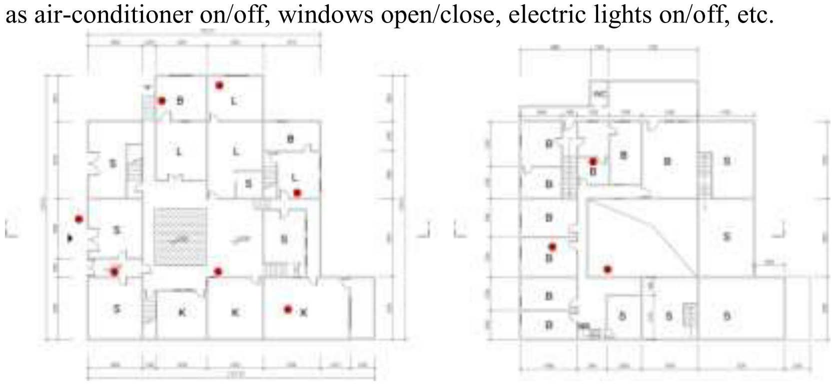


Fig. 3. Location of measurement sports in a room

3. Basic information of the selected site

Due to the page limitation, we only selected Tongzi, Chongqing in this paper, which is one of the four sites, for the analysis of social factors effects on energy-related features. The site location is shown in figure 4. It has a long and hot summer from June to September, and about 30°C average temperature. On the other hand, the winter is from December to February, and the average low temperature in winter is around 6°C.

Among all current available buildings in this area, there are 20% timber Dougong-through structure dwellings which are characteristic southwest vernacular structural typology. This investigation selected totally 50 representative rural houses and over 105 questionnaires for residents. All modern dwellings were made of concrete and built in recent years, and the vernacular dwellings were made of timber or stone and built in 100~300 years ago. The figure 5 presents the diversity of the building construction typology.

In addition, the buildings' orientation and layout varied considerably. Generally, the building geometry is the L or the courtyard layout when they have only 1-2 storeys, and the building geometry with 3-6 storeys tends to the cubical type of layout.

