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ELECTRICITY USE IN URBAN HOUSEHOLDS IN CHINA: OCCUPANCY PATTERNS, ATTITUDES, AND POLICY INITIATIVES

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EXECUTIVE SUMMARY

Urban population in China is expected to increase by 42% over the next two decades, and roughly 70% of the total population in China is estimated to be living in urban areas by 2030 (Berkelmans and Wang, 2012). With a higher level of living standards required in urban areas, increasing energy use in the urban domestic sector has become an urgent issue to address. Based on a review of studies into domestic energy use in China, the following three research gaps are identified: 1) the deficiency of knowledge about the link between occupants' energy saving attitudes and behaviour in the context of China; 2) the limited research based on the socio-technical approach or mixed methods that cross disciplines to address the complexity of energy use behaviour; 3) the lack of research in using data-mining techniques to extract energy use related occupancy patterns from smart meter data.

To address these gaps, this thesis focuses on three research dimensions, namely the practical dimension, the policy dimension, and the theoretical dimension. From the practical perspective, this thesis proposes to understand the characteristics of domestic energy use behaviour, explore the factors that affect occupants' attitudes and behaviour, and figure out the reasons behind these attitudes and behavioural patterns. For the policy dimension, taking young urban households in Shanghai as a case study, this thesis aims to provide further insight into behavioural factors in domestic energy use and to explore which energy saving policies could be feasible in communicating with consumers more efficiently. Regarding the theoretical dimension, this thesis intends to investigate how useful the Theory of Planned Behaviour (TPB) is in understanding occupants in the context of domestic energy saving.

The research has adopted a mixed-method approach. Initially, a survey study was designed to investigate energy use behaviour and factors that affect electricity use in different energy categories (from level 1 to level 3 consumers according to the progressive electricity pricing system in China). The survey responses were analysed by three statistical methods, includes descriptive statistics, correlation analysis and regression analysis. Subsequently, an interview study was carried out to explore the embedded reasons and motivations behind energy use behaviour and energy saving attitudes, drawing a distinguishing between "comfort-driven" consumers and "conscious" consumers. Finally, smart meter data was used to test whether it is possible to extract occupancy patterns from data sets for more practical policy design, and the

energy saving potential of two behavioural measures as identified in the survey study was then tested with the single-zone simulation. Three types of data were collected through a) a survey in Shanghai area with 341 effective responses; b) 5 in-depth interviews; and c) smart meter data collected in 126 households in Shanghai, with more than 70 recorded days.

The variables based on TPB were applied in the design of both the survey and the interview questions. Socio-psychological variables, including attitude, subjective norm and perceived behavioural control, are discussed in this thesis to determine factors in relation to the intention to save energy under potential energy saving policy instruments. In the analysis of the survey study, TPB was used to investigate the relationship between attitude and behaviour, and to identify the factors that affect these two components.

Regarding the results from survey, the key findings were: 1) high consumers (level 3) are more likely to have higher income levels, and longer heating and cooling hours, as well as more extended heating and cooling seasons; 2) occupants are likely to have moderate comfort requirements (to accept a higher temperature in summer and to have shorter cooling hours per day) if they start to use air conditioners for cooling later in the summer; 3) respondents are more likely to accept fiscal incentives and communication instruments than consumption or price control in energy use; 4) even though high (level 3) consumers have more critical attitudes toward energy saving policies, they are more likely to accept real-time electricity pricing; 5) domestic energy use is strongly correlated to factors like family income level and family size; 6) energy saving intentions appear to be related to attitudes and also the subjective norms of family members.

The interviews revealed the diversity of occupants' energy use patterns and attitudes, even within the same target group of young urban households in Shanghai. Different attitudes, norms, and perceived control, resulted in different occupancy patterns and final energy consumption. According to their responses of their attitudes, norms and controls, two types of consumers were identified, including "comfort-driven" consumers and "conscious" consumers. Based on the TPB and the interview results, it was summarised norms shaped by educational background and influence from family members were identified as primary factors that shape energy use behaviour and attitudes. The "conscious" consumers' attitudes towards energy saving were shaped by their education background or previous experiences and their norms and energy use practices were affected by their parents and partners. Two "conscious" interviewees mentioned they started to pay attention to energy use and bill costs after they got married and need to pay the bill themselves.

From the cluster analysis of smart meter data, three groups of energy users were summarised based on temporal differences in their occupancy patterns, concluding that 1) high consumers use air conditioners for the highest number of recorded days in winter and summer, even when air conditioners are not necessary; 2) high consumers have longer occupational hours at home; 3) the base load of the high consumers is higher. Based on the single-zone simulation, it was found each behavioural measure (adjust heating and cooling temperature and reduce heating and cooling hours) could have a potential energy saving of 20% on average, but with a wide variation. These two behavioural measures were identified from the previous survey results as key parameters to bring level 2 consumers closer to level 1 patterns.

In conclusion, based on the findings from each empirical chapter, four policy initiatives were identified to address two groups of consumers, includes smart meters with in-home displays; a dynamic real-time energy pricing system; a review, reward and restrain feedback system; and stricter standards for buildings and appliances.

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ACRONYMS AND ABBREVIATIONS

ABC	Attitude-Behaviour-Context model
AC	Air Conditioner
BEERC	Building Energy Efficiency Research Centre at Tsinghua University
CC	Cooling capacity
CNIS	China National Institute of Standardization
COP	Coefficient of Performance
CV	Coefficient of Variation
DB index	Davies-Bouldin index
DECC	Department of Energy and Climate Change, UK
DSM	Demand-Side Management
EER	Energy Efficiency Ratio
EIA	U.S. Energy Information Administration
EPE	Building Energy Performance Evaluation
FCM	Fuzzy C-Means
FYP	Five-Year Plan
GBEL	Green Building Energy Labelling
GBP	British Pound sterling
HSCW	Hot Summer and Cold Winter climate zone
HVAC	Heating, Ventilation and Air Conditioning
IHD	In-Home Display
MEPS	Minimum Energy Performance Standards
MOC	Ministry of Construction, People’s Republic of China
MOF	Ministry of Finance, People’s Republic of China
MOHURD	Ministry of Housing and Urban-Rural Development, People’s Republic of China
MOHURDS	Ministry of Housing and Urban-Rural Development, Shanghai
MOS&T	Ministry of Science and Technology, People’s Republic of China
NDRC	National Development and Reform Commission, People's Republic of China
PBC	Perceived Behavioural Control
PME	Building Energy Performance Measurement and Evaluation
RMB	Renminbi, CNY
RMSD	Root-Mean-Square Deviation
SAC	Standardization Administration of China
SGCC	State Grid Corporation of China
SMIP	Smart Meter Implementation Program
SN	Subjective Norm
SOM	Self-Organising Mapping
TPB	Theory of Planned Behaviour
VBN	Value-Belief-Norm Theory

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Chapter 1 – INTRODUCTION

1.1 Background

China became the world's largest CO_2 emitter with an expanding energy consumption in 2006, with 29.1 billion tons of CO_2 emissions contributing to 25.9% of the global emissions in 2014 (EIA, 2015). Due to the rapid growth in carbon emissions, the Chinese government has started to focus on energy and emission issues and to implement a series of policies to address the problem. Under the 13th Five-Year Plan (FYP) (2016–2020), the government plans to cut carbon intensity by 40–45% before 2020, compared with the carbon intensity level in 2005, with a further goal of 60–65% before 2030 (EIA, 2015).

The building sector is one of the three largest sectors contributing to energy consumption and carbon emissions in China, accounting for 21–24% of the total energy consumption in China in 2013 (BEERC, 2013). The building energy consumption in China increased 1.7 times from 2000 to 2014, from 301 to 814 million tons of standard coal equivalent, and is expected to boost to 35% of the total energy consumption in China by 2020 (Huo et al., 2019). In order to achieve the national carbon reduction goal, the building sector is an important target.

The residential sector is the second largest energy use category in China, occupying 10% of the total primary energy use, and urban residential energy use accounted for 63% of the total domestic energy use in 2012 (Zhao et al., 2012). According to the National Bureau of Statistics of China (2017), the average domestic electricity use per resident per year was 115.0 kWh in 2000, and increased to 383.1 kWh in 2010 and to 551.7 kWh in 2015, increased by 3.8 times from 2000 to 2015. With China's urban population expected to increase by 42% over the next two decades, roughly 70% of the country's population is estimated to be living in urban areas by 2030 (Berkelmans and Wang, 2012). Consequently, because of the relatively higher living standards in urban areas, the electricity use per person is more likely to increase in the future.

The increasing energy demand in China has been discussed in many research. Hu et al. (2016) conducted large-scale surveys and in-depth measurements in the hot summer and cold winter (HSCW) climate zone in China. They suggested that the heating demand in urban residential areas is relatively low at present, but is increasing rapidly, due to the higher comfort level expectations and more frequent use of heating equipment with longer heating hours. Hu et al.

(2017) concluded that the average electricity consumption was 1690 kWh/year per household in China in 2015, and continued to grow because of the residents' requirements for higher quality of life. They also indicated that the current energy consumption level is still low compared with other countries, even with diversified energy use behaviour. They proposed the strategy for energy saving to be keeping traditional energy use behaviour and lifestyles, to promote outcome-based energy saving policies. Wang et al. (2015) summarised from a survey study that the current residential heating energy use in China was 9.8 kWh/m^2 in 2015, and is estimated to increase by 31% due to residents' higher expectations for more optimised and comfortable indoor environments. Several studies have noted that the behaviour of older generations is more energy saving than younger generations (Feng et al., 2016; Chen et al., 2013; Ruan et al., 2017), which has suggested the selection of the young urban population as the target group in this thesis. The increasing income level stimulates occupants to prioritise more thermal comfort rather than energy or cost saving in the future. Thus the domestic energy use in an urban city was selected as the research target in this thesis.

The Ministry of Construction (MOC), which was renamed to the Ministry of Housing and Urban-Rural Development (MOHURD) in 2008, implemented the first "Domestic Building Energy Conservation Standard in China" in 1986 (MOHURD, 1986). Since then, MOHURD has supervised the formulation of building codes for Building Energy Efficiency, which are regularly updated to ensure residential energy performance. Current energy saving policies in the domestic sector in China mainly are mainly applied to control the energy performance of the building components, but with less attention on the actual energy consumption (Huo et al., 2019).

There is a tremendous potential of energy saving from behavioural change in the domestic sector. Carlsson-Kanyama et al. (2005) indicated an energy saving potential of 10–20% could be achieved by behavioural change in Sweden. In the context of China, it has been suggested that energy use behaviour in domestic buildings could save 10% of electricity use (Ouyang and Hokao, 2009) and reduce 3–18% of the heating load (Xu, Xu and Shen, 2013). Potential policies to encourage behavioural change in China have been under-explored. In China, the key energy saving policy to address domestic energy use behaviour is the 3-level progressive electricity pricing system supported by the peak-and-valley time-dependent tariff. However, there is a lack of feedback-based instruments to target on behaviour. These will be discussed in detail in chapter 2.

Occupants' views, habits, practices and resources determine whether and how energy saving policies can be implemented. Previous research suggests that occupants' attitudes toward energy use can be shaped by physical, social, cultural, institutional, or political factors and information provision (Owens and Driffill, 2008). Occupants' energy use behaviour can be influenced by economic factors, environmental awareness, trust and commitment to society, cultural norms from society and family members, daily routine habits and practices, and social networks, as well as factors bedded in the built environment, such as comfort, cleanliness and convenience (Shove, 2003; Jackson, 2005). Occupants' energy saving practices can be affected by gender and age factors, and motived by reduced costs and reduced environmental impact (Carlsson-Kanyama et al., 2005; Gyberg and Palm, 2009). To design practical policies for behavioural change, it is important to explore occupants' attitudes of which policy instruments are more acceptable than the others. However, there have been limited studies to examine occupants' attitudes toward potential energy saving policies in China.

1.2 Research gap

Sovacool et al. (2015) identified three strategies for energy saving from the demand side, including 1) technical solutions for more energy-efficient appliances; 2) sociological approaches to leverage energy use engagement techniques; and 3) socio-technical behaviour programs with the support of smart monitoring systems and demand-side management technologies. In order to further understand energy use behaviour and explore the potential for energy saving, an interdisciplinary investigation is required that explores these three strategies by integrating physical, sociological, and socio-technical research.

Several studies have been done into domestic energy use behaviour and factors that affect energy use behaviour in China, mainly based on the survey method (S. Chen, Yoshino and Li, 2010; X. Feng, Yan, Wang and Sun, 2016; Ruan et al., 2017; Ding, Wang, Liu and Long, 2017). Existing research often uses the descriptive statistical methods to summarise information from the survey data, without the use of theoretical framework. However, a survey on energy use behaviour cannot provide knowledge about the reasons behind the practices, and the support of a more qualitative method is required. Thus, research using a mixed methods approach is required to understand the full spectrum of energy use behaviour.

In the context of China, the available data about domestic energy use characteristics is limited. Assumptions made regarding energy use patterns in building energy codes can lead to large performance gaps between actual and simulated energy demand. Bosch and Budde (2018) noted that uncertainties related to energy savings could be addressed by considering diverse energy use patterns. Consequently, a better understanding of occupancy energy use behaviour could contribute to more effective policies and accurate simulations. In order to implement more effective policies, it is essential to explore energy use characteristics in different climate zones in China.

With the development of smart infrastructure in China, the exponential growth of data collected inside buildings could provide policymakers with the opportunity to understand more about consumers. Information extracted from energy use data could be used to understand the occupants better and then design the policies to target on a specific group. However, there is a lack of data-mining techniques to extract occupancy patterns from energy use data in China (as will be explained in detail in chapter 3).

1.3 Research questions and methodology

Two pilot studies in the early stage of this research revealed several findings which were helpful to the design of this research: 1) there is a lack of statistical data on domestic energy use in China; 2) there is a large performance gap between the simulated (based on Western standards) and actual consumption based on three sample buildings; 3) the actual consumption is much lower than the simulation results, but is much higher than the national average level; and 4) there is a great diversity between different households, even those living in houses with similar characteristics. Thus, this thesis was designed to better understand these characteristics, with a focus on urban households, so that building performance simulation and energy saving policies can be improved.

This research was designed and structured with three dimensions, as shown in Figure 1.1. In the practical dimension, this thesis aims to understand energy use behaviour, the reasons behind practices, occupants' attitudes toward smart meters and related energy saving policies, and the information that could be extracted from smart meter data for policy design in the context of urban households in China, selecting Shanghai as an example. In the policy dimension, this thesis aims to explore occupants' attitudes toward different policy instruments and proposes energy saving policies for urban households like Shanghai. In the theoretical dimension, this thesis explores the applicability of the theory of planned behaviour (TPB) to understand occupants in the context of domestic energy use and energy saving policies. The aim of this research is not to generalise findings from small samples of each empirical research, but is to explore specific knowledge for a target group and provide insights of the application of an appropriate theoretical framework and research methods in the specific policy context.

This thesis was designed to address the following research questions:

1) What kind of factors relate to occupants' energy use behaviour in urban households in China, and what are these occupants' attitudes toward smart meters and energy saving policies?
2) What kind of motivations and demographical factors are behind occupants' attitudes and behavioural patterns?
3) How can occupancy patterns be extracted from smart meter data to understand energy use characteristics and explore the energy saving potential of policy design?
4) What policy instruments could be used to address the energy use behaviour of urban residents in Shanghai?
5) How useful is the theory of planned behaviour (TPB) to understand domestic energy saving in these households, and what kind of methods are required?

There are diverse methods that could be used for domestic energy use research, such as building performance simulation (quantitative), building monitoring evaluation through a survey about occupants' energy use practices and comfort preferences (mixed methods), and interviews to determine occupants' acceptability and requirements with site investigation (qualitative). To answer the research questions, this thesis used the mixed methods approach. Firstly, survey questionnaires were collected from Shanghai urban residents to understand their energy use behaviour and attitudes toward energy saving policies (question 1). Secondly, interviews with young urban residents were conducted to explore the reasons behind energy use attitudes and behaviour (question 2). Thirdly, smart meter data was collected from Shanghai urban flats to explore the information that could be extracted for policy design (question 3). Figure 1.1 displays the conceptual design. Details of the research design are discussed in chapter 4.

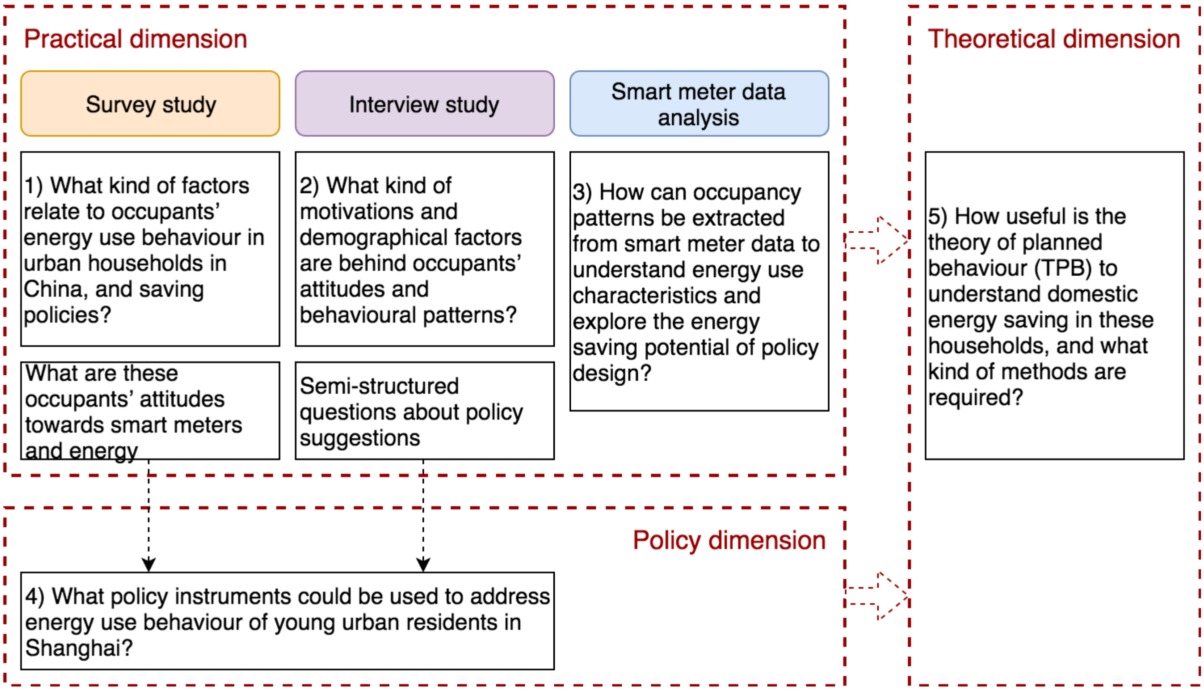


Figure 1.1. Conceptual research design

(Source: by Author)

Research question 1 is answered by the survey study. The quantitative survey can be used to explore variables such as property types, occupant characteristics, and level of energy consumption (Ambrose, Goodchild and O'Flaherty, 2017). The survey method is a widespread research method used to explore domestic energy use behaviour in China. From the existing survey studies, the interactions between occupants and their built environment can be summarised, as can the occupants' daily routines and their effects on energy consumption. However, one critical limitation of the survey method is that this method uses rigid constructs and closed questions, which limit the opportunity for respondents to explain their perspective and view.

Research question 2 is answered by the in-depth interviews. Compared to the survey method, a qualitative interview can provide a more profound understanding of occupants' motives, rationales and routines. However, the qualitative method is more expensive and time-consuming, and may not be able to represent an alternative to large-scale surveys, where large numbers of samples are needed. Otherwise, the small-scale interview method has the limitation of less prediction power. In this research, the interview method was used to explore knowledge about the reasons behind energy use practices, which context the limitations of the interview method are acceptable.

Research question 3 is answered by the analysis of smart meter data from two aspects, includes cluster analysis and single-zone simulation. Data-mining from building monitoring data is a method used in Western countries to extract occupancy patterns and understand energy use characteristics (McLoughlin, Duffy and Conlon, 2015). However, there have been limited studies on applying data-mining techniques to the context of China for policy design.

Furthermore, there is a need to identify the differences between the terms "energy saving" and "energy efficiency" in this research. Energy efficiency means that occupants do not have to sacrifice comfort to save energy, while energy saving involves a change in behaviour to save energy. The energy saving policies discussed in this thesis are part of a broader concept that not only includes the requirements for a physical upgrade of the building components or energy-efficient appliances, but also involves a promotion of behavioural change for energy saving.

This thesis mentions "smart meters" in several chapters. It is admitted that there is no universally accepted definition of "smart meter". According to Darby (2010), the phrase "smart meter" refers to several systems, such as net meters, digital meters, automated meters, and two-way communication devices. The definition used in this thesis is an advanced meter device with a two-way communication system (Haney, Jamasb, Platchkov and Pollitt, 2010). The two-way communication system in this thesis refers to the in-home display (IHD), which is an in-home monitor that connects to a smart meter and provides consumers with information on real-time energy use and unit price (Darby, 2010).

The term "smart meter" is frequently mentioned in recent Chinese regulations and policies, with huge investment being made into the smart grid under the 12th and 13th Five-Year Plans (FYP). However, there is a need to note that the electricity meter mentioned in the Chinese rollout policy is not the "smart meter" mentioned in this thesis. The new electricity meter is more advanced and smarter than a traditional meter which requires manually reading. However, the main difference between the new electricity meter in China and a smart meter in the UK is that the new electricity meter only enables one-way communication which can only send energy use data to the electricity company, so that consumers do not have an IHD showing their real-time electricity consumption.

Finally, it is necessary to describe what is meant by "young households", as urban young households were selected as a target group in this thesis. In the Oxford dictionary (2016), the "younger generation" is defined as "*the next or rising generation, especially viewed in contrast to one's own, and often concerning the attitudes and values associated with it*", in which attitudes and values are especially mentioned but not the age. In this thesis, the "young generation" is defined as the age group below 30. This classification does not come from their age, but because this generation was born in a unique decade with the rapid development of the society. As indicated by Chen, Wang and Steemers (2013), people grew up in the 90s experienced economic and technological improvements, which equipped them with distinctive attitudes and values, with a higher expectation of thermal comfort. It was also indicated by Chen et al. (2013) that China experienced moderate socio-economic development during the 1950s and 1970s, so the old generation's attitudes toward energy saving were affected by these socio-economic aspects. In this thesis, the "old generation" is defined as the age group above 60 due to this unique social and cultural influence.

1.4 Thesis structure

The thesis takes the structure as shown in Figure 1.2. Chapter 2 reviews the literature on domestic energy saving policies in China and identifies the limitations in existing policies. This chapter also reviews effective policy instruments for domestic energy saving and proposes potential energy saving policies for Chinese households.

Chapter 3 presents a review of existing behavioural studies in China, including domestic energy use behaviour and the factors that affect attitude and behaviour. This chapter identifies the limitations of current behavioural research in China, and also reviews social psychological models that could be used to understand the relationship between occupants' attitudes and behaviour.

Chapter 4 illustrates the importance of interdisciplinary and mixed research methods in understanding domestic energy use and exploring effective energy saving policies. This chapter also presents the findings from previous pilot studies and explains the methods used in the empirical part for answering each research question.

Chapter 5 analyses the survey results from Shanghai residents, and is divided into two parts. Section 5.2 reviews the demographics, occupancy patterns and electricity consumption, including analysis of the relationship between socio-demographic variables and electricity consumption. Section 5.3 illustrates the psychological variables in TPB, including occupants' attitudes toward smart meters, subjective norms, and perceived behaviour control, as well as the intention to save energy if smart meter policies were implemented. The analysis is undertaken of the relationship between psychological variables and intention to save energy.

Chapter 6 presents interview results targeting on young urban residents in Shanghai, and is also divided into two parts. Section 6.2 also lists the demographics, occupancy patterns and electricity consumption obtained from interviews. Section 6.3 analyses the reasons behind occupants' attitudes and behaviour using the TPB framework, and proposes potential policy instruments to address domestic energy use behaviour.

Chapter 7 analyses smart meter data from Shanghai residential buildings as a case study. This chapter uses the cluster method to test the information that the government could extract from smart meter data to understand more about the occupants. This chapter also uses the smart meter data to extract occupancy patterns in a single-zone simulation to test the energy saving potential of two behavioural measures identified in the survey study.

Chapter 8 summarises the findings from this research and proposes policy instruments for domestic energy saving in this target group.

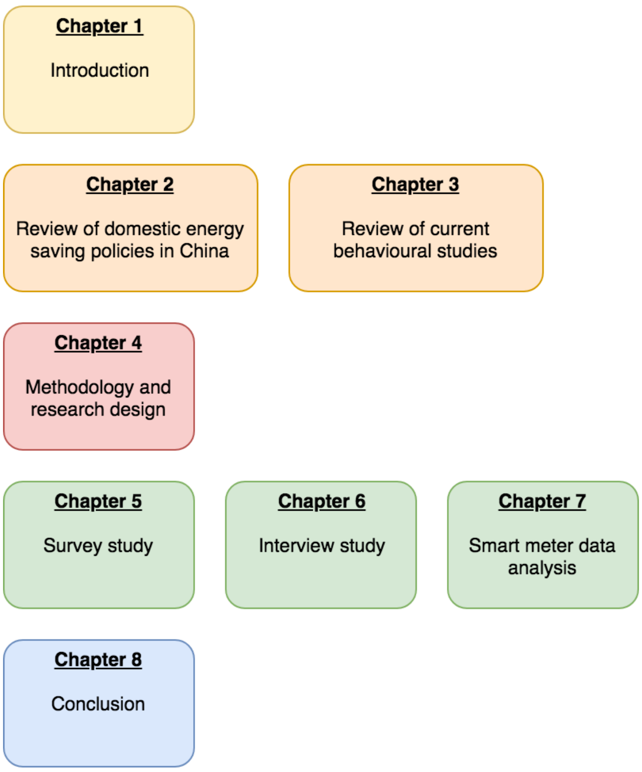


Figure 1.2. Thesis structure

(Source: by Author)

Chapter 2 – DOMESTIC ENERGY SAVING POLICIES IN CHINA

2.1 Introduction

Chapter 2 provided a literature review of domestic energy saving policies in China. Section 2.2 lists the general information of the urban housing stock in China. Section 2.3 highlights the recent focal point of building energy efficiency in the most primary national Five-Year Plan in China. Section 2.4 reviews the existing policy instruments for domestic energy saving, divided into the control and regulatory mechanisms and the market-based instruments and incentives. It also summarises the limitations of existing domestic energy saving policies based on the review. Section 2.5 proposes potential policy instruments to address the identified limitations, taken experiences from the developed counties as examples. Section 2.6 summarises findings from this chapter.

2.2 Urban housing stock in China

This section reviews the current situation of urban housing stock, including the increasing floor space, short lifespan, high demolish rate, residents in public rental housing, and the lack of public available data about building stocks.

Recently, with the rapid urbanization, tremendous buildings are being constructed in China. Based on estimation by Hong et al. (2016), the total Building Floor Space (BFS) in China is projected to boost from 47.7 billion to 90.7 billion sq.m from 2012 to 2050, nearly doubling within only 38 years. Among the total BFS, the residential BFS will reach 67.3 billion sq.m by 2050, with 80% of the population living in urban areas. The average housing space per person in urban China increased by 35.6% between 2000 to 2010, from 22.36 to 30.33 sq.m per person (Shi, Chen and Wang, 2016).

The average building lifespan of urban residential buildings in China is assumed to be 30 years for the buildings built between 1980–1999 and 40 years for the buildings built between 2000–2019 (Hong et al., 2016), and the urban residential buildings are constructed with a designed lifetime of 50–70 years (Baldwin et al., 2018). However, in reality, based on a study by Wang, Zheng and Wang (2018), the average building lifespan in China is between 25 to 35 years, much shorter than the designed lifespans of buildings.

The practice of the Chinese real estate market is to demolish and reconstruct, unlike the Western style of maintenance and retrofit. From instance, according to statistics from the Shanghai Municipal Statistics Bureau (2017), among the total BFS of urban housing stock in Shanghai, 167.15 million sq.m was built between 1978–1990 (some were destroyed for reconstruction, but with no statistics), 161.20 million sq.m was built between 1991–2000, 224.17 million sq.m was built between 2001–2010, and 93.56 million sq.m was built between 2011–2016. In the contrast, when compared to Western countries, according to LSE Housing and communities (2010), of the 23 million housing stock in England, over 18 million (78%) were built before 1980, 13 million were built before 1965, 9 million were built before the Second World War, and more than 5 million were built before 1914.

In the past three decades, China has experienced a large-scale of demolition and rebuilding due to the rapid urbanization. It was estimated by Shepard (2015) that China dismantled about 16% of its housing stock between 2005–2010. If demolition trend continues, almost every structure built before 1999, roughly half of the current housing stock, will be demolished within 20 years (Shepard, 2015). It was also indicated by Hong et al. (2016) that buildings built before 2010 would be gradually demolished by 2050 and replaced by new ones, due to the implementation of stricter building codes.

In urban China, some citizens choose to live in the privately-owned houses, and some have to live in rental houses. It was indicated by Yu, Sun and Zheng (2014) that the housing ownership rate ranges from 55–90% in the 31 provinces of China, with an ownership rate of about 65% for Shanghai. Due to the extremely high housing price in Shanghai, the housing ownership rate is much lower than in other provinces. In order to address the problem for low-income urban residents, the government launched a series of affordable housing programs, such as public rental housing, low-cost rental housing, and economy and comfortable housing (Quercia and Song, 2007). The public rental housing is the only type of public housing that can be provided to migrants (residents without local residence card) and the rent price is slightly lower than the general market rate. The public rental housing program is to solve the housing problem of the “sandwich layer” residents, for those who without enough savings to buy affordable housing and cannot meet the requirements of low-cost rental housing (Gan et al., 2017).

Based on the review of urban housing data in China, there is a lack of general and authoritative data about building stocks in China. Even the China Statistical Yearbook provides very general information of building floor space area of each type of residential building, the construction information of the buildings built in different years and the demolish rate of current building stocks are very limited in understanding the current situation. It is not possible to build up a city-scale model for housing energy prediction based on the public available data.

2.3 National Five-Year Plan

This section illustrates the gradually increasing focus of building energy saving in the national master plan, as well as in the municipal or local five year plan. In China, regulations and standards are implemented based on the national master plan.

The Five-Year Plan (FYP), short for "Five-Year Plan for National Economic and Social Development of the People's Republic of China", plays a vital role in the national master plan in China, and is announced every five years in the National Congress. Many primary policies, include national and municipal, are implemented based on the key strategies identified in the Five-Year Plan. Since the 11th FYP (2006–2010), the central government has started to address environmental issues and focus on energy saving and carbon reduction (Ning, 2015). Under the 13th FYP (2016–2020), the government plans to cut carbon intensity by 40–45% before 2020, compared with the carbon intensity level in 2005, with a further goal of 60–65% before 2030 (EIA, 2015). At present, building energy efficiency has become a focal point in China's energy strategy and the legal framework that aims to promote building energy efficiency has been established (Zhang and Wang, 2013).

National policies and regulations related to building energy saving were implemented by each functional department of the central government based on the development strategies identified in the FYP. Since the 11th FYP, the building energy efficiency goals have been highlighted in policies and regulations, for instance, the Ministry of Housing and Urban-Rural Development (MOHURD) implemented an action plan of improving the urban domestic energy performance by 20% by the year of 2020 based on the 2015 level and announced the "13th FYP Building Energy Conservation Special Plan" (MOHURD, 2015a). Table 2.1 lists the building energy efficiency targets in the special plan under the 13th FYP.

Table 2.1. Building energy efficiency targets under the 13th FYP (2016–2020)

Area	Target	
New construction	Improve building energy efficiency by 20% at 2015 level	
Existing residential building retrofits	North heating region	Energy efficiency retrofits for heating systems for 800 million sq.m, with 25% reduction in heating requirement
	Transition and south region	50 million sq.m of residential building retrofits
Renewable energy application in buildings	>13% use of building energy consumption in cities should be renewable energy; >20% use of building heating energy consumption in Changjiang River Basin should be renewable energy	
Large-scale promotion of green building	50% of new construction should be green	

(Source: MOHURD, 2015a)

Further, local governments established related policies and regulations based on the FYP and local conditions. The municipal building energy efficiency policies in more developed cities in China are designed to provide extra impetus for building energy efficiency that goes beyond the national standards. A stricter local building energy efficiency plan could help the city to achieve a higher sustainable level. For instance, Shanghai established the green building target under the 13th FYP, indicating that all new residential buildings should achieve the Green Building Energy Labelling (GBEL) rating, which is at least 5% stricter than the national standards for building envelopes (MOHURDS, 2016).

2.4 Existing policy instruments of domestic energy saving

Based on the classification of policy instruments, the existing domestic energy saving policies in China discussed in section 2.4 will be divided into the control and regulatory mechanisms and the market-based instruments and incentives. Based on a study by Zhang and Wang (2013), the incentive instruments are more effective than the regulatory instruments in China.

2.4.1 Control and regulatory instruments

In China, the control and regulatory mechanism is the dominant policy instrument employed in the building sector, characterised by laws, standards and codes. China has started to implement policies to promote domestic energy saving since early 1980s. In 1986, the Ministry of Construction (MOC), which was renamed to the Ministry of Housing and Urban-Rural

Development (MOHURD) in 2008, launched the first building energy standard in China, named “Residential Energy Conservation Design Standards (Heating District)” (JGJ26-86) (MOHURD, 1986). The building standards establish the minimum requirements for residential building components, HVAC, and power system. Since then, MOHURD has supervised the formulation of building standards for residential energy saving. Based on the average temperature of the coldest (January) and hottest months (July), China is categorised into five climate regions, including severe cold, cold, temperate, hot summer and cold winter region, and hot summer and warm winter region. Building energy conservation standards are designed for each climate region (MOHURD, 1993), based on the great variations of different climate conditions and energy use characteristics in each climate region. Table 2.2 lists different versions of the residential building standards for different climate regions, which are regularly updated to ensure building energy performance.

Table 2.2. List of residential design standards in the different climate regions

Standards	Series no.	Year
Severe Cold and Cold Region Residential Energy Conservation Design Standards (Heating City)	JGJ26-86	1986
	JGJ26-95	1995
	JGJ26-2010	2010
Hot Summer and Cold Winter Region Residential Energy Efficiency Design Standards	JGJ134-2001	2001
	JGJ134-2010	2010
Hot Summer and Warm Winter Region Residential Energy Efficiency Design Standards	JG75-2003	2003
	JG75-2012	2012

(Source: by Author)

The energy saving goals for residential buildings in China were classified into the following steps. First, during the ten years from 1986 to 1996, the energy use level per household should be reduced by 30% compared to the pre-1986 benchmark. Second, from 2001, the energy consumption level per household should be reduced by 30% compared to the 1996 benchmarks, which represents a 50% saving compared to the pre-1986 benchmark. Third, from 2005, the energy consumption level per household should be reduced by 30% compared to the 2001 benchmarks, which represents a 65% saving compared to the pre-1986 benchmark. With a powerful enforcement of building codes, about 6.9 billion sq.m of new BFS has been built under the step-three building codes nationwide, during the ten years from 2006 to 2016. The government is now encouraging Beijing and other more developed cities to pilot the adoption of a 75% saving over the pre-1986 benchmark (Xu, Anadon and Lee, 2016).

