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Energy Procedia 104 (2016) 245 – 250

Energy Procedia

CUE2016-Applied Energy Symposium and Forum 2016: Low carbon cities & urban energy systems

# An empirical study of influencing factors on residential building energy consumption in Qingdao City, China

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**Abstract**

Residential building sector is one of the major contributors to global electricity energy consumption. Current researches have demonstrated that the residential building energy consumption is determined by many factors, including climate conditions, household and building characteristics, and occupant behavior. However, the extent to which each factor contributes to the total energy consumption has remained unclear, especially in developing countries such as China. To partially answer this question, an empirical study was conducted in five residential real estates in Qingdao city. Questionnaires were distributed to around 500 families, whose electricity consumption from Feb to Aug, 2015 was then collected from local electricity bureaus. Based on the collected data, correlation analysis was performed to exploit the relative role of each factors. Results reveal that occupant behavior is the most important parameter on cooling energy use, compared with household characteristics and urban geometry.



Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.

Keywords: residential building; energy consumption; household characteristics; urban geometry; China

## 1. Introduction*

Residential building energy consumption occupies a significant portion of global energy usage. Residential building energy use could be attributed to by four variables: building (shape, material and construction), system (electrical appliances), occupant (household statistics and energy related behaviour), and context (urban geometry and local climate). The relationships have been widely studied [1-5]. Fan surveyed 3446 households in the greater Sydney region in Australia, and both electricity usage and household statistics of each household were collected [1]. Among the factors investigated, the number of occupants is found to have the largest impact on household energy consumption. Chen studied the residential building winter energy use in seven typical cities in China, and found that the influential factors differ significantly in different cities [2]. In Chongqing city, the influential factors include construction year, annual income, orientation, and the usage of heaters; while in Hong Kong, only family income is

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Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, CUE2016: Low carbon cities and urban energy systems.
doi:10.1016/j.egypro.2016.12.042

identified as the major factor. The importance of household characteristics was proved by Chen again. For both new and old residential buildings in Shanghai, floor area and number of family members are identified as the main reason causing energy use differences [3].

To study the impact of occupant behaviour, Chen collected data in Hangzhou city, China (642 families in winter, and 838 families in summer) [4]. His analysis shows that occupant age is a more influential factor than family income. A study of the US residential energy use by Steemers was also dedicated to exploit the role of occupant. It is found that occupant behavior do affect the energy consumption, significantly in summertime but marginally in wintertime. [5].

Through the literature review, the roles of microclimate (caused by both urban geometry and building typology) and occupant behaviour on building energy use have been commonly accepted, but the extent to which energy use is affected by these two set of factors is seldom studied. With the identified gap in mind, a residential building energy survey was recently taken in Qingdao City, a northeastern city of China. During the survey, the impact of occupant behaviour on space cooling is mainly focused.

## 2. 2. Description of the survey procedure and preprocessing techniques

### *2.1. Survey procedure*

The first step is to choose the survey samples. To make the urban geometry variable rather comparable, five housing estates were selected: Lushang, Hai'er Eastern Town, Lihai Garden, Haiqing Garden and Dianye. Lushang, Dianye and Haiqing Garden are in the Zhuhai Rd. Neighborhood, while Hai'er Eastern Town and Lihai Garden are in the Fushan Hou Neighborhood, as shown in Fig. 1. From Table 1, these five estates have different floor area ratios (FAR), which means the local building typologies are different, and different the green area ratio(GAR), which might lead to different microclimates conditions. Further, since these five estates were built at different years, the level of building insulation and airtightness level might vary dramatically as well. Furthermore, the market price of Lushang is about 50% higher than that of other four estates, thus the residents of these five estates are expected to have different economic status.

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Fig 1. Location of the surveyed real estates

Table 1. Information of the surveyed estates

| Names | Construction year | Floor Area Ratio | Green Area ratio | Proximity to sea（m） | Neighborhood |
|---|---|---|---|---|---|
| Lushang | 2013 | 5.2 | 30% | 1000 | Zhuhai Rd. |
| Hai'er | 2006 | 1.6 | 40% | 3100 | Fushan hou |
| Lihai | 2003 | 1.15 | 45% | 2100 | Fushan hou |
| Haiqing | 1999 | 3 | 35% | 500 | Zhuhai Rd. |
| Dianye | 1970 | 1.9 | 40% | 500 | Zhuhai Rd. |

Secondly, in each estate, around 100 survey questionnaires were distributed to its residents through the local residential committee. The questionnaire mainly includes three types of questions: household characteristics, occupant preferences, and energy usage. Finally, the exact amount of electricity usage of each housing unit was fetched through local electricity bureau.

