Stock modelling of residential appliance energy considering technology and occupant behavior evolution: case study of television in urban China

Y. Zhang1*, D. Yan1#, S.Y. Guo1 and S. Hu1

1Building Energy Research Center, Tsinghua University, Beijing, China

yanda@tsinghua.edu.cn

Abstract. During the last decade, the energy consumption of residential appliance has grown rapidly in China and accounted for 20% of total urban residential energy consumption in 2015. Many studies show that the occupant behavior has a great influence on the appliance energy consumption. Due to the changes of Chinese residents’ lifestyle, the total energy consumption of residential appliance has changed a lot, so it is an important factor when we select the technology roadmap and make policy suggestions. For existing research of macro energy modelling, there is less consideration on occupant behavior. So we develop a new macro energy model to analyze the residential appliance in urban China, considering the influence of both technology and occupant behavior. This research developed a bottom-up model and did a case study on China urban residential television. The energy consumption of television in China urban households was calculated and scenarios are established to analyze the related policy suggestions. For model input, we got the panel data by conducting many regional range or nationwide survey during 2008~2015, and arranging the data from yearbook or database. The survey and modelling analysis output the total residential television energy use in urban China by different technology, different province and different occupant behavior. The results show that total energy consumption of television starts to decline from 2011, this is mainly due to the continuous decrease of television watching duration in China urban households and the technical progress. For other appliance, the occupant behavior should also be carefully considered by researchers and policy makers.
1. INTRODUCTION

During the last decades, the energy consumption of residential appliance has grown rapidly in China. From 2001 to 2015, it has increased from below 600kWh to above 1200kWh, and accounted for 20% of total urban residential energy consumption in 2015, only after the energy consumption of cooking[1].

In influence factors, many studies show that the occupant behavior has a great influence on the building energy consumption[2]. In recent years, Chinese resident’s life style changed a lot, directly lead to the changing on the usage pattern of residential appliance. For example, the average using duration of television (TV) has decreased from 184min/day/cap to 161min/day/cap (2001~2014)[3], this will influence the macro energy consumption of TV.

Many researchers have established bottom-up models to calculate the building energy consumption, but the existing studies give less consideration on the occupant behavior. International energy agency (IEA)’s annual report World Energy Outlook adopt the building demand scenario analysis model [4], the terminal energy use intensities of different sectors were directly put into the model and didn’t consider the influence of technology and occupant behavior. In the China energy consumption model of the Lawrence Berkeley National Laboratory[5], the terminal energy use was considered influenced by the technology efficiency, also ignore the impact of occupant behavior. The China building energy model of BERC [6] consider the influence of both technology and occupant behavior, but in this model the energy use intensities were directly given by high, middle and low, it’s difficult to use this model to conduct the scenario analysis. So in this paper, a new building energy consumption model was established based on the bottom-up approach, in this model the technology and occupant behavior was specially considered as variables. In addition, a case study on China urban residential television was conducted to analyze the influence of both technology and occupant behavior on the residential appliance energy consumption.

2. METHODOLOGY

2.1. Model structure and definition

A bottom up model was established to analysis the total appliance energy consumption in the urban residential area, Figure 1 shows the model structure.
In this model, the energy consumption of different typical households (with different types of appliance and different occupant behavior), the distribution of different typical households and some macroscopic factor was chosen as the input variables. Based on these inputs, the energy consumption intensity matrix and distribution matrix of typical households can be sorted out, and the total energy consumption of appliances in a certain area can be calculated, the equation is as follows:

\[ E_{\text{total}} = HH \times \eta \times \sum_i^n (I_i \times D_i) \]  

(1)

HH is the quantity of households in different region, \( \eta \) is the penetration rate of TV in China urban area, matrix I is the appliance energy use intensity of different typical households, matrix D is the proportion of each typical households. \( \sum_i^n (I_i \times D_i) \) represents the average household appliance energy use, the E\text{total} represents the total appliance energy use of a certain region.

In this paper, the television was chosen as a case study, the appliance type and occupant behavior are defined by referencing the Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Flat Panel Televisions [7] and the results of a large-scale survey, which will be discussed in detail later. The occupant behavior was divided into five levels by total TV using duration, and five kinds of TVs were considered in the model as is listed in Table 1.

| No. | Appliance type                                      | No. | Occupant behavior            |
|-----|----------------------------------------------------|-----|------------------------------|
| A1  | Cathode Ray Tube (CRT) TV                          | B1  | Usage duration per day 0~1.5h |
| A2  | Flat Panel Display (FPD) efficiency level 1        | B2  | Usage duration per day 1.5~3.5h |
| A3  | FPD level 2                                        | B3  | Usage duration per day 3.5~5.5h |
| A4  | FPD level 3                                        | B4  | Usage duration per day 5.5~10.5h |
| A5  | FPD without efficiency attestation                 | B5  | Usage duration per day over 10.5h |

2.2. Input data collection
There are three types of input data, 1) Typical energy consumption data of different kinds of households. 2) Distribution data of households with different appliance type and occupant behavior. 3)
The macroscopic factor, in this case, the quantity of households and penetration rate of TV in China. These data can be obtained from different sources as follows.