Apart from the regulations on building components, the "Administration Regulation on Energy-Efficiency Labelling" was launched in 2005 to ensure the energy efficiency of domestic appliances (NDRC, 2005). It requires manufacturers to register products at the China National Institute of Standardization (CNIS) website and attach a China Energy Label (mandatory energy information label) on each model with their energy efficiency grade before entering into the market. The Minimum Energy Performance Standard (MEPS) was provided to guide the minimum allowable values of energy efficiency (mandatory thresholds), energy efficiency grades, evaluation value for energy saving, energy consumption test methods and inspection rules (Fridley et al., 2007). Refrigerators and air conditioners are the first appliances to be regulated, as they account for the largest two components of residential energy consumption (consuming 17% and 24% of electricity use individually in the domestic sector in 2009).

The MEPS category is regularly updated to upgrade the minimum allowable energy efficiency. For instance, the air conditioner MEPS category has been updated four times since it was initially established, from GB12021.3-1989 to GB12021.3-2000, GB12021.3-2004 and GB12021.3-2010. Table 2.3 lists the Energy Efficiency Ratio (EER) grades for air conditioners in the 2004 version, with EER 2.3 (Grade 5) as the minimum allowable value for the single-package air conditioner as improved to EER 3.1 (Grade 1). Table 2.4 lists the 2010 version in which the EER grades are reduced from 5 to 3 levels, with a much stricter minimum allowable value. It suggests an overall energy efficiency ratio improvement of 25% between 2004–2010.

Table 2.3. Energy efficiency grade specification for air conditioners in 2004 version

Category	Rated Cooling Capacity (CC) (Watts)	Energy Efficiency Ratio (EER) in 2004 (W/W)				
		5	4	3	2	1
Single-package	CC≤14,000	2.3	2.5	2.7	2.9	3.1
Split-unit	CC≤4,500	2.6	2.8	3.0	3.2	3.4
	4,500<CC≤7,100	2.5	2.7	2.9	3.1	3.3
	7,100<CC≤14,000	2.4	2.6	2.8	3.0	3.2

(Source: Fridley et al., 2007)

Table 2.4. Energy efficiency grade specification for air conditioners in 2010 version

Category	Rated Cooling Capacity (CC) (Watts)	Energy Efficiency Ratio (EER) in 2010 (W/W)		
		3	2	1
Single-package	CC≤14,000	2.9	3.1	3.3
Split-unit	CC≤4,500	3.2	3.4	3.6
	4,500<CC≤7,100	3.1	3.3	3.5
	7,100<CC≤14,000	3.0	3.2	3.4

(Source: SAC, 2010)

2.4.2 Market-based instruments and incentives

The domestic energy saving policies in China have shifted to economic and financial incentives and market-based instruments in recent years. Zhang and Wang (2013) indicated that China's incentive instruments mainly included tax preference, funds support, concessional loan and pricing policy, and that the first two instructions are relatively effective.

In 2006, the Ministry of Housing and Urban-Rural Development (MOHURD) released the "National Standard Evaluation Standard for Green Building" (GB/T50378-2006), offering a market-based instrument to promote sustainable buildings with a three-star rating system. The three-star rating system, also named the Green Building Energy Labelling (GBEL) system, is an integral part of the green standard. The green standard defines green buildings as buildings that save a maximum amount of resources (including energy, land, water and materials), protect the environment, reduce pollution, provide comfortable and efficient space for people, and exist harmoniously with nature throughout their lifecycle (MOHURD, 2015b). The standards provide a detailed technical guide for both new buildings and retrofitting existing buildings. Table 2.5 presents a sample of the GBEL rating system for residential buildings. In the rating system, "level 3" means that the building has the highest level of sustainability regarding the 40 rated items.

Table 2.5. Green Building Energy Labelling rating system of residential buildings

Rating Level	General Items (Total: 40 items)						Preferred Items
	Land Use & Outdoor Environment	Energy Efficiency	Water Efficiency	Resource Efficiency	Indoor Environment	Operational Management	
	Total: 8	Total: 6	Total: 6	Total:7	Total: 6	Total: 7	Total: 9
★	4	2	3	3	2	4	-
★★	5	3	4	4	3	5	3
★★★	6	4	5	5	4	6	5

(Source: MOHURD, 2015b)

The "Domestic Building Energy Conservation Standard" mentioned in the previous section is a regulatory instrument that must be complied, but the "Green Building Evaluation Standard" mentioned in this section is a voluntary rating system for advanced design, usually supported by incentives. Some municipal governments will gradually make the green building standards mandatory. For instance, Shanghai requires all of the new residential buildings should achieve the GBEL rating under the 13th FYP (MOHURDS, 2016).

The market-based incentives for green buildings could stimulate the boost of building energy efficiency in China. For instance, in 2012, an incentive of 45 RMB (5 GBP) per sq.m was provided for 2-star GBEL buildings and 80 RMB (9 GBP) per sq.m was provided for 3-star GBEL buildings. In 2016, in Shanghai, the incentive was increased to 50 RMB (5.5 GBP) per sq.m for 2-star GBEL buildings and 100 RMB (11 GBP) per sq.m for 3-star GBEL buildings. The market-based incentive helped to achieve the 22.34% share of green buildings among all new constructions in 2015; and the target of share is increased to 50% by the end of 13th FYP (Khanna et al., 2014).

Strongly supported by government incentives, green buildings are increasing dramatically in China. During the 11th FYP (2016–2010), 127 residential building projects got the GBEL rating, on average saving 58% more energy than buildings built using the mandatory building codes (Tian et al., 2012). By the end of 2013, 1260 building projects in total achieved the GBEL rating in China (Tang and Liao, 2014). During the first half of 2015, 656 projects got the GBEL rating in China, with a total construction area of 68.2 million sq.m. By June 2015, 3194 projects were certified in China in total, with a total construction area of 359 million sq.m. In Shanghai, during the 12th FYP (2011–2015), 297 projects achieved the GBEL rating with a total construction area of 26.67 million sq.m, with 32.4% of projects being residential buildings (MOHURDS, 2016).

Even the market-based instruments with incentives for green buildings could increase the number of green buildings in China and improve the building components, whether the actual energy consumption in green buildings is reduced should be considered. Many buildings demonstrate good energy performance during design stage but may not perform well during the operation stage. This problem is caused by the unregulated operating conditions and the elements not mandated in prescriptive standards, which ignores the impact from the diversity of how residents use domestic appliances and air conditioners. To address this performance gap, an outcome-based building energy standard to regulate actual building energy use has been recently developed (Feng et al., 2017).

In 2012, MOHURD (2012) released the "Standard for Building Energy Performance Certification" (JGJ/T288-2012), which could provide a market access system for energy-efficient buildings. The certification system contains two steps of evaluation. The first is the Building Energy Performance Evaluation (EPE), after construction but before building check and acceptance. The second is the Building Energy Performance Measurement and Evaluation (PME) which follows one year of building operation and an occupancy rate of more than 30%. Some more developed provinces published local technical standards and guidelines based on local conditions, such as Jiangsu (DGJ32/TJ135-2012) and Shanghai (DG/TJ08-2078-2010).

Table 2.6 lists the requirements of the 3-level rating grade of the labelling system (level 3 being the most energy efficient). Firstly, the basic option is the relative energy-efficiency ratio compared to the annual consumption of a comparative building. For example, for a building with a one-star rating, it means this building is 0–15% more energy saving than a reference building. Secondly, the prescribed options state that the building envelops and HVAC system should be in accordance with the mandatory building standard. Thirdly, the alternative options add a score for new technology and the use of renewables.

Table 2.6. Building energy efficiency labelling standards

Grade	Relative energy-efficiency ratio (η)	Prescribed options	Alternative options	η relative to 80's standard with reduction level 65%	η relative to 80's standard with reduction level 50%
★	$0 \leq \eta < 15\%$	All items must comply	Score more than 60, one more ★ added	$65\% \leq \eta < 70.2\%$	$65\% \leq \eta < 57.5\%$
★★	$15\% \leq \eta < 30\%$			$70.2\% \leq \eta < 75.5\%$	$57.5\% \leq \eta < 65\%$
★★★	$\eta \geq 30\%$			$\eta \geq 75.5\%$	$\eta \geq 65\%$

(Source: MOHURD, 2012)

However, once the building energy efficiency labelling is issued to a household, the certificate provides very limited information of how to save energy to achieve a higher efficiency grade. Even the market-based PME takes a step forwards and considers human factors in building energy efficiency labelling, the labelling system still fails to address the potential of building energy efficiency and provide feedback of how to change their behaviour to improve building energy saving.

In addition to building components, the government provides market-based incentives for energy-efficient products. The labelling and grading schemes, which is a regulatory instrument as mentioned in section 2.4.1, could help to create market transparency for consumers to select the preferred energy-efficient appliances (Zheng et al., 2015). Incentives are provided to support consumers to buy the top 15%–20% energy-efficient products in the market (Zheng et al., 2015). There are two tiers of the subsided energy-efficient products and Tier-2 is the lower requirement for an energy-efficient product. During the first subsidy period (2009–2010), the discount price of an energy-efficient air conditioner was 2,000 RMB (222 GBP) cheaper for Tier-1 products and 1,500 RMB (166 GBP) cheaper for Tier-2 products than original price on sale (Zheng et al., 2015). Under the 12th FYP (2011–2015), a higher financial budget was provided by the central government to support the broad deployment of energy-efficient products. With total financial support of up to 26.5 billion RMB (3 billion GBP), five categories of domestic appliance were subsidised, including air conditioners, refrigerators, flat-panel TVs, washing machines, and water heaters. With the support of market based incentives, consumers are more likely to consider to buy the more energy-efficient product with subsided prices. However, if consumers think that if an appliance is energy-efficient then they can use it more regularly, the final energy consumption might be higher. Thus, it is also important to consider behavioural factors in improving domestic energy efficiency.

The 3-level progressive electricity pricing system with peak-and-valley time-dependent electricity tariff are influential economic and market-based instruments that target on domestic energy use behaviour for building energy efficiency. Table 2.7 presents the electricity price at different times of the day and different levels of accumulated annual electricity consumption for residential buildings in Shanghai. The purpose of this pricing system is to promote residents' sustainable awareness and energy use efficiency by price levering (Wu and Zhang, 2017). The 3-level progressive electricity pricing system is mandatory from one aspect that, if the accumulated electricity consumption is higher than a certain level within a year, the electricity price per unit of kWh increases; from another aspect, is market-based that, the residents have the right to decide the way of consuming energy, by taking the unit price at different time of the day into consideration. The time-dependent electricity pricing scheme is voluntary and market-based, in which occupants can choose to participate or not based on their energy use habits. For instance, the normal electricity price is 0.617 RMB/kWh for level 1 consumers without the program, while the price for participation is 0.617 RMB/kWh for peak time (6:00–22:00) and 0.307 RMB/kWh for valley time.

Table 2.7. Electricity pricing system in Shanghai in 2015

Level	Electricity consumption (kWh/year)	Electricity price (RMB/kWh)		
		Normal	Peak-and-Valley	
Level 1	Lower than 3120	0.617	Peak	0.617
			Valley	0.307
Level 2	3120-4800	0.667	Peak	0.677
			Valley	0.337
Level 3	4800 and higher	0.917	Peak	0.977
			Valley	0.487

(Source: Shanghai Municipal Commission of Economy and Informatization, 2012)

However, based on a nationwide survey by Hu et al. (2017), sixty-one percent of respondents expressed that they did not know about the 3-level progressive electricity pricing system. Seventy-eight percent of respondents indicated that their energy use behaviour was not affected by economic factors. Forty-two percent of respondents knew the information about the time-dependent electricity tariff, but only sixteen percent of respondents were encouraged to use electricity during the valley period. It can be inferred from the survey results that, in order to ensure that the policies work more effectively, it is primary to provide consumers with enough information about the 3-level progressive electricity pricing scheme and time-dependent electricity pricing tariff after policy implementation. Otherwise, these policies are ineffective if consumers do not have an awareness of them. Wang, Zhou and Yang (2017) pointed out the challenges in the 3-level electricity pricing system are inadequate level of public acceptance, insufficient reflection in regional differences, less combination with other pricing system, and inadequate sue of smart meters.

2.4.3 Limitations in existing policy instruments

Even though the domestic energy saving policies in China have been improved step by step in recent years, the implementation of domestic energy saving is still under expectation. In this section, two limitations were identified from the review of existing domestic energy saving policies in China.

Firstly, there is a lack of feedback-based instruments to address domestic energy use behaviour in China. Most domestic energy saving policies implement regulatory instruments and market-based incentives to improved building components and energy-efficient appliances, such as the mandatory residential building codes, minimum performance standards for appliances, and voluntary green building standards with incentives. Even the Building Energy Performance Measurement and Evaluation was launched in 2012, starting to consider the human factors in building energy labelling after one year running of the building, the labelling only provides information of actual annual energy use after one year, but without guidance on how to reduce consumption through behaviour changes. The most influential energy saving policy for domestic energy use behaviour is the 3-level progressive electricity pricing system with the voluntary peak-and-valley time-dependent electricity tariff. However, based on the previous survey studies, consumers are not likely to pay attention to energy saving with respect to differences in electricity price at different times of the day, or even, they never heard of information on this instrument (Hu et al., 2017).

Secondly, there is a lack of communication in the design and implementation of policy instruments for building energy saving. Current domestic energy saving policies in China mainly depend on the top-down communication, which regards citizens as passive recipients. However, consumers' views, habits, practices and resources determine whether and how domestic energy saving policies could be implemented, and affect how energy use behaviour changes before and after the implementation of domestic energy saving policies. Public engagement, involving a two-way flow of knowledge, was proposed as a more useful instrument than top-down communication (Owens and Driffill, 2008). To formulate more practical policies, it is essential to understand occupants better and to provide adequate information for occupants. Due to this limitation, this thesis was designed to provide further insight into which kind of policy instruments could be more acceptable and approachable by occupants and which information is more effective in encouraging occupants to save energy.

2.5 Policy proposals to promote domestic energy saving in China

The intention with policy instruments for behavioural change is to affect energy use in a more environmentally friendly direction for which, the environmental impact can be addressed (Lindén et al., 2006). Experience and practice have proved that the well-designed policy instruments can result in substantial energy saving (Geller et al., 2006). According to Itard and Meijer (2008), policy instruments can be theoretically grouped into three categories, including regulatory, incentive, and communicative instruments, and different instruments are used in various combinations to improve policy efficiency. In section 2.4, the regulatory and incentive instruments for domestic energy saving are introduced, but there is a lack of communicative instruments in China.

Based on the review of existing domestic energy saving policies in China, two limitations were identified, including a lack of feedback-based instrument to target on energy use behaviour and a lack of communicative instruments to improve a two-way flow of knowledge and information. To address the limitations, energy use feedback systems may be identified as a potential approach. The smart meter, an energy use feedback system, is a link between individuals, technologies and society (Martiskainen and Ellis, 2011), defined as an advanced device supported by the two-way communication system (Haney, Jamasb and Pollitt, 2009) in this thesis. The more advanced technology of the smart meter and the more informative billing system are useful for promoting more responsive demand and for addressing behaviour in domestic energy use, to improve the security of supply, reduce CO_2 emissions and tackle the problem of fuel poverty (Haney, Jamasb and Pollitt, 2009). Thus, the smart meter could potentially address two limitations in existing domestic energy saving policies in China, by providing feedback for occupants and improving a two-way flow of information.

Further, the experiences could also be learnt from more developed countries. The smart meter program in the UK, named "Smart Meter Implementation Program" (SMIP), aims to install smart meters for electricity and natural gas, with in-home displays (IHD), for every household in the UK by 2020 (Smart Energy GB, 2017). The SMIP was identified as the largest national infrastructure project in the UK (Smart Energy GB, 2017).

The National Development and Reform Commission of China (NDRC) plays an essential role in the development of China by formulating national plans, approving investment projects and providing fiscal support (Yuan et al., 2014). In China, the smart grid was developed quickly with substantial fiscal support from the central government, with 2 trillion RMB (0.22 trillion GBP) under the 12th Five-Year Plan (FYP) (2011–2015) and further 1.7 trillion RMB (0.19 trillion GBP) under the 13th FYP (2016–2020), aiming to rollout of "smart meters" (the government uses "smart meter" in the Chinese policy document) in China by 2020 (MOS&T, 2012).

However, the electricity meter mentioned in the Chinese rollout policy is not a typical smart meter. Admittedly the new electricity meter is more advanced and smarter than a traditional round meter which requires manual meter readings every month. However, the primary difference between the new electricity meter in China and the smart meter in the UK is that the electricity meter in China only enables one-way communication, which can only send the electricity consumption data to the electricity company. In the UK rollout plan of smart meters, the in-home display (IHD) is planned to be installed for every household, showing real-time consumption and real-time price of electricity and gas, which enables two-way communication.

By the end of 2012, higher than 122 millions of advanced electricity meters had been installed by the State Grid Corporation of China (SGCC), and it is predicted that the cumulative number of installed advanced electricity meters will be 340 millions by the end of 2020 (Zhou, Yang and Shen, 2017). In China, the two-way communication smart meter with IHD was not mentioned in policies, but it was only installed for research purposes.

There are numerous challenges in the implementation of smart meter policies in the UK and those experiences could be learnt by China to design and implement policies better. Sovacool et al. (2017) grouped the challenges of rolling out smart meters in the UK into technical barriers and socio-technical challenges (vulnerability and resistance). They indicated that a smart meter is less useful for some groups of consumers, such as the old people, the ill, the less educated people, and those people living in social housing or rural areas. They summarised that consumers are likely to resist smart meters, due to: 1) the lack of consumer interfaces in technical guides of smart meters; 2) the lack of meaningful information on IHDs for behaviour change; 3) the unfair burden on households for taking responsibility to install smart meters and IHDs for carbon reduction; 4) concerns that smart meters "compromise security" and "invade privacy"; 5) concerns for reclining comfort and disruption in household routines; 6) mistrust about the energy suppliers that will profit from the SMIP or manipulate the smart meter data; and 7) concerns about the health effects. Based on the experiences in the UK, there have been experiences and lessons for China to learn if the Chinese government decided to implement smart meter policies in the future. Apart from technical barriers, the socio-technical challenges (vulnerability and resistance) are crucial to consider in the design stage of domestic energy saving policies in China.

The experience from SMIP highlights two points that can be applicable for China, if it is to implement a similar policy instrument. Firstly, how to deal with vulnerable groups of consumers, such as the old people, the less educated people, and the people in social housing or in rural areas. Secondly, how to increase consumers' interests in smart meter policies and encourage them to change behaviour by providing adequate information, and thus overcoming possible elements of resistance to smart meters. In the early stage of smart meter policies in China, young urban residents could be selected as a pilot target group to test the efficiency of the policy, as this group of urban residents is likely to consume more energy with a comfort-driven lifestyle, and it is also more likely to accept new information and technology when compared with the old group. In addition, it is a challenge for consumer engagement campaigns to provide enough information to make sure every consumer is likely to accept installing smart meters at home and with sufficient guidance of how to adapt behaviour to save energy.

2.6 Summary: policy gaps and proposals

Chapter 2 reviewed the existing domestic energy saving policies in China. Section 2.2 provided the general information about urban housing stock in China. This section stressed the rapid urbanisation speed and the increasing building floor space in urban China, as well as the short building lifespan when compared to the Western countries. It also identified the lack of public available data about building construction and demolition information in China. Section 2.3 highlighted the recent focal point of building energy efficiency in the most primary national Five-Year Plan in China since the 11th FYP, and introduced the national 40–45% carbon reduction goal by 2020 in the 13th FYP. It also present energy efficiency policies and special plans based on the strategy identified in FYP, and introduced an example of the action plan of improving the urban domestic energy efficiency by 20% by 2020 based on the 13th FYP.

Section 2.4 reviewed the existing policy instruments of domestic energy saving in China, divided into regulatory and incentive instruments. The regulatory instruments were used more frequently in the previous years, including the building energy codes and standards for domestic appliances. The market-based instruments and incentives were implemented more in recent years, including the green building standards with incentives, the pre- and post-occupancy building energy performance labelling system, the incentives for energy-efficient appliances and the 3-level progressive electricity pricing system with the time-dependent electricity tariff. Section 2.4 also summarised two limitations from the review of existing policy instruments in China. First, there is a lack of feedback-based instruments to address domestic energy use behaviour in China. Second, there is a lack of communication in the design and implementation of policies. Thus, it is important for the policy-makers to explore which policies are more acceptable by consumers and how to implement the policies in an effective way to maximise the cost-effectiveness of policy instruments.

Section 2.5 proposed policy suggestions for domestic energy saving with regard to limitations identified in the review of existing policy instruments in China. Energy use feedback systems, such as the smart meter, may be identified as a potential approach, which could also improve a two-way communication system from the government to consumers. Experiences could be learnt from the UK smart meter policies to implement more effective policies in the future. Thus, it is essential to explore whether the smart meter policy is acceptable by consumers and which instrument that related to smart meters is more effective for different types of consumers. This thesis was designed to address the research question to explore effective domestic energy saving policies.

The next chapter will review behavioural studies of domestic energy use in China, exploring the factors that affect occupants' attitudes and behaviour, as well as how to address energy use behaviour by considering these factors.

Chapter 3 – REVIEW OF BEHAVIOURIAL STUDIES

3.1 Introduction

Chapter 3 reviews the behavioural studies. Section 3.2.1 discusses the importance of occupant behaviour in domestic energy saving. Section 3.2.2 reviews the factors that affect occupants' behaviour and attitudes. Section 3.2.3 identifies the limitations of current behavioural studies in China. To address the limitations, section 3.3 provides a review of social psychological models that can be used to understand occupants' behaviour and attitudes. Section 3.4 reviews cases of installing smart meters and applying data-mining techniques for exploring energy use patterns, which could be applied in the context of China in the future. Section 3.5 summarises the findings from this chapter.

3.2 Review of existing studies on domestic energy use

3.2.1 Energy savings from building improvements

Extensive studies have been done on energy saving potential from the improvement of building fabrics and domestic appliances in the context of China. Researcher mainly uses the building performance simulation and field energy monitoring methods to test the energy saving potential of more sustainable buildings. Ouyang, Ge and Hokao (2009) used an existing residential building in Hangzhou, China as a case study to analyse the economic benefits from thermal retrofit measures through the Life Cycle Cost method. They found the actual heating and cooling loads of the case building are 12.28 kWh/m^2 per year, occupying 33.94% of the annual electricity consumption. They compared the actual energy savings with simulated results and found the energy saving estimation in simulation is over-predicted. They indicated the largest energy saving potential could be achieved by improving insulations of building envelopes. They highlighted the cheap electricity price is a puzzle in achieving more sustainable buildings. Guo, Akenji, Schroeder and Bengtsson (2018) analysed the technical and economic potential in domestic energy saving in Xiamen, China. They concluded that the technical potential of energy savings is about 20%, with 75% from adopting more efficient appliances. Wang et al. (2018) applied an interview study to compare retrofit models of central government-led model, local government-led model and old neighbourhood retrofit model and concluded occupants' motives, intentions and living habits are influential in improving the effectiveness of energy saving measures. They highlighted the importance of public participation in implementing and developing energy saving policies. Zhao, Künzel and Antretter (2015) adopted the simulation analysis to assess the impact of various parameters in designing residential buildings in each Chinese climate zone on heating and cooling energy demands. They indicated the improvement of three most sensitive design parameters in each zone could help to achieve the annual energy reductions of 75 kWh/m^2 in the severe cold zone, 40 kWh/m^2 in the cold zone and the hot summer and cold winter zone, 50 kWh/m^2 in the hot summer and warm winter zone, and 35 kWh/m^2 in the mild zone. In the hot summer and cold winter climate zone, U-value of the external walls, window to wall ratio on the south facade and infiltration rate were identified as three most sensitive parameters. They proposed the total energy demand of standard buildings could be reduced by 50% in five climate zones with three improvement measures. Zhou et al. (2018) applied simulation analysis to compare the heating consumption of five residential buildings based on the third-step energy efficiency standard in China (65% saving compared to the pre-1986 benchmark mentioned in section 2.4.1), with the building designed based on the German standards. They revealed that the annual heating energy consumption can be reduced by 14.9%, 21.9%, and 36.1% respectively, if the buildings are designed based on the German standards (WSVO-1995, EnEV-2002 and EnEV-2009).

3.2.2 Importance of behavioural factors in domestic energy saving

There exist great variations in domestic energy use behaviour, with respect to the use of lighting, appliances, and air conditioners (Jian et al., 2015), and variations in energy use behaviour lead to significant differences in final energy consumption. In order to improve domestic energy efficiency, the behavioural factors should be considered in policy design and more behavioural research should be conducted. D'Oca et al. (2016) urged the research into energy use behaviour is supportive in capturing the complexity and diversity of behaviour to support policy design for behavioural change. Hong et al. (2017) pinpointed the knowledge gained from behavioural research could be used by policy-makers to develop informed, effective energy saving policies. Hong et al. (2015) proposed archetypal occupancy profiles could improve the effectiveness of policies by applying policies for each occupancy profile instead of using blanket policies, grouped by spatial differences in social conditions. To conclude, occupants' behavioural factors are important to consider in the design of domestic energy saving policies, as a better understanding of occupants could help to predict energy saving potentials of different technical solutions or behavioural measures more accurately by simulating different possible behavioural patterns, and understand impacts from demographic variables in affecting energy use behaviour so as to the final energy use and identify the target group for more effective energy saving policies.

As mentioned in chapter 1, it is important to identify differences between the terms of "energy saving" and "energy efficiency". Energy efficiency means occupants do not have to sacrifice comfort to improve building energy performance, while energy saving often involves a change in behaviours. The energy saving policies discussed in this research represent a broader concept that not only includes physical upgrades of building fabrics or domestic appliances, but also involves the promotion of behavioural change for energy saving. It is relevant to consider behavioural factors as the common problem with energy saving policies is the policies without considering behavioural factors might reproduce and stabilise unsustainable concepts of energy use demand instead of reducing consumption (Shove, 2017). This opinion agrees with the research by Owens and Driffill (2008) that, energy efficiency measures might not be as effective as estimated, as domestic energy use behaviour has become more energy-intensive with the improvement of building fabrics and other technical solutions. In the context of China, modifying energy use behaviour in residential buildings could save 10% of electricity use (Ouyang and Hokao, 2009) and reduce 3–18% of the heating load (Xu, Xu and Shen, 2013).

Some studies have explored the factors that affect energy use behaviour in supporting domestic energy saving. Jian et al. (2015) pointed out that energy use behaviour could be improved if provided with more energy saving knowledge. They found occupants had very limited knowledge of how their behaviour affected energy use, and they also suggested that if provided with detailed information on how energy is consumed, the occupants' saving energy awareness and energy use behaviour could be improved. They also selected the internet is a practical tool for the government to communicate with publics than traditional media. Hu et al. (2017) conclude from their research that public attention to electricity costs was limited, and proposed it is urgent to retain the current energy use culture to insulate households' traditional energy use patterns from the Western countries. Tan et al. (2017) and Yu et al. (2011) advocated policy-makers could make use of available channels and education systems to transfer information on how to improve energy use behaviour in reducing energy consumption. Tan et al. (2017) also suggested that if residents can monitor their actual energy use, they are more likely to save energy. Ma et al. (2017) indicated communicative instruments can be applied to encourage interactions between neighbourhood households for energy saving, and suggested that intervention by neighbourhood committees could help to enhance public participation, cooperation and mobilisation.

3.2.3 Factors that affect behaviour and attitudes

This section provides a literature review of existing behavioural studies on occupants' energy use attitudes, behaviour and intentions to save energy. This section reviews impact factors that affect these elements, and also reviews existing research in China to summarise the key findings and limitations in methodologies.

Previous research has been done on the factors that affect occupants' energy use attitudes, behaviour and intentions to save energy. Occupants' energy use attitudes can be influenced by physical, social, cultural, institutional, or political factors and information provision (Owens and Driffill, 2008). Occupants' energy use behaviour can be affected by economic factors, environmental awareness, trust and commitment to society, cultural norms from society and family members, daily routine habits and practices, and social networks, as well as factors bedded in the built environment, such as comfort, cleanliness and convenience (Shove, 2003; Jackson, 2005). Occupants' intentions with energy saving policies can be influenced by gender and age factors, and motived by reduced costs and reduced environmental impact (Carlsson-Kanyama et al., 2005; Gyberg and Palm, 2009).

Several studies have explored domestic energy use behaviour in China. Based on Chen et al. (2010)'s research in Shanghai, they found dissatisfaction in the indoor environment, intensive use of air conditioners and a high-income level are three primary factors that lead to high energy use. They suggested behavioural measures for moderating the use of air conditioners and increasing the set cooling temperature for domestic energy saving. Feng et al. (2016) highlighted the potential of improving energy use behaviour in domestic energy saving, such as energy saving education for how to behave sustainably. They summarised from the survey that the most significant parameters that affect domestic energy use are household characteristics, especially respondents' age and income levels. They indicated the old generation tends to exhibit more frugal behaviour, as they were exposed to food and resource scarcity before the 1980s. Similarly, research by Chen et al. (2013) and Ruan et al. (2017) all indicate respondents' age is the most significant factor in affecting domestic energy use. Ding et al. (2017) pointed out urban residents with a stronger sense of environmental values present a greater tendency in achieving energy saving, but residents' energy saving consciousness in China is weak, as they regard comfort as a critical pursuit in living habits.

A survey method is the most frequent research method applied is exploring domestic energy use behaviour in China, but in slightly different ways. Hu et al. (2017) used the online survey method to explore urban domestic energy use behaviour in China, with 4964 effective answers in response. The advantage of an online survey is the low cost and short period spent in collecting responses, however, it is more likely to receive responses from younger and more fluent respondents, as they tends to use internet more. Guo et al. (2014) employed the mixed-method of measurement, interview and survey to investigate domestic winter heating behaviour in Shanghai. However, their research only summarised statistics of energy use behaviour, without exploring hidden reasons behind practices, contributing to a limited knowledge output from this time-consuming, sophisticated methods. For instance, they did interviews of 14 households about winter heating habits, however, the limited findings from interviews can also be obtained from a survey study, which is less time-consuming, and the advantage of the qualitative interview was not proved in their research. The qualitative interview can be used to explore latent variables that affect energy use behaviour. Different from Guo et al., this thesis aims to apply mixed methods to understand occupant behaviour, with a more profound output of hidden factors that affect complex, complicated domestic energy use behaviour, but using less-time consuming research methods to maximise the knowledge gained.

Several studies have explored the factors affecting households' intentions with energy saving policies in China. Wu and Zhang (2017) applied the survey method in Guangdong, China to explore the effects of implementing the 3-level electricity pricing system on energy saving and examine the factors that fact the energy saving willingness of residents. From the analysis, they summarised that age, gender, education level, and having a family would affect residents' energy saving awareness. They suggested the government could divide residents into groups to target advertising based on the demographic factors of the intended audiences. Jia, Xu and Fan (2018) summarised the acceptance of energy saving measures will be more advanced for the younger generation and people with high environmental concern. They suggested that the incentive energy saving policies could be targeted on different household groups, categorised by the heterogeneity in preferences for energy saving measures. Wang et al. (2017) indicated that residents' environmental values, past purchasing experiences, age, and educational background affect the intention of buying energy-efficient appliances more than policy environment and media propaganda. Yang and Zhao (2015) pointed that higher family income can help to transfer green attitudes into purchase intentions for energy-efficient appliances. Zhou and Bukenya (2016) indicated information inefficiency is the primary constraint in promoting the China Energy Label system.

A survey method is also a widespread method in exploring energy saving intentions. Harris (2006) used a survey method to analyse factors that affect environment-related behaviours in China. Harris (2006) indicated that respondents with a higher education level and a higher income level are more likely to have a more positive attitude toward being environmentally-friendly. Harris (2006) highlighted that Chinese people have a negative view for the natural world in "*it exists for the benefit of people*", with the drawbacks of focusing on getting rich and adopting comfort and energy-consuming lifestyles. Harris (2006) suggested that environmental education and making environmental protection fun are useful in encouraging environmental values, targeting on urban youth and the new middle class. With the experience from his study, this research also selected urban young population and the middle class as the target group for survey and interview studies in chapters 5 and 6. Abrahamse and Steg (2011) explored the relationships between psychological and socio-demographic variables regarding occupants' domestic energy use and occupants' intention to save energy. They did a survey study of 199 samples selected from 7,000 energy consumers of a Dutch utility company. They used the regression method and applied elements in the theory of planned behaviour (TPB) and value-belief-norm (VBN) as the psychological variables to test the relationships. Based on regression analysis, they concluded that domestic energy use was strongly related to socio-demographic variables, and the intention to save energy was positively related to the perceived behavioural control and attitudes toward energy saving. This case helps the development of this thesis, as the regression analysis is also applied in chapter 5 to test the relationships between socio-demographic and psychological variables with domestic energy use and the intention to save energy.

Huang, Mauerhofer and Geng (2016) analysed the existing energy saving policies in China. They summarised that the control and regulatory instrument is identified as the most efficient policy due to its long execution period and popular implementation. However, 86% of respondents pinpointed a lack of incentives for innovative policy instruments. Among the existing economic and market-based instruments, they identified five limitations in achieving higher policy efficiency, including high transaction costs, limited information provided to the public, lack of applicable methodologies, and limited law basis and financial regulation system.

Based on the review of studies on domestic energy use in China, it could be a suitable option to make use of the mass media to widely advocate the advantages and the necessity of energy saving, as well as the benefits of energy saving policies. This instrument could help to improve public's knowledge in energy saving, such as how to behave more environmental-friendly to reduce domestic energy consumption. It could also help to change public's attitudes to the implemented domestic energy saving policies, such as the promotion of energy-efficient apartments and appliances.

A smart meter was identified as a potential policy tool in China to promote domestic energy saving in section 2.5. It is important to explore whether the smart meter will be acceptable by the consumers in the design stage of smart meter policies, and explore which policy instrument related to a smart meter will be more effective. However, there has been limited research in China to explore occupants' attitudes toward potential policy instrument of smart meters. Research experience could be learnt from more developed countries that Krishnamurti et al. (2012) employed a behavioural decision method to understand occupants' beliefs about smart meters. They conducted 22 interviews to explore occupants' attitudes toward smart meters in the first stage, and then reported on a survey with 126 respondents using questions based on the beliefs observed in the interviews, as well as the wording used in describing them. Surveys were distributed to 500 potential smart meter customers affiliated with a U.S. utility company. They tested the hypothesis generated from 22 interviews with larger samples of 126 effective responses from surveying. The survey results showed most respondents claimed they accepted installing smart meters at home. However, the preferences were based on misunderstandings about functions of smart meters with in-home displays. The results suggested the government should provide more information about smart meters to address occupants' misunderstandings. This case study is very important in developing this thesis for the following two reasons. Firstly, they used the combination of literature review, interview, and survey method to explore the attitudes of domestic residents toward smart meters, which they called the behavioural decision method. This thesis also applied the mixed methods approach to explore occupants' energy use behaviour, attitudes toward smart meters and intentions to save energy with potential energy saving policies. Secondly, they tested occupants' attitudes toward eight statements of beliefs about smart meter summarised from literature review and in-depth interviews. Based on their research, in this thesis, the eight statements of beliefs about smart meters were used to test attitudes toward smart meters of Shanghai residents. The attitudes of Shanghai residents from this thesis will be compared with the U.S. residents from their study to explore the differences in beliefs about smart meters between different countries.