### *2.2. Data preprocessing*

Before doing the analysis, a three step approach is taken to verify the validation of the collected data. First, questionnaires with more than three blanks are discarded; second, surveyed electricity utility bill is compared with that retrieved from local electricity bureau for each housing unit, records that don't match are discarded; thirdly, records with extraordinarily large electricity usage are discarded, as that may be caused by some unknown factors. After deploying above steps, a total of 281 samples are kept.

For each housing unit, electricity utility bill for three charging periods were retrieved: March and April, May and June, and July and August. The outdoor temperature from March to June is between 8°C and 24°C, thus space cooling demand is negligible during this period. As shown in Fig.2, it is clear that the difference between March/April and May/June is small, compared with the difference between May/June and July/August. For this reason, the energy data is divided into two periods: March to June as transition season, and July to August as summer season. Based on these data, a transition season monthly electricity usage Et and a summer season monthly electricity usage Es are calculated, and then the electricity usage for air conditioning Ea is then determined by subtracting transition season monthly electricity usage Et from summer season monthly electricity usage Es.

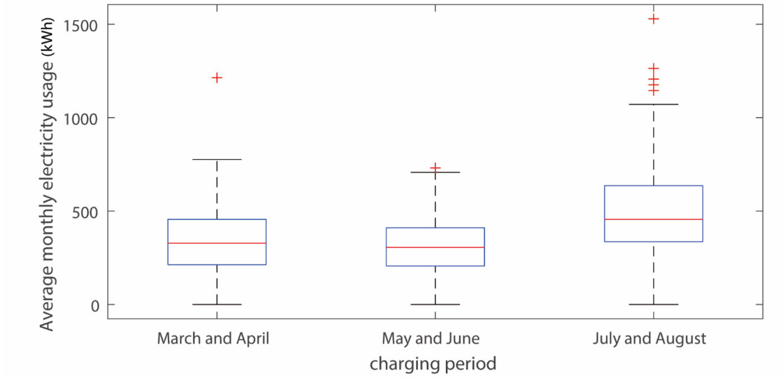


Fig 2. Electricity usage in three charging periods

## 3. Influencing factors on cooling energy consumption

### *3.1. Impact of household characteristics*

As shown in Table 2, higher air conditioning energy use in summer season is typically associated with younger people. This is because that older people are more likely to use fan, and even if they use air conditioner, they turn on it for shorter time and at a higher temperature.

Family income also affects energy consumption in summer seasons. Take Lushang as an example, the household with income less than 8000 RMB/month consumes 68.09 kWh for cooling, approximately 60% of that consumed by the contrastive sample. However, there is an exceptional case – Dianye estate. In this estate, rich people spend less money on air conditioning than poor people. This is because of a strong positive correlation found between occupant age and family income ($R^2$=0.36, p = 0.03). Since old people (also rich people in this case) prefer indoor environment with higher temperature, it is not strange that they turn on air conditioners with shorter time than young people (also poor people in this case).

Household area also plays an important role on energy consumption in summer seasons. As shown in Table 2, the households with area larger than 110$m^2$ spend 33kWh more electricity for space cooling than those below 110$m^2$ on average. On average, residential buildings spend $0.89\ \text{kWh} / (\text{m}^2\ \text{month})$ for space cooling in Qingdao area.

The impact of the number of family members is not straightforward in this study. While larger number of family numbers causes higher energy consumption in Lushang, it is negatively correlated with energy use for cooling in the other estates. It is not surprising since cooling is provided for the whole space rather than each occupant. Although more occupants do mean higher internal thermal load, this effect seems negligible in this study.

Table 2. Variables analysis for cooling energy use in summer season

| Variables | | All | Lushang | Hai'er | Lihai | Dianye | Haiqing |
|---|---|---|---|---|---|---|---|
| Age | <53 | 111.9 | 110.3 | 132.3 | 70.2 | 133.4 | 122.2 |
| | >53 | 80.1 | 80 | 104 | 62 | 70.5 | 87.3 |
| Income | <8000 | 88.2 | 68.1 | 120.2 | 63.5 | 124.7 | 90 |
| | >8000 | 121.4 | 107 | 149.9 | 77.3 | 73.5 | 108.6 |
| House area | <110 | 82.9 | 69.1 | 109.7 | 66.6 | 73.8 | 96.7 |
| | >110 | 115.6 | 105.5 | 128.1 | 104.9 | 112.8 | 119.2 |
| Number of AC | 1 | 83.3 | 70.3 | 107.2 | 62.5 | 85.9 | 89 |
| | >1 | 111.4 | 90.6 | 185.2 | 96 | 117.7 | 113.4 |
| Number of members | 1 | 113.9 | 35.3 | 327 | 83.3 | 92.7 | 172.1 |
| | 2 | 86.9 | 84 | 110.6 | 65.5 | 84.8 | 93.1 |
| | 3 | 100.3 | 82.7 | 151.3 | 70.1 | 59.8 | 103.3 |
| | >3 | 78.8 | 118.3 | 83.4 | 62.9 | 91.8 | 74.8 |