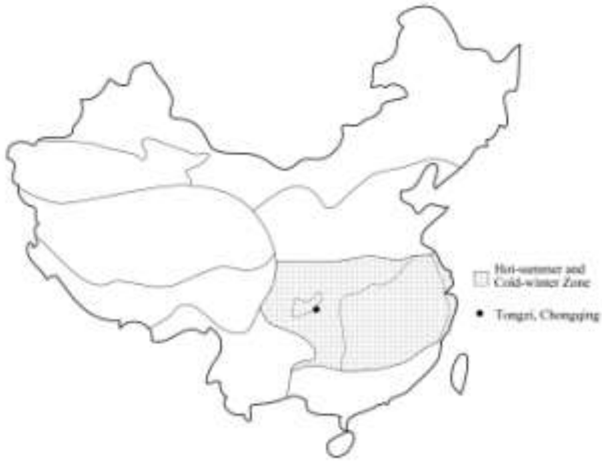


Fig. 4. Climate zone and location of Tongzi in Chongqing

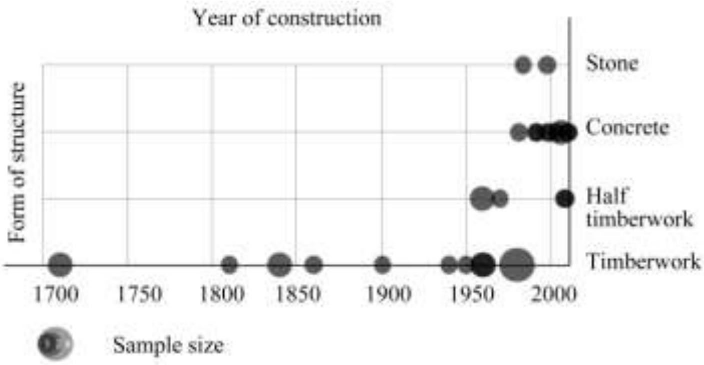


Fig. 5. Completion year and building construction typology

4. Analysis of energy-related effects from social factors

4.1. Thermal comfort and social factors

In this paper, we concentrate on the thermal issues in winter. In terms of operative temperature, the neutral temperature calculated by Thermal Sensation Vote (TSV) in winter observed in Tongzi rural houses was 10.2 ℃. The range of operative temperature for 90% thermal acceptability in winter was 6.85℃ -13.60 ℃. Other studies have explored the thermal comfort zone in free running (FR) rural houses in southwest China in this climate zone, e.g. 8.41℃-15.65℃ in Yue Yang, Hunan Province[12], 11.2℃-16.8℃in Nan Yang, Henan Province[13], and 8.6℃~26℃ in Pengzhou, Sichuan Province[14]. The much lower average outdoor temperature in winter may be the reason why the resulting thermal comfort zone is slightly lower than other field measurements in Southwest China. However, when it comes to the comparison with the thermal comfort responses in urban residential buildings in the same climate zone [12], the rural population showed better acclimatization.

In this research, the female population showed a small difference (around 0.6℃) in that they preferred to be in warmer conditions compared with the male subjects. During the winter this is explained by the fact that the female subjects wore showed differences in insulation and variation of clothing. In the age aspect, some studies imply that older subjects (>65 years of age) would like to keep warmer than other age groups [15, 16]. However, our field studies report differences in neutral temperature and the thermal comfort zone for different age groups are not conclusive (P-value is 0.948).

Another interesting relationship is between life pattern and thermal operative temperature. We utilized particular questions and some observations to record the hours the rural residents spent outdoor and indoor. The group with more hours per day spent in the outside reported the lower level at the indoor operative temperature, compared with the group with more indoor hours (P-value is 0.042). This may imply that the persons with longer indoor hours adapt thermal conditions less effectively.

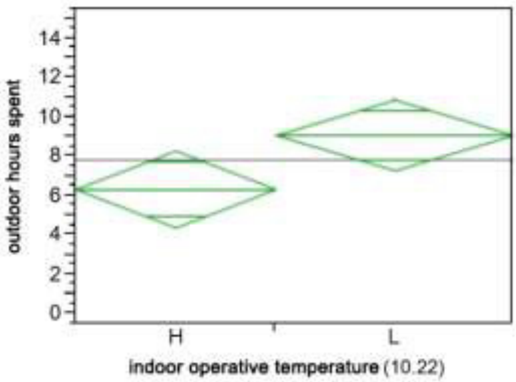


Fig. 6. One way analysis of outdoor hours by indoor operative temperature

4.2. Occupants' life pattern and energy impacts

In this field study, one section related to hourly-time-step daily routine in questionnaires was filled out by the subjects, along with questions of the task's room location and researchers' observations. The following generated figure (fig 7) shows the average hours used in four main spaces in a regular day. After comparison of this average daily routine and the continued measurements of living room, kitchen, and bedroom, we can find when and how much each room temperature indices are within the thermal comfort zone in the specific time span. The following table 2 shows the percentage within thermal comfort zone for each room in three selected houses. It can be seen that the indoor temperatures in three living rooms during the reported hours (8:00~14:42 and 18:48 ~ 21:48) were within the thermal comfort zone for three houses. The bedrooms in stone house and timberwork house during the reported hours (21:24~6:36) had no time to be in the thermal comfort zone.