A recent research by Du, Guo and Wei (2017) applied a survey method to explore the impact of information feedback on domestic energy demand in China. They tested five hypotheses, include: 1) the more information accessed, the less electricity consumed; 2) ex ante information feedback is related to less electricity compared to ex post feedback; 3) explicit information feedback is associated with lower demand compared to implicit feedback; 4) more frequent feedback is related to less electricity demand; and 5) smart meter user is associated with lower electricity use. This study is a step forward in the research context of China, however, they only examined the feedback source of meter-reader, bank billing system, prepaid record and the feedback format of used quantity, monetary cost and price, rather than the real-time or monthly feedback on energy use suggestions. From their survey results, there were 566 smart meter users, accounting for 41% of total respondents, but only 28 users had the in-home displays. They also pointed out the information feedback of smart meter system is absent in China. Even in the capital city (relatively more well-educated and wealthier) of Beijing, some residents do not fully understand the information from smart meters and get feedback from this system.

The smart meter was further validated as a policy proposal, based on the limitations identified in the review of occupants' attitudes towards energy saving and intentions to save energy. There are three reasons to select a smart meter as a potential policy tool. Firstly, a smart meter can improve occupants' awareness and consciousness about domestic energy use (Buchanan et al., 2016). Secondly, a smart meter can promote community benefits and social benefits, such as making new friends and comparing consumption with them, as well as connecting with others and taking part in games (Buchanan et al., 2016). Thirdly, a smart meter can enable a two-way communication system for the government to understand more about occupants and for the occupants to receive information regarding how to change behaviour for domestic energy saving (Haney et al., 2009). The energy use data enabled by the smart meters allows policy-makers to understand energy use patterns better through robust analysis (Hamilton et al., 2013), which is helpful in identifying target groups and designing practical policy instruments. However, research on applying data-mining techniques and extracting occupancy patterns from smart meter data is still under-explored in the research context of China.

3.2.4 Limitations of the energy use studies in China

From the review of existing studies on domestic energy use behaviour in China, three gaps were identified: 1) the lack of a theoretical framework and understanding of the links between attitudes and behaviour; 2) the lack of deep mixed methods research that crosses disciplines taking a socio-technical approach to address the complexity of energy use behaviour; and 3) the lack of data-mining studies by using energy use data in exploring occupancy patterns. Further, from the exploration of public data, there exists a significant shortage of energy consumption data in China's domestic energy use. If these gaps can be targeted, the behaviour of occupants could be better understood when designing more effective policies.

Firstly, most energy use research in China applies descriptive statistical method to summarise information from the survey, without the support of a theoretical framework. Existing studies on domestic energy use promote more on technological solutions (see section 3.2.1), but ignore social psychological factors that affect occupants' behaviour and attitudes. The improvement of building components and energy-efficient appliances could help to achieve 20–50% of electricity consumption based on the simulation based on the previous research. However, there is a lack of research in China focusing on the energy saving potential through behavioural change. Further, there has been very limited research to examine occupants' intention to save energy with potential energy saving policies. Energy use characteristics could be concluded from a survey, but latent socio-psychological factors cannot be observed directly, such as energy concern, intention to save energy, norms, attitudes, trust, and emotions. This gap could be addressed with the application of a theoretical framework. Section 3.3 will review several social psychological models used in the research field of energy use behaviour and attitudes. Chapter 4 will select the appropriate model for this thesis and apply the model in the design and analysis stage.

Secondly, many researchers used a survey method to explore energy use behaviour in different regions in China, such as occupancy schedules, or heating and cooling set point temperatures. They also used statistical methods to summarise the factors that affect energy use behaviour, and found energy consumption is mainly influenced by age and income level. There has been very limited research on energy and building research in China that seeks to cross disciplines using a socio-technical approach to address the complexity of energy use behaviour and attitudes. Based on the limitation of previous energy use studies in China, this thesis aims to seek an effective mixed methods approach to maximise the understanding of energy use behaviour. Chapter 4 will explain each individual research method used in this thesis in detail and explain the reason and necessity of applying that method. Chapters 5–7 will present findings from each empirical study.

Thirdly, a smart meter was identified as a potential solution in domestic energy saving, however, there has been very limited study in China that use smart meter data to understand energy use behaviour and explore energy saving potentials. With the development of smart infrastructure in China, the exponential growth of data collected inside buildings provides policy-makers with the opportunity to understand more about consumers. Advanced data-mining techniques are crucial to extract novel and valid knowledge from the available data (Han et al, 2006). Section 3.4 will review previous studies that used data-mining techniques to explore the occupancy patterns from big data streams. Experiences from previous case studies in other countries can be used in the context of China to support demand-side management and other energy saving policies. Smart meter data could be collected to extract occupancy patterns and understand energy use characteristics of different groups for demand-side management, and policies might be more effective in targeting on different groups clustered by smart meter data. Occupancy patterns with single-zone simulation could be simulated to predict energy saving potentials of behavioural measures, to reduce performance gap when compared with simulation with limited information from building codes. Chapter 7 will apply the data-mining method to extract information from smart meter data and explore the information could be obtained from analysis.

3.3 Social psychology perspective on energy use behaviour

Social psychology is defined as the study of how people's thoughts, feelings, and behaviour are affected by the presence of other people (Hogg and Graham, 2013). The purpose of this thesis is to understand occupants' thoughts and feelings, as well as domestic energy use behaviour, and how their attitudes and behaviour could be modified for domestic energy saving. The application of the social psychological model is crucial in achieving the research objective of this thesis, for the following two reasons. Firstly, appropriate models could provide frameworks for exploring and conceptualising behaviour, especially for understanding social and psychological influences on energy use behaviour. Secondly, models can be used as frameworks to test the relationships between each variable.

Rational choice model

Some existing behaviour models are based on the rational choice model, which guides many policy designs. The rational choice model is a form of an expectancy-value model, which assumes that behaviour is the result of deliberative and cognitive processes. The rational choice model defaults the consumers make decisions of behaviour by calculating the costs and benefits from each possible action and choosing the option maximising the net benefits (Jackson, 2005). This model regards consumers who could make decision rationally and are free to act on this decision with identifiable constraints or barriers. Due to its firm grounding in classic rational views, this model has frequently been used by the government. Figure 3.1 shows the linear model of decision-making and behaviour. Policies based on this assumption are straightforward. Firstly, the policy should provide sufficient information so that consumers can make informed choices about the available options. Secondly, the policy is required to make the external costs visible for decision-making.

Figure 3.1. Linear model of decision-making and behaviour

(Source: Jackson, 2005)

However, the rational choice model has received extensive criticism due to its limitations. The primary criticism is the cognitive limitation on the ability to take deliberative actions, such as habits, routines, cues and heuristics. The process of routinisation of daily behaviour makes behaviour less visible to rational deliberation, less obvious to understand, and less accessible to policies. The second criticism is that affective responses (emotions, feeling, moods) confound cognitive deliberations (knowledge, meaning, beliefs) in a decision-making context. Thirdly, the assumption of self-interest in the rational choice model has been criticised, as social and interpersonal factors also shape and constrain consumer choices.

Theory of planned behaviour (TPB)

In the expectancy-value theory, it is assumed that choices are made based on the expected outcomes from a choice, and the value with the outcome. This assumption is the basic concept of adjusted expectancy-value models, with correction according to psychological antecedents of consumer preferences. Among the adjusted models, the theory of planned behaviour (TPB), indicated by Ajzen (1991), is the most famous. TPB incorporates the effect of people's perceptions about their control over the situation. There are three components in TPB: attitude, the subjective norm, and perceived behavioural control. These three variables affect occupants' intention regarding behaviour, which then affects their final behaviour. In TPB, attitude is defined as a willingness organised through experience, which has effects on people's response to the other people, objects, and situations. The subjective norm is defined as the perceived external pressure to execute or not to act on the behaviour, and perceived behavioural control is defined as people's perceived ease or difficulty in acting on a behaviour. Figure 3.2 presents a diagram of the theory of planned behaviour (TPB).

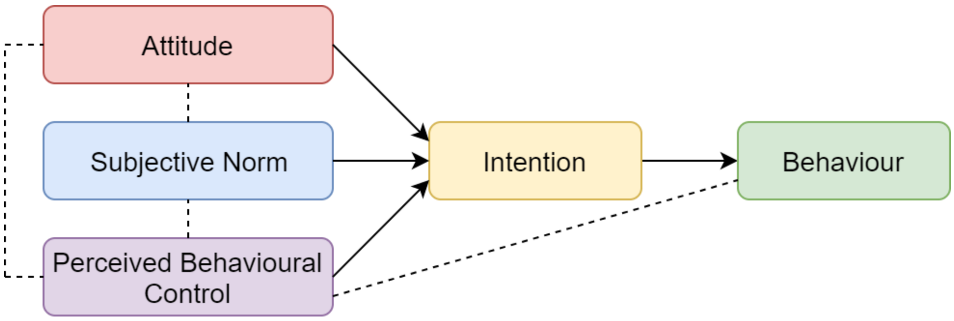


Figure 3.2. The theory of planned behaviour (TPB)

(Source: Ajzen, 1991)

Many energy saving studies have employed TPB as a theoretical framework. For instance, Greaves, Zibarras and Stride (2013) used TPB to understand the energy use behaviour of 2000 British employees. They found that three components in the TPB were able to explain the great variance in employee's intentions of changing their behaviour to save energy, such as switching off computers. Wang, Wang and Guo (2017) applied TPB to investigate the factors that affect residents' intention to save energy in China. They concluded that residents' environmental value, past purchasing experiences of domestic appliances, social relationships, age, and education level have impacts on their intention to purchase more energy-efficient appliances. Tan, Ooi and Goh (2017) applied TPB with a moral extension to examine the determinants of residents' attitudes toward energy saving policies. They found that the factor of perceived behavioural control has a great impact on residents' attitudes toward energy saving. They also proved that the moral extension is a significant predictor of residents' behaviour.

Value-belief-norm theory (VBN)

Similar with TPB, the value-belief-norm (VBN) model is an adjusted expectancy-value model which incorporates moral beliefs to improve its predictive power (Chan and Bishop, 2013). This model attempts to elucidate the impacts from people's moral beliefs and normative considerations to the emergence of a personal norm to act in a given way (Stern, 2000). Figure 3.3 presents a diagram of the value-belief-norm theory.

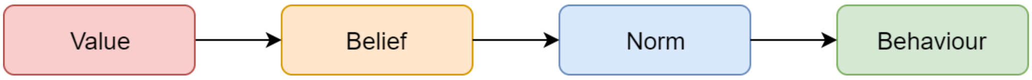


Figure 3.3. The value-belief-norm theory (VBN)

(Source: Stern, 2000)

VBN can provide insight into the value basis of different behaviour and behavioural intentions. Abrahamse and Steg (2011) used VBN to explore the relationship between psychological variables with domestic energy use and the intention to save energy.

Triandis' theory of interpersonal behaviour

The previous section noted that the most common criticism of the rational choice model is the routinisation of everyday behaviour. In some adjusted expectancy-value models, such as TPB and VBN, the impact factors of the norm, belief, and control are taken into consideration, but the role of habit is not evaluated. Stern (2000) acknowledged this problem and proposed an integrated prediction model consisting of four factors: attitudes, contextual factors, personal capabilities, and habits. Triandis agreed with Stern and proposed a theory of interpersonal behaviour (Figure 3.4) that considers the impact from social factors and emotions in forming intentions for pro-environmental behaviour. In this theory, intention and habit are immediate antecedents of behaviour, with the influence from facilitating conditions.

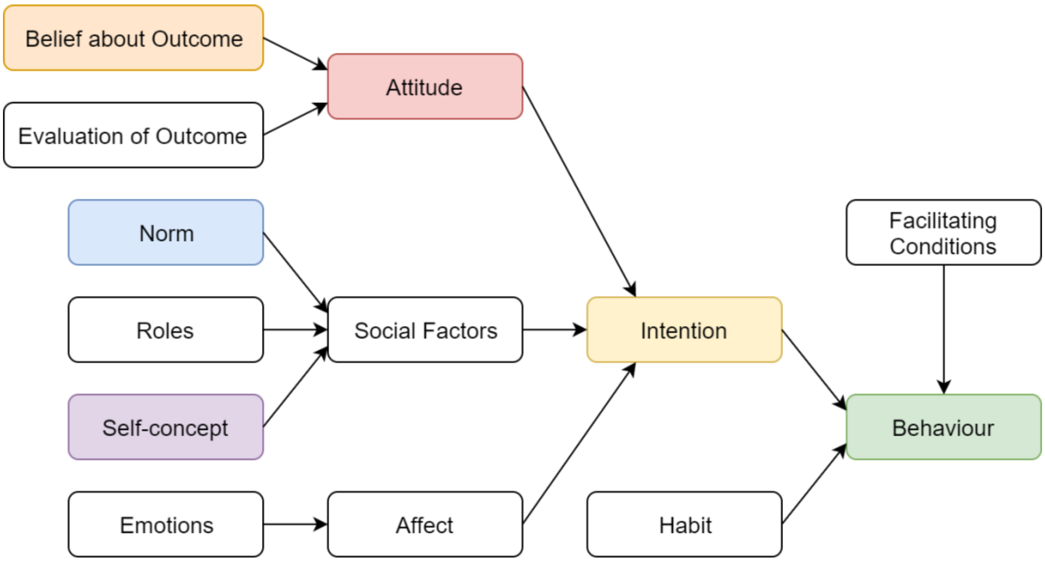


Figure 3.4. Triandis' theory of interpersonal behaviour

(Source: Jackson, 2005)

3.4 Technical perspective on energy use behaviour: smart meters and data-mining

3.4.1 Research on data-mining techniques

According to Hand (2007), data-mining is defined as the analysis of large data sets to identify unsuspected relationships and to summarise the data in novel ways so that users can effectively understand and extract information from the data. Data-mining has been employed to discover patterns from data sets in wide ranges of fields. In the energy use domain, data-mining has been proven to be a powerful tool to extract knowledge of occupancy patterns from internal load profiles, enabling the estimation of energy saving potentials, and formulation of energy saving policies (D'Oca, Corgnati and Hong, 2015).

The availability of energy use data in buildings is helpful in characterising occupancy patterns and demand forecasting. The vast volume of data collected in the database also leads to a substantial amount of embedded potential. To eliminate the gap between data and knowledge, it is urgent to apply appropriate data-mining methods to extract the valid, novel, and understandable knowledge from large data sets from building energy use (D'Oca et al., 2015). After that, policymakers can use the results extracted from the dataset to make decisions in policy design.

Several data mining techniques for identifying and improving occupant behaviour in building have been developed recently. There are mainly four categories of data mining method for behaviour learning from smart meter data, including classification, clustering, association rule and regression. This section briefly introduces the definitions and popular methods applied in each data mining method. Chapter 4 will explain the reasons of selecting the specific data mining technique in this thesis.

Classification

Classification, which adopts a model or classifier to predict grouped labels, is the most frequent applied technique for prediction problems (Han, Kamber and Pei, 2011). A whole classification process involves two steps – learning and validation. Initially, a classification model is built by training a full dataset with predefined class label attributes. The derived model can be grouped by three forms, namely classification rules, mathematical formula, and decision trees. Secondly, to verify the reliability and accuracy of the derived model, a cross validation process is applied. Specifically, the data set is separated into n subsets of data with the same size. Among the subsets, one subset of data is considered as a test data set and the remaining n-1 data subsets retained as training sets. Validation should be iterated for n times to ensure every data subset to be used as test data. The final estimation is defined as the average value of results generated from n times repetitions. If it is within the acceptable error rate, this derived model then can be employed as a classifier for future classification and prediction for new data set (D'Oca and Hong, 2014). To date, there are several popular classification algorithms to build classifiers, including rule-based algorithm, decision tree, Support Vector Machine (SVM), Naïve Bayesian (NB), K-nearest neighbours and Neural Networks (NNs).

Clustering analysis

Classification is generally known as supervised machine learning due to the predefined class label information; while clustering analysis is categorised as unsupervised machine learning, as the information of class label is unknown so that its learning process is not based on examples but observations. Clustering is defined as a procedure partitioning a set of observations into several clusters or subsets, thus substances in the same cluster demonstrate high similarities (Han et al., 2011). Clustering has been applied by some large electricity suppliers to group customers who reflect similar electrical characteristics for demand-side management. There are several methods of cluster analysis, and they can be classified as two sub-headings: Hierarchical and Partitional. The most popular clustering algorithms involve Hierarchical clustering, K-means, Self-Organising Mapping (SOM), fuzzy clustering and Follow-the Leader clustering.

Hierarchical clustering generates a tree like structure of nested clusters. Either a divisive (top-down) or an agglomerative (bottom-up) method of clustering data can be taken. To define individual customer groups, a similarity matrix is used. Each customer must be assigned to a particular cluster based on the distance metric to the similarity matrix and a linkage criteria. It is an iterative process that each small cluster is repeatedly merged into a larger one until all data is represented by a single cluster. The number of clusters is not pre-defined in this method and it can be cut at a particular height to divide the population into a specific number of clusters. However, this method is more susceptible to outliers as all data will combine into one cluster at the end.

Partitioning is the fundamental of cluster analysis by dividing the data into several predefined clusters. Currently, the most popular approaches of Partitional clustering methods are: Self Organising Maps (SOM) and K-medoid Maps (SOM). The advantage of this method is that there is no overlap between the clusters since they are predefined. However, comparing with Hierarchical clustering, this extra predefining process before the data clustering becomes a significant disadvantage.

Association rule mining

Association rule mining is another type of classification technique to extract correlations and relative association among attributes in a data set (Han et al., 2011). In a given database, the frequent relationships are identified through the frequent pattern mining seeking. Typically, this method involves two basic steps: 1) frequent itemsets which satisfy the threshold of support are discovered and extracted; 2) in order to reach the pre-determined minimum value of support and confidence, the robust association rules are then established based on the frequent itemsets found in the previous step. Association rule mining has two popular methods, including Apriori Algorithm and FP-Growth. Apriori algorithm is considered as one of the most popular and powerful way of association rule mining. By adopting an iterative search method, the k+1 item is explored according to the previous k item. As for FP-Growth (frequent pattern growth) method, it compresses all frequent items in a database to construct a classification tree.

Regression

Like classification, regression also involves supervised learning process. Through regression, the value of dependent variable can be predicted based on the values of independent variables. The main difference between regression and classification is that the outputs of classification are discrete values rather than contiguous values of regression. The popular regression algorithms include Gauss-Newton regression (GNR) algorithm, logistic regression, support vector regression (SVM) and multiple linear regression (MLR).

3.4.2 Existing studies on the application of smart meters

In the context of China, with the development of smart infrastructure, the collected electricity use data can be used by the government to cluster electricity load profiles and assist with demand-side management strategies such as load forecasting and time-of-use tariffs. The one-way communication electricity meter developed in China is useful to provide information for the government to understand more about the occupants. Due to the specific situation in China, none of the electricity use data is available to the public or provided by the government for research purposes. However, in European countries, smart meter data is available online for research purposes. For instance, the Customer-Led Network Revolution project (CLNR, 2015) provided electricity consumption interval data from 9200 domestic customers in London collected during May 2011 and September 2013. Researchers can download the smart meter data from the website for research purposes. It is recommended that the sharing of smart meter data for research purposes should be improved in the future in China.

Several studies have been done to extract consumer profiles from smart meters by installing one sensor for total electricity consumption instead of multiple sensors. Yu et al. (2011) proposed a framework for extracting consumer profiles through three data-mining methods, consisting of cluster analysis, classification analysis, and association rules mining. They combined the use of cluster analysis and classification analysis to explore internal load profiles, to identify general energy-inefficient energy use behaviour. However, the application of data-mining to building energy use and operational data is still under investigation in China. Ozawa, Furusato and Yoshida (2016) proposed two methods to identify household lifestyles from electricity use data over an 18-month period, collected from 1072 detached houses in Japan. First, they classified and compared the load profiles over the same period for each single household, with weekly profiles of different households for frequency analysis. They grouped all households into 12-h period groups (morning-oriented lifestyles) and 24-h period groups (night-oriented lifestyles). They analysed the average daily use of each group and indicated that the 24-h period group used more electricity than the 12-h period group from spring until autumn, especially in summer, due to the need for space cooling at night. On the other side, the 12-h period group used more electricity in winter, due to the need for lighting and heating demand in the early morning. They suggested motivating residents to shift their lifestyles toward morning-oriented as the morning-oriented lifestyles could help to reduce domestic electricity use by 5.3%, except in winter. The results from this research can be used to give feedback to each household. The study also contributed to the design of this thesis, as it provides a clue of how to analyse the smart meter data and provide energy saving advice to each household. McLoughlin, Duffy and Conlon (2015) investigated three most popular clustering techniques (K-means, K-medoid and Self Organising Maps) to analyse smart meter data over a 6-month period from 3941 residential buildings in Ireland. They used the K-means method to extract the Profile Classes to represent common energy use patterns of each household. They also employed multi-nominal logistic regression analysis to link household characteristics with each Profile Class. It was concluded that it is possible to classify consumers and their energy use behaviour based on household characteristics, even without information of their previous electricity consumption.

Unlike in developed countries, in China the research into smart meters in reducing domestic energy use is still in the early stage. Xu et al. (2015) did a pilot study in Shanghai by installing smart meters with in-home displays (IHD). They collected smart meter data from 131 sample apartments, arranged into two groups: 76 without IHD and 55 with IHD. Demographic information about the number of family members, age, and family income level was collected. The maximum electricity use in households without IHD was as high as 287.5 kWh per month, and the maximum value was only 180.6 kWh for households with IHD. They found that standby power in a single-family household with IHD was about 27 W, smaller than a household without IHD (31 W). The use of IHD could thus help to save 12.9% on electricity costs. Their study indicates the effectiveness of IHD in changing domestic energy use behaviour. It was found that the use of smart meters with IHD could help to improve energy saving awareness, and attitudes toward energy saving. This study has guided the selection of smart meters as a policy instrument for behavioural change in this thesis. The smart meter data used in their study was also obtained as a case study to test whether the information could be extracted for policy design, as will be explained in detail in chapter 4.

3.5 Summary: research gaps

Chapter 3 provided a literature review of behavioural studies. Section 3.2 reviewed the existing studies on domestic energy use. Section 3.2.1 highlighted the importance of considering behavioural factors in designing energy saving policies, as behavioural measures can reduce energy use, energy saving potentials could be better predicted with accurate behavioural patterns, and energy saving policies might be more effective when designed for each target group. Section 3.2.2 reviewed studies on factors that affect occupants' energy use attitudes, behaviour and the intention to save energy. Existing behavioural studies in China indicate that occupants' age and income level have a large effect on energy consumption, and that energy saving education and feedback systems have the potential to affect energy use behaviour. A survey method is the most frequently applied method in previous energy use research in China.

Section 3.2.3 identified three gaps based on the review of domestic energy use studies in China. Firstly, there is a lack of a theoretical framework and missing links between energy use attitude and behaviour and there has been limited research to explore the latent social psychological variables affecting energy use behaviour. To address this limitation, section 3.3 reviewed several social psychological models in this research field. Secondly, there is a lack of mixed methods research that crosses disciplines to understand the complexity of energy use behaviour in a full angel, as a survey method is the most frequently applied method with limited findings. To address this limitation, chapter 4 will explain the detail information of each individual method applied in this thesis. Thirdly, there has been limited studies in China by using data-mining methods in exploring occupancy patterns and predicting energy saving potentials. To address this limitation, section 3.4 reviewed studies of using smart meter data and data-mining methods from more developed countries.

This thesis aims to address these research gaps identified in the review of existing behavioural studies in China and provide a deeper understanding of occupants' behaviour and attitudes for designing more practical policy instruments.

Chapter 4 – METHODOLOGY

4.1 Introduction

Chapter 4 introduces the methodology and research design in this thesis. Section 4.2 provides reasons for selecting the appropriate theoretical framework in this thesis. Section 4.3 reviews the research methods applied in this thesis, including quantitative survey, qualitative interview, and quantitative analysis of smart meter data. Section 4.4 illustrates the research design and the process of how to develop this research. Section 4.5 introduces key findings from two pilot studies in the early stage, which helped to formulate this research. Section 4.6 summarises findings from this chapter.

4.2 Theoretical framework

4.2.1 Socio-technical and interdisciplinary approach

A socio-technical approach is often used to elaborate the interactions between sophisticated social infrastructure and human behaviour (Walker et al., 2008). To address the limitations of existing domestic energy saving policies as identified in section 2.4, with the lack of in-depth understanding of domestic energy use behaviour in the Chinese context, this thesis aims to propose a socio-technical approach that combines the perspectives of both technology and the society. As mentioned in section 3.2, there has been limited energy and building research in China that seeks to cross disciplines following a socio-technical approach, which has had only a limited view of the complexity of energy use behaviour.

Several researchers have illustrated the importance of using a socio-technical premise in their study. Barley (1988) indicated the limitations of focusing on each single perspective include the focus on material elements of the technology itself results in inappropriate materialism, and the concentration on social aspects results in an overdependence on social aspects as primary drivers, to social determinism. Therefore, though a socio-technical approach, the complex relationships between technology, social histories, situated context, and human choices can be understood. Mumford (2006) also indicated the socio-technical method could help to solve the most difficult problems in real life, which cannot be achieved by each single focus.

Research on the built environment often crosses disciplinary barriers to draw upon the methods and theories of other fields that share an interest of the topic of domestic energy saving, but from different perspectives. It is hard to define the research domain of this thesis under any single domain. From the theoretical standpoint, this research could be defined in the field of social psychology to test a theoretical framework in understanding domestic energy use and factors in relation to behaviour and attitude. From the policy perspective, this research aims to propose potential instruments for domestic energy saving for each target group. In the light of the fact that this study examines occupants' behaviour and attitudes as well as possible policy instruments, it benefits from a socio-technical perspective from social psychology and engineering.

As mentioned in section 3.2, even though there is an increasing focus on interactions between occupants and the built environment, most researchers pay attention to technological solutions but ignore social psychological factors that affect occupants' behaviour and attitudes. Social psychology research has a principal place in energy saving research because it can help to discover what consumers' want, need, think, aspire to, and reveal the underlying reasons for quantitative aspects. To address the limitations of existing behavioural studies, more human-focused research approaches and interdisciplinary collaborations are required.

Reflecting on existing research gaps and methodological directions, this thesis aims to follow an interdisciplinary path where both socio-psychological and technical elements contribute to an in-depth understanding of occupants' behaviour and attitudes, to explore effective policy instruments for domestic energy saving. The following sections present how this interdisciplinary approach was applied to this thesis, with the support of a theoretical framework and mixed methods approach.

4.2.2 Positivist vs. phenomenological approach in energy studies

Ambrose, Goodchild and O'Flaherty (2017) proposed four methods for exploring building and energy issues, including technical assessment of buildings, building oriented research, people-oriented surveys and in-depth qualitative study (as shown in Figure 4.1). Each approach stands at a point in a spectrum from positivism to phenomenology. Among these, technical assessment and building-oriented research are positivist, even they differ in the use of surveys with the engagement of people, both as users and institutional actors. A closer approach to positivism often involves a focus on objects rather than subjects, and is more likely to focus on individuals rather than the broader society or social practices. A positivistic approach is often associated with the quantitative method to extract energy use patterns and explore impact factors, taking the survey method as an example (Ambrose, Goodchild and O'Flaherty, 2017). On the other hand, the people-oriented surveys and in-depth qualitative research, in varying degrees, accord to the principles of phenomenology and other forms of interpretative analysis, involving the participating of building occupants. The phenomenological method explores the difference between subject and object, focuses on the qualitative experience of in a place or space, taking the interview method as an example (Ambrose, Goodchild and O'Flaherty, 2017).

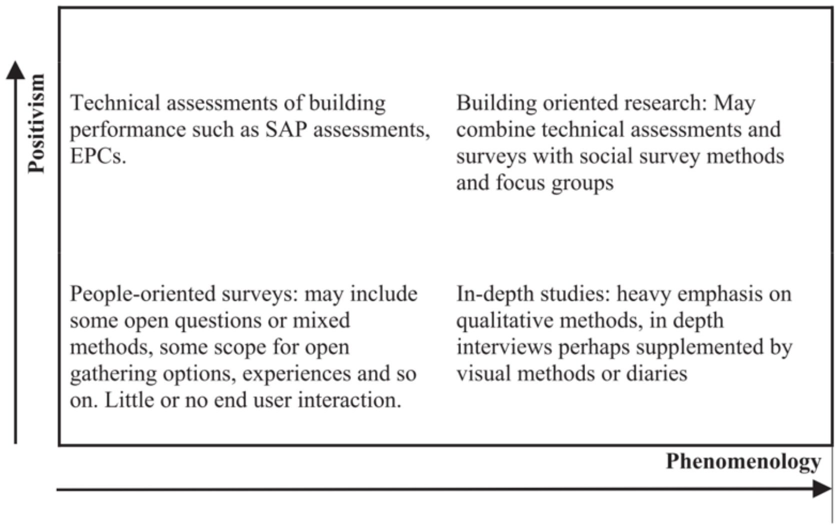


Figure 4.1. Classification of different approaches

(Source: Ambrose, Goodchild and O'Flaherty, 2017)

The advantages and disadvantages of positivistic and phenomenological approaches are often compared in recent studies. Positivist critique pinpointed general and context-free knowledge is relatively more valuable compared to the concrete and contextually-specific knowledge (Ambrose, Goodchild and O'Flaherty, 2017). The phenomenological response argues that particular findings can increase the usefulness of knowledge and experience, and comes with a more profound understanding compared to the general knowledge from positivistic approaches.

In this thesis, the objective is to explore occupants' behaviour and attitudes, as well as the factors that affect behaviour and attitude. This research also explores the effectiveness of applying an appropriate theoretical foundation with suitable research methods for the formulation of policy instruments for domestic energy saving. The quantitative method is applied to summarise occupants' behaviour and attitudes from large-scale quantitative surveys. The quantitative approach is supported by in-depth interviews to expand the research depth. All in all, this research is designed to engage occupants in a more qualitative way. Regarding the research objective, the phenomenological approach is the main method used in this thesis. The aim of this research is not to generalise findings from small samples, but to explore specific knowledge for a specific group and provide insight into applying appropriate research methods to a specific policy context.

4.2.3 Theory of planned behaviour (TPB)

As mentioned in section 3.2, one limitation in existing behavioural studies in China is the lack of a theoretical framework in exploring occupants' behaviour and attitudes. Most behavioural studies in China use the survey method to explore the relationships between energy use behaviour and final electricity use, with a lack of knowledge of the links between behaviour and attitude, and a lack of research from the social psychological perspective. From the review of social psychological models in section 3.3, this thesis selects and tests an appropriate theory and explains the reasons. Figure 4.2 summarises the logic flow of why the theory of planned behaviour (TPB) was selected as the theoretical framework for this thesis.

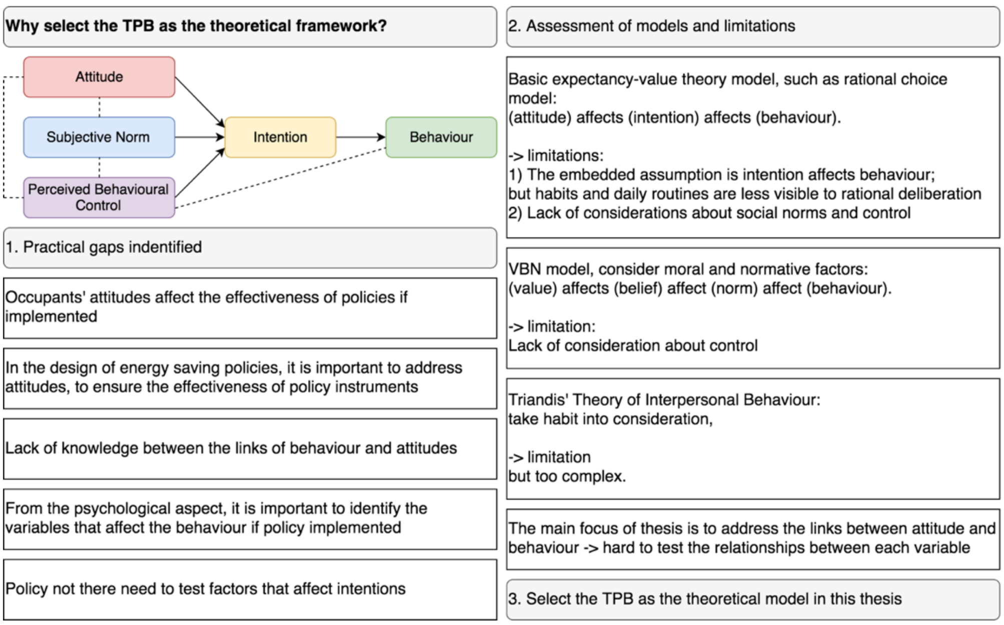


Figure 4.2. Logic flow of the TPB was selected as the theoretical framework

(Source: by Author)

According to the review of behavioural studies, occupants' attitudes affect the effectiveness of policies after they have been implemented. In the design of energy saving policies, it is principal to address occupants' attitudes to ensure the effectiveness of the policies. However, in existing behavioural studies in China, there has been a lack of knowledge of the links between behaviour and attitude. From the social psychological perspective, it is also necessary to identify the variables that will affect behaviour if the policies are implemented, since the actual behaviour with potential policy instruments cannot be tested before these policies are implemented. Thus, it is possible to explore the occupants' intention to save energy in the scenario that the policies are implemented. In summary, it is crucial to select an appropriate theoretical framework to explore the relationship between attitude, intention and behaviour.

In the review of social psychological models, the expectancy-value models assume consumer behaviour is the result of deliberative and cognitive processes. To bridge the gap between occupants' attitudes and behaviour, the expectancy-value theory was selected due to the embedded assumption of intentional behaviour. However, the practice theory, which states that attitude is not related to behaviour but to the social norm, was not considered in this thesis because the embedded assumption does not fit into this research context and cannot bridge the research gap identified in chapter 1.

Jackson (2005) proposed in his study that "*the theory of planned behaviour has been one of the most widely used models in pro-environmental behavioural research, including research in recycling, travel mode choice and energy consumption*". The theory of planned behaviour (TPB), one of the adjusted expectancy-value models, was selected as a theoretical foundation for this thesis. It not only uses the basic concept of expectancy-value models but also unravels the psychological antecedents of consumer preferences, which incorporates the impact of people's perceptions of their control over the situation. Figure 4.2 presents a schematic diagram of TPB. There are five components in TPB, including attitude, subjective norm, perceived behavioural control, intention, and behaviour. The definition of each component was explained in detail in section 3.3. Through the survey and interview analysis, TPB was used as a framework to explore the embedded factors that affect occupants' behaviour and attitudes.

Despite the extensive use of expectancy-value theory models, they have been criticised extensively. The most common criticism is the cognitive limitation on the ability to take deliberative actions, such as habits, routines, cues, and heuristics. Even TPB only partly overcomes the limitation of expectancy-value models, such as social norms. The central limitation still exists that habits and daily routines are not accounted for in TPB due to the assumptions embedded in the expectancy-value model, such as turning on lights, using heating systems, and the actions occupants undertake without thinking. Cognitive psychology proposes that the process of routinisation of everyday behaviour makes it less visible to rational deliberation, less obvious to understand, and less accessible to policies (Darby, 2010).

Section 3.3 also reviewed other expectancy-value models. TPB was compared to these models, and was selected as a theoretical framework for this thesis. The VBN model is a complex model that takes the norm into consideration, with a structure in which value affects belief, which affects norms, and finally affects behaviour. However, the VBN model mainly focuses on moral and normative aspects, with a lack of consideration for control aspects. The Triandis' theory of interpersonal behaviour considers the relationships between attitude, intention and behaviour from a full angle, however, the critical limitation is of Triandis' theory is that it is too sophisticated and it is hard to test the relationship between each variable. Since the aim of this thesis is to address the links between attitude and behaviour, TPB was selected as a theoretical framework.