### *3.2. Impact of occupant behavior*

Fig.3 clearly shows the effect of occupant behaviour on space cooling energy consumption. It is found that using fan rather than AC helps reduce the consumption by 87% (from 91 kWh/m to 12 kWh/m); being energy cautious brings down the space cooling energy use by 46%; and preferring a higher indoor temperature level decreases the energy use by 20%. This suggests that increasing temperature setpoint is not as effective as being energy cautious in saving energy use.

### *3.3. Impact of urban geometry*

The difficulty of studying the effect of urban geometry lies in the variation of other factors (household statistics, occupant behaviour, etc.), which are generally conceived as more influential than urban geometry. The study by Koen Steemers et al. has found that occupant behavior can accounts for 47% of the variation in cooling energy while building explains less than 10% variation [5]. To analyse the relative role of urban geometry in isolation from other factors, the collected samples were filtered so that each non-urban geometry factor lie in a small range. It is expected that when the sample size is large enough, the range can be greatly narrowed down, hence the effects of all other factors to the space cooling energy use can be viewed as negligible. However, some unknown factors (such as envelope insulation, glass thermal properties, etc.) could still cause difference, however, since most of the estates (except for Dianye) were constructed at the same period, this difference can be ignored without sacrificing much precision.

It is clear that there is a sharp variation in cooling energy consumption amongst these surveyed estates, as shown in Fig.5. The mean energy consumptions of households living in Lihai and Dianye are approximately half of that in the other three estates, suggesting that the urban geometry parameters might lead to dissimilar energy consumption profile. The urban form parameters investigated in this paper include floor area ratio(FAR), green area ratio(GAR), construction year(CY) and Proximity to sea(PS). Dianye, as mentioned above, are close to a sea which functions as heat sink. As a result, the urban heat island effect(UHI) there will be reduced. It widely recognized that the reduction in UHI can result in the energy

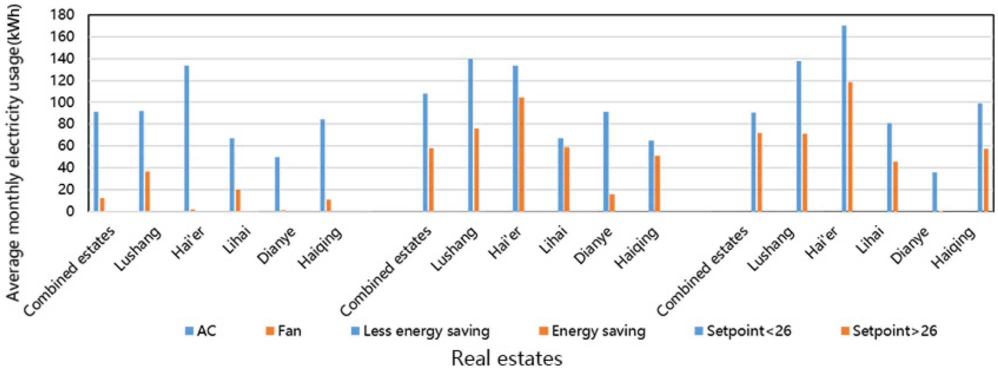


Fig.3. Household average monthly energy consumption in five estates for different occupant preference: AC/Fan(left), Energy Saving (middle) and Set point(right)

saving by mainly two aspects, mitigation of cooling load and improvement of COP for air-source air conditioners. Similar to Dianye, Lushang and Haiqing are also close to the sea, but energy savings are not so evident. This might be caused by the comparatively high GAR of Dianye. In coincidence with this, Lihai, which has highest GAR, also exhibits an energy-saving feature. To validate the hypothesis that GAR is negatively correlated to UHI, on July 2015, we conducted a field measurement in Lushang and Lihai with different GAR value of 30% and 45%, respectively. In average, the daytime UHI in Lihai and Lushang are 0.48 °C and 1.38 °C, respectively. The results show that Lushang have a higher UHI although close to heat sink. In addition, FAR seems to be unrelated to energy consumption. Construction year, which is expected to influence the building characteristics since the thermal standards of construction become higher in recent years, doesn't exhibit a significant correlation with energy consumption too.