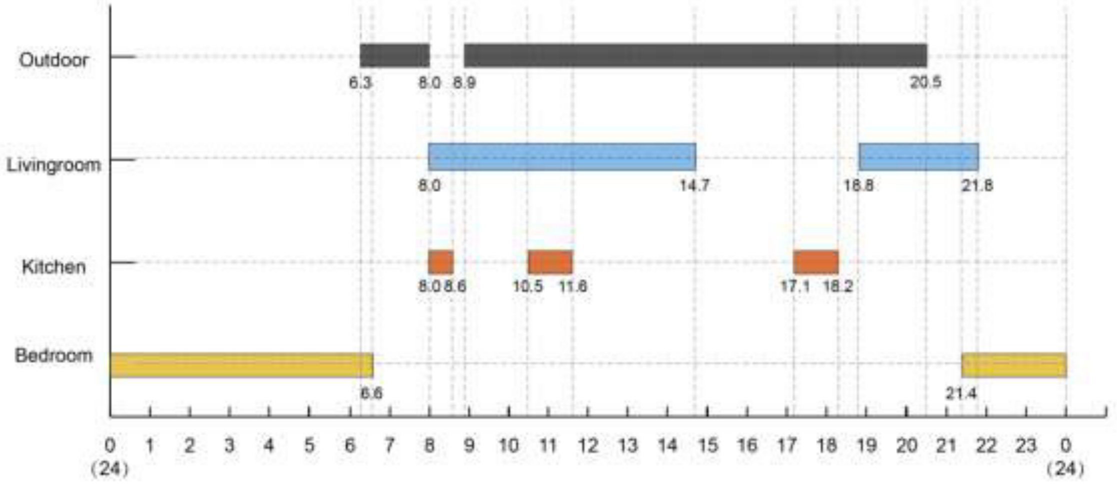


Fig. 7. Hourly-time-step daily routine with main rooms

Table 2: The percentage of each room temperature within thermal comfort zone in 24 hours

	Timberwork house	**Concrete house**	**Stone house**
Living room	47.3%	36.5%	69.8%
Kitchen	33.1%	95.2%	100%
Bedroom	0	98.6%	2.5%

In particular, the above fig. 7 shows that cooking activities in Tongzi rural houses required energy around 2.8 hours a day. The reason why we focus on cooking activities and use of kitchen is that cooking is a very demanding activity in rural society and it currently still requires coal and biomass (firewood, straw, crop residues, etc.) in most rural households [17]. Rural cooking time generally took 2.5 times more hours per day than did its' urban counterparts [18]. However, in other reports, cooking time in rural houses is more than 4 hours a day [19] which is longer than our result. With the comparison of gender groups, we found that the female took more hours in kitchens than the male over 33%. Considering the continued increasing ratio of female in rural areas, this may imply that female population plays increasingly more significant role in cooking energy consumption of rural houses.

Because cooking energy occupies over 50 percent of energy consumption for rural houses [20], the role of women becomes more important. However, in the rural areas of southwest China, educated women are the minority (74.6% below high school education [21]) which may explain poor awareness and knowledge on the use of biomass fuels and other energy-efficient cooking devices in the kitchen environment.

In addition, we found a weak correlation between the cooking hours and the age groups (P-value is 0.216). However, the following figure 8 reveals a tendency that the age group from around 30 to 55 has fewer hours spent in kitchens compared with other groups. This may be explained by the fact the age group of 30~55 are usually working outside during the daytime in the current rural society.