4.3 Research design

4.3.1 Mixed methods approach

According to the review of energy use studies, diverse research methods were used, such as quantitative building performance simulation, building monitoring evaluation and comfort preferences (mixed methods), qualitative site investigation, and qualitative studies regarding occupants' acceptability and requirements. Different methods are designed for different research purposes. Qualitative methodology, such as in-depth interviews and focus groups, is often employed to explore how individuals or groups related to a social problem, and quantitative methodology, such as surveys, is applied to test theories by examining relationships between each variable (Hughes, 2012). In other words, the quantitative method can indicate how much of each thing is happening, and the qualitative method is used to understand what is happening and how and why (Crouch and McKenzie, 2006; Flyvbjerg, 2006). Different types of quantitative methods can be used to explore energy use behaviour, include surveys and building monitoring. Based on the review of existing studies on energy use, there is an increasing trend of applying the survey method to investigate domestic energy use behaviour, as an appropriate survey design can help to generalise survey results from small samples to a large population by extrapolating a quantitative description of future trends. The survey method could be used to discover the knowledge of the relationships between each variable. With the help of appropriate theories, surveys could be used to measure latent variables that cannot be measured directly, such as energy concern, intentions, norms, attitudes, trust, and emotions (Steemers and Manchanda, 2010). The human-centred qualitative method is often applied to explore how consumers behave and make decisions in a particular context to understand energy use (Sovacool, 2014). Stern (1993) suggests the qualitative method could help to obtain a more accurate understanding of lifestyles, rather than being limited to demographic variables. However, the use of a qualitative method might result in a limited understanding of actual patterns and limited forecasting of behaviour.

As observed in chapter 3, existing energy use studies in China have mainly used a single research method, such as survey study or building performance simulation. In section 4.2, a socio-technical, interdisciplinary, and positivist approach was selected for this thesis. In order to fully understand domestic energy use behaviour and attitudes, a mixed methods approach that combines quantitative and qualitative methods was designed for this thesis. There are many advantages of applying mixed research methods to a research project, even though the mixed methods approach is more sophisticated than a single method. Firstly, the mixed methods approach can be used to validate findings from a single method. Secondly, the application of mixed methods can help to enhance or strengthen a result. Thirdly, the sequential application of each method is helpful to the development of the theory or knowledge, for instance, the findings from the first method might inform the design of the second method. Finally, findings from each single method might spark off each other in a dialectical stance to generate interesting ideas or new findings.

Different research designs are selected for different research aims. The research design of a mixed methods approach is generally divided into two types: component designs that each component method keeps methodological separation and integrity; and integrated designs, with an interplay of methods throughout the research. In this thesis, a component design was selected due to the multi-dimensional research objectives designed in this research. The survey method was designed to understand occupants' energy use behaviour and attitudes, however, there is limited knowledge of why the behaviour and attitudes are formed. The survey method alone is not enough to fully understand occupants' energy use behaviour and attitudes. To address this limitation in the survey method, the interview method was designed to understand the reasons behind behaviour and attitudes, as well as the motivations for domestic energy saving. Despite a small sample size, the more profound understanding of occupants is helpful in formulating useful instruments to overcome behavioural biases. The analysis of smart meter data is helpful for understanding the actual occupancy patterns and testing the information that can be extracted for policy design purposes, as well as to examine the energy saving potential of each behavioural measure. The combination of survey and interview method could help to explore the complexity of energy use behaviour, and expend both depth and breadth of study about human factors in limited time and limited cost. As a smart meter was identified as a potential solution in domestic energy saving, with limited study on a smart meter in China, it is also essential to analyse smart meter data and extract occupancy patterns for the design of more precise energy saving policies.

4.3.2 Shanghai as a case study

Shanghai was selected as a case study for this thesis due to its importance as an urban centre in China. According to the Shanghai Municipal Statistics Bureau (2016), the total population in Shanghai increased from 16.7 million in 2000 to 23 million in 2010, with a growth rate of 37.5% in 10 years, with 20.6 million (89.3% of all) of the population living in urban areas in 2010. The largest age group was between 35 and 59 years old, accounting for 38.2% of the registered population in 2015.

According to the Shanghai Municipal Statistics Bureau (2016), the annual domestic electricity consumption in Shanghai increased from 5.32 to 18.55 billion kWh from 2010 to 2015, tripling in 5 years, and the total floor area of residential buildings in Shanghai tripled from 209 to 630 million m^2 from 2000 to 2015. This phenomenon reflects the fact that electricity consumption in the domestic sector increased much faster than the total floor area of residential buildings. Compared to the average electricity consumption of 526 kWh/year per capita in China in 2014 (National Bureau of Statistics of China, 2016), the average electricity consumption was 718 kWh/year per capita in Shanghai in 2014 (Shanghai Municipal Statistics Bureau, 2016), which was 1.4 times the average level in China. Thus, it is critical to understand why residents in Shanghai use more electricity and to implement effective energy saving policies for this group.

Shanghai was selected as a case study in this thesis for three reasons. Firstly, the population in Shanghai increased quickly in the past and will grow faster in the future due to its rapid development as an urban centre in China. Secondly, the total annual domestic electricity consumption in Shanghai grew dramatically over the last five years, faster than the growth speed of the total floor area. Thirdly, the average electricity consumption per year per capita in Shanghai was 1.4 times the average level in China. Therefore, it is required to address the problem of a rapidly growing population in Shanghai with increasing electricity use level. The young population was selected as a criteria of the target group, as from findings in chapter 3, domestic energy consumption is related to consumers' age as the old generation tends to use less energy (Feng et al., 2016; Chen et al., 2013; Ruan et al., 2017). With the increasing young urban population, their energy use behaviour and attitude should be analysed and targeted.

Shanghai is located in the hot summer and cold winter region, with a tropical monsoon climate. Based on the China Meteorological Administration (2014), the average temperature of a year is around 16.4°C, with the highest average temperature at 28.8°C in July and the lowest average temperature at 4.8°C in January. Shanghai has four seasons, including four months each of winter and summer, and two months each of spring and autumn. Classified as a range of 10 and 22°C, the spring starts in March, the summer begins in June, the autumn starts in September and the winter starts in December. Summer in Shanghai is hot and humid, with an average of 8.7 days annually with temperatures higher than 35°C.

In Shanghai, air conditioners are used for both space heating and cooling. The use of air conditioners is related to the indoor temperature, which is affected by the outdoor temperature and the operation of windows. Table 4.1 lists the average outdoor temperature in Shanghai for each month, which will be discussed in the empirical chapters. The heating period in Shanghai was assumed to last from 1st December to 28th February, and the cooling period was assumed to last from 15th June to 31st August, based on assumptions in building codes.

Table 4.1. Average outdoor temperature in Shanghai in 2016 at each month (°C)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
4.4	6.9	11.0	16.7	20.6	24.2	29.9	29.5	24.9	20.8	13.6	9.1

(Source: National Bureau of Statistics of China, 2017)

4.3.3 Research design

Figure 4.3 introduces the research timeline of the research project, divided into three steps: 1) preparatory, 2) data collection, and 3) analysis. A review of related literature was undertaken throughout the whole research period to keep information updated. Throughout the research timeline, each step provided important findings in developing this research. Two pilot studies were helpful in identifying research gaps and designing a research plan. The analysis of each empirical study will be introduced in chapters 5–7. Figure 4.4 presents the critical steps in developing this research.

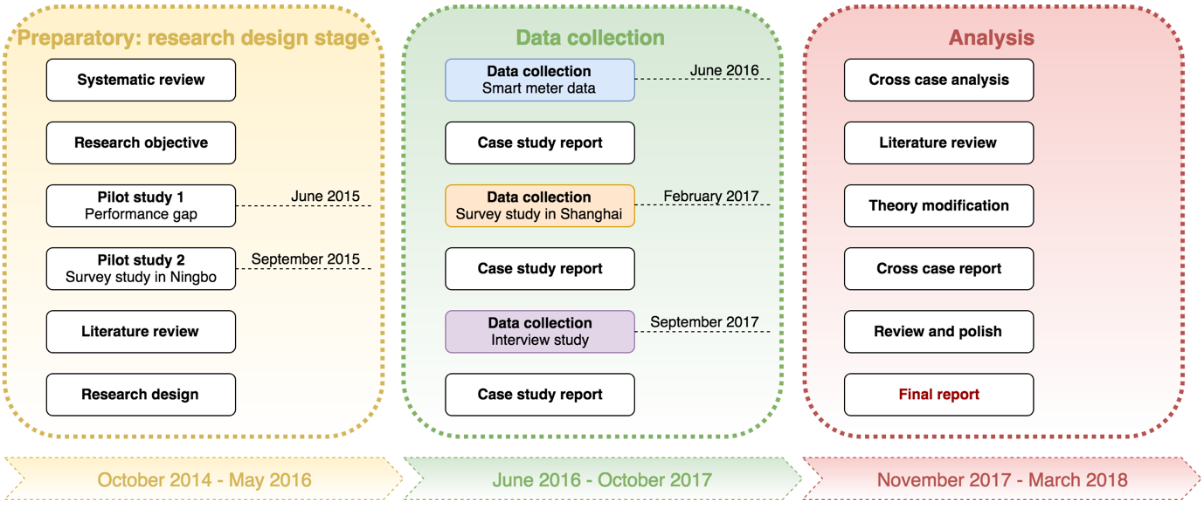


Figure 4.3. Research timeline

(Source: by Author)

Figure 4.4 introduces the logic flow of developing this research. During the preparatory stage, the review of domestic energy saving policies in China identified a lack of feedback-based instruments that target energy use behaviour, as well as the lack of communicative policy instruments. With the importance of human factors in domestic energy saving policies, the smart meter with in-home display (IHD) was identified as a potential policy instrument (see chapters 2 and 3). To address the limitations in existing energy saving policies and research gaps in energy use studies in China, this research was designed to provide further insight into behavioural factors in domestic energy use, and to explore further insight into which policy is more attractive and how to communicate with consumers more effectively. The objective of this thesis is to address the three research dimensions: practical, policy, and theoretical.

Based on the research objectives, this thesis uses mixed methods to obtain a full understanding of occupants and proposes effective policy instruments for domestic energy saving. The survey study was designed to explore domestic energy use behaviour, as well as the factors that affect behaviour and attitudes. The interview study was designed to investigate the embedded reasons underlying behaviour and attitude. The smart meter data was used to extract occupancy patterns for policy design, and was tested with single-zone simulation for energy saving potential of each behaviour measure. Figure 1.1 in chapter 1 presents the conceptual design of this thesis.

This thesis was designed as the structure mentioned in Figure 1.2 in chapter 1. Chapters 2–4 provide findings from the preparatory stage of this research. Chapters 2–3 provide a review of existing domestic energy saving policies and energy use studies in the context of China. The research objectives and research questions were designed to address the research gap identified in the literature review. Chapter 4 explained the selection of research methods for this thesis, followed by the conceptual design.

Chapters 5–7 provide findings from the data collection stage of this research. In chapter 5, survey data from residential consumers were collected from young urban Shanghai residents to understand their energy use behaviour and attitudes (question 1). In chapter 6, interviews with young highly-educated residents were designed to explore the further reasons behind their energy use behaviour and attitudes (question 2). In chapter 7, smart meter data from Shanghai residential buildings were collected to analyse the information that could be derived from cluster results and used for government policy design (question 3).

Chapter 8 summarises the findings from this research, which is the analysis stage as shown in Figure 4.3. Chapter 8 answers research question 4 of policy suggestions based on the cross analysis of findings from each empirical chapter. Chapter 8 also answers research question 5 about the value of applying an appropriate theoretical framework and research methods to this research context.

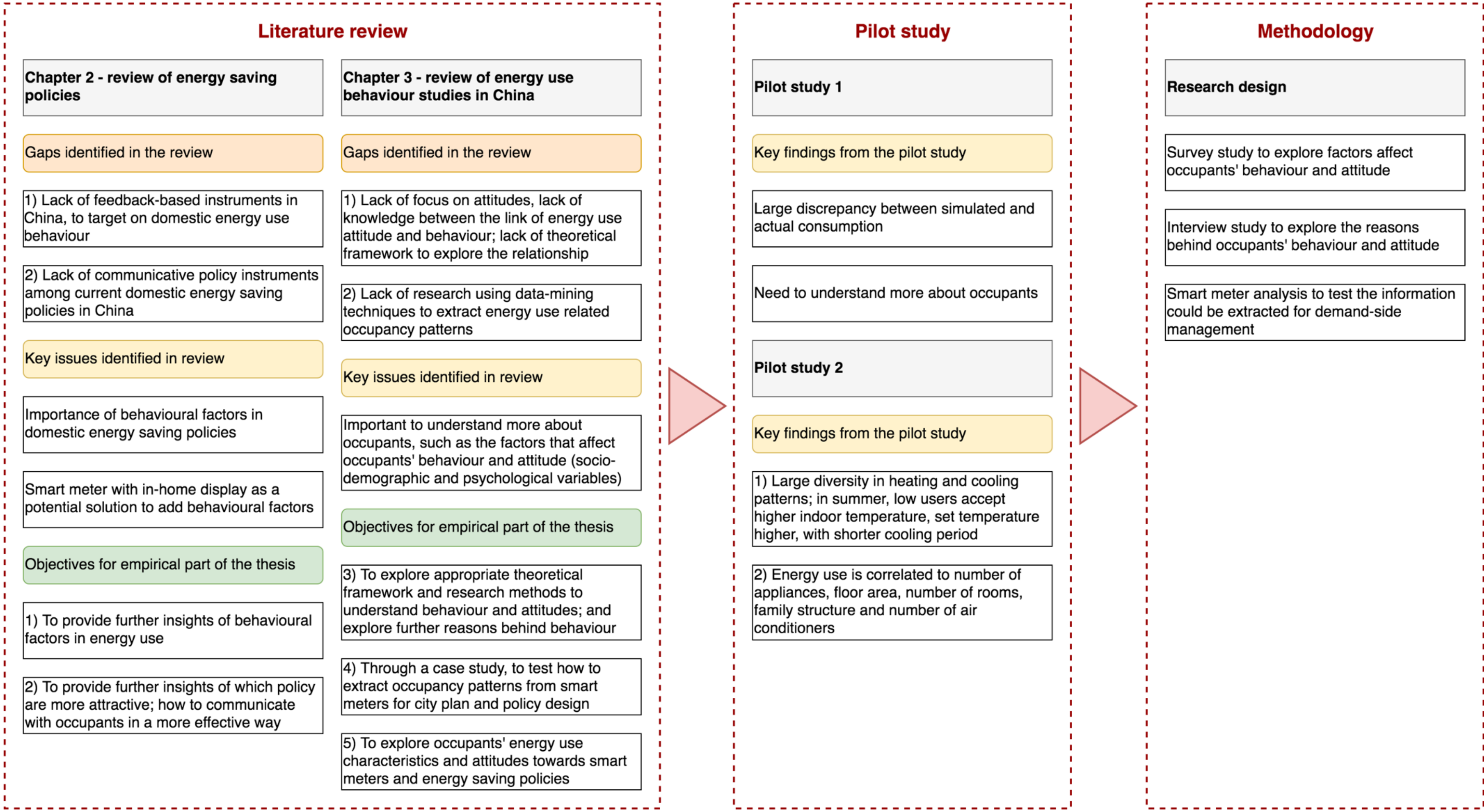


Figure 4.4. Research steps and logic flow of developing this research

(Source: by Author)

4.4 Data collection and data analysis methods

The mixed methods approach was selected for this thesis, divided into three empirical studies, including a survey study, an interview study and the analysis of smart meter data. The data collection and data analysis methods applied in this thesis will be explained in detail in the next part of this section.

4.4.1 Quantitative survey

As mentioned in section 4.3.1, the mixed research methodology was selected in this thesis, with respect to the multidimensional research objectives and research questions. Chapter 5 adopts the survey method to explore occupancy patterns, electricity use, attitudes toward smart meters and related energy saving policies, and the intention to save energy through potential policies. The questionnaire is attached in Appendix A. Chapter 5 answers the question of "*what are the factors and occupancy patterns in relation to occupants' energy use behaviour in urban households in China, and what are occupants' attitudes toward smart meters and energy saving policies?*"

The survey was divided into three parts. Part one was about demographics and building information. The basic information collected in part one is meaningful to the survey design, due to the influence from building fabric on domestic energy use. Part two was about energy use characteristics. In reality, there is a huge gap between assumptions about energy use behaviour in national building codes and the actual behaviour, thus it is important to explore more into occupants' energy use behaviour. Part three was about occupants' psychological variables that link energy use attitudes and behaviour, including occupants' attitudes toward smart meters, occupants' attitudes toward smart meter policies, subjective norms, perceived behaviour control, as well as the intention to save energy if smart meter policies were implemented. As indicated in the literature review, occupants' attitudes, habits and practices determine whether and how energy saving policies can be implemented, and affect how energy is consumed before and after the implementation of policies. There is also a gap in governments' knowledge about occupants' actual attitudes and opinion on policy, thus it is urgent to explore occupants' attitudes at the policy design stage.

Part one of the survey included questions such as family and building information. The survey results were analysed by summarising the count in each choice of interval questions or the average value of scale questions. In addition, the annual electricity bill of each respondent was grouped into three levels based on the 3-level progressive energy pricing system in China (see chapter 3), in order to identify the occupancy patterns of high consumers. The results could also be used to identify the target group for energy saving policies.

Part two of the survey included questions related to energy use characteristics, such as heating and cooling temperature, air conditioning hours and air conditioning periods. The occupancy patterns were summarised and the count in each choice of interval questions based on the 3-level progressive energy pricing level. The characteristics of energy use in high and low users were summarised for further policy analysis.

Part three of the survey included questions that related to occupants' psychological variables that link energy use attitudes and behaviour. Based on the selection of theory of planned behaviour (TPB) in this research, the survey questions were designed to assess the variables, including occupants' attitudes toward smart meters, occupants' attitudes toward smart meter policies, subjective norms, perceived behaviour control, as well as the intention to save energy if smart meter policies were implemented. It first asked for the respondents' agreement with the description of smart meters formulated as "smart meters can" on 5-point Likert scales, with "1=strongly disagree" and "5=strongly agree". There is a need to note that the statements about smart meters were quoted from the previous study by Krishnamurti et al. (2012). The survey results from this research will also be compared with Krishnamurti et al. (2012)'s research. Secondly, it asked for the respondents' willingness to accept different energy saving policies that related to smart meters, as well as other psychological variables in TPB. The survey questions were designed based on Abrahamse and Steg (2011)'s research mentioned in section 3.2, as this research tested the relationships between psychological and socio-demographic variables regarding occupants' domestic energy use and occupants' intention to save energy.

The survey results were analysed by descriptive statistics, correlation analysis and regression analysis. The survey analysis consisted of three main parts: the relationship between socio-demographic variables and annual electricity consumption, the relationship between psychological variables and the intention to save energy under smart meter policies, and thirdly, the correlation between socio-demographic and psychological variables. Firstly, the respondents' demographic information and energy use characteristics were summarised by descriptive statistics. Correlation analysis was then used to explore the relationship between socio-demographic variables and annual electricity consumption. Secondly, attitudes toward smart meters and attitudes toward energy saving policies were summarised through descriptive statistics. Regression analysis was then used to explore the relationship between psychological variables and the intention to save energy under smart meter policies. The elements in the theory of planned behaviour (TPB) were used as the psychological variables for analysis. Thirdly, a correlation analysis was employed to examine the relationship between socio-demographic and psychological variables. As these variables are not normally distributed, Spearman's rank correlation was used as a nonparametric measure of rank correlation.

The survey analysis is explained in more detail in chapter 5.

4.4.2 Qualitative interviews

Chapter 6 answers the question of "*which reasons and demographical factors are behind occupants' attitude and behaviour*". The aim of chapter 6 is qualitative as it seeks to discover whether social and demographic variables play significant roles in attitudes toward energy saving policies and, if so, how to design effective policy instruments that target energy use behaviour for domestic energy saving.

The design of the interviews was semi-structured rather than a list of questions and answers. The interviewees were selected from the survey participants. This enabled the respondent to describe their energy use behaviour and energy saving attitudes in their own words, which is helpful in redefining the scope of interview questions where appropriate. A typical length of the interview took 45–60 mins, and interviews were carried out at interviewees' home if permitted, preceded or followed by a site investigation. The site investigation was helpful as it could help the interviewees to explain their energy use behaviour, providing the interviewer a complete view of the interviewees' daily energy routine and what level of participation the homeowner had in energy saving.

The interview was conducted in the interviewees' native language of Chinese, in which it was easier for them to explain their attitudes more precisely. The interview questions sought to explore the factors related to their energy saving attitudes and behaviour. They were highly focused, and divided into four main parts: 1) energy use practices, 2) attitudes, norms and controls, 3) reasons behind practices, and 4) policy recommendations. The part two of semi-structured interview questions were designed based on the variables TPB so that it could assess occupants' psychological variables and to find the differences in occupants' attitudes, norms and controls and their energy use attitudes and behaviour. Appendix B presents the interview questions, in Chinese and translated into English.

The semi-structured interviews were recorded, transcribed, and translated. Before the interview, the author asked the interviewees' permit of recording the conversation. During the interview, the key words from each interviewee were taken down and explored further in interview. After the interview, the record was transcribed and translated in Microsoft Word. The professional interview analysis software such as NVivo was not used, as this research only analysed five interview cases and the key words could be identifies and summarised manually in a more precise way. After transcription and translation, the key sentences were highlighted and the key words were marked by using the "New Comment" function under the "Review" section in Microsoft Word. By analysing the highlights and comments of interview responses, combined with the understanding of the theory of planned behaviour (TPB), five interviewees were grouped into two types of consumers.

An Ethical Approval to conduct the interviews was granted by the Ethics Committee of the School of Humanities and Social Sciences (shown in Appendix C). In order to obtain approval, a research proposal, interview schedules, a participant information letter (Appendix D), a participant consent form (Appendix E) and a signed letter from the Architecture Department regarding the conduct of the interview were submitted.

The interviews are analysed in detail in chapter 6.

4.4.3 Smart meter data clustering and single-zone simulation

Chapter 7 answers the research question of "*how can occupancy patterns be extracted from smart meter data to understand energy use characteristics and explore the energy saving potential of policy design?*". The smart meter data from Shanghai residential buildings was used as a case study to test the information that could be extracted for policy design.

Cluster analysis

There were four types of data-mining techniques used with smart meter data: classification, clustering, association rule and regression. D'Oca and Hong (2015) define cluster analysis as a process that groups a set of observations into several clusters, where each substance in the same cluster has high similarities. The cluster analysis was selected as a data-mining algorithm in this research. It has been used by electricity companies to group customers with similar energy use characteristics. As mentioned in section 3.4, McLoughlin, Duffy and Conlon (2015) applied the K-means cluster method to extract the Profile Classes to represent common energy use patterns of each household. Similar with their research objectives, chapter 7 aims to summarise the common energy use patterns and explore the information could be extracted for demand-side management.

There are two methods of clustering: Hierarchical and Partitional. Partitional clustering is the fundamental method of clustering analysis. This method divides data sets into a predefined number of non-overlapping clusters. The most prevalent approaches to Partitional clustering are K-means, K-medoid, and Self Organising Mapping (SOM) (McLoughlin et al., 2015). The K-means method was applied in this thesis, as it was also selected in other studies that aims to extract occupancy patterns. McLoughlin, Duffy and Conlon (2015) used the Davies-Bouldin indicator to evaluate the performance of clustering algorithms (including K-means, K-medoid, and SOM) in their research and finally the K-means method was selected based on adequacy measures.

Equation 1 describes the K-means algorithm, which aims to partition n observations into k subsets, to minimise the within-cluster sum of squares where μ_j is the geometric centroid of the data points in S_j in order to achieve a global minimum for J.

$$\text{Equation 1: } J = \sum_{j=1}^{k} \sum_{n \in S_j} \left\| x_n - \mu_j \right\|^2$$

The cluster analysis in chapter 7 has two steps. The first step is the K-means cluster analysis. Before the clustering analysis, it was urgent to decide upon the number of clusters. The root-mean-square deviation (RMSD) was used to test the differences between measured data and centroid points, and the coefficient of variation (CV) was used to compare several data sets with different sample sizes. This method was used to select the appropriate number of clusters in many previous studies (Heo, Ren and Sunikka-Blank, 2016; Tahmasebi and Mahdavi, 2015). In Equation 2, $x_{1,t}$ is the measured data, $x_{2,t}$ is the cluster centroids for each point t, and x is the mean value of the within-cluster data.

$$\text{Equation 2: } RMSD = \sqrt{\frac{\sum_{t=1}^{n} \left(x_{1,t} - x_{2,t}\right)^2}{n}}$$

$$\text{Equation 3: } CV(RMSD) = \frac{RMSD}{\bar{y}}$$

In step two, the results obtained from step one were translated into valid information for the government to understand more about occupants. Correlation analysis was used to explore the relationship between clusters and impact factors (such as the time of the day, the day of the week, or seasonal influence), to test for the impact factors that affect occupancy patterns. For the variables that cannot be defined as a normal distribution, Spearman's rank coefficient is employed as a nonparametric measure of ranking.

Single-zone simulation

The second part of chapter 7 aims to explore the energy saving potential from behavioural change measures. The predictive performance of the simulation model depends much on assumptions and simplifications made in the model and the reliability of the model input parameters (Ghiassi et al., 2017). Indeed, a modelling process often involves subjective judgement to efficiently create the simulation model that reasonably represents the actual situations. The simplifications often made in the simulation process include reducing the number of thermal zones and using typical occupancy-related schedules of each type of the room specified in national standards. The common practice for thermal zoning is combining rooms with similar activities into one zone, but further simplications of modelling a building as a single-zone have been observed in urban-scale energy studies to facilitate modelling a large number of buildings (Tian et al., 2015; Heo et al., 2015; Booth and Choudhary, 2013). In general, many energy researchers in the building scale use the typical occupancy-related schedules specified in national standards in energy performance simulation (Heiple and Sailor, 2008; Dascalaki et al., 2011; Ballarini et al., 2014). These simplications, however, unavoidably impact the accuracy of model outputs, which may possibly bias retrofit decision-making.

Several studies have investigated the effect of modelling simplications on the accuracy of energy predictions. Korolija and Zhang (2013) compared the prediction accuracy of detailed simulation models in which every room is modelled as a separate zone and simplified simulation models in which each floor is modelled as a single zone for domestic buildings. The comparative study indicated that the simplified thermal zoning strategy reduced the simulation time by 30% on average and resulted in the mean absolute relative error of 10.6% for predicting annual heating demands. Harrou et al. (2016) also investigated the effect of thermal zoning strategies on heating demand predictions. The simulation results indicate that single-zone simulation yields roughly half the annual heating demand prediction of multiple-zone simulation. Based on the review, the smart meter data could also be used to extract occupancy patterns to support single-zone simulation to achieve a higher simulation efficiency and efficacy. The simulation method selected in this thesis not only reduces the simulation complexity, but also captures occupancy diversity which is considered in the traditional simulation method.

A single-zone simulation with smart meter data is used in the research to explore the energy saving potential from behavioural measures identified in the survey results. To extract heating and cooling patterns from internal load data for the single-zone simulation, the following steps were processed in Matlab. First, the average electricity use was calculated for each hour of the day in June (transition season) for each household. Second, the average electricity use was calculated for each hour of the day in August (cooling season) and December (heating season). Third, the average electricity use in the transition season was subtracted from the average electricity use for each hour of the day in the cooling season and heating season, to calculate the average heating and cooling demand for each household at each hour of the day. Meanwhile, two original profiles of small and large flats were generated in EnergyPlus. Matlab was then used to rewrite the assumptions that related to occupancy patterns and generate IDF profiles for each household. Finally, multiple simulations were run by the "Group Simulation" function in EnergyPlus.

Table 4.2 introduces the simulation design in chapter 7. The original actual annual demand of each household was collected from the smart meter data. There are two types of plan layout for the recorded households. The traditional multiple-zone simulation with assumptions from the Chinese standard was simulated in EnergyPlus with the output of annual consumption of the two types of plan layout. Then a single-zone simulation with occupancy patterns extracted from the smart meter data was conducted in EnergyPlus. In the next step, section 7.5 tested the two behavioural measures identified from the survey study through single-zone simulation: (a) adjusting the heating and cooling temperature, and (b) reducing the heating and cooling hours.

Table 4.2. Simulation design in chapter 7

Step	Notation	Occupancy schedule
(0)	0	Actual annual demand of each household: 126 values
(1)	1-small 1-large	Multiple-zone simulation with Chinese standard, JGJ134-2010: 2 simulations
(2)	2-small 2-large	Single-zone simulation with original occupancy profiles: 126 profiles and 126 simulations
(3)	3-small-a 3-large-a	Quantify effect of behavioural measure (a) set temperature for air conditioners: 126 profiles and 126 simulations
(3)	3-small-b 3-large-b	Quantify effect of behavioural measure (b) air conditioning hours: 126 profiles and 126 simulations

(Source: by Author)

The clustering analysis and single-zone simulation are explained in more detail in chapter 7.

4.5 Pilot study in Ningbo

Two pilot studies in Ningbo were helpful in designing the research scope of this thesis. This section only summarises the key findings from these two pilot studies. The detailed information of the pilot studies will be attached in Appendix F for pilot study 1 and Appendix G for pilot study 2. These two pilot studies were conducted in Ningbo, a city near Shanghai, located at the East part of Zhejiang Province, with a total area of 9816 km^2 and the urban area of 2461 km^2. The total population in Ningbo was 5.78 million in 2012, with a population of 2.26 million in the urban area (Ningbo Municipal Statistics Bureau, 2015). Similar to the climate in Shanghai, Ningbo has an average temperature of 16.4°C, with four seasons, including four months of winter and four months of summer, and two months each of spring and autumn. January is the coldest month with an average temperature of 4.8°C, and July is the hottest month with an average temperature of 31.2°C (China Meteorological Administration, 2014).

4.5.1 Pilot study 1: performance gap in simulation

Pilot study 1 presents a simulation of the energy use of three sample buildings in Ningbo, built at different ages. Table 4.3 lists the information of sample buildings, and the plan layout of each sample building is attached in Appendix F.

Table 4.3. Sample buildings in pilot study 1

Sample	Year of built	Floor area (m^2)	Level	Wall U-value (W/m^2K)	Window U-value (W/m^2K)	Energy intensity ($kWh/m^2/year$)
Sample 1	1984	76	3 of 5	2.215	3.835	12.49
Sample 2	1993	97	2 of 7	0.818	1.960	39.45
Sample 3	2003	101	19 of 25	0.350	1.960	28.81

(Source: by Author)

Sample building 1 was built in 1984, located on level 3 of a total number of 5 storeys. The total area of the room is around 76.12 m^2. The air change rate was set as 3.5 for the 1984 built residential building. According to the collected data, the energy intensity is around 12.49 kWh/m^2 per year.

Sample building 2 was built in 1993, located on level 2 of a total number of 7 storeys. The average electricity consumption is around 180 kWh each month. During the heating period, the electricity demand is around 300 kWh, and during the cooling period, the electricity demand doubles to 400 kWh. The total energy consumption for each year is around 3827 kWh/year. The total air-conditioned area is 97 m^2. The energy intensity is around 39.45 kWh/m^2 per year. The air change rate was set as 2.5 for the 1993 built residential building.

Sample building 3 was built in 2003, located on level 19 of a total number of 25 storeys. The average electricity consumption is 182 kWh each month, with an electricity bill of 88.54 RMB each month. During the heating period, the electricity demand is around 242 kWh, and during the cooling period, the electricity demand doubles to 364 kWh. The total energy consumption for each year is 2910 kWh/year. The total air-conditioned area is 101.01 m^2. The energy intensity is around 28.81 kWh/m^2 per year. The air change rate was set as 1.5 for the 2003 buildings.

The models were built and analysed in DesignBuilder. The indoor temperature was set as 16–28°C. The window to wall ratio was around 30% according to estimation. As the construction material was hard to obtain, the construction material was simulated according to the building codes for that period. In addition, the lighting and air-conditioning schedule was set using the default settings in DesignBuilder. Table 4.4 shows the simulation results of sample buildings, in the unit of annual energy intensity.

Table 4.4. Simulation results of pilot study 1

Sample	Year of built	Floor area (m^2)	Actual energy intensity (kWh/m^2/year)	Simulation energy intensity (kWh/m^2/year)
Sample 1	1984	76	12.49	105.78
Sample 2	1993	97	39.45	106.60
Sample 3	2003	101	28.81	101.48

(Source: by Author)

Table 4.4 shows that there is a remarkable gap between the simulation results and the actual energy intensity. For instance, regarding the sample building 1 built in 1984, the estimated energy intensity is about seven times higher than the actual energy intensity. There might be several reasons that lead to the considerable difference. Firstly, the assumptions built into the method for calculating the energy rating might be inaccurate, such as the heat transfer rate. Secondly, inaccurate assumptions in the energy rating algorithms may also lead to the deviation between the simulation and actual energy use, such as there might be a relatively low occupancy level per floor area in single-family homes, and differences in the cooling and heating hours. There are many uncertainties in a simulation regarding a real situation.

Pilot study 1 showed that there is a huge performance gap between actual and simulated electricity consumption, which may lead to overestimation of the energy saving potential of a retrofit, and may affect the design of energy saving policies. It was found that the performance gap exists due to the lack of information about occupant behaviour in existing building standards. In order to design an appropriate energy saving strategy, it is essential to understand more about energy use behaviour, such as heating and cooling hours.

4.5.2 Pilot study 2: behavioural survey

Due to the existence of the performance gap, the questionnaire survey was conducted to explore more information about occupancy patterns and building characteristics. A better understanding of occupants can not only provide more accurate occupancy patterns to support the simulation and thus support urban planning and policy making, but will also help to identify potential ways to reduce energy consumption. Therefore, pilot study 2 was designed for the following research objectives: 1) to explore domestic energy use characteristics and building information; 2) to explore factors that affect household electricity use; and 3) to explore why there is a gap between the simulated and actual energy consumption.

The questionnaire was handed out to randomly selected citizens in Ningbo in September 2015, through the Internet in the Chinese language. The English version of the survey is attached in Appendix G. The questionnaire was divided into five sections. The first section asked for general information about respondents, including gender, age, family structure, and so on. As a result, 153 responses were collected, with 73 being male and 80 being female. As some respondents were not aware of the energy use of the electricity bill, which is the primary parameter in the survey, 125 responses were finally selected out of the 153 for further analysis. The second section focused on the physical characteristics of the dwelling, including the building construction year, floor area, building type, room structure, and the number of occupants per dwelling. The third section focused on domestic appliance ownership and how they are used (but not for air conditioners), such as the number of air conditioners, occupants' habits of using lights and appliances, and the operation of windows for ventilation. The fourth section focused on heating practice in winter, including the time they start and stop heating, the lowest acceptable indoor temperature, occupants' indoor comfort level and the highest monthly electricity use in the coldest month. The fifth section was about cooling practice in summer, including the appliances used for cooling, the frequency of using them, the time they start and stop cooling, the highest acceptable indoor temperature, set temperature for cooling, air conditioning hours, expectations for the indoor environment, and the highest monthly electricity use in the hottest month.