2.2.1. Typical energy consumption data of different kinds of households

The typical energy consumption data can be calculated by unit time energy consumption of different kinds of TVs multiply the total using duration of different kinds of households as the following equation:

\[
\text{TV energy use of typical households (kWh/day)} = \text{TV energy use intensity (kWh/h)} \times \text{Using duration (h/day)}
\]

The energy use intensity of different kinds of TVs was obtained from equipment testing and the standard “Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Flat Panel Televisions”[7]. For using duration of different kinds of households, this study defined five levels, and obtained the average using duration of different group from the questionnaire results collected in 2015. Then 25 kinds of typical households can be defined by combining the appliance type and occupant behavior, and their energy use can be calculated, as shown in the Figure 2.

![Figure 2 TV energy consumption of 25 defined typical households](image)

2.2.2. Distribution data collection

The distribution data describe the proportion of different kinds of typical households in China. To obtain this kind of data, Building Energy Research Center conducted large-scale questionnaire surveys in 2015 on a national scale.
**Questionnaire content:** The purpose of the questionnaire survey is to obtain the status of energy use in China urban households. The questionnaire includes family information, equipment information, occupant behavior, etc. A summary of questions is shown in the Table 2.

| Item                  | Content                                      |
|-----------------------|----------------------------------------------|
| Family                | Location, family members, age, education, career, income |
| Building              | Unite size, building type, age of construction |
| End users             | Space heating, space cooling, domestic hot water, lighting, cooking, other appliance |
| Appliance information | Number of appliance, appliance type, appliance efficiency |
| Occupant behavior     | Using frequency, using duration, other using pattern |

The type and using pattern of TV are all involved in the questionnaire, the results were used as distribution input, the detail was discussed in the “results and analysis”.

**Sampling and data processing:** A proper sample size is the basis for the success of the questionnaire survey, based on previous research, the following formula was used to determine the sample size at a 99% confidence level:

\[
\text{Sample size} = \frac{z^2 \times p(1-p) / e^2}{1 + z^2 \times p(1-p) / e^2 N}
\]

N is the population size of the research group, which is 749 million in this study (China urban population); z is the z-score, which is 2.58 at a 99% confidence level; e is the margin of error, which is 0.02; p is the percentage of the sample that picks a particular answer, when determining the sample size needed for a questionnaire survey, it is common to consider the worst case percentage (50%). The calculated minimum sample size was 4160.

With the development of internet, the online questionnaire survey reduces the costs and the time requirements and give researchers opportunity to create large-scale database with limited cost, but there are also some obvious disadvantages. The main disadvantage is the limited demographic focus because people who participate in online surveys are most likely younger, richer, and live in the central areas of China.

In this study, a professional company was chosen to conduct this online survey. In order to offset the drawbacks, two rules were used for sample quality control. (1) People older than 40 must constitute 40% of valid samples collected, since the percentage of population older than 40 in 2013 was 45% in China[8]. (2) Annual household income distribution in the samples should be similar to the average income distribution of Chinese urban residences[8].

Finally, 11517 samples were collected in the China urban area, samples with answer time less than 5 min were eliminated, and get 11287 valid samples in the end. The age and income distribution was shown in Figure 3 and Figure 4.
2.2.3. Macro parameter collection

The macro parameter of China urban households were obtained from national statistical reports China statistical yearbook[9] and China TV rating yearbook[3]. China’s urban household TV penetration rate has stabilized at around 98% since 2000, the quantity of China urban households is shown as Figure 5.
3. RESULTS AND ANALYSIS

3.1. Survey results

The results of survey were analyzed statistically and obtained several characteristics of TV use in China urban households, the main findings are as follows:

1) The using duration of TV in urban households is decreasing in recent years, for example, in Beijing, the average using duration of TV in urban households per day was 5.13 hours in 2008, while it had decreased to 4.89 hours in 2015. For this issue, literature review was also did to support this finding, as shown in Figure 2 the average TV watching duration per capita per day in urban area decreased from 184min (2000) to 152min (2016)[10]. With the diversification of the way of entertainment, there is a trend for TV becoming less important in the urban residential households.

2) In 2015, the total TV using duration per day of most households in China urban area is among 1.5~3.5h and 3.5~5.5h, account for 35% and 22% respectively, the average value is 4.8h.
3) The quantity of TV owned per 100 households in urban area is 121.7, in 2015. This number was supported by statistical data, that the quantity of TV owned per 100 households in urban area is 122.3 in 2015, which published by the National Bureau of Statistics of China [11].

4) The quantity of TV owned per 100 households has a significant distribution law across China, decline from southeast to northwest, for example, in Shanghai, Zhejiang and Jiangsu province, there is above 150 sets of TV per 100 households in urban area, but in Gansu, Ningxia and Xinjiang province, the number is below 100 (Figure 3).

5) The majority type of TV owned in urban China is the Flat Panel Display (FPD), the households that mainly use the FPD and CRT TV equate to proportions of 83% and 17%, respectively.

6) For efficiency grade of FPD, China established the national standard “Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Flat Panel Televisions” from 2011. In 2015, the majority of FPDs used in China urban households are first level and second level (the first level has the best efficiency), account for 38% and 30% respectively. The FPDs without efficiency attestation only account for 8%.
3.2. Energy consumption of TV in China urban households

The total energy consumption of TV in China urban households in 2015 was 38.4 billion kWh, as shown in Figure 6, this energy consumption account for nearly 10% of the total urban residential energy consumption of China in 2015. The average energy intensity per household was 141 kWh/year, about 0.39 kWh/day. From the view of the changing trend, the total energy consumption of TV sustained increased during the first decade of 21st century, and start to decrease from 2011. This is due to the establishment of FPD standard and the continuous decline of TV watching duration in China urban households.

According to the China TV rating year book [10], the TV penetration rate in China urban area remain stable for more than ten years, it is around 98% from 2000 to 2015. So the changing in TV efficiency and occupant behavior is the main cause of changing in total energy consumption.

3.2.1. Energy consumption for different types of television

The questionnaire survey results show that the most common TV in China urban area in 2015 is the FPD, and the households that mainly use the CRT TV accounts for 17%. But from the view of energy consumption, CRT TV still accounts for 25% of total (Figure 7). There is scope for further decreasing the proportion of CRT TV to reduce the total energy consumption.
3.2.2. Energy consumption for different province
The average household TV energy use of different province in 2015 ranges from 87kWh/hh/year to 171kWh/hh/year. Among these provinces, Zhejiang, Shanghai, Jiangsu and etc. have the highest energy consumption, while Ningxia, Xinjiang, Qinghai and etc. have the lowest energy consumption (Figure 8). So there is an obvious distribution law: average household TV energy use decrease from Southeast China to Northwest China.

3.2.3. Energy consumption for different occupant behavior
The questionnaire survey results show that most households have a TV using duration per day between 1.5h to 3.5h in 2015, but the households that have a using duration between 5.5~10.5h account for the biggest part of total energy consumption, 34% (Figure 9). This group of households should be the focus when carry out the energy saving practice.
3.2.4. Further discussion

According to the ETP 2016 [12], the energy consumption of TV is still in the upward trend and more efforts need to be stepped up to promote the energy standard. So why there is a difference in China, and whether it is urgent that China should do more efforts to promote the energy standard on the existing basis, is an issue worthy of discussion.

A scenarios analysis was employed to provide different changing path of TV energy consumption during the past 15 years with different scenarios: 1) There is no occupant behavior changing and no energy standard. 2) There is occupant behavior changing but no energy standard. 3) There is occupant behavior changing and establishment of energy standard (present situation).

The result is shown in the Figure 10. Scenario 1 represents the average TV watching duration in China urban households was kept as the level in 2000 during these 15 years, and there is no energy standard, as a result, the energy consumption keeps the trend of continuous rising due to the growth of urban households and quantity of TV.

Scenario 2 consider the changing in occupant behavior, the energy consumption started to keep a stable decrease after 2012, the reason is the ownership of TV in China urban area have become stable in recent years, the occupant behavior and the technology become the key influence factors on the changing trend of energy use. Due to the TV becoming less important in the urban households, there is little probability that TV energy consumption continue to increase henceforth.

Scenario 3 is also the present situation, the implement of TV energy consumption standard promotes the efficiency of TV and further reduce the total energy consumption.

![Figure 12 Energy consumption of households with different TV using duration per day](image)

Figure 12: Energy consumption of households with different TV using duration per day.
4. CONCLUSION
This research developed a bottom-up model and did a case study on China urban residential television. The survey and modelling analysis output the total residential television energy use in urban China by different technology, different province and different occupant behavior. And there is mainly following conclusion:

1) The total energy consumption of television started to decline from 2011, this is mainly due to the continuous decrease of television watching duration in China urban households and the technical progress.

2) The ownership of TV in China urban area have become stable in recent years, the occupant behavior and the technology become the key influence factors on the changing trend of energy use. In pace with TV becoming less important in the urban households, there is little probability that TV energy consumption continue to increase henceforth.

3) The implement of TV energy consumption standard has promoted the efficiency of TV and reduce the total TV energy consumption in China urban area effectively.

4) Occupant behavior is an important factor in the macro building energy modelling research. For other appliance, the occupant behavior should also be carefully considered by researchers and policy makers

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