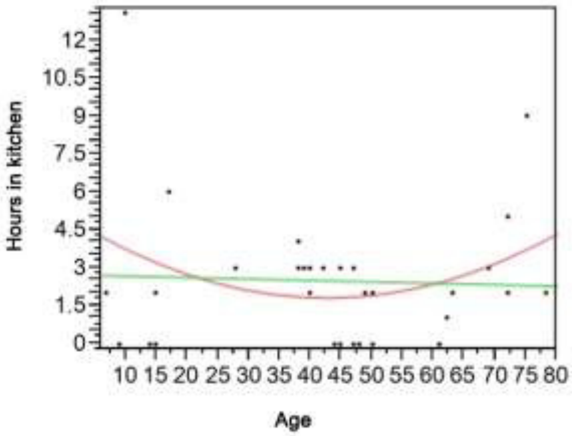
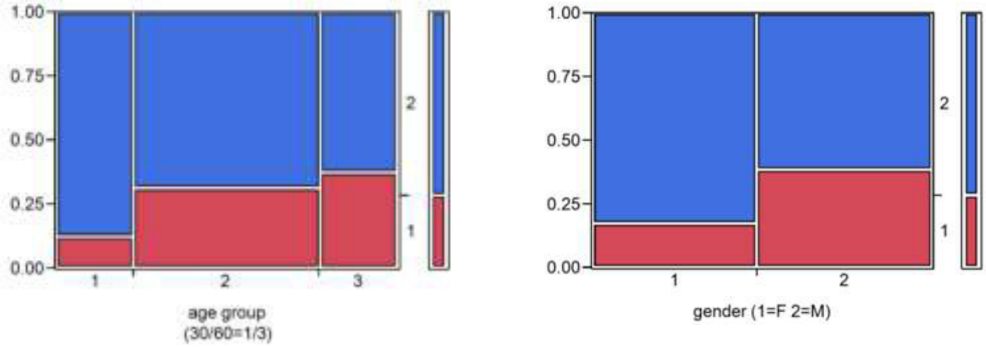


Fig. 8. Relationship of age and hours in kitchens

4.3. Heating methods

In the data, we found two basic heating choices of the rural occupants in winter: charcoal braziers (28.6%) and indoor sun exposure (71.4%). In order to know what factors contribute to these heating method choices, we collect the information of passive design, e.g. orientation, shadings, thermal mass usages, etc. However, there was no one which showed strong correlations to heating choices (all P-values are < 0.3). We also conducted an analysis on the relationship of construction type (timber, half-timber works, stone, and concrete) of houses and heating methods. Either indoor operative temperature or heating choices did not show the strong correlations to building construction. This may imply that physical architectural features are not the factors affecting the occupants to choose different heating methods.

Nevertheless, some social factors are evident to affect the heating choices. In order to know the roles of occupants' age and gender in choosing heating methods, we generalized the following figures 9 via JMP10.0. The figure 9 showed that use of charcoal braziers compromised with aging and the male group.



Contingency analysis of heating methods by age and gender (red = charcoal braziers, blue = sun exposure)

5. Discussion and conclusions

Although the climate and the building physical characteristics are crucial to building energy consumption and indoor environmental performance, this paper demonstrated that some social factors related to residents can affect the energy-related components, especially in the FR rural houses. The role of social aspect is evident and is essential to be considered for proposing appropriate sustainable design strategies and designing suitable indoor environmental qualities.

Firstly, compared with the male group, the female group preferred warmer thermal conditions and spent more 33% more hours in kitchens which have been reported to consume over 50% total building energy in rural houses. Therefore, future thermal comfort studies and design strategies should place more attention on the female. Not only these, but we also need to introduce rural women with awareness and knowledge on appropriate energy use for cooking. This trend is likely to be reinforced by the increased ratio of female in households of rural areas in China.

The second finding is about the daily life routine. The group with more hours per day spent in outside were with the lower operative temperature (P-value is 0.042). This may imply that the persons with longer indoor hours adapt thermal conditions less effectively. As rural construction developed, e.g. stores, factories, physical activity areas, etc., rural occupants spend more time outside rather than inside. In respect of this, indoor environmental qualities of rural houses should be more to do with the time periods of indoor activities and related spaces which are shown through the figure 7.

Finally, the field studies reveal 28.6% occupants in our samples were still choosing traditional charcoal braziers for heating in winter and more uses were related to older persons. However, we did not find strong correlations of neutral temperature and the using of charcoal braziers or different age groups. The future investigation needs to compare the architectural design features of the room using solar heat gains and the room using charcoal braziers in greater detail. This can lead alternative solutions related to passive sustainable design instead of traditional charcoal braziers which have the problems of soot particles, carbon monoxide, and low efficiency.

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