Among the 125 respondents, the average annual electricity use was 2432 kWh/year. The energy intensity, calculated as the annual electricity consumption divided by the floor area, ranged from 12.31–81.40 kWh/m^2 per year, with an average value of 22.34 kWh/m^2. It was also found that the newer buildings tended to have a higher average value of annual electricity consumption. This result is different from the previous findings where older buildings with higher U-values tended to consume more energy.

According to the survey results, the oldest building in the survey was built in 1980 and the newest was in 2015. Compared to Europe, the building ages are very different in China. The practice of the Chinese housing market is to demolish and rebuild, unlike the European style of maintenance and retrofit. Among 125 responses, 38 buildings were built before 2001, 65 buildings were built between 2001 and 2010, and 22 buildings were built after 2010. The average floor area of the dwellings was around 114 m^2. The results suggested that apartments are the predominant dwelling type in China: 109 out of 125 of respondents live in apartments, with 60 living in “low-rise” flats (less than 7 floors) and 49 living in “high-rise” flats (buildings higher than 7 floors). A flat with 3 bedrooms and 2 living rooms is the most prevalent room structure from the survey results.

Table 4.5 presents a correlation analysis of demographic and housing information with annual energy consumption. The Pearson’s correlation coefficient (r) is a measure of the level of linear dependence between two variables with a value between −1 and +1 (inclusive). The proportion of shared variance (R^2) is calculated by squaring Pearson’s r so that R^2 represents the ratio of variability in one variable that is accounted for by another variable. In a range from 0 to 1, the larger value means the more correlation. The significant value (p-value) is a measure of the probability of obtaining a result at least as extreme as the one that is observed, so the lower the value (usually below 0.05 or 0.01), the more significant the result (Chen et al., 2013). It can be seen from Table 4.5 that respondent age is negatively correlated with energy consumption, suggesting that old occupants were likely to consume less electricity than young occupants. This finding is also supported by the studies by Chen et al. (2013) and Hori et al. (2013).

Table 4.5. Correlation between demographic and housing information and annual energy consumption

		Sqrt. of Area	Sqrt. of Elec. use	Number of Room	Family Structure	Age	Number of AC
Sqrt. of Area	Pearson	1	.535**	.735**	.320**	0.093	.455**
	Sig.		0	0	0	0.301	0
Sqrt. of Elec. use	Pearson		1	.291**	.192*	-0.156	.247**
	Sig.			0.001	0.032	0.083	0.006
Number of Room	Pearson			1	.266**	.244**	.685**
	Sig.				0.003	0.006	0
Family Structure	Pearson				1	0.104	0.169
	Sig.					0.248	0.06
Age	Pearson					1	.254**
	Sig.						0.004
Number of AC	Pearson						1
	Sig.						

Note: ** $p < .01$; * $p < .05$.

(Source: by Author)

The survey results suggest incredible diversity in heating and cooling patterns. For instance, the air conditioning hours vary from 2–20 hours per day in summer and winter. The length of the cooling season varies dramatically from 1–5 months. For heating in winter, high energy users operate air conditioners more frequently, but some low users never use air conditioners for heating. On the other side, low users accept lower indoor temperatures in winter, and the set temperature is lower with a shorter heating period. Similar to winter, low energy users seem to bear a higher indoor temperature, and the set temperature in summer is higher with a shorter cooling period. It was indicated that the large difference in energy consumption is mainly caused by the number of appliances in each household and the way these appliances are used, especially for air-conditioners.

Pilot study 2 was conducted to learn more about domestic energy use behaviour in Ningbo. The survey results suggested that the extreme diversity of temperature settings and heating or cooling periods makes it challenging to set preferences for building simulations. The correlation analysis showed that floor area has the largest correlation with annual electricity consumption, followed by the number of rooms and the number of air conditioners. The key finding from pilot study 2 is that young people used air conditioners more frequently with a higher expectation for thermal comfort than the older generation. Therefore, the eight variables about heating and cooling preferences were tested in the survey study in chapter 5. Young people was more likely to use air conditioners for more extended hours, at a higher temperature in winter, and a lower temperature in summer. This phenomenon reflects a problem that, if the energy behaviour remains the same for the current age group, in the future, if more of the young generation is born, the energy consumption will increase dramatically. This result also contributes to the selection of a young urban population as a target research group in this thesis.

4.6 Summary

Chapter 4 presented the data collection and data analysis methods used in this thesis, as well as the research design. An interdisciplinary socio-technical approach was adopted in this thesis due to the limitations of each single method in understanding the complexity of behaviour. This thesis was designed to apply a mixed methods approach to understand more about occupants, from occupancy patterns to occupants' energy use behaviour and attitudes, to reasons behind behaviour and attitudes, to occupants' intention to save energy with potential policies, to policy suggestions to target behaviour. The theory of planned behaviour (TPB) was adopted as the theoretical framework in this thesis, but mainly for the survey (quantitative) and interview (qualitative) empirical studies.

The next three chapters present the results from three empirical studies: the survey study about energy use behaviour and occupants' attitudes toward smart meters and related policies, the qualitative interview about occupants' reasons and motivations behind different energy use behaviour and attitudes, and the analysis of smart meter data for demand-side management and assessing potential behavioural measures.

Chapter 5 – SURVEY: DOMESTIC ELECTRICITY USE IN YOUNG URBAN HOUSEHOLDS IN SHANGHAI

5.1 Introduction

Chapter 5 adopts the survey method to explore the occupancy patterns, consumption, attitudes toward smart meters and related energy saving policies. The survey questionnaire is shown in Appendix A. Chapter 4 explains the reason for selecting the target group of young urban residents in Shanghai. Section 5.2 shows the demographics, occupancy patterns, and electricity consumption from survey results, with analysis of the relationship between socio-demographic variables and actual electricity consumption. Section 5.3 presents the social psychological variables based on TPB, including occupants' attitudes toward smart meters and smart meter policies, subjective norms, and perceived behaviour control, as well as the intention to save energy if smart meter policies were implemented. Section 5.3 presents the regression analysis of the relationship between social psychological variables and the intention to save energy. Section 5.4 summarises the findings from the survey study.

5.2 Demographics, occupancy patterns and consumption

Section 5.2 presents the survey results of demographics, occupancy patterns and annual electricity consumption. Sections 5.2.1 used the descriptive statistical method to summarise socio-demographics from the survey study, and then applied the correlation analysis to explore the relationship between socio-demographic variables and annual electricity consumption. Section 5.2.2 used the descriptive statistical method to summarise the occupancy patterns, and annual electricity consumption in three levels of domestic energy users according to the 3-level electricity pricing system in China. The unique characteristics of high energy consumers were analysed in particular to understand the factors that affect energy use behaviour, and explore how to select policies to target this group of high users. In addition, the results from this survey study will be compared with other previous studies into energy use characteristics in China.

5.2.1 Demographics and building characteristics

Table 5.1 presents the socio-demographic information and building characteristics of effective responses from survey results. There is a total amount of 341 effective responses collected from the survey study in Shanghai, with 148 (43%) male respondents and 193 (56%) female respondents. The age of respondents ranged from 18 to 69, most of whom are in the age groups of 25–30 and 30–35, with an average age of 34 years old. The age of the surveyed samples was younger than the registered population in Shanghai, in which the largest age group was between 35 and 59 years old in 2016, according to data from Shanghai Municipal Statistics Bureau (2016). The difference between the Shanghai average age and the survey samples resulted from the distribution method of the questionnaires (using the internet), since the old generation in China is not familiar with the internet.

Among the 341 effective responses, 69 respondents (20%) had an education level of high school or lower, 218 respondents (64%) held an undergraduate degree, and 54 respondents (16%) held a postgraduate education level. Among the 341 effective responses, 119 respondents (35%) had a family annual income of 100,000–200,000 RMB (11,000–23,000 GBP), and 77 respondents (23%) had a family annual income of 200,000–300,000 RMB (23,000–34,000 GBP). Table 5.1 shows that the annual electricity bill ranged from 420–6000 RMB (48–682 GBP) per household, with an average annual bill of 1875 RMB/year (213 GBP/year). It reflects the fact that even within the same target group of young urban residents in Shanghai, there is great variability in electricity consumption. Based on the electricity price in Shanghai, the annual electricity bill can be roughly calculated into the annual electricity consumption, which ranges from 600–9000 kWh per household, with an average value of 2778 kWh/year.

According to the National Bureau of Statistics of China (2017), 2694 out of 7801 samples (34.5%) in Shanghai were from a 2-occupant family, and 2044 out of 7801 samples (26.2%) in Shanghai were from a 3-occupant family. Compared with the Shanghai statistics, the survey results (38% of respondents from a 3-occupant family and 21% respondents from a 2-occupant family) were slightly different.

Table 5.1. Respondents' demographics and building characteristics

			Interval			Scale	
Variable		Obs.	Count	Freq.	MIN	Mean	MAX
Age (S1)		341					
(1)	=<20		4	1%			
(2)	20–30		157	46%			
(3)	30–40		106	31%			
(4)	40–50		41	12%			
(5)	50–60		27	8%			
(6)	>60		6	2%			
Gender		341					
(0)	Male		148	43%			
(1)	Female		193	57%			
Education level (S2)		341					
(1)	High school or lower		69	20%			
(2)	Undergraduate		218	64%			
(3)	Postgraduate		54	16%			
Family annual income (S5)		341					
(1)	0–100,000 RMB		50	15%			
(2)	100,000–200,000 RMB		119	35%			
(3)	200,000–300,000 RMB		77	23%			
(4)	300,000–500,000 RMB		68	20%			
(5)	More than 500,000 RMB		27	8%			
Number of occupants (S3)		341					
(1)	1		18	5%			
(2)	2		73	21%			
(3)	3		132	38%			
(4)	4		64	19%			
(5)	5 or more		54	16%			
Private housing (S4)		341					
(0)	Rent		98	29%			
(1)	Private		243	71%			
Pay elec. Bill		341					
(0)	No		8	2%			
(1)	Pay		333	98%			
Number of bedrooms		341					
(1)	1		53	16%			
(2)	2		192	56%			
(3)	3		86	25%			
(4)	4 or more		10	3%			
Built year		341			1917	2001	2016
Floor area		341			40	94	222
Annual elec. Bill (RMB)		341			420	1875	6000

According to the National Bureau of Statistics of China (2017), 2915 out of 19274 samples (15.1%) in Shanghai hold an undergraduate degree, 553 out of 19274 samples (2.9%) hold a postgraduate degree, and the rest (82.0%) is below the undergraduate level. Compared to the Shanghai statistics, the survey results (64% of respondents holding an undergraduate degree, 16% holding a postgraduate degree, and 20% below the undergraduate level) were different. The demographic characteristics of respondents were different from the general Shanghai statistics. The reason for this difference is from the distribution method, as the survey was distributed through the Internet with the help of relatives and friends of the authors that might result in a limited sample size for less-educated respondents. According to the Shanghai Municipal Statistics Bureau (2017), the average annual income per capita in urban Shanghai was 52,962 RMB (5,945 GBP) in 2015 and 57,692 RMB (6,476 GBP) in 2016, an increase of 9.0% in one year. If a couple both have income, the average family annual income was about 115,384 RMB (12,952 GBP) in 2016. It shows some similarity with the survey results in which 35% of the survey respondents had an annual family income in the range of 100,000–200,000 RMB.

Table 5.1 also lists the building stock information, including the construction year, floor area, the number of occupants, and the number of bedrooms. Among 341 effective responses, 132 respondents (38%) have 3 occupants per household, 73 respondents (21%) have 2 occupants per household, and 64 respondents (19%) have 4 occupants per household. The floor area per household ranges from 40-222 m^2, with an average value of 94 m^2. The building construction year ranges from 1917–2016, with an average value of 2001. The survey results agree with the findings from Chen et al. (2011) that more than 85% of Chinese residential buildings were built after 1990. The building construction year in Europe is much older than China. According to Lane et al. (2010), of the 23 million housing stock in England, over 18 million (78%) were built before 1980, 13 million were built before 1965, 9 million were built before the Second World War, and more than 5 million were built before 1914.

Table 5.2 presents the appliance information from the survey results. Out of the 341 effective responses, 122 respondents (36%) have 3 air conditioners (AC), 78 respondents (23%) have 2 ACs, and 76 respondents (22%) have 4 ACs. Out of the 341 effective responses, 97% of respondents have ACs in the bedroom, and 65% of respondents have ACs in the lounge. Among the 341 effective responses, 44% of them use an electric water heater, 52% of them use a gas water heater, and 12% of them have installed a solar water heater. The survey results about the appliance information show similarity with the findings from a previous study about domestic appliances of 215 families in six cities in China (Yu, Li and Zeng, 2005).

Table 5.2. Information on domestic appliances

Variable	Obs.	Count	Frequency
Number of air conditioners	341		
No		7	2%
1		38	11%
2		78	23%
3		122	36%
4		76	22%
5 or more		20	6%
Air conditioner in bedroom	341		
No		11	3%
Yes		330	97%
Air conditioner in lounge	341		
No		120	35%
Yes		221	65%
Electrical water heater	341		
No		190	56%
Yes		151	44%
Gas water heater	341		
No		165	48%
Yes		176	52%
Solar water heater	341		
No		300	88%
Yes		41	12%

(Source: by Author)

In the next, Spearman's correlation was used to assess the monotonic relationships between the variables of socio-demographic variables and annual electricity consumption. The Spearman's correlation coefficient (r_s) is a measure of the level of linear dependence between two variables with a value between −1 and +1 (inclusive). The correlation level (r_s) is categorised into five groups, with an absolute value of 0.00–0.19 for very weak, 0.20–0.39 for weak, 0.40–0.59 for moderate, 0.60–0.79 for strong, and 0.80–1.00 for very strong. Unlike the coefficient of correlation (r_s), the significance of correlation (p-value) with a smaller value represents a more significant correlation. Based on the similar study from Chen et al. (2013), a p-value smaller than 0.05 indicates that there is strong evidence against the null hypothesis, which should be rejected, and a p-value of smaller than 0.01 indicates a very significant level of correlation.

Figure 5.1 presents the correlation analysis of the socio-demographic variables and building characteristics with the annual electricity demand, with the value in coefficient of correlation. In this figure, the distribution of each variable is shown on the diagonal, the bivariate scatter plots with a fitted line are displayed on the bottom, and the value of the correlation plus the significance level as stars (*** $p < .001$; ** $p < .01$; * $p < .05$). The accuracy of this figure from the survey results was validated by analysing the relations of each variable. For instance, the family annual income level is significantly related to education level, number of occupants, private housing or not, building built year and total floor area. The explanation is reasonable that the people with higher education level are likely to have higher family annual income level; more family members tend to have higher family annual income level (couple higher than single); higher income people are likely to own their private house with larger floor area and built in more recent years.

Based on the Figure 5.1, the annual electricity demand is significantly correlated to the number of occupants, private or rental housing, family annual income level, built year, and floor area. Firstly, it reflects the fact that the building condition plays a vital role in energy consumption. Buildings with larger floor areas and more bedrooms consume more electricity. However, the built year was positively related to the annual electricity bill. Based on the previous study, new buildings built with stricter building standards can reduce heat transmission between the indoor and outdoor environments (Andersen, 2009). However, the survey results suggest the opposite trend in that occupants of new buildings tend to consume more electricity than those living in old ones. Compared to old buildings, residents living in new buildings enjoy better insulation, but have more appliances and potentially a larger floor area. Consequently, even if building fabrics and domestic appliances are becoming more energy efficient, the increased expectation for thermal comfort means that energy use may still increase. Secondly, the socio-demographic variables of number of occupants, private or rental housing, and family annual income level would affect the final energy consumption. It agrees with the some previous studies in China that the socio-demographic variables have an effect on domestic energy use (Chen et al., 2013; Feng et al., 2016; Ruan et al., 2017). However, different from the previous study, respondents' age and education level did not reflect a significant correlation. The differences might be from the reason that for the young respondents with low education level, they are still living with their families and still consume more energy(three occupants higher than two occupants). The socio-demographic variables act as opportunities and constraints for energy consumption patterns.

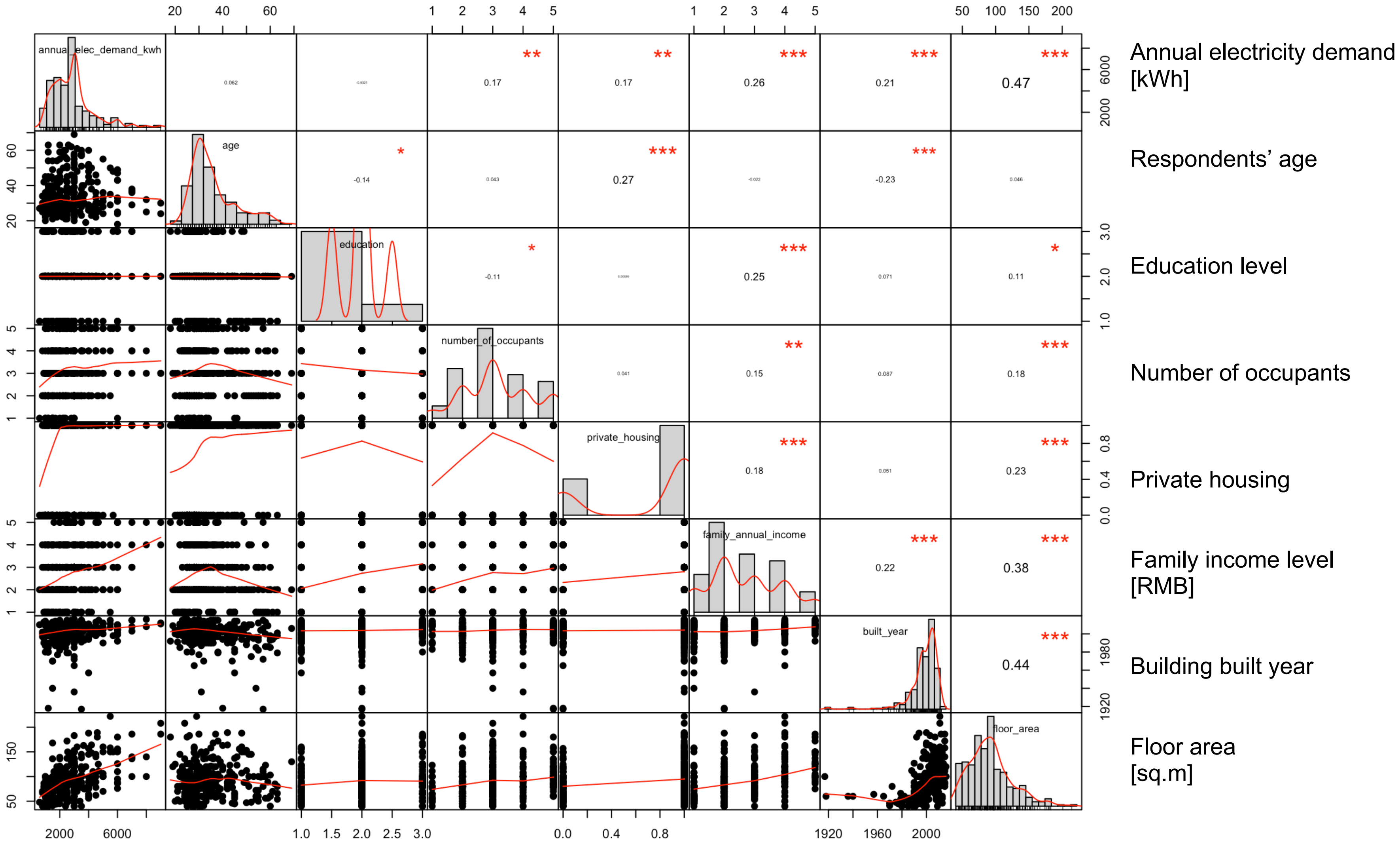


Figure 5.1. Correlation between socio-demographic variables, building characteristics and the annual electricity demand

5.2.2 Identifying high consumers and heating and cooling patterns

According to the 3-level progressive segmentation of electricity pricing system in China mentioned in section 2.4, all consumers can be grouped into three levels, from low users (level 1) to high users (level 3), as shown in Table 5.3. Households with an annual electricity bill of lower than 2000 RMB (226 GBP) were grouped as level 1 consumers. Households with an annual electricity bill of 2000-3000 kWh (226-338 GBP) were defined as level 2 consumers. Households with an annual electricity bill of higher than 3000 RMB (338 GBP) were defined as level 3 consumers. Table 5.3 also presents the number of observations in each group. The survey results also suggest that even for the target group of young urban population, the annual electricity consumption is not homogeneous but shows great variety.

Table 5.3. Progressive energy pricing system in Shanghai

Electricity price level	Electricity consumption (kWh)	Electricity price (RMB/kWh)	Annual electricity bill (RMB)	Number of households
Level 1	Lower than 3120	0.617	Lower than 2000	240
Level 2	3120-4800	0.667	2000-3000	67
Level 3	4800 and higher	0.917	Higher than 3000	34

Note: 0.617RMB = 0.07GBP; 0.667RMB = 0.08GBP; 0.917RMB = 0.10GBP

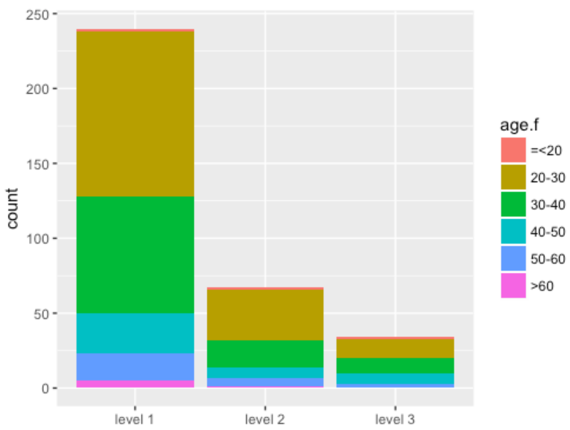
(Source: by Author)

The demographic and building construction information for each level based on the progressive segmentation of energy pricing levels is summarised in Table 5.4 and Figure 5.2. There were four findings based on the survey results. Firstly, from Figure 5.2 (left), there is no >60 age group among level 3 consumers. It agrees with the previous study that the older generation uses less electricity than the young generation in China, as indicated by Chen, Wang and Steemers (2013) and Hori et al. (2013). It results from the fact that China experienced moderate socio-economic development during the 1950s and 1970s, and socio-economic aspects affected the old generation's attitudes toward energy saving. Conversely, people who grew up in later decades enjoyed economic and technological development, and have a higher expectation of living standards.

Table 5.4. General characteristics of households' dwellings and energy use based on the 3-level energy pricing system (Level 3 is the highest consuming households)

	Level 1	Level 2	Level 3	All
Average number of occupants	3.13	3.31	3.35	3.19
Average built year	2001	1999	2007	2002
Average floor area (m^2)	87	100	132	94
Average number of bedrooms	2.02	2.33	2.76	2.16
Average family annual income (ten thousand RMB)	26.3	27.0	33.8	27.2
Average annual elec. bill (RMB)	1408	2420	4102	1876

(Source: by Author)



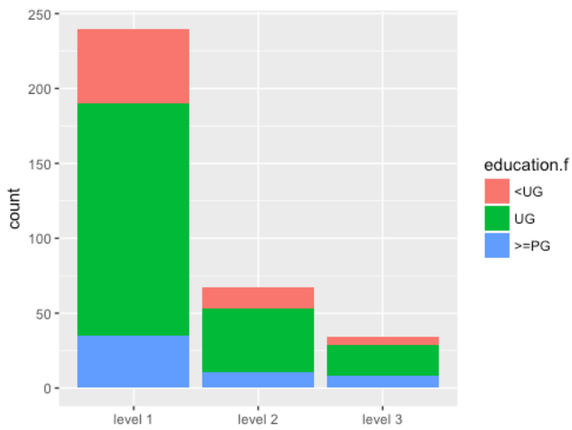


Figure 5.2. Respondents' age (left) and education level (right) based on progressive energy pricing level and the number of responses

(Source: by Author)

Secondly, from Figure 5.2 (right), there is a higher percentage of level 3 consumers with a postgraduate education level. It suggests that people with a higher education level seem to be more likely to consume more electricity. It disagrees with previous findings by Barr, Gilg and Ford (2005) that increased education results in more pro-environmental behaviours. It might be because the higher education level group has a higher annual income level which has a higher impact. From Table 5.4, the average family annual income was 338,000 RMB (37,600 GBP) for level 3 consumers, which is much higher than the average family annual income of the other two groups. In addition, level 3 consumers are more likely to live in homes with a larger floor area, with more bedrooms, more air conditioners, and a larger air-conditioned area. To conclude, people with higher income levels seem to be more likely to consume more electricity.

Thirdly, the average built year of the buildings that level 3 consumers live in is 2007, which is 5 years newer than the overall average age. In other words, households living in old buildings, which meet a lower building standard, tend to consume less electricity than new buildings. This result disagrees with the finding from previous studies that new buildings with better construction materials can save domestic energy use. It suggests the "pre-bound effect" indicated by Sunikka-Blank and Galvin (2012) that, if the old buildings were planned to be retrofitted, due to the extreme energy saving behaviour, the actual energy saving would be much smaller than calculated.

Fourthly, the average annual electricity bill of level 1 is only 1408 RMB (156 GBP), less than half of level 3, which is 4102 RMB (456 GBP). The large difference is from the classification method of the three groups, based on the 3-level electricity pricing system in China. There is a need to note that there are only 34 observations (10%) of level 3 consumers. Due to the small number of level 3 users, it is not appropriate to generalise the survey results to the Shanghai population or nationwide. However, the findings from the survey study can be used as an input for policy design. The small proportion of consumers at level 3 reflects the electricity pricing strategies that the government plans to use, to keep the electricity price constant for normal consumers, but to increase the electricity price for consumers with extremely high usage. According to Shanghai Municipal Development and Reform Commission (2012), level 1 consumers are designed to cover 80% of all consumers, and both level 1 and level 2 consumers are designed to cover 95% of all consumers.

In the next, occupancy patterns for heating and cooling could be summarised for each level of consumers. The heating and cooling energy use behaviour is related to the outdoor temperature. Table 4.1 in chapter 5 lists the average outdoor temperature in Shanghai for each month of the year. According to the survey results of all respondents, December is the most common (50% of all respondents) heating start month with an average outdoor temperature of 9.1°C, and February is the most common (43%) heating stop month, with an outdoor temperature of 6.9°C. The occupants choose to set the temperature at an average value of 24°C for heating, for an average of 3 heating hours, ranging from 0–10 hours. July is the most common (46%) cooling start month and September is the most common (52%) cooling stop month. The occupants choose to set the temperature at an average value of 25°C for cooling, for an average of 5 cooling hours, ranging from 1–20 hours.

This section presents eight parameters of occupancy patterns, including heating temperature, heating hours, cooling temperature and cooling hours explained in Table 5.5 and heating start month, heating stop month, cooling start month and cooling stop month shown in Figure 5.3. The eight parameters were grouped into three groups based on the 3-level electricity pricing system. The average heating and cooling temperature is similar for all three groups. There is a need to note that, from the survey results, the heating temperature (20–26°C) is relatively high when compared to the UK design standard (18–20°C). The difference in set heating temperature is from the difference in heating systems (radiator in the UK vs. air conditioners in Shanghai) and the way of how the residents operate air conditioners (UK residents set heating on for specific time period at specific time vs. Shanghai residents switch heating on when they feel cold and switch heating off when it is warm enough). The result of the way how Shanghai residents use their air conditioners was obtained from the interview study (will be detail explained in chapter 6). The main difference is the average value of heating and cooling hours, which is only 2.52 hours for heating and 4.75 hours for cooling for level 1 consumers, increasing to 3.87 hours for heating and 10.01 hours for cooling for level 3 consumers. Regarding heating and cooling periods, level 3 consumers have a higher percentage in the early start period and later stop period, with more extended heating and cooling periods.

Based on the results of occupancy parameters in Table 5.5 and Figure 5.3, the heating hours and cooling hours are the most important impact factors among the eight parameters, while the temperature setting (comfort standard) is likely to be similar. However, whether the Chinese style of operating air conditioner at 26°C for a short period (switch on and off) or the UK style of operating radiator at 20°C for a long period (constant on) is more energy saving needs to be explored further. The high energy (level 3) consumers have longer heating and cooling hours and have a higher percentage in the early start period and later stop period. Despite the small sample size, level 3 consumers with longer air-conditioning hours have the largest potential to save electricity. From the survey results, it was found for the occupants who start heating in October (earliest), they have the highest average value in annual electricity bill. In other words, occupants who start to use air conditioners earlier consume more electricity annually. In terms of the heating stop month, occupants who stop heating in April (latest) have the highest average annual electricity bill. It means that occupants who stop using air conditioners for heating later, consume more electricity annually. These two figures lead to the conclusion that occupants with longer heating periods are likely to have higher electricity bills and consume more electricity. Conclusions for the cooling period are similar to those of the heating period.

Table 5.5. Heating and cooling patterns based on progressive energy pricing level

	Level 1	Level 2	Level 3	Average
Average heating temperature (°C)	24.65	20.28	25.57	24.22
Average heating hours (h)	2.52	2.58	3.87	2.73
Average cooling temperature (°C)	24.79	25.22	24.48	24.93
Average cooling hours (h)	4.75	5.03	10.01	4.87

(Source: by Author)

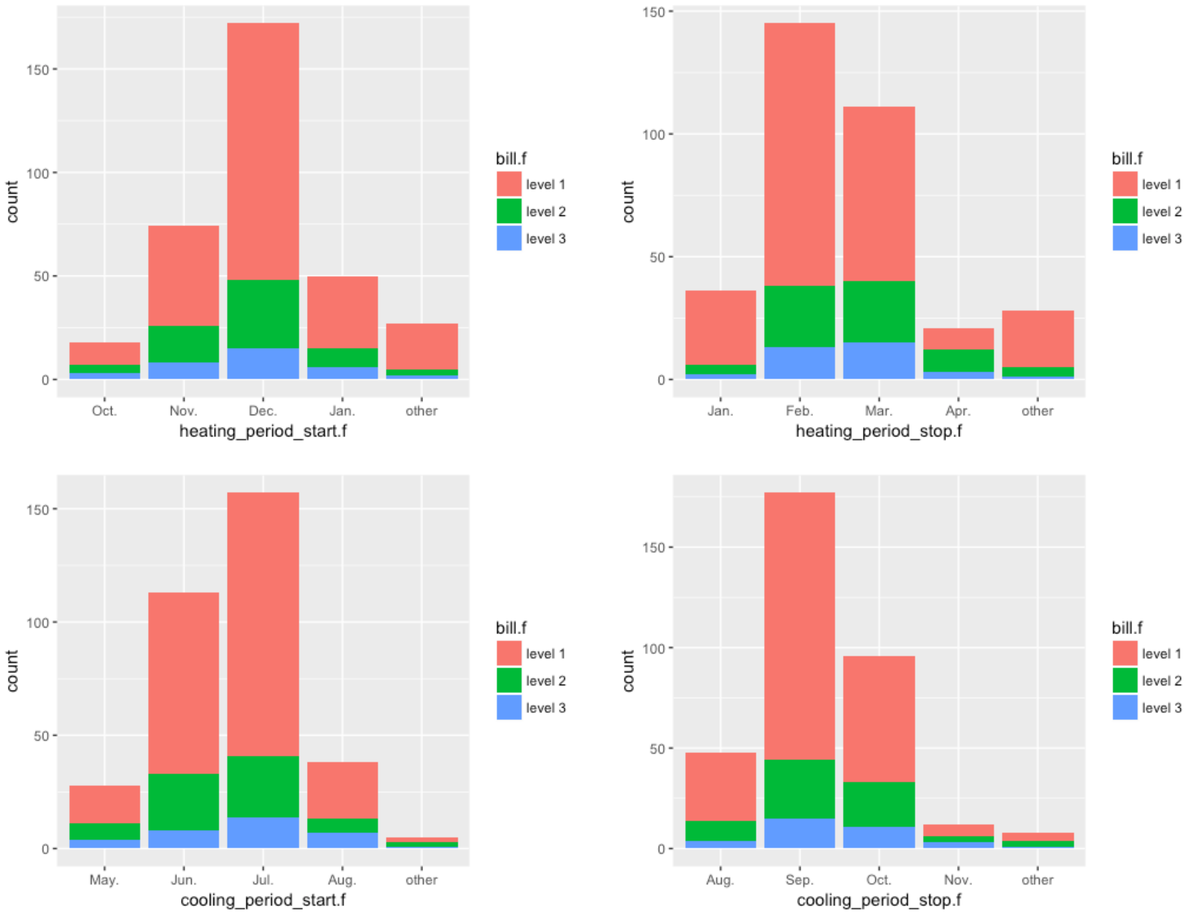


Figure 5.3. Heating and cooling patterns based on progressive energy pricing levels and number of responses

(Source: by Author)

5.3 Attitudes, norms, control and intention to save energy

Chapter 3 concluded that there have been very limited studies to examine occupants' attitudes toward smart meters and related energy saving policies in China. The theory of planned behaviour (TPB) was selected as the theoretical framework for this thesis. According to TPB, consumers' intention to save energy has an impact on their behaviour. To implement effective policy instruments, the occupants' attitudes toward these policy instruments have an impact on their behaviour when the policies are implemented.

Section 5.3 explores the psychological variables based on TPB, including occupants' attitudes toward smart meters, occupants' attitudes toward smart meter policies, subjective norms, perceived behaviour control, as well as the intention to save energy if smart meter policies were implemented. The survey questions were designed based on the elements in TPB, to test the relationship between occupants' attitudes, intentions and behaviours. This part of thesis was learn from the previous research by Abrahamse and Steg (2011)'s (introduced in section 3.2), as their research also explored the relationships between psychological and socio-demographic variables regarding occupants' domestic energy use and occupants' intention to save energy.

Section 5.3.1 reveals the survey results of occupants' attitudes toward smart meters, particularly addressed to level 3 high consumers. Section 5.3.2 shows the survey results of occupants' attitudes toward energy saving policies. Section 5.3.3 discusses the gender difference in attitudes toward energy saving policies. Section 5.3.4 reveals the survey results of the psychological variable of subjective norms and perceived behaviour control. Section 5.3.5 shows the occupants' intention to save energy if smart meter policies were implemented. Section 5.3.6 presents the regression analysis between psychological variables based on TPB and the intention to save energy.

Correlation and regression analysis are statistical methods to quantify associations between independent variables and dependent variables. In correlation analysis, the independent variable can be continuous or ordinal. In regression analysis, the independent variable can be dichotomous. The test of correlation was based on the case study in section 3.2 by Abrahamse and Steg (2011).

5.3.1 Attitudes toward smart meters

The survey included rating-scale questions about respondents' attitudes to smart meters. Participants were asked for their level of agreement with eight statements about smart meters formulated as "smart meters can" on 5-point Likert scales, anchored at "1=strongly disagree", "3=average" and "5=strongly agree". The statements about smart meters were quoted from a previous study by Krishnamurti et al. (2012) (introduced in section 3.2), and the results from the survey are compared with their results.

Table 5.6 lists the eight statements about smart meters and the level of agreement from all respondents. Most participants agree that smart meters can let them (B1) check the accuracy of bill (51.6% agree plus 23.5% strongly agree), (B2) save money (36.4% agree plus 25.8% strongly agree), and (B3) tell them how much electricity each appliance used (46.0% agree plus 29.9% strongly agree). The statements of B1–B3 are positive attitudes toward smart meters. Furthermore, most participants hold a neutral opinion that smart meters can (B5) control the air conditioning system (29.3% in average), (B6) let the electricity company control electricity use (32.6% in average), (B7) cost money (29.3% in average), and (B8) violate privacy (34.9% in average). The statements of B6–B8 are negative attitudes toward smart meters.

Table 5.6 also presents the results from the study by Krishnamurti. Krishnamurti et al. (2012) used behavioural decision methods to understand consumers' beliefs about smart meters, targeted at potential smart meter customers of an electricity utility in the U.S. mid-Atlantic. The survey results about the Shanghai urban population from this thesis can be compared with their results. Generally, the respondents from Shanghai are more likely to agree with the statements about smart meters, compared with the 500 U.S. households. It can lead to the conclusion that an information campaign is essential in implementing smart meter policies as, if the residents agree with "*the use of smart meters can reduce domestic electricity consumption*", they would be more likely to accept installing smart meters at home.

Among the eight statements, the statements of (B1) check accuracy of the bill, (B2) save money, and (B4) reduce the risk of blackouts, are correct with the smart meters only. However, the statement of (B3), regarding telling them how much electricity each appliance uses, cannot be achieved by the smart meters but could be achieved with the plug-monitor of each appliance. The statement of (B5), controlling the air conditioning system, cannot be achieved by the smart meters but could be achieved with an advanced smart home control system, supported by sensors and activators. It is worth mentioning that this misunderstanding about smart meters should be considered, in case it becomes an obstacle to promoting smart meters and related energy saving policies. For instance, if the occupants believe smart meters can (B3) tell them how much electricity each appliance uses and (B5) control their central air conditioning, if they discover these functions cannot be achieved, they might feel disappointed about smart meters and be unwilling to participate in energy saving.

Another finding is that, generally, level 3 consumers are on average relatively more negative with all the statements, but are more likely to agree with the statement of (B3), telling them how much each appliance used, and (B5), control the central air conditioning. However, these two statements are incorrect based on current technology in China, which might affect the effectiveness of energy efficiency policies that target level 3 consumers. If the households hold negative opinions about smart meters, who are concerned about extra costs and privacy problems, they might not be able to accept installing smart meters at home. Thus an information campaign is important to promote energy saving policies, which agrees with the findings by Martiskainen and Ellis (2011).

From respondents' attitudes, since most of them agreed with the statement of "*the use of smart meters can save you money*", it is recommended that the Chinese government could install smart meters for each household. In the UK, the government plan to install smart meters for every household by 2020 (UK Green Building Council, 2016), which is a good example for China to learn. According to findings from previous studies, the use of smart meters could help to save 10–30% electricity from behaviour changes (Owens and Driffill, 2008). The use of smart meters with in-home displays would contribute to future energy saving.

Table 5.6. Comparison of occupants' attitudes toward smart meters in the case study in Shanghai and the study by Krishnamurti et al. of U.S. households

		Mean of study by (Krishnamurti et al., 2012)	From Shanghai survey study					
			Mean	Strongly disagree	Disagree	Average	Agree	Strongly agree
B1	Let you check the accuracy of your electricity bill	4.0	3.903	3.2%	1.8%	19.9%	51.6%	23.5%
B2	Save you money	3.7	3.718	4.1%	7.9%	25.8%	36.4%	25.8%
B3	Tell you how much electricity each appliance used	3.5	3.979	2.9%	2.1%	19.1%	46.0%	29.9%
B4	Reduce the risk of blackouts	3.3	3.713	5.0%	4.4%	26.4%	42.8%	21.4%
B5	Control your central air conditioning	3.2	3.481	5.9%	10.9%	29.3%	37.2%	16.7%
B6	Let electricity company control your electricity use	2.7	3.202	8.5%	17.3%	32.6%	28.7%	12.9%
B7	Cost you money	2.6	2.865	12.3%	28.7%	29.3%	19.4%	10.3%
B8	Violate your privacy	2.6	2.997	12.0%	20.2%	34.9%	21.7%	11.1%

(Source: by Author)

Table 5.7. Occupants' attitudes toward energy saving policies

	Policies	Instruments	Mean	Strongly disagree	Disagree	Average	Agree	Strongly agree
P1	The government will install smart meters for free	Communication	3.94	3.5%	2.9%	15.2%	52.5%	25.8%
P2	The government will install smart meters for free and will provide monthly suggestions for how to reduce energy consumption	Communication	3.94	2.9%	2.1%	18.5%	51.6%	24.9%
P3	The government will install smart meters for free and will inform you to switch off domestic appliance with high energy consumption	Communication	3.77	3.8%	4.7%	23.8%	46.0%	21.7%
P4	The government install smart and will cut off electricity when you use electricity of more than up-limit at peak time	Consumption control	2.98	16.1%	21.4%	22.3%	28.4%	11.7%
P5	"Green Point" scheme: for the occupants with a higher green point in their account, they could enjoy a lower interest rate for the bank's loan when you want to buy a new house	Fiscal incentive	3.98	3.2%	2.6%	17.3%	46.6%	30.2%
P6	Real-time electricity pricing: higher electricity price if they use electricity at the peak time; in the opposite, pay less	Price control	3.67	6.2%	7.6%	21.7%	41.6%	22.9%
P7	Stage electricity price: pay more if they use electricity of more than a limit for each month; in the opposite, pay less	Price control	3.54	7.0%	8.5%	25.2%	42.2%	17.0%

(Source: by Author)

5.3.2 Attitudes toward energy saving policy instruments

This section explores whether households are willing to accept energy saving policies related to smart meters, on 5-point Likert scales, anchored at "1=strongly unwilling to accept" and "5=strongly willing to accept". Interventions, such as giving feedback on energy consumption, can make occupants aware of their routine behaviour, resulted in energy saving of 5–15% and 0–10% from direct and indirect feedback (Darby, 2006). Previous research has identified fiscal and administrative instruments as effective policy instruments. Table 5.7 lists the smart meter policies and the category of every policy instruments.

The proposed policy instruments were selected based on a review of current behavioural studies in China or foreign experiences for China to learn. For the policy instruments of (P1) free smart meter installation, (P2) smart meters with monthly suggestions, and (P3) smart meters with real-time suggestions, these are experiences for China to learn. It was mentioned in section 2.5 that the rollout of smart meters before 2020 is the primary policy target for the UK government to achieve (UK Green Building Council, 2016). In the UK, the government cooperates with electricity companies to promote the rollout of smart meters across the whole country. The electricity companies' websites provide guidance and information for consumers to save energy at home, with real-time and monthly suggestions. The policy instrument of (P4) real-time electricity use cap was developed based on (P3) smart meters with real-time suggestions, so that a compulsory electricity cap would attract consumers' attention to save energy if they consume too much electricity at a specific time. However, these two policies cannot be achieved by smart meters alone, but require the help of in-home displays.

The policy instrument of (P5) "Green Point" scheme was developed based on the current Chinese national condition that many Chinese citizens would apply for a bank loan to pay part of the expensive housing price. Lower interest rates might be a strong motivation for them to save energy for economic factors. This policy instrument might not be directly related to smart meters, but the smart meters can record residents' electricity use and provide real-time displays with suggestions to guide the residents on how to save energy.

The policy instruments of (P6) real-time electricity pricing and (P7) stage electricity pricing were developed based on the findings from previous research that the energy use behaviour of consumers may be influenced by the electricity price. For the real-time electricity pricing system, it is also a proposal in many European countries to discuss what might be put into effect in the future. Staged electricity pricing was based on the current 3-level electricity pricing system in China, which sets the limit for each level of electricity price for each year, but the key difference is the proposed policy sets the limit for each level of electricity price for each month. As the energy use behaviour is very different at each month of the year, this policy instrument might be more useful to target energy saving in summer or winter. Similarly, these two policy instruments are not directly related to smart meters, however, they cannot be applied without the use of smart meters and in-home displays to provide real-time electricity price information for residents.

Table 5.7 presents the respondents' level of agreement with the policy statements. Generally, respondents hold positive attitudes toward the potential policy of (P1) free smart meter installation (52.5% agree plus 25.8% strongly agree), (P2) free smart meter installation with monthly suggestions (51.6% agree plus 24.9% strongly agree), (P3) free smart meter installation with real-time suggestions (46.0% agree plus 21.7% strongly agree), (P5) Green Point scheme (46.6% agree plus 30.2% strongly agree), (P6) real-time electricity pricing (41.6% agree plus 22.9% strongly agree), and (P7) stage electricity pricing (42.2% agree plus 17.0% strongly agree). Only the attitudes toward (P4) electricity-cap are distributed evenly from strongly disagree to strongly agree with around 20% for each level of agreement, as cutting off electricity when usage exceeds a limit will bring inconvenience into life. Generally, respondents are more likely to agree with policy instruments of fiscal incentives and intervention instruments, rather than consumption and price control instruments.

The attitude toward energy saving policies of level 3 consumers is especially necessary in order to reduce electricity consumption since these were identified in the previous section as the target group for policy design. Generally, the average value of agreement level of policy statements for level 3 consumers is smaller than the average value of all users, which suggests that level 3 consumers might have more critical attitudes toward energy saving policies and are less likely to accept energy saving policies. When compared to the average value of all users, (P1) free installation of smart meters and (P6) real-time electricity pricing were more preferred by level 3 consumers, because the average value of these two policies for level 3 users was equal to or higher than the average value of all users. From the survey study, the target group of level 3 users are more likely to accept the policy of installing smart meters and real-time electricity pricing.

5.3.3 Gender differences in attitudes

Females in China still do a disproportionate amount of housework at home, even though most females now have their jobs. It has been suggested that the design of energy saving policies would be more useful if it engages better with different target groups, considering the gender difference (Sunikka-Blank and Galvin, 2016).

In this section, females were also selected as a target group for analysis. From the survey results, Figure 5.4 shows that, compared with male attitudes, females hold more positive views about (P1) free smart meter installation, (P2) smart meters with monthly suggestions, and (P3) smart meters with real-time suggestions, but holds more negative views on (P6) real-time electricity pricing and (P7) stage electricity pricing, which are related to different electricity pricing strategies. The policies of electricity price require occupants to pay more if they use more electricity, but they can pay less if they use less. The finding in gender difference is important that females are more likely to agree with the policy instruments of installing smart meters for free, with monthly and real-time suggestions, and are less likely to accept policy instruments that related to electricity price control. The results suggest that females are more sensitive to price changes and more cautious about potentially increasing the electricity bill.

It can be concluded from this section that, compared with male participants, female participants had a higher level of agreement with the policies that can provide advice on how to reduce consumption (communication instruments) rather than potential increases in electricity price (price control). On average, a female participant is more conscious about electricity price, suggesting that the price control instrument might be powerful in regulating energy use behaviour through price control.

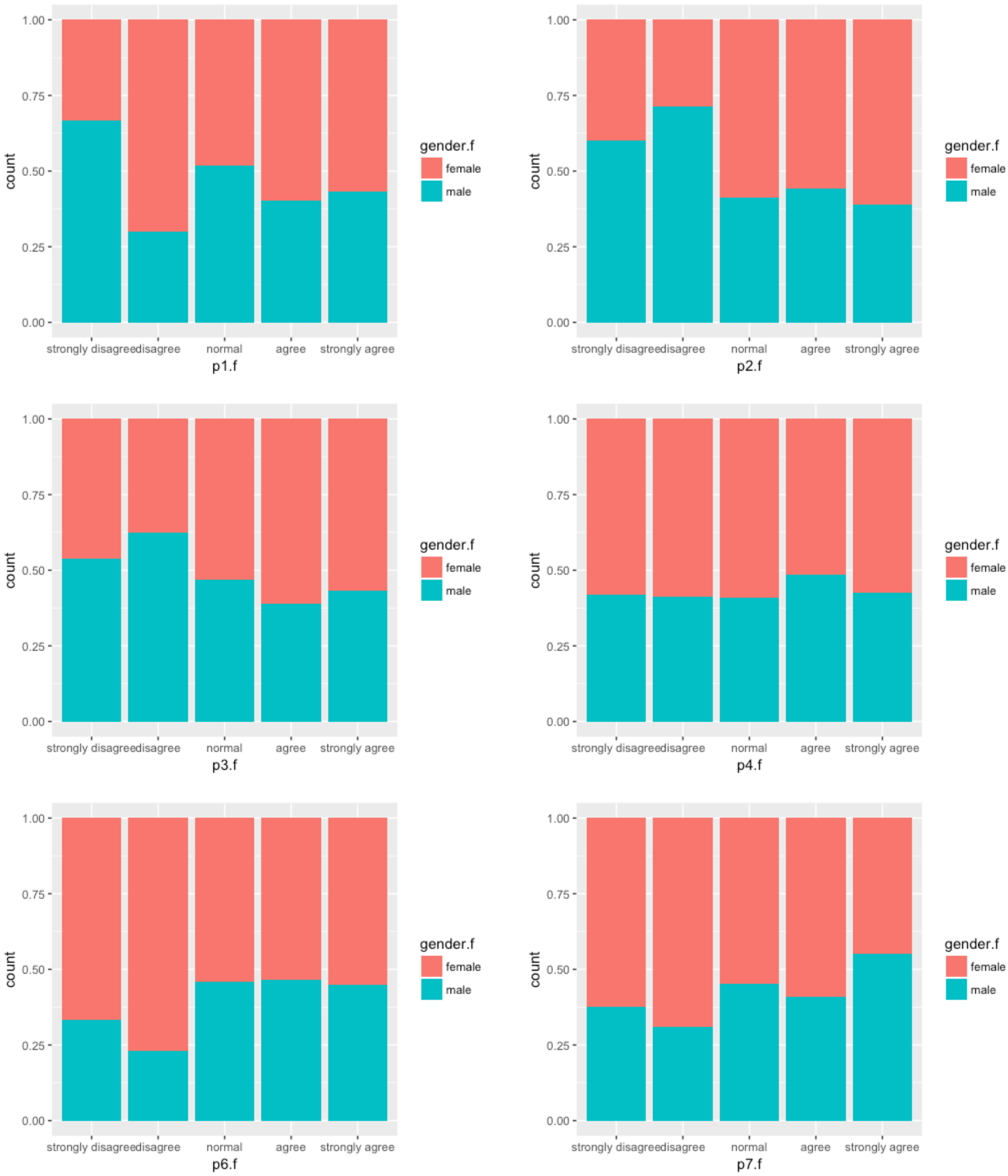


Figure 5.4. Female and male's attitudes toward selected energy saving policies in percentage

(Source: by Author)

5.3.4 Subjective norms and perceived behavioural control

The survey also asked questions about occupants' norms and control, which are two psychological variables in the theory of planned behaviour (TPB). As mentioned in chapter 4, subjective norm (SN) is defined as the external social pressure to act or not to act on the behaviour, and perceived behavioural control (PBC) is defined as the individuals' perceived ease or difficulty in acting on a specific behaviour (Ajzen, 1991).

Subjective norm (SN) was measured by asking questions about to what extent they thought they should be energy saving. As reference groups that affect respondents are diverse in daily life, the influences from reference groups about energy saving are different. It was suggested by Abrahamse and Steg (2011) to use a single-item measure of subjective norm, in "*family members' attitudes toward energy saving and sustainability*", on 5-point Likert scales, anchored at "1=strongly unwilling to" and "5=strongly willing to", as it is the reference group most relevant to respondents. Table 5.8 suggests that most family members of respondents hold positive attitudes toward energy saving (44.3% willing to plus 12.0% strongly willing to, but with 37.2% in normal). On average, households are neutral to positive concerning whether their family members are in favour of domestic energy saving ($M = 3.60;\ sd = 0.84$).

Table 5.8. Subjective norm and perceived behavioural control

Psychological variable		Obs.	Count	Freq.
Subjective norm (SN)		341		
(1)	Strongly unwilling to		8	2.3%
(2)	Unwilling to		14	4.1%
(3)	Normal		127	37.2%
(4)	Willing to		151	44.3%
(5)	Strongly willing to		41	12.0%
Perceived behavioural control (PBC)		341		
(1)	Very difficult		9	2.6%
(2)	Difficult		9	2.6%
(3)	Normal		117	34.3%
(4)	Easy		155	45.5%
(5)	Very easy		51	15.0%

(Source: by Author)

Perceived behavioural control (PBC) referred to the level of respondents' feeling of difficult or ease to save energy at home. The question was formulated as "*do you think it is difficult to* *change behaviour to save energy at home?*" on 5-point Likert scales, anchored at "1=very difficult" and "5=very easy". Table 5.8 suggests that most respondents have positive attitudes toward changing behaviour for energy saving (45.5% in easy plus 15.0% in very easy, with 34.3% in normal). On average, households are neutral to positive with respect to their perceived capability to save energy ($\mathrm{M} = 3.67;\ \mathrm{sd} = 0.86$).

5.3.5 Intention to save energy

This section discusses the psychological variable of intention to save energy based on the theory of planned behaviour (TPB). Intention to reduce energy use under energy saving policies was measured by asking "*are you willing to change behaviour for energy saving if you notice too much real-time electricity consumption on the in-home display?*" on 5-point Likert scales, anchored at "1=strongly unwilling to" and "5=strongly willing to". Table 5.9 presents the intention to save energy with smart meter policies from the survey study. It suggests that most respondents hold positive attitudes toward changing behaviour for energy saving with smart meter policies (34.0% willing to plus 38.4% strongly willing to). On average, the respondents hold positive attitudes about energy saving ($\mathrm{M} = 4.00;\ \mathrm{sd} = 1.02$).

Table 5.9. Intention to change behaviour with smart meter policies

		Obs.	Count	Freq.
		341		
(1)	Strongly unwilling to		12	3.5%
(2)	Unwilling to		12	3.5%
(3)	Normal		70	20.5%
(4)	Willing to		116	34.0%
(5)	Strongly willing to		131	38.4%

(Source: by Author)

Apart from the general question of "*are you willing to change behaviour?*" the survey also asked the question of "*which behaviour measure are you willing to consider when you notice high real-time consumption?*" with the yes-or-no choices of "0=no" and "1=yes" about six different behavioural measures. Table 5.10 presents the behavioural measures and respondents' choices. The mean value of higher than 0.5 represents positive attitudes to the behavioural measure, while an average value of lower than 0.5 represents negative attitudes to the behavioural measure. It was found that only the behavioural measure of switching off air conditioners received the positive attitudes, with the mean value of 0.546. Thus, real-time suggestions about energy saving could consider the provision of more comments about the more disciplined use of air conditioners.

Table 5.10. Choices of behavioural measures

		Obs.	Count	Freq.	Mean
Switch off air conditioners		341			0.546
(0)	no		155	45.5%	
(1)	yes		186	54.5%	
Change time to use washing clothes		341			0.460
(0)	no		184	54.0%	
(1)	yes		157	46.0%	
Change time to wash dishes		341			0.158
(0)	no		287	84.2%	
(1)	yes		54	15.8%	
Change time to heat up water		341			0.343
(0)	no		224	65.7%	
(1)	yes		117	34.3%	
Change time to use kettle		341			0.337
(0)	no		226	66.3%	
(1)	yes		115	33.7%	
Change time to take shower		341			0.205
(0)	no		271	79.5%	
(1)	yes		70	20.5%	

(Source: by Author)

5.3.6 Socio-psychological variables and energy saving intentions

Regression analysis

Based on the selected theoretical framework of the theory of planned behaviour (TPB), the fundamental assumption is that choices are assumed to be made based on the expected outcomes from a choice and the value attached to outcomes, which incorporates the influence of occupants' perceptions about their control over the situation. In TPB, the intention is influenced by attitudes, subjective norms, and perceived behavioural control, and then affects behaviour. There is a need to note that actual behaviour under energy saving policies cannot be tested as the policy is not implemented yet, thus this section only tests the relationship between psychological variables and the intention to save energy through regression analysis.

This section examines to what extent the socio-psychological variables can explain the energy saving intention with smart meter policies.

Intention to reduce energy use under energy saving policies was used as a dependent variable in the regression, measured by asking "*are you willing to change behaviour for energy saving if you notice too much real-time electricity consumption on the in-home display?*" Table 5.9 presents the intention to save energy with smart meter policies from the survey study. On average, the respondents hold positive attitudes toward energy saving $(\mathrm{M} = 4.00;\ \mathrm{sd} = 1.02)$.

There are three psychological variables based on the theory of planned behaviour (TPB): attitude (A), subjective norm (SN), and perceived behavioural control (PBC). Attitude (A) was measured through occupants' attitudes toward smart meter policies (only examined P1: the government will install smart meters for free), with their level of agreement to the policy instrument of installing smart meters for free, listed in Table 5.7 in section 5.3.2. On average, households hold positive attitudes toward smart meter policies $(\mathrm{M} = 3.94;\ \mathrm{sd} = 0.92)$. Subjective norm (SN) was measured by asking respondents to what extent they thought they should be energy saving. On average, households are neutral to positive with respect to whether their family members are in favour of energy saving $(\mathrm{M} = 3.60;\ \mathrm{sd} = 0.84)$. Perceived behavioural control (PBC) referred to the extent to which respondents felt capable of saving energy at home. On average, households are neutral to positive with respect to their perceived ability to save energy $(\mathrm{M} = 3.67;\ \mathrm{sd} = 0.86)$. Table 5.8 shows the psychological variables of subjective norm (SN), and perceived behavioural control (PBC).

Regression analysis was used to explore the extent to which the three psychological variables were able to explain the energy saving intention with smart meter policies. In Table 5.11, about 17.9% of the variance in intention to reduce energy use under smart meter policies could be explained by attitude, subjective norm, and perceived behavioural control ($R = 0.423, R^2 = 0.179, F = 24.528, p < 0.001$). Respondents with more positive attitudes toward smart meter policy ($\beta = 0.331, t = 6.079, p < 0.001$) and more restrained subjective norms from family members ($\beta = 0.152, t = 2.323, p < 0.05$) tend to be more likely to change their behaviour for domestic energy saving if these policies were implemented. Perceived behavioural control suggests a weak correlation to the explanation of intention to save energy with smart meter policies.

Table 5.11. Psychological variables and energy saving intention (N = 341)

	β	t	R	R^2	F
			.423	.179	24.528***
Attitude	.331	6.079***			
Subjective Norm	.152	2.323*			
Perceived Behavioural Control	.023	.342			

Note: *** p < .001; ** p < .01; * p < .05.

(Source: by Author)

Based on the theory of planned behaviour (TPB), the psychological variables affect consumers' intentions and affect their behaviour. In line with this hypothesis, the psychological variables could explain the variance (17.9%) in the intention to save energy. Figure 5.5 displays the regression results of psychological variables and energy saving intention. In contrast to expectation, perceived behavioural control is not significantly related to behavioural intentions, with a significant value larger than 0.05.

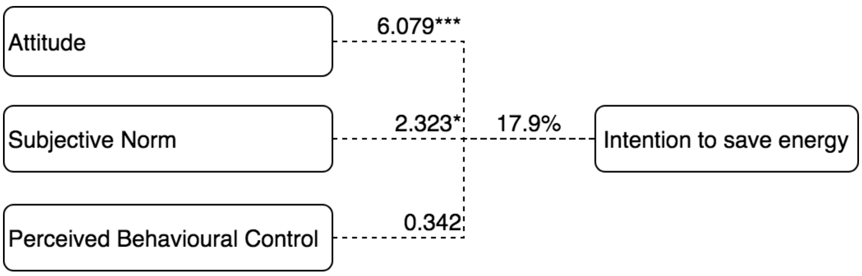


Figure 5.5. Psychological variables and energy saving intention

(Source: by Author)

Correlation analysis

This section uses correlation analysis to explore the relationships between psychological variables and socio-demographic variables, to test to what extent the five socio-demographic variables are able to explain variances in psychological variables based on TPB. Table 5.12 presents the correlation results between psychological and socio-demographic variables.

Table 5.12. Psychological and socio-demographic variables (N = 341)

	Attitude	Subjective Norm	Perceived Behavioural Control
Age	0.051	.320**	.341**
Education level	0.054	.205**	.129*
Number of occupants	-0.081	-0.008	-0.022
Private housing	-0.01	.122*	0.069
Family annual income	.113*	0.066	0.08

Note: ** $p < .01$; * $p < .05$.

(Source: by Author)

Regarding the socio-demographic variables that affect the psychological variable of attitude (A), only the family annual income level showed a significant positive correlation with attitude. The socio-demographic variables of age, education level and whether the housing is privately owned showed significant correlation with the psychological variable of subjective norm (SN). The socio-demographic variables of age and education level showed a significant correlation with perceived behavioural control (PBC). According to the correlation results in Table 5.12, the socio-demographic variables can partly explain the variation of the psychological variables in TPB. In general, the socio-demographic variables of age and education level held a good explanatory power of the psychological variables of subjective norm and perceived behavioural control. More importantly, the socio-demographic variable of family income level has the best explanatory power of attitudes toward smart meter policies.

In Table 5.12, the demographic variable of family annual income level indicated a positive correlation with the psychological variable of attitude (A). The demographic variables of age and education level revealed significant correlations with the psychological variables of subjective norm (SN) and perceived behavioural control (PBC). Figure 5.6 combines the results from regression and correlation analysis. The correlations analysis shows that the demographic variables can partly explain the variation of the psychological variables. Figure 5.6 suggests that the age and education level indicate a significant correlation with the subjective norm and perceived behavioural control, which has prediction power of the intention to save energy with smart meter policies, which will affect their potential behaviour if smart meter policies were implemented.

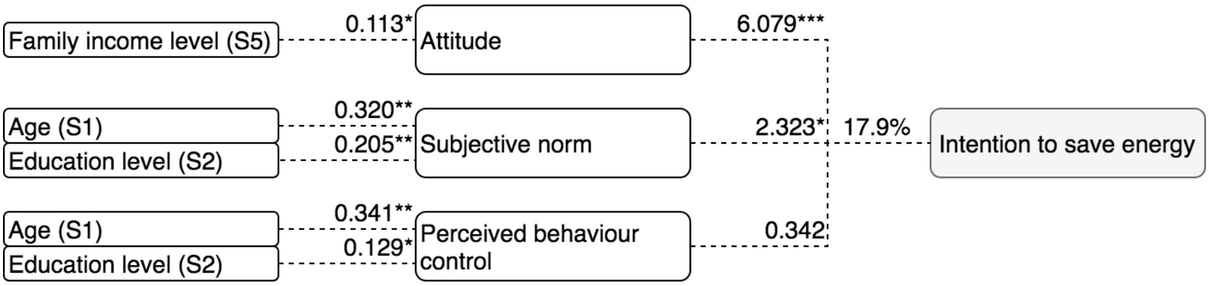


Figure 5.6. Demographic and psychological variables with energy saving intention

(Source: by Author)

The correlation analysis between socio-demographic and psychological variables suggests that family income level has the best prediction power of attitudes toward smart meter policies. Section 5.2.1 suggests that the family income level is positively related to annual electricity consumption. To combine the two findings, a family with a higher income level has a higher level of actual annual electricity use, but they have more positive attitudes toward smart meter policies. Therefore, the implementation of smart meter policies can be targeted first on households with higher income levels. The family income level could be used as a criterion to select a target group for energy saving. An information campaign is essential in developing positive attitudes toward smart meter policies, which would strengthen the energy saving intentions for this high income level target group.

5.4 Summary of the survey study

Chapter 5 used the survey method to explore the occupancy patterns, consumption, attitudes to smart meters and energy saving policies, and intention to save energy, as well as the factors that affect behaviour and intention to save energy with smart meter policies. The theory of planned behaviour (TPB) was applied as a theoretical framework. There were six findings from this chapter: 1) level 3 high consumers are more likely to have higher family income level, who have longer heating and cooling hours, and have a higher percentage in the early start period and later stop period groups; 2) occupants are likely to have lower requirements for indoor temperature if they start to use cooling later, accept higher temperature in summer, and have a shorter cooling period; 3) respondents are more likely to agree with policy instruments involving fiscal incentives and communication than those regarding consumption and price control; 4) level 3 consumers have more critical attitudes toward energy saving policies, and they are more likely to accept the policy of real-time electricity pricing; 5) domestic energy use is strongly correlated to the factors that shape energy use patterns, including family income level and household size; and 6) energy saving intention appears to be related to attitude toward smart meter policies and subjective norms from family members.

Consequently, if the government understands the socio-demographic factors of households, it can make more accurate predictions of electricity use and implement more effective policy instruments, based on the socio-demographic factors of age, income level, and education level.

The next chapter aims to use the qualitative research method to explore the reasons behind behaviour and attitudes.

Chapter 6 – INTERVIEWS: ATTITUDES, NORMS, PERCEIVED CONTROL

6.1 Introduction

The survey results in chapter 5 suggest that the residents' preferences for thermal comfort or energy saving are diverse, as well as their practices for heating and cooling. According to the theory of planned behaviour (TPB), attitude, subjective norm and perceived behavioural control are the psychological variables that affect the intention of behaviour and the corresponding behaviour. This chapter explores the interviewees' attitudes and the factors that affect those attitudes. Similar to the structure in chapter 5, it structures the contents according to: 1) demographics, occupancy patterns and energy use; and 2) attitudes, norms and control. Section 6.2 lists the information of the interviewees, building characteristics and domestic appliances, current electricity meters and billing systems, and occupancy patterns. Section 6.3 introduces the interview results of two target groups for policy, structured under four headings of: 1) occupants' attitudes, norms and control, 2) factors affecting attitudes, 3) interviewees' knowledge about policies, and 4) interviewees' suggestions for energy saving policies. Section 6.4 summarises the findings.

6.2 Demographics, occupancy patterns and consumption

6.2.1 Young urban residents as a target group

Five participants with the characteristics of young and highly-educated households from the survey (chapter 5) were selected for in-depth interviews. All samples are level 1 consumers, according to the 3-level electricity pricing system in China. The aim is not to generalise but to use the qualitative study as supporting material to the positivist approach mentioned in chapter 4. The focus on this target population is twofold. Firstly, from the previous study mentioned in chapter 3, household energy consumption is related to households' age and income level, and the old generation tends to exhibit frugal behaviour (Feng et al., 2016; Chen et al., 2013; Ruan et al., 2017). Secondly, from the previous study mentioned in chapter 3, the higher education level might equip them with attitudes more positive toward saving energy, and in theory should be more responsive to environmental concerns (Harris, 2006). The selection of the high education group can help to understand why the survey result is different from the previous study. Thus, the interview results from the selected group of young highly-educated urban residents within the level 1 (lowest) electricity price band could help to understand why they have a moderate level of energy use but with the socio-demographic characteristics of potential high energy consumers. A recent study about the behavioural aspects of energy saving argue that this type of segmentation can help to better calibrate specific policy recommendations (Egmond, Jonkers and Kok, 2006; Pollitt, Shaorshadze, Pollitt and Shaorshadze, 2013; Haines and Mitchell, 2014)

The interviews with Shanghai residents were conducted in the interviewees' homes, preceded or followed by a site investigation of how they use the appliances and air conditioners. A list of residents' characteristics and pseudonyms is given in Table 6.1.

Table 6.1. Interviewees' characteristics and pseudonyms

Pseudonym	Age	Gender	Education background	Residents per household	Live with	Build built year	Floor area (m^2)	House ownership
Alex	29	Male	Environmental science	4	Brother and others	2008	140	Rental
Belle	29	Female	Finance	2	Friend	1995	75	Rental
Chris	28	Male	Engineering	6	Girlfriend and others	2006	140	Rental
Dora	27	Female	Law	2	Husband	2009	85	Self-owned
Emma	29	Female	Finance	2	Friend	1995	56	Rental

(Source: by Author)

6.2.2 Building characteristics and appliances

Alex, Chris and Dora live in relatively new houses built after 2005, and Belle and Emma live in a rental house built in 1995. External shading is not permitted for the residents living in high-rise buildings, as the shading influences the appearance of the buildings. Alex, Chris and Dora live in high-rise buildings built after 2005, with no external shading (Figure 6.1 left). They mainly use the aluminium curtain to prevent heat transfer in a hot summer. There is a need to note that Chris lives on the top floor, on which the heat gain in summer is more intensive than in others. Belle and Emma live in a rental house built in 1995, with small external shadings (Figure 6.1 right).

Figure 6.1. Examples of no-shading (left) and shading (right)

(Source: by Author)

In general, the electric appliances at each household meet the basic requirements of life. All the interviewees have gas water heaters, air conditioners, fridges, and washing machines in their home. The energy efficiency labels show that the appliances in Dora’s home are more efficient possibly because she owns the flat. Figure 6.2 shows the appliances in Alex’s home, in which almost all the appliances are the most energy-consuming except for the fridge. Figure 6.3 presents the appliances in Belle’s home, which are relatively more energy-saving than the appliances in Alex’s home.

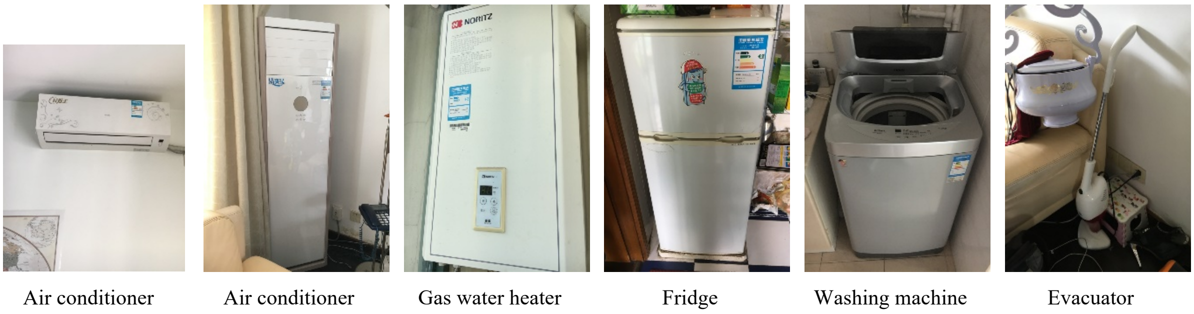


Figure 6.2. Appliances in Alex’s home

(Source: by Author)

Air conditioner Fridge Gas water heater Kettle Washing machine

Figure 6.3. Appliances in Belle's home

(Source: by Author)

6.2.3 Electricity meters and billing system

Figure 6.4 exhibits the electricity meters installed at each interviewees' home. This meter is smarter than traditional meters that require meter readings every month. However, this electricity meter is not the same as the smart meter in European countries, as it only enables one-way communication which can send the electricity use information to the State Grid electricity company, while the consumers do not have an in-home display that provides direct feedback of real-time energy consumption.

Figure 6.4. Electricity meters installed in Shanghai residential buildings

(Source: by Author)

Figure 6.5 shows a sample of an electricity bill sheet in Shanghai. It presents how much electricity is consumed at each electricity price level, categorised at peak and valley times. It also shows how much electricity is left for the current electricity price level for this year, according to the 3-level progressive electricity pricing system. The electricity bill should be paid every month; otherwise, the households would face over-due fines.

On the top right side of the electricity bill sheet, there is a barcode which allows the consumers to scan and pay through a mobile application, named Alipay, operated by ALIBABA – the Chinese version of Amazon and eBay, which is the most famous e-commerce company in China. Alipay had more than 550 million enrolled users in December 2010, and has gradually become the world's largest online and mobile payment platform in the world (Liu, 2015).

Figure 6.5. Sample of electricity bill sheet in Shanghai

(Source: by Author)

Alipay works similar to a combination of Apple Pay and Paypal, with many functions that relate to cash flow management. In the UK, Apple Pay and contactless cards are very popular due to the convenience. However, Alipay is more popular than Apple Pay in China. Alipay is convenient for daily living, since it enables the transfer of funds, payment of fees, refunds, assurance, and the management of cash flows. Users can pay utilities, mobile fees, and so on, without going out or incurring extra fees. In the homepage of Alipay, there is button named "utilities", with the function of paying electricity, gas and water bills, and the users can check the electricity bill for each month in the past if their house account number is connected with the Alipay account. This payment method provides consumers with the convenience of paying the electricity bill at home by smartphone, without the need to go to the electricity company or bank to pay the electricity bill.

6.2.4 Occupancy patterns

This section presents the occupancy patterns, as well as heating and cooling patterns of the five interviewees, summarised in Tables 6.2–6.5. Table 6.2 lists the interviewees' floor area, annual electricity bill and occupancy patterns. For Alex and Chris, the floor area and the number of residents are larger than other interviewees; thus the electricity bill is also higher. In the table, the electricity use per person was calculated according to the annual electricity bill and number of households. At Emma's home, the electricity use per person is as twice that of the others. The electricity intensity was calculated according to the annual electricity bill and floor area.

Table 6.2. Occupancy patterns and consumption

Alias	Floor area (m^2)	No. of residents	Annual electricity bill (RMB)	Electricity use per person (kWh/person)	Electricity intensity per year (kWh/m^2)	Occupancy per day	Occupancy per year
Alex	140	4	1855	752	21.49	7pm–7am	Normal
Belle	75	2	1016	823	21.95	10pm–7am	Random
Chris	140	6	1700	459	19.67	7pm–7am	Normal
Dora	85	2	1100	891	20.96	9pm–6am	Normal
Emma	56	2	1500	1216	43.43	6pm–7am	Normal

(Source: by Author)

There is a need to note that Belle's occupancy patterns are different from those of the other four interviewees. She mentioned that, from January to April, she arrives home late and goes to work early due to the extensive workload of financial auditing work during this period. Furthermore, she and her roommate escaped the 40°C hot summer for half a month in July. Belle has very random occupancy patterns, with the lowest occupancy hours but a similar intensity level. The lifestyle of Belle and Emma is more energy-consuming compared with others, according to the calculated results of energy use intensity.

Table 6.3 and Table 6.4 present the heating and cooling patterns of all interviewees. All interviewees indicated they use the air conditioners all night during the hottest summer period.

Usually, they start cooling in June and July and stop cooling in September, except for Belle, who starts cooling in May.

Table 6.3. Cooling patterns and consumption

Alias	Cooling temperature (°C)	Average cooling hour per day (h)	Summer peak monthly bill (RMB)	Cooling start month	Cooling stop month
Alex	24–26	6	400	Jun.	Sep.
Belle	25–26	9	100	May.	Sep.
Chris	23–25	6	400	Jul.	Sep.
Dora	25–28	7	210	Jun.	Sep.
Emma	23–26	6	250	Jul.	Sep.

(Source: by Author)

Table 6.4. Heating patterns and consumption

Alias	Heating temperature (°C)	Average heating hour per day (h)	Winter peak monthly bill (RMB)	Heating start month	Heating stop month
Alex	25	6	360	Dec.	Feb.
Belle	20–28	9	165	Dec.	Feb.
Chris	18–24	3	300	Dec.	Feb.
Dora	22–25	7	170	Dec.	Feb.
Emma	26	6	150	Dec.	Jan.

(Source: by Author)

In terms of cooling temperature in summer, Alex and Dora pointed out they often maintain the temperature at about 26°C as they heard from social media that 26°C is the most energy saving temperature setting in summer. It can be inferred from this information that the publication of energy saving knowledge is important. The average cooling hour per day is about 6–7 hours on average, except Belle, who uses 9 hours AC for cooling on average if she stays at home. They often start heating in December and stop cooling in February. They use the similar amount of hours for heating per day compared with cooling, except Chris, who uses 6 hours for cooling but uses 3 hours for heating on average. The peak monthly electricity bill in summer and winter reflects the effect from the combination of floor area, occupancy schedule, and heating and cooling patterns.

In terms of heating or cooling hours, the interview results in this section challenge the survey results in chapter 6 in that the air conditioning hours from the interview results (6–7h) are more intensive than the average patterns of level 1 consumers in Table 5.5, with the average heating hour of 2.5h and average cooling hour of 4.8h. In terms of heating or cooling temperature, from the interview results, the heating or cooling temperature is about 26°C on average, and from the survey results, the average heating or cooling temperature of level 1 consumers is about 25°C. On the other side, in terms of heating or cooling periods, the interview results agree with the survey results that, most level 1 consumers start heating from December and stop heating at February, and start cooling from July and stop cooling at September.

6.3 Attitudes, norms, and control

Based on the interview results of attitudes, norms and control, the interviewees could be characterised as two types: "comfort-driven" consumers and "conscious" consumers. At the same time, the electricity consumption of "comfort-driven" consumers' is higher than that of the "conscious" consumers. The motivations and practices of these two groups are explored in this section.

6.3.1 "Comfort-driven" consumers

Belle and Emma, the "comfort-driven" consumers, seem to prioritise thermal comfort over energy consumption, with slight differences in attitudes. For Belle, there is a sense of entertainment, which may also be perceived as "lack of control", as she thought it is hard to save energy. Belle mentioned her roommate also uses electricity in the same way. Belle explained her use of electricity at home that:

> *"I think it is very hard for us to save energy at home. My roommate and I use air conditioners without consideration for energy saving, but the maximum electricity bill is no more than 165 RMB in winter. For instance, for the residents with monthly income of higher than 50,000 RMB, do you think they will care about how much they paid for electricity? With the development of the society, we earn more so that we can live in a better way. Electricity is merchandise, and I paid more for what I used. Why do you want to restrain me?"*

Emma holds a similar idea of "*it is inefficient to spend time to save energy*". She regards her use of energy as a necessity. She considers the electricity price is too low, when compared with the income level. Emma said:

> *"I would not consider saving electricity as it is inefficient to do so. Electricity is a necessary product for me, and I would not consider spending time on it, as I have many other important things to pay attention. The electricity bill varies less than 100 RMB per month, which is so small compared to the income level. Do you think the residents with the income level of higher than 40,000 RMB would care about their electricity bill?"*

Generally, this type of user prioritises thermal comfort more than energy saving. They believe they work hard for a better life, and they don't see a reason to sacrifice thermal comfort for energy saving. They also believe the electricity bill is so cheap when compared with their income level, so they don't pay attention to it. They believe it is hard and inefficient to spend effort on energy saving. They regard electricity as merchandise, and it is normal that they paid more for more electricity used, so the government has no right to restrain their energy use. They believe electricity is a necessity with their lifestyle, and the change of price would not change their use.

In the theory of planned behaviour (TPB), the consumers' behaviour is affected by their behaviour intention, which is in relation to attitude (A), subjective norm (SN) and perceived behaviour control (PBC). This type of consumer holds a negative attitude (A) toward energy saving, with relatively weak subjective norms (SN) that do not believe protecting the environment is their responsibility. Or they presume it is hard for society to improve the awareness of energy saving, so they would not consider saving energy for themselves. It also reflects their lack of belief in perceived behaviour control (PBC) that they do not believe they can save energy in daily life.

The following factors were identified as the main factors affecting psychological variables and their answers. The influence from parents seemed to be effective for all the five interviewees. Belle can be taken as an example:

> *"I use the electricity just like my parents. My father often switches on the lights and appliances when he enters a room, and leaves the lights and appliances on when he*

leaves. My father usually switches on air conditioners when he at home in summer and winter no matter what the outdoor temperature is."

Education seems to be a relevant factor that affects attitudes, norms and perceived control. For Belle and Emma, who major in business and accounting, their primary concern is thermal comfort without any concern for energy saving or social responsibility. The income level has an impact on their attitudes. Belle said:

> *"When I was a child, the air conditioner was very expensive compared with income level, as well as the electricity price. For instance, if the monthly electricity bill was about 100 RMB, at that time the monthly income was 1000 RMB, so the electricity bill occupied 10% of the income. But for now, the monthly income is higher than 10,000 RMB, so the electricity bill is less than 1% of the income level. Do you think we should consider saving money to sacrifice the thermal comfort?"*

Emma holds the similar idea that:

> *"Electricity is a necessity for me. I only use electricity when I need to use it. If I need to consider energy saving, it will cost me lots of time to find out how to save energy. The maximum variation of the electricity bill in each month is less than 100 RMB. I would not consider saving electricity as it is not cost-effective to do so."*

This section answers the interview question of "*do you know any energy saving policy in Shanghai?*" Belle has limited knowledge about energy saving policies and holds a negative attitude toward energy saving policies. She mentioned the air conditioners in her office are switched off after 6:00 pm, so people have to use electric fans for cooling. When asked about the policies on domestic electricity saving, she replied no. When asked "*is that because you didn't pay attention to energy saving?*" she answered "*highly possible*". It reflects the behavioural bias of "status quo bias" that the consumers stick to default settings and defer decision-making for behavioural changes.

Emma mentioned the rubbish recycling advertisements on social media. She indicated that the house tenors told her about the peak-and-valley electricity pricing system when she moved into the house. When asked will she consider to use the electricity at the valley electricity price, she said "*no, as I don't care about electricity price*".

On the question of "*do you have any suggestion for energy saving in Shanghai?*" Emma replied that "*I don't have any suggestion as I think it's inefficient to spend time and sacrifice thermal comfort for energy saving.*" Furthermore, Belle and Emma showed no interest in smart meters with in-home display systems.

Belle proposed the promotion of energy-efficient appliances through government subsidies, as well as for solar hot water systems. This policy instrument is effective for the "comfort-driven" consumers, like Belle. From Belle's point of view:

> *"It is hard to reshape energy use behaviour for saving money as we don't have the motivation to do so. Energy-efficient appliances might be a good idea as we can reduce the consumption without restraining behaviour and affect comfort."*

6.3.2 "Conscious" consumers

Alex, Chris and Dora, the "conscious" consumers, have more positive attitudes toward energy saving and they are in principle prepared to have an intention to save it, even though they live in similar houses to the "comfort-driven" consumers. Alex, who has a degree in environmental science, explained that:

> *"I think we should save energy for sustainability. If we crazily use energy, it means we will use up the existing resources on the earth finally. The resource is so limited on the earth, and we cannot depend on everything on renewable energy."*

Chris defined himself as:

> *"I think I am not super energy saving, but above average. I would consider thermal comfort at first, and then consider to save energy and save money. I would consider energy saving if thermal comfort could be maintained."*

Dora explained:

> *"I think I am environmentally-friendly, but sometimes I might forget to switch off the light. Sometimes I think we should save energy, but normally I consider to save the use of paper more often. My husband is super energy saving that he always cut off the electricity after use."*

Generally, this type of user would consider saving energy if thermal comfort could be maintained, with a positive attitude (A) toward energy saving. They believe it is our duty to save energy, with a relatively higher subjective norm (SN), influenced by their family members. They never mention any word related to "*it is hard to save energy*" when discussing energy saving in daily life. Instead, they would try to save energy if thermal comfort could be maintained, with relatively high perceived behaviour control (PBC). In conclusion, the questions of "*what made conscious consumers different from comfort-driven consumers?*" and "*why did conscious consumers consume less than comfort-driven consumers?*" would be discussed.

The following factors were identified as the main factors affecting psychological variables and their answers. The first influence was from their family members. Dora mentioned she was influenced by her husband that:

> *"I think if two persons live together, each personal habit would affect each other. Indeed, I use the air conditioner less because my husband does not like the dry air in the air-conditioned room."*

The change of social structure is also an impact factor in energy saving attitudes. The new couple is more energy saving compared with others. For Chris and Dora, who are married, they said they will check the monthly electricity bill sheet. If the electricity is very high for one month, they would pay attention to electricity use. Dora also mentioned she started to pay attention to energy saving when she needed to pay the electricity bill by herself that:

> *"When I started to pay the living expenses, I started to realise I need to save energy. As I need to pay the electricity and water bill monthly, it would be better if I could save as much as possible."*

Education seems to be an impact factor that affects their energy use behaviour. Alex pointed out that his knowledge in environmental science has shaped his energy saving attitudes. Alex explained:

> *"The largest change occurs since I went abroad for undergraduate study. It was because of two reasons: firstly, my major is environmental science, which equipped me with knowledge of energy saving; secondly, the living experience in Europe influenced my attitudes toward energy saving, for example, every household*

> *classifies their rubbish for recycling and many residents choose to reuse the shopping bag until the bag is broken."*

The social development is also important in shaping energy use behaviour. Chris mentioned that when he was a child, his family did not use air conditioners as often as at present. Chris explained that:

> *"When I was a child, I remembered my family used the air conditioner not as usual as nowadays and we switched off the air conditioner if the temperature was suitable. But at present, we often switch on the air conditioner when we come back home in summer or winter. Oh, there is one more thing that, when I was a child, we did not use the air conditioner for heating in winter. With the development of society, we use the air conditioners more to maintain thermal comfort."*

As a response to the question on "*do you know any energy saving policy in Shanghai?*" Alex said he has general knowledge but holds a negative attitude toward energy saving policies. He pointed out the energy saving advertisements by the government in underground stations. When asked about the peak-and-valley electricity pricing system, he said he knows the electricity pricing system. When asked will he consider to use electricity at the valley electricity price, he said he often uses the washing machine at night after 10:00 pm, but mainly due to his daily routine rather than from considering the electricity price.

Chris also mentioned the peak-and-valley electricity pricing system in Shanghai. When asked will he consider to use electricity at the valley electricity price, he said no and explained:

> *"I would not consider washing clothes after 10:00 pm because it is not convenient. It would be too late if I need to dry clothes after one hour and I need to get up early tomorrow."*

Dora has general knowledge about energy saving policies with positive responses to policies. Dora mentioned the policy to promote electric cars in Shanghai. The government issues buyers with a free car licence for the electric car they bought. Otherwise, potential buyers must queue to buy a car licence for more than 90,000 RMB (10,000 GBP). Dora also mentioned the one-hour blackout activity in her office. Her company participated in the electricity cut-off activity one time every year, to cut electricity from 8:00–9:00 pm to remind everyone of energy saving. When asked will she consider to use electricity at the valley electricity price, she said:

"If I can save money without any inconvenience, it would be better to do so. I will consider the electricity price a little bit, but mainly follow my daily routines."

There is a need to note that, as indicated in section 6.2.4, Alex and Dora mentioned they often maintain the temperature at about 26°C as they heard from social media that 26°C is the most energy saving temperature setting in summer. It can be seen that they are more likely to pay attention to the information of energy saving from social media, when compared with the "comfort-driven" consumers (none of them mentioned information from social media in the interview), and they are more likely to respond to information if it does not affect their daily routines or bring them inconvenience.

On the question of "*do you have any suggestion on energy saving in Shanghai?*" policy publicity was suggested by Alex and Chris. Alex suggested the central government can take steps to nudge behavioural change:

"I think the policy should go through the National People's Congress. Then the most important social media – Xinwen Lianbo (national news every day) will broadcast it to the whole country. Otherwise, I think the white paper thing is useless, as there are many white papers published each year and not many people pay attention to it."

However, Dora held a different view from Alex and Chris but highlighted influence from peers. This opinion agrees with the theory of planned behaviour (TPB) that consumers' behaviour is affected by the behaviour intention, which is in relation to the subjective norms (SN) of peers. Dora said:

"I think policies are far away. I think seminars and flyers are more like a slogan thing than its real effectiveness. I think the ideas from peers are more influential for me. For instance, we are at the similar age and similar stage of life, when I was thinking about which appliance to buy, we will exchange experiences in choosing the appliances. I think communication with friends is more effective, which makes me feel it is life."

Alex recommended advertisements for energy saving on Alipay that:

"I recommend promoting energy saving on the platform of Alipay. It is because there is a barcode on top of the electricity bill sheet, and the households could scan the barcode to pay the electricity bill through Alipay. Almost everyone in Shanghai

uses Alipay every day, if 1% of users can be influenced, the effect would be powerful."

When asked which factors would affect his energy saving behaviour, Alex mentioned three points of "price, information publicity, and the reward and restrain system" and explained the reward and restrain system he proposed:

> *"If households use too much electricity, they should receive a notification of higher carbon tax. If households use less electricity, they can get government rewards."*

Alex also proposed a restrain system for high-income households who ignore the increased price and continuously use too much electricity. Alex mentioned the credit system for driving licences as an example, and explained that it is hard to change the residents' behaviour shortly through education, but the restrain system is more powerful. Therefore, it can be inferred that smart meters with a notification system could be applied to this type of consumer.

Chris also proposed the promotion of energy-efficient domestic appliances, like Belle, but in a different way. Belle suggested a subsidy for buying energy-efficient domestic appliances for consumers, but Chris suggested a punishment system for the factory which manufactures an inefficient appliance. Chris proposed that:

> *"The government should provide subsidies for the factories which manufacture the energy-efficient product and punish the factories who manufacture the inefficient product. Then the product in the market will move to more energy-efficient."*

As this type of consumer shows interests in the smart meter system, the question of "*can you indicate effective information on the in-home displays (IHD), which is useful for you to save energy at home?*" was proposed for this target group. Alex explained his idea of consumption comparison that:

> *"If you want to increase residents' sense of energy saving, it would be better if you could provide the comparison of your consumption with the Shanghai average level. Otherwise, the number cannot provide much information. For instance, if the display shows my consumption is 20% higher than average, I can have an idea of how much electricity I use. I think the comparison with the average level of residents in similar flats would be valuable, as it could have similar demographic conditions which could provide the equal comparison."*

Both Chris and Dora suggested a visualisation system for in-home displays:

> *"The number only is not useful, so the visualisation would be more straightforward. For instance, the display can provide the RGB bar, in which, the green shows the energy savers, the yellow shows the normal users, and the red shows the intensive users. I think as a resident, it might be more straightforward to pay attention to the price. The display can present the information of real-time electricity use and the electricity price in a straightforward way."*
>
> *– Chris*

> *"It would be better if the system could provide a review system. When you send the electricity bill sheet, you could indicate the rating for the monthly consumption. The review system can record my monthly electricity consumption in recent years. Then the review system can provide an estimation of monthly consumption for each month. If the monthly use is lower than estimated, the review system shows green. If the monthly consumption is within the range of minus and plus 10% of the estimation, the review system shows yellow. If the monthly consumption is higher than estimated, the review system shows red."*
>
> *– Dora*

The review system suggestion from Dora reflects the "anchoring effect" that if the set target is better than the experience of the consumers themselves, the desire to complete the target is higher. If the target is too high, it might be not possible to meet the purpose of setting the target.

6.4 Summary of the interview study

Chapter 6 reported qualitative interviews with the targeted sample of young urban highly-educated residents in Shanghai. According to the interview results, two potential target groups for energy saving policies were identified, including "comfort-driven" consumers and "conscious" consumers. They are the three findings from this chapter.

Firstly, within the target group of young highly-educated urban residents, even though they have similar demographics, they are not homogeneous. Different attitudes, norms, and perceived control, resulted in different occupancy patterns and final energy consumption. This finding agrees with the theory of planned behaviour (TPB) that energy use behaviour is in relation to the psychological variables of attitudes (A), subjective norms (SN) and perceived behaviour control (PBC). Thus, TPB was useful because it helped to clarify that attitudes, norms and control are diverse within the same group.

Secondly, it was found that family influence, change of social structure, educational background and income level were influential in affecting the psychological variables and shaping energy use behaviour. Among them, educational background showed a great impact on the psychological variable of attitudes (A) and affected behaviour, and the family influence shows some impact on the psychological variable of subjective norms (SN) and affected behaviour.

Thirdly, according to occupants' attitudes toward smart meters and policy instruments, different policy instruments should be applied to each target group. The interviewees suggested four policy instruments for energy saving: including publicity, reward and restraint system, energy-efficient appliances, and visualisation of consumption. Among them, publicity, reward and restraint system, and visualisation of consumption seem to be more applicable for "conscious" consumers, and energy-efficient appliances seem to be useful for "comfort-driven" consumers, as they prefer thermal comfort more than energy saving.

The next chapter uses the smart meter data from Shanghai residential buildings as a case study to both explore the quantitative characteristics of energy use and to understand the information that can be obtained from the smart meter data for policy design.

Chapter 7 – SMART METER DATA CLUSTERING: BEHAVIOURAL PATTERNS AND ENERGY SAVING POTENTIAL

7.1 Introduction

The combination of survey and interview method could help to explore the complexity of energy use behaviour, and expend both depth and breadth of study about human factors in limited time and limited cost. Based on chapters 5 and 6, it was concluded that smart meters with in-home displays could be a potential policy tool for domestic behavioural change. As a smart meter was identified as a potential solution in domestic energy saving, with limited study on a smart meter in China, it is also essential to analyse smart meter data and extract occupancy patterns for the design of more precise energy saving policies.

Chapter 7 uses the smart meter data from Shanghai residential buildings as a case study to illustrate the information that could be obtained from the smart meter data, including occupancy patterns and energy saving potential from behavioural change. Section 7.2 provides an overview of the smart meter data used for analysis. Section 7.3 provides the analysis results based on the average profiles of individual households. Section 7.4 uses cluster analysis to extract considerable information from all the data that could be used by the government to understand more about occupants for policy design. Section 7.5 provides an analysis of the energy saving potentials from behavioural change. Section 7.6 summarises the findings from chapter 7.

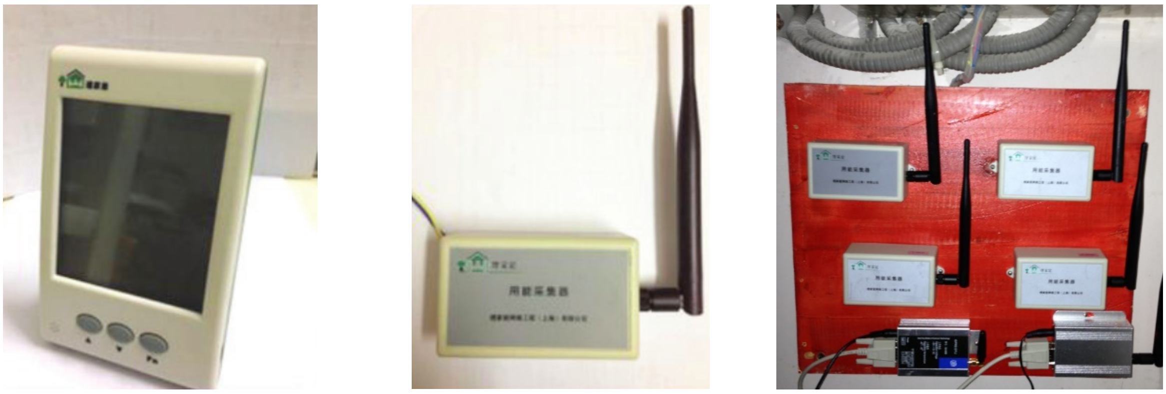
7.2 Data source and visualisation

The smart meter data was obtained by monitoring the electricity use households in two public housing communities in Shanghai during the period of May 2013 to December 2015:

- Community A (located in Yangpu District) was built in 2012. The air-conditioning unit (671 W), washing machine, and refrigerator (0.49 kWh per day) were pre-installed before the residents moved in. There are 40 metered households in this community with a floor area of 60 m^2 (large) and with 2–3 residents on average. This community is built near a famous university in Shanghai.
- Community B (located in Putuo District) was built in 2013. The basic domestic

appliances were pre-installed for residents similar to community A. There are 132 metered households in this community with two apartment configurations of 45 m^2 (small) and 60 m^2 (large) size, and with an average of 2–3 residents per household.

There is a need to note that the smart meter data was obtained in collaboration with a research group lead by Professor Da Yan from Tsinghua University and Dr Xingxing Zhang from the University of Nottingham, Ningbo China. The research group aimed to use the data to understand the influence of smart meters with in-home displays (IHD) for domestic energy saving. They installed a central signal transmission panel near the electricity meter on each floor, with four different IDs on the panel. Figure 7.1 presents the devices that were used in this system, including smart meter, IHD, and transmitter. The transmission panel collected the real-time electricity consumption data every 15 minutes and then transmitted it to the data centre.



IHD   Smart meter   Transmitter

Figure 7.1. Devices of IHD, smart meter and transmitter

(Source: Xu et al., 2015)

The first step of data analysis, once it was obtained from China, was data cleaning and pre-processing. The first step was used to restructure the dataset and eliminate invalid data. The raw data was collected at 15-minute intervals in the format of "ID, date time (dd/mm/yyyy hh:mm), total consumption (kWh), voltage (V), current (I), power (kW)" with some useless data. The raw data was processed in Matlab and structured into daily electricity consumption from 1:00 till 24:00 for each single day of all households, in the format of "ID, date, h1, h2, h3, …, h22, h23, h24". The data was analysed using Matlab and several curves were discarded as corrupted, or noisy data. Finally, relatively complete data for households with more than 70 recorded days were selected for analysis. Section 7.3 uses Matlab to visualise the clean data of all recorded days of all households.

Figure 7.2 presents a framework of the smart metering and IHD networks. This system contains the smart metering unit, IHDs, data transfer network (ICT), databases, statistical analytical unit, web server and customer computers (Xu et al., 2015). The electricity data was collected by the smart meter installed in electricity box of each household and then transmitted to the IHDs and the GPRS terminals through the ZigBee network. The raw data was downloaded in June 2016 from the data centre by using the SQL data management software. Even the smart meter data was obtained from collaboration, and the data was verified by calculating the annual electricity consumption of randomly selected households, and then compared with the Shanghai average annual electricity consumption.

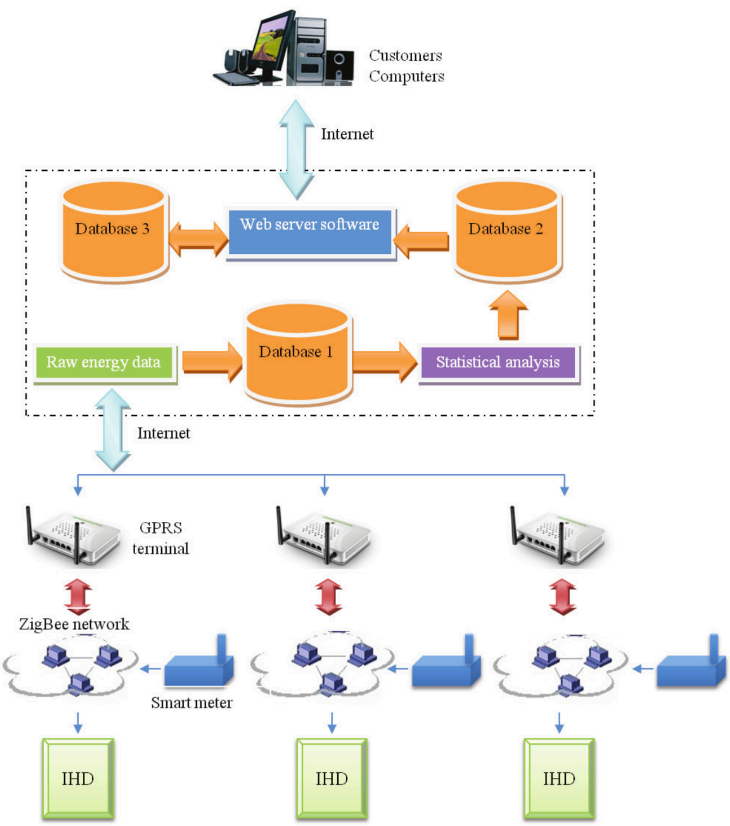


Figure 7.2. Framework of the smart metering and IHD networks

(Source: Xu et al., 2015)

However, as the data was transmitted through the ZigBee network, which struggled to penetrate thicker walls (Sovacool et al., 2017), some data was lost during recording. Thus, relatively complete energy use data with more than 70 recorded days of individual households was selected for analysis. As a result, 126 out of 172 households were finally selected for analysis in chapter 8.

There are two layout configurations in the 126 households that were installed with smart meters and IHD: 62 cases with the small floor area of 45 m^2 (from community B) and 64 cases with the larger floor area of 60 m^2 (from both community A and community B). Figure 7.3 presents typical layouts of the small and large flats of recorded households. The basic domestic appliances were pre-installed before residents moving in, with 1 air conditioner for the small flat and 2 units for the large flat. The case study is suitable for the research purpose of studying occupancy patterns, as the influences from building fabrics and layouts, as well as domestic appliances can be eliminated.

Figure 7.3. Flat plan layout: small (left), large (right)

(Source: online, http://www.shcngz.com/pages/house_info.aspx?houseid=4)

Shanghai is located in the hot summer and cold winter climate zone, specified in MOHURD (1993). The design of residential buildings in Shanghai should meet the requirements in the building codes for this climate region, which is the Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone (JGJ134-2010) (MOHURD, 2010). In simulation, many unknown parameters can be assumed to be in accordance with the building codes, which is a common method for dealing with unknown parameters (Caputo, Gaia and Zanotto, 2013). The orientations of the recorded households face in different directions. The building walls are built with insulation and the windows are double glazed. As the detailed U-values of building materials were unknown, the material was assumed to meet the minimum requirement according to the building standard, with a U-value of 1 W/m^{2}K for walls and 2.8 W/m^{2}K for windows. The glazed area occupies 30% of the external wall area, based on the roughly calculation of building appearance figures. According to the building codes (MOHURD, 2010), air conditioners are used for space heating and cooling, with the cooling COP of 2.3 and heating COP of 1.9. According to the building codes, the heating temperature was assumed to be 18°C and cooling temperature was assumed to be 26°C, with the air change rate of 1 ACH. According to the building codes, the heating period was assumed to last from 1 December to 28 February, and the cooling period was assumed to last from 15 June to 31 August. The air conditioners were pre-installed in bedrooms before the occupants moving in, thus the bedrooms were assumed as the air-conditioning space and other rooms were as non-air-conditioning space in simulation.

In addition, as mentioned before, the two communities are public housing communities owned by the government. There is a need to note that the research group waived detailed information of the households to protect the privacy of the monitored residents. However, the basic demographic information of residents can be inferred from the known information. Community A is near a famous university in Shanghai, thus many residents in this community are university lecturers. In Shanghai, as the rental price of public housing is much lower than the market price, the rules for applying to live in public housing are strict, with the requirements of 1) at least a 1-year contract of working in Shanghai, 2) has a Shanghai resident's permit card, and 3) owning less than 15 m^2 of domestic floor area on average for each family member. In general, the residents in public housing, or at least one family member, are working in Shanghai, are relatively young without the money to buy a flat, and have a low-middle income level.

Figure 7.4 illustrates the actual daily profiles of all recorded days of all households, categorised into two groups by floor area. The "small" represents the households with the floor area of 45 m^2, and the "large" represents the households with the floor area of 60 m^2. The plan layout of these two house types is shown in Figure 7.3. Generally, the internal load profile for the large floor area is higher, as the air-conditioning area is larger. For the small floor area flat, the maximum electricity consumption during the night sleeping period is about 2.5 kWh; while for the large floor area flats, the maximum electricity consumption during night sleeping period is about 4 kWh per day in a 24-hour period. This suggests the influence of floor area and the number of air conditioners on the maximum electricity consumption.

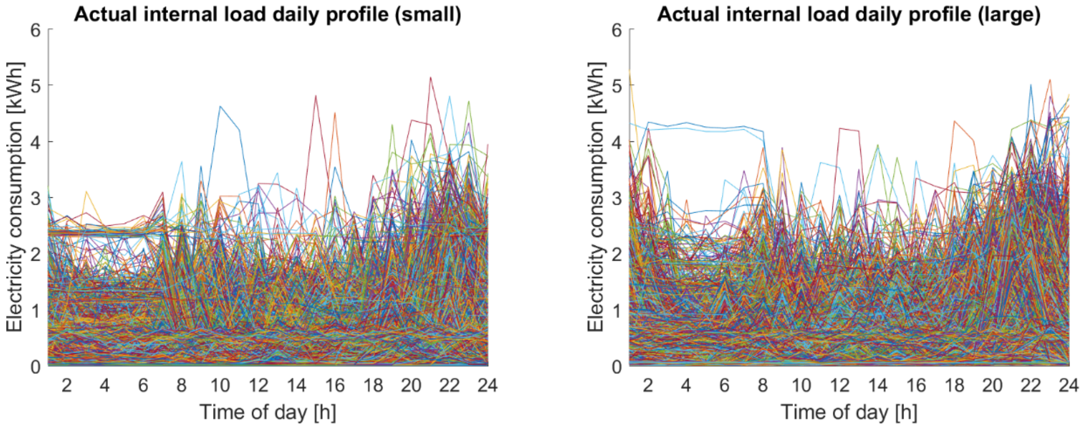


Figure 7.4. Actual internal load daily profiles in the monitored and surveyed households: small flats (left), large flats (right)

(Source: by Author)

Figure 7.5 presents the daily profiles in spring (April, May), summer (July, August), autumn (October, November) and winter (December, January). It indicates the maximum electricity consumption value in winter is more than twice that of summer, and the maximum electricity use per hour in summer and winter is higher than in spring and autumn. This implies that, despite other impact factors, electricity demand for heating is higher than cooling, based on the daily electricity use profiles in Figure 7.5. The finding from the smart meter data analysis is important that, as from survey and interviews, it does not reflect the information of higher consumption in heating than cooling. It might be because air conditioner is the only equipment used for heating in winter, but electric fans are used for cooling when the room temperature is cooled down by air conditioners. The use of electric fans consumes less electricity than air conditioners.

Figure 7.5 suggests the occupancy patterns vary dramatically for households with similar demographic characteristics. The electricity use in winter can be taken as an example. During the night period from 0:00 to 8:00, some occupants constantly use air conditioners for heating (magnitude varies from 1–2.5 kWh), some occupants even do not use air conditioners, and some occupants switch on air conditioners at a specific time, as some peaks occur during this period.

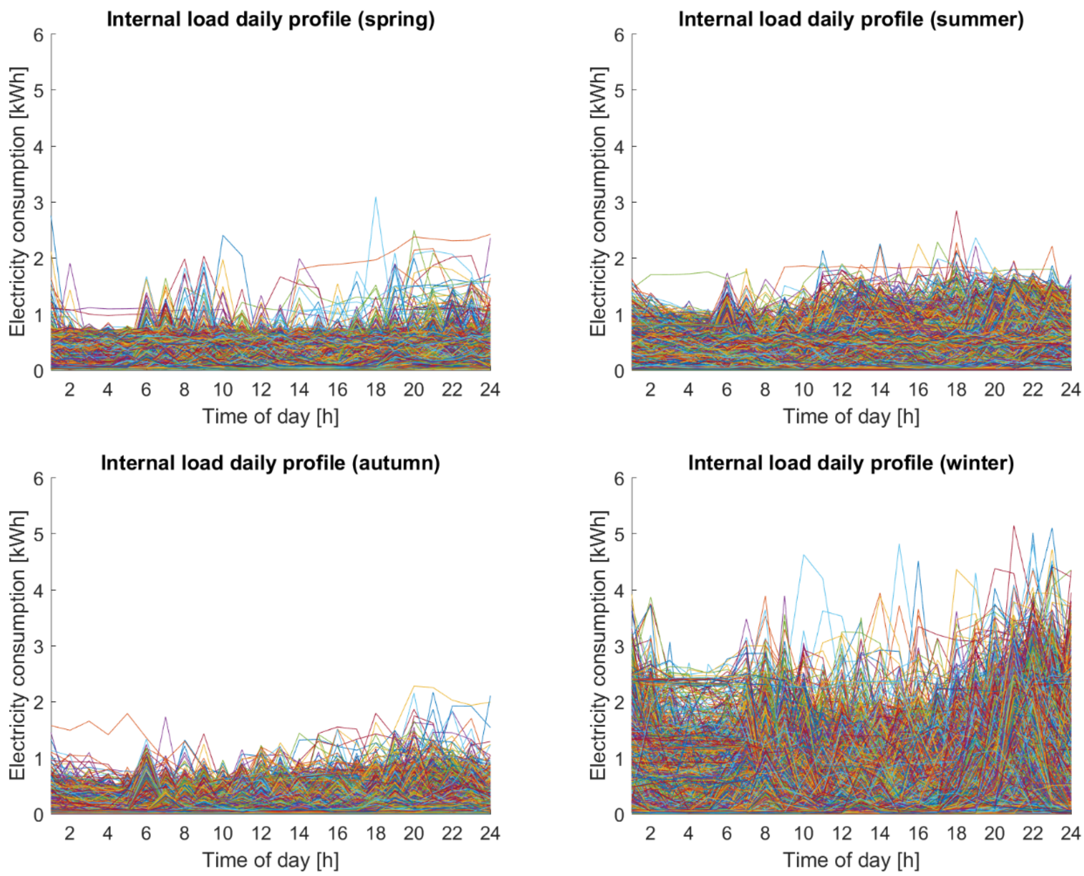


Figure 7.5. Electricity use (kWh) in all households in spring, summer, autumn and winter, per time of day

(Source: by Author)

According to Figure 7.5 (winter), the use of electricity is random during the period when not sleeping, while the use of electricity is relatively constant during the sleeping period. According to Figure 7.5 (summer), the use of electricity is more random compared with winter profiles, which suggests a great variation in energy use patterns during summer. This agrees with previous research by Jian et al. (2011) that summertime electricity use is strongly affected by occupancy patterns.

Figures 7.2–7.5 provide the overview of smart meter data, which, as expected, demonstrates that the domestic electricity use is related to the floor area and seasons. In winter, the occupants use more electricity than in other seasons, and the electricity use in winter is as about twice that of summer. In spring and autumn, the hourly electricity use is under 1 kWh normally, with some peaks reaching 2 kWh. The next section analyses the average profile of individual households to explore the variation in occupancy patterns between each household. Thus, according to the analysis of smart meter data, heating use behaviour might be a higher priority to target than cooling use behaviour, as heating use consumes more electricity than cooling.

7.3 Analysis based on individual households

Section 7.3 is analysed based on the unit of an individual household. Thus there are 126 average profiles, one for each individual household. In addition, the monthly and annual consumption of each household can be calculated for analysis based on consumption level.

7.3.1 Average profiles of individual households

The average profile was calculated by the mean value of all recorded day data for each individual household at each hour of the day. Figure 7.6 presents the average profiles of households in small and large floor area. It reflects a great variation in energy use patterns between each household. The average profiles range from 0.1–0.8 kWh per hour, with small peaks at 8:00 in the morning and higher peaks at 22:00 in the evening. However, the magnitude of the average profile is slightly different. The average profile varies even for occupants that live in the same floor area. For instance, for small flats, the average electricity use at 1:00 ranges by a factor of six, from 0.1–0.6 kWh. As mentioned before, in general, the peak value for households with a large floor area is higher than those with a small floor area.

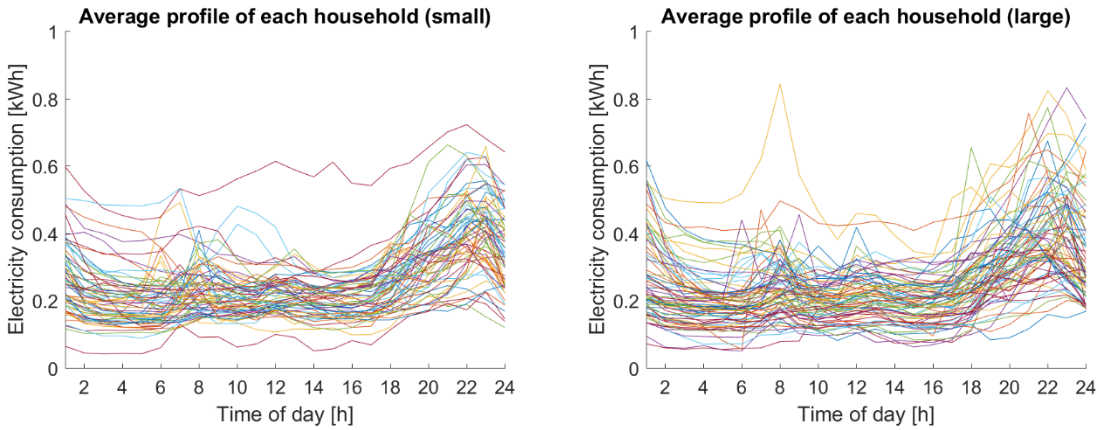


Figure 7.6. Average profile of each household: small flats (left), large flats (right)

(Source: by Author)

7.3.2 Identifying high consumers

The 126 samples were grouped into 3 levels based on the progressive electricity pricing system in China, according to the annual electricity consumption of each household. Level 1 consumers had the lowest consumption, below 3120 kWh. Level 2 consumers had an annual consumption between 3120-4800 kWh, and level 3 consumers had a consumption level higher than 4800 kWh. The 126 households in the sample are not the same households as in the survey, as the research group waived the demographic information of the monitored residents for privacy considerations.

According to the analysis of the smart meter data from 126 households, the annual electricity consumption ranged from 1000–5000 kWh, with an average value of 2197 kWh. Even for the households living in similar apartments, the electricity consumption varied by a factor of six. Table 7.1 demonstrates the comparison of annual electricity consumption from this research, including the survey, interview and smart meter data, as well as the statistics of the Shanghai average and Chinese average. The average annual electricity consumption per household is similar across the three empirical studies, with 2778 kWh from the survey study, 2324 kWh from the interview study, and 2179 kWh from analysis of the smart meter data. However, the average values from this research are 3–4 times higher than the Shanghai average value, and much higher than the Chinese average value. The difference in the average value is the result of the selection of the target group in this thesis: relatively young, middle-income, urban residents. However, even for residents within the target group, the annual electricity consumption can vary by a factor of six.

Table 7.1. Comparison of annual electricity consumption per household in relation to averages in Shanghai and China

	Annual electricity consumption per household
Survey (chapter 5)	1875 RMB; 2778 kWh
Interview (chapter 6)	1324 RMB; 2324 kWh
Smart meter data (chapter 7)	2197 kWh
Shanghai average	718 kWh in 2014
Chinese average	526 kWh in 2014

(Source: by Author)

Table 7.2 lists the number of cases at each level based on the 3-level progressive electricity pricing system in China. As there is only 1 household categorised as a level 3 consumer, which is identified as the outlier, this household was eliminated in the comparison in section 7.3. Even though there are only 9 households categorised as level 2 users, it is acceptable for this section, as the purpose of this section is to compare the energy use characteristics at each level, but not to generalise the findings. In the following, selected samples of households at level 1 and level 2 will be analysed.

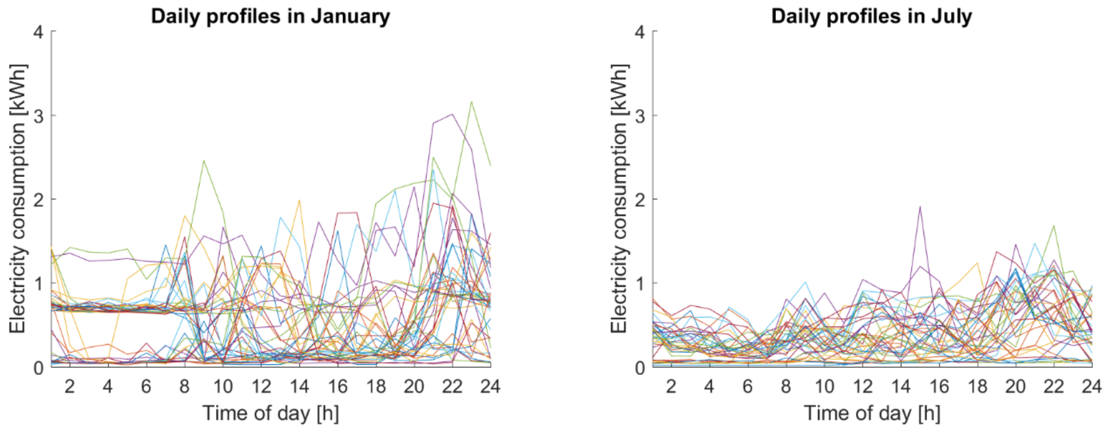
Table 7.2. Number of cases in each level

Level	Electricity consumption (kWh/year)	Number of cases in each level
Level 1	Lower than 3120	116
Level 2	3120-4800	9
Level 3	4800 and higher	1
		126

(Source: by Author)

Figure 7.7 presents the two samples of level 2 consumers. The households used electricity frequently on almost every recorded day in winter and summer, even though the daily profiles peak at different times of the day. It suggests that the households use air conditioners almost every day in winter or summer. The annual electricity consumption was 4076 kWh for sample 1, and the annual electricity consumption was 3281 kWh for sample 2. In general, cooling use is more random than heating use during the sleeping period of 3:00–7:00. There is another key finding from Figure 7.7 that the constant electricity use during the sleeping period remains the same for each household (about 0.8 kWh for sample 1, and about 1 kWh for sample 2). This suggests air conditioners often work at the same power during the sleeping period at different days for each household.

↓ level 2 – sample 1 (4076 kWh)



↓ level 2 – sample 2 (3281 kWh)

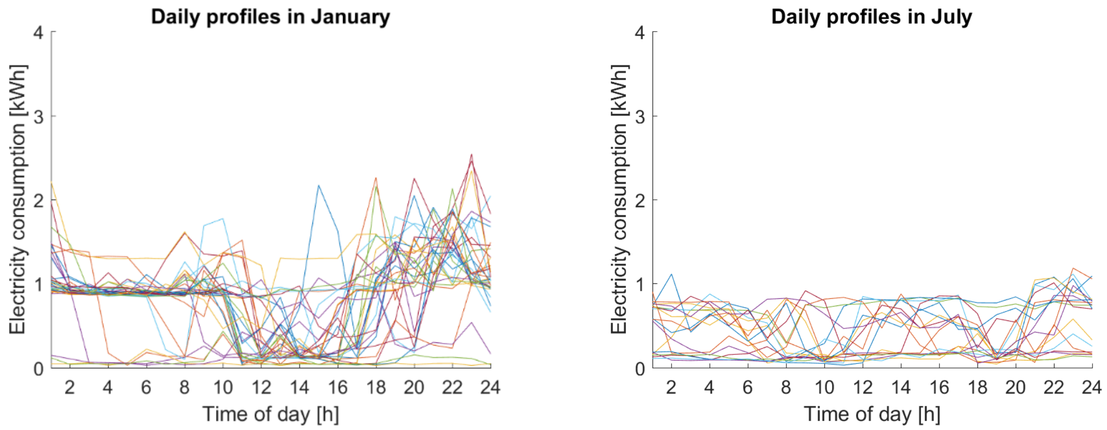
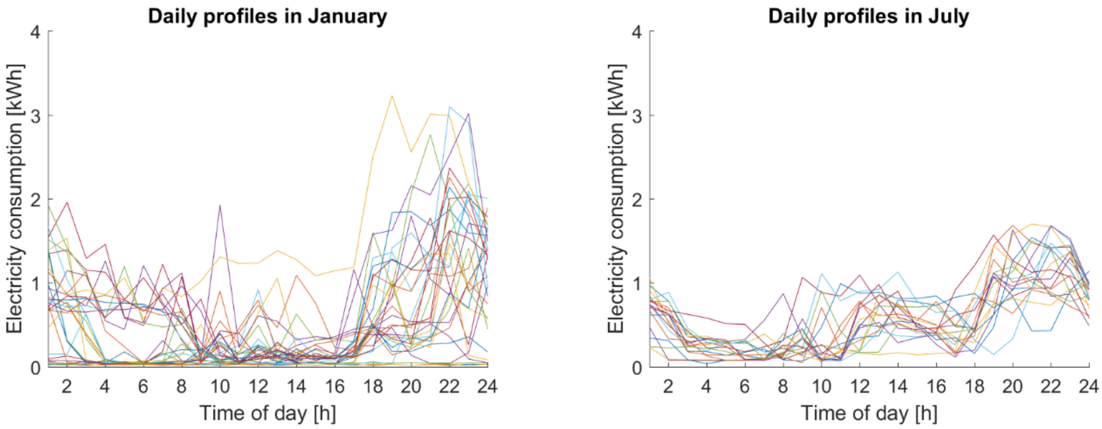


Figure 7.7. Two samples of level 2 consumer households and their electricity use (kWh) per time of day in January and July

(Source: by Author)

Figure 7.8 presents two selected samples of level 1 consumers. The annual electricity consumption is 3118 kWh for sample 1, which is close to the level 2 band (3120 kWh). There is an obvious valley in both winter and summer during the daytime from 10:00–17:00, which suggests that the occupants are less likely to stay at home during this period. The annual electricity consumption is 1270 kWh for sample 2, which is much lower than the average value of 2197 kWh for all recorded households. Even both sample 1 and sample 2 are in level 1 band, the occupancy patterns and electricity use profiles are very different.

↓ level 1 – sample 1 (3118 kWh)



↓ level 1 – sample 2 (1270 kWh)

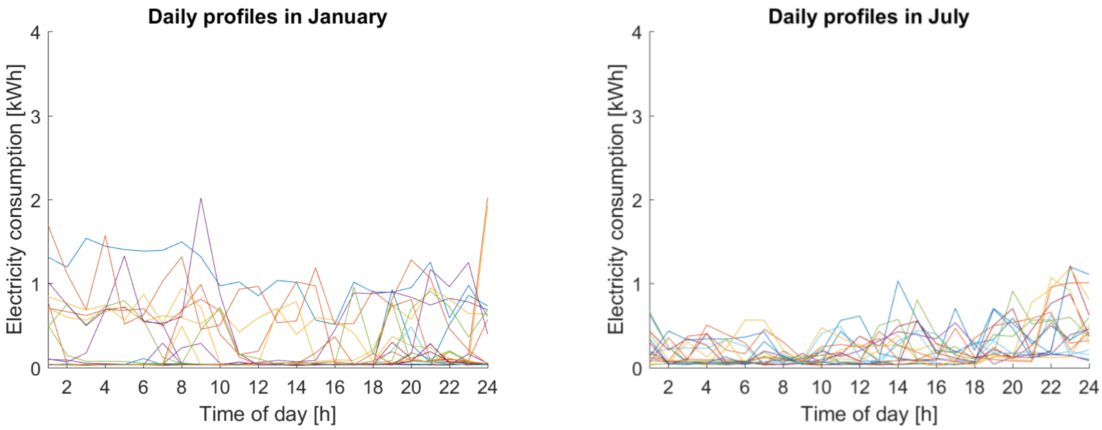


Figure 7.8. Two samples of level 1 consumer households and their electricity use (kWh) per time of day in January and July

(Source: by Author)

The differences between level 1 and level 2 consumers are obvious. Even though there are some peaks for level 1 consumers in winter or summer, generally, the base load is low, which suggests that the occupants do not use air conditioners for most days in winter or summer. The figures suggest that the level 1 consumers use air conditioners less frequently than the level 2 consumers, especially for night heating during the winter period.

The analysis of smart meter data could also provide further information on the understanding of complex energy use behaviour. It reflects the fact that lower energy users also have lower standby energy use, in which none of the participants noticed and mentioned in the survey and interview studies.

7.3.3 Monthly consumption of each household

Figure 7.9 shows the monthly consumption of each household extracted from the smart meter data. It can be seen the monthly electricity consumption varies dramatically for each household. The electricity consumption varies by a factor of 8, from 100–800 kWh in January. The monthly electricity consumption in June, July (summer) and December, January (winter) is higher in the than other months. The average electricity consumption in winter and summer is in the range of 200–300 kWh per month, while the average electricity consumption in non-air-conditioned months is about 150 kWh per month. From the interview results in chapter 6, the interviewees indicated that they use about 300 RMB electricity (about 486 kWh) in summer. The average monthly electricity consumption from smart meter data is lower than the interview results. Since community A is located near a university and most residents are lecturers, many rooms might not be occupied during the summer vacation (August, September). The monthly electricity consumption is not high in August and September as the room is not occupied during this period.

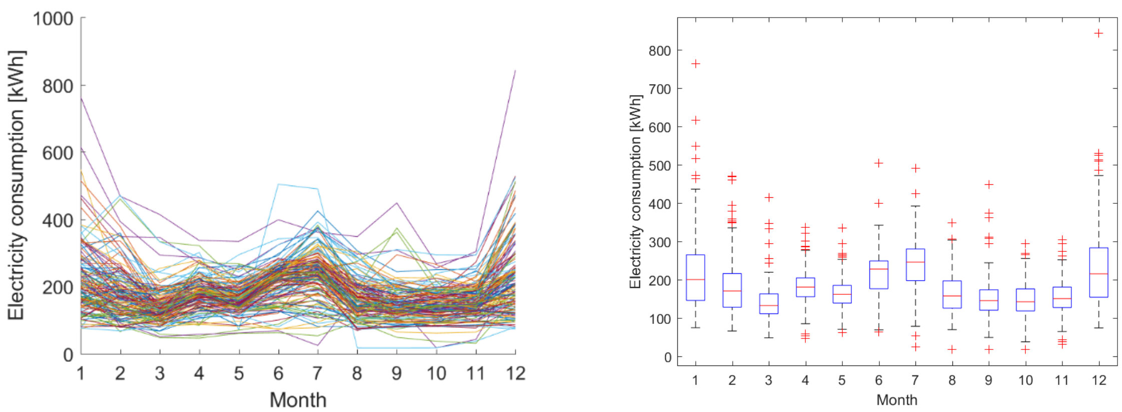


Figure 7.9. Monthly consumption of individual households

(Source: by Author)

7.4 Cluster analysis based on all readings

The analysis of the smart meter data in section 7.3 was based on individual households. In section 7.4, the analysis is based on all readings of smart meter data, which covers all recorded days of all households. In this research, the hourly electricity consumption at each hour of the day was used as parameters fed into the Matlab, with 47045 readings in total and each reading includes 24 points. The K-means method was used to cluster the 47045 readings, trying to extract information for demand-side management.

7.4.1 Cluster analysis

Section 7.4 presents the cluster analysis. Section 4.4.3 explains the selection of K-means cluster method in thesis, as this method could be used to group all recorded households into several groups with similar energy use patterns. K-means is a unsupervised clustering method that cluster a heterogeneous dataset into a number of more homogeneous groups of objects, but some supervision is needed to partition objects which have some similarities into one cluster. The hourly electricity consumption at each hour of the day was used as parameters fed into the Matlab for cluster analysis. However, the number of clusters should be manually decided in K-means method.

Deciding upon the number of clusters is the first step. The Root-mean-square error (RMSE) was used to test the difference between the measured points and the centroid data, while the coefficient of variation (CV) was applied to compare several data sets with different sample sizes (Royapoor and Roskilly, 2015). The equations were introduced in chapter 4. Figure 7.10 presents the CV(RMSE) values against different number of clusters. In Figure 7.10, the rate of decrease in the case of CV(RMSE) is gradual, while the calculation time of the clustering process doubled as the cluster number exceeds 15. As a result, the number of 10-cluster was selected in this section to balance efficiency and accuracy.

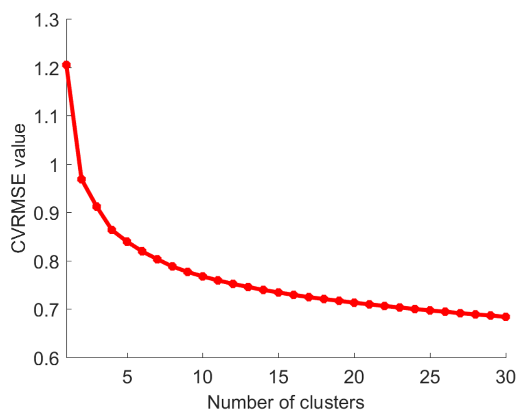


Figure 7.10. CV(RMSE) value at different number of clusters

(Source: by Author)

Figure 7.11 illustrates the centroids of hourly electricity consumption patterns of all 47045 readings. The 10 clusters represent 10 different electricity use patterns. Figure 7.11, it also presents the number of daily profiles in each cluster in the box on the right side. Cluster 1 has the largest proportion of profiles, with 20144 readings out of 47045 readings in the mix of smart meter data from large and small flats. Figure 7.12 displays daily profiles in each cluster according to the cluster results. In the next part, cross analysis was employed to find the relationship between the clusters and other impact factors (time of the day, season of the year), and to test the effect of these factors on energy use patterns.

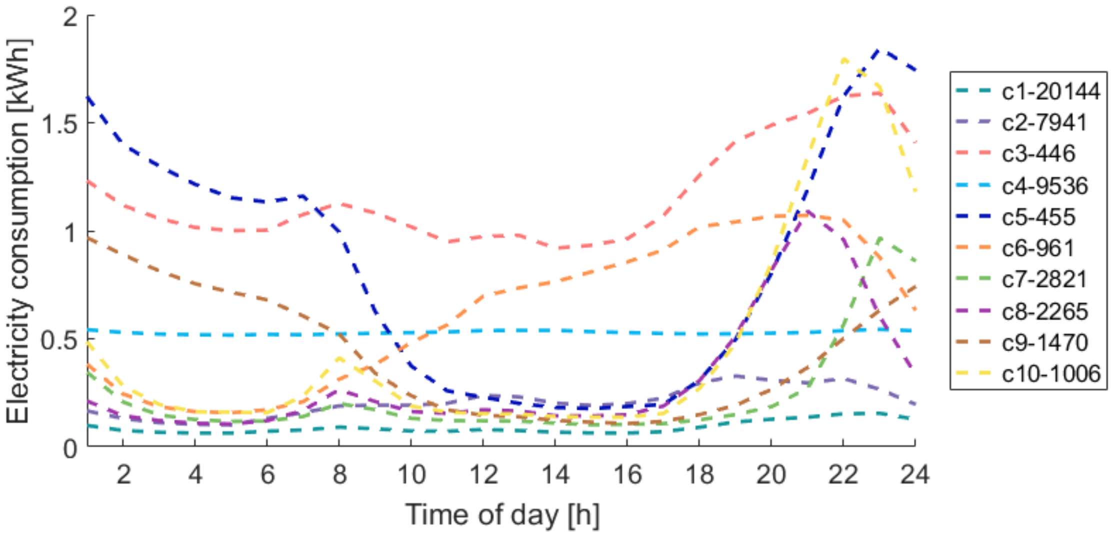
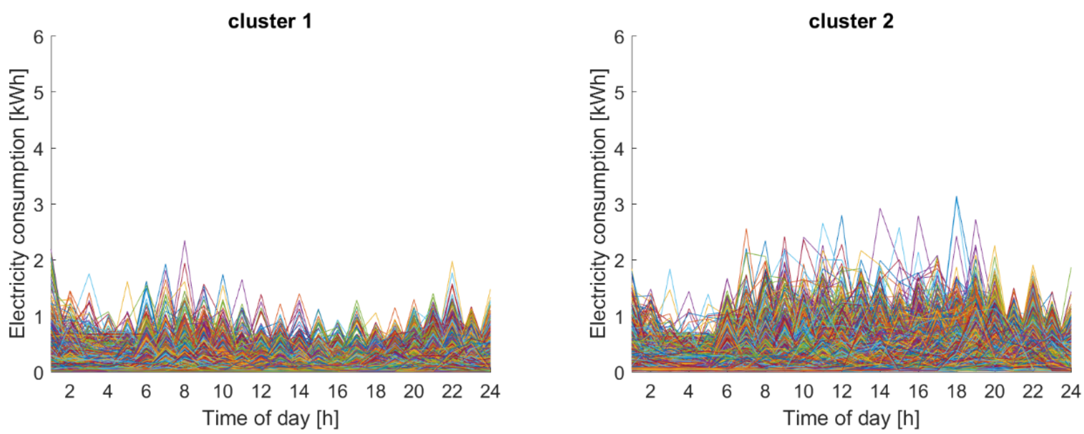


Figure 7.11. 10-cluster centroids of all readings

(Source: by Author)



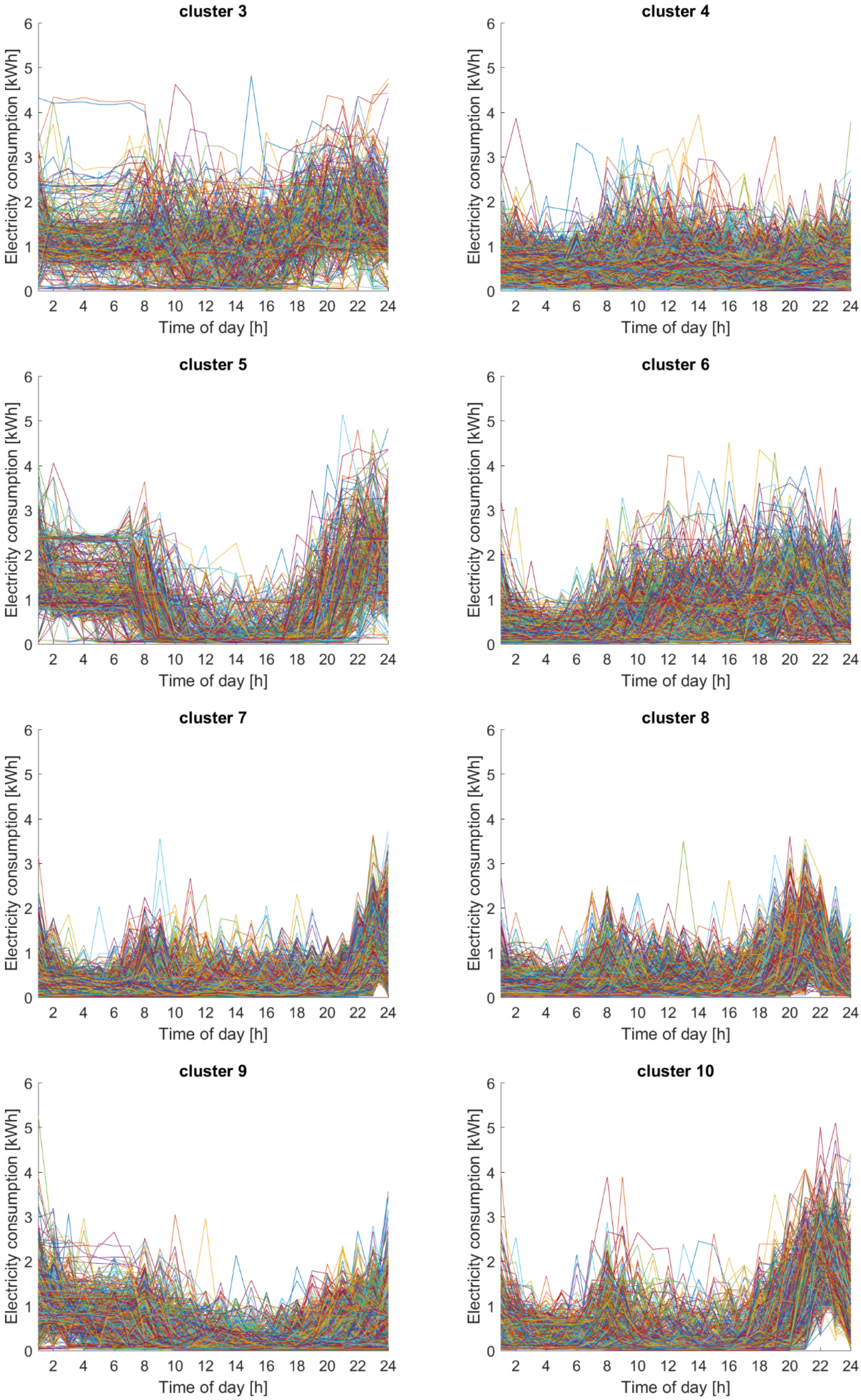


Figure 7.12. Clustering results of 10 clusters

A number of findings could be extracted from the smart meter data for demand-side management: Figure 7.11 shows the cluster centroids and Figure 7.12 presents the daily profiles in each cluster. In Figure 7.11, C1 and C2, which may be potentially categorised as the level 1 (low) consumers according to the 3-level electricity pricing system in China, exhibit evenly distributed mid-day energy demand that extends well into evening. The load profiles of C1 and C2 are distinguished by relatively evenly energy use distribution and low electricity use levels. The occupants with C1 and C2 profiles demonstrate energy-conscious behaviour in energy use. In contrast, C7, C8 and C9, which may be potentially categorised as the level 2 (high) consumers, present double peaks, with low morning use and high evening consumption levels. The occupants with C7, C8 and C9 profiles use lights and domestic appliances more frequently in kitchens, bathrooms and living rooms, both in the morning and evening. In addition, C3, C5 and C10, which may be also categorised as the level 2 (high) consumers, have extremely high night-time electricity use levels, possibly from air conditioning.

There are many factors that affect the differences in the daily profiles of the 10 clusters, such as the orientation, the floor number and the number of people. After from that, the diversity of energy use behaviour is the main impact factor when compared with other variables. For instance, some occupants choose to keep air conditioners on for heating during the night-time, but some occupants prefer to switch it off when the room temperature could achieve their comfort requirement. The difference in electricity consumption that results from the diversity of energy use behaviour is much higher than other factors such as room orientation. Figure 7.13 presents the daily electricity consumption in units of kWh of each daily profile in each cluster. The diverse daily electricity consumption in each cluster suggests great potential for energy saving by improved energy use behaviour, especially for clusters belonging to the level 2 high consumers. The potential energy saving policies from the smart meter data analysis, as well as the survey and interview studies, will be discussed in chapter 8.

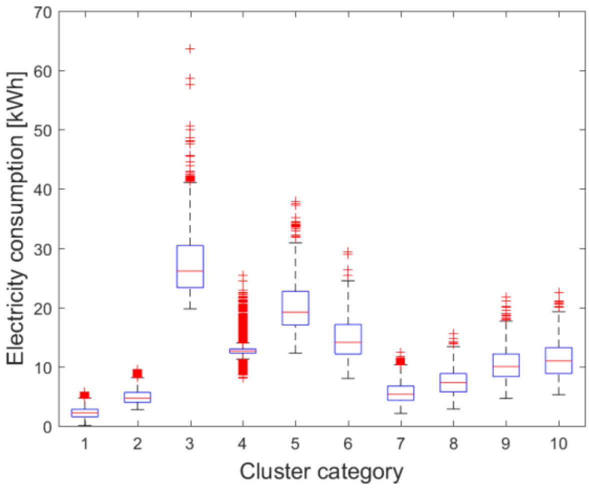


Figure 7.13. Daily electricity consumption in each cluster

(Source: by Author)

7.4.2 Cross analysis for demand-side management

Table 7.3 presents the cross analysis between each month with different clusters. In Figure 7.11, the numbers inside the right box indicate great variations in the number of daily profiles in each cluster. For instance, there are 20144 daily profiles in cluster 1 and 446 daily profiles in cluster 3, varying by a factor of five. To minimise the influence from the different amount of profiles, the data in each cluster was normalised to percentage values. Thus percentage data in each month would perform a more direct evaluation of seasonal impact. For instance, in Table 7.3, 33% of daily profiles in cluster 3 are monitored in January. Table 7.3 also suggests that seasonal differences in electricity use are driven by increased heating and cooling demands. Based on seasonal energy use, the energy use pattern of the 10 clusters can be categorised as: dominated by the heating period in winter (C3, C5 and C10), dominated by both heating and cooling period (C6, C7, C8 and C9), no distinguished features (C1 and C2) and dominated by the transitional-seasons (C4).

Table 7.3. Adjusted percentage between cluster and month

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Total
Jan	7%	9%	33%	2%	39%	19%	19%	23%	26%	33%	10%
Feb	8%	7%	22%	1%	25%	23%	12%	15%	16%	22%	8%
Mar	9%	10%	7%	1%	8%	5%	11%	10%	8%	7%	8%
Apr	3%	3%	0	7%	0	1%	1%	1%	1%	1%	3%
May	13%	10%	0	22%	0	0	1%	1%	0	0	12%
Jun	11%	9%	0	32%	0	0	2%	2%	1%	0	13%
Jul	3%	6%	3%	28%	1%	12%	13%	8%	11%	2%	10%
Aug	10%	13%	2%	4%	0	13%	15%	11%	11%	3%	9%
Sep	10%	9%	0	0	0	2%	3%	3%	1%	0%	6%
Oct	13%	8%	0	0	0	0	0	0	0	0	7%
Nov	7%	8%	0	0	0	1%	3%	3%	2%	1%	5%
Dec	6%	9%	33%	2%	27%	24%	20%	23%	23%	31%	9%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	/	/	W	Non	W	W/S	W/S	W/S	W/S	W	

(Source: by Author)

Table 7.4 presents the relationship between daily profiles in each cluster with the day of the week. Similar to the previous table, Table 7.4 indicates that 73% of daily profiles in cluster 1 are on a weekday and 27% of daily profiles in cluster 1 are on a weekend. As weekend days occupy 28.6% (2/7) of a week and weekdays occupy 71.4% (5/7) of a week, C2, C3 and C6, with the percentage in weekend days of 39%, 40% and 45%, indicate significant load shifting to weekend days. The daily profiles in Figure 7.12 show that, in C2, C3 and C6, the readings have random peaks during daytime between 9:00–17:00, reflecting the random use of energy during daytime hours.

Table 7.4. Relationship between cluster and the day of week

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Total
Weekday	73%	61%	60%	70%	76%	55%	76%	75%	74%	78%	70%
Weekend	27%	39%	40%	30%	24%	45%	24%	25%	26%	22%	30%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
		Weekend	Weekend			Weekend					

(Source: by Author)

A comprehensive summary of the domestic energy use based on this case study is shown in Table 7.5. The combination of K-means cluster analysis and cross analysis presents a viable approach to identifying and characterising different electricity use patterns. Information extracted from the smart meter data, such as Table 7.5, can be used by the government for demand-side management, such as the real-time electricity pricing system.

Table 7.5. Electricity consumption characteristics of each cluster

C	Night	Morning	Daytime	Evening	Important characteristics
1			Small peaks		/
2			Random peak		Weekend
3	Constant		High peaks	4kWh@21:00	Winter, weekend
4			Random peak		/
5	Constant	4kWh@8:00		5kWh@23:00	Winter, weekday
6			High peaks		Weekend
7		2kWh@7:00		3kWh@23:00	Weekday, later peak
8		2kWh@7:00		3kWh@21:00	Weekday
9	Constant				Winter/summer
10		4kWh@8:00		5kWh@22:00	Weekday

(Source: by Author)

7.5 Energy saving potential

7.5.1 Simulation design

In section 7.3, smart meter data was analysed based on each individual household. The average daily profiles of each household were calculated and it was found out that households with larger floor area consumed more energy and have higher peak value. Daily profiles in winter and summer of sample households from level 1 (low) and level 2 users, based on the 3-level progressive electricity pricing system in China, were extracted to explore why high users consumed more than low energy users. It was found the base load for level 1 consumers is low, which suggests that low users do not use air conditioner for most days in winter or summer, when compared with high users.

In section 7.4, smart meter data was analysed based on all readings of actual daily profiles, with 47045 readings in total, for a mixture of large or small flats. Ten clusters were classified according to the K-means cluster analysis: daily profiles in C1 and C2 may be categorised as low users, daily profiles in C7, C8 and C9 as high users, and daily profiles in C3, C5 and C10 as higher users. The differences in daily profiles from the cluster analysis can