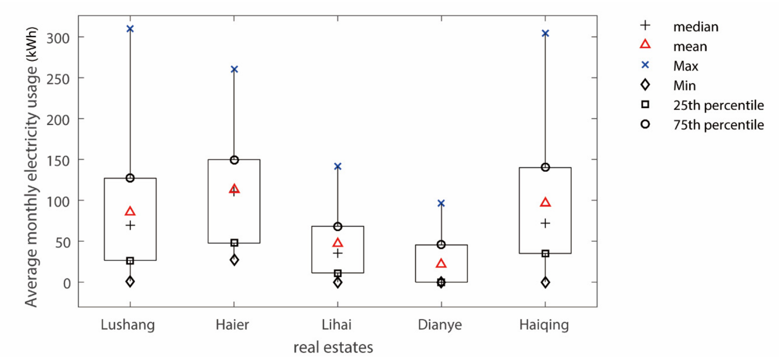


Fig. 4. Boxplot for monthly electricity usage in summer season

### 3.4. Regression analysis of all related factors

The final equation mainly consists of three parts: (1) OB is the occupant behavior, (2) HC is household characteristics, and (3) UG is urban geometry, as in Eqn. 1. The results are shown in Table 3. The model has an R2 value of 45%(p<0.01), slightly lower than the results (47%) in US by Koen Steemers et al. [5].

$$\ln(E_{cooling}) = Const + OB + HC + UG \tag{1}$$

As expected, occupant behavior has a strong influence on cooling energy consumption due to its closest association with energy use. In particular, using Fan/AC as main cooling type ranks firstly ($R^2 = 0.208$), followed by energy saving attitude towards space cooling and setpoint. The second most important set of variables relates to household characteristics, within which average adult age is shown to have a most significant effect. The households with two or more occupants does not consume more energy that the households with one occupant, which confirms the conclusion that the impact of the number of family members is not straightforward. It is not surprisingly that urban geometry has a relatively weak correlation with energy use, among which the impact of green area ratio and proximity to sea is quite evident.

Table 3. Regression model for cooling energy consumption in summer season

| | | Beta | Std.err | p value | partial correlation | partial $R^2$ |
|---|---|---|---|---|---|---|
| | Constant | 46.133 | 29.178 | 0.117 | | |
| Household characteristics | Age | -0.009 | 0.008 | 0.265 | -0.201 | 0.040 |
| | 2 occupant vs 1 occupant | -0.494 | 0.399 | 0.218 | -0.049 | 0.002 |
| | 3 occupant vs 1 occupant | -0.918 | 0.434 | 0.037 | -0.017 | 0.000 |
| | 4 or more occupant vs 1 occupant | -1.083 | 0.568 | 0.059 | -0.030 | 0.001 |
| | income | 4.55E-05 | 2.09E-05 | 0.032 | 0.087 | 0.007 |
| | household area | 0.004 | 0.005 | 0.432 | 0.029 | 0.001 |
| | 1 AC vs 0 AC | 0.013 | 0.704 | 0.986 | 0.150 | 0.023 |
| | 2 AC vs 0 AC | 0.687 | 0.700 | 0.328 | 0.138 | 0.019 |
| | 3 AC vs 0 AC | 0.834 | 0.909 | 0.361 | 0.038 | 0.001 |
| Occupant behavior | AC vs Fan | 0.895 | 0.393 | 0.025 | 0.456 | 0.208 |
| | Setpoint above 26 vs below 26 | -0.357 | 0.252 | 0.160 | -0.221 | 0.049 |
| | Energy saving vs Less energy saving | -0.443 | 0.226 | 0.053 | -0.271 | 0.073 |
| Urban geometry | Construction year | -0.019 | 0.015 | 0.219 | 0.017 | 0.000 |
| | Floor Area Ratio | -0.245 | 0.302 | 0.417 | -0.015 | 0.000 |
| | Green Area Ratio | -13.518 | 7.550 | 0.076 | -0.083 | 0.007 |
| | Proximity to sea | 0.000 | 0.000 | 0.040 | 0.193 | 0.037 |

## 4. Conclusions

Three categories of energy-related parameters were found to affect the cooling energy use in summer season to different degree. The most significant parameters are occupant behavior. This suggests that for policy-maker, apart from building energy regulation, the occupant behavior should gain tantamount attention, such as energy-saving education, in order to meet the energy and environment target. The second most important category of parameter is the household characteristics, especially age and income. The current old generation tend to exhibit a frugal behavior is mainly because they have been exposed to the food and resource scarcity before 1980s. The income is shown to have a positive relation with energy consumption, and as the Chinese economy continue to grow up, the energy use is projected to grow as well in the near future. The third category is related to urban geometry. Both proximity to sea and green area ration was found to have a positive influence on energy demand reduction, while the former are less controllable in practice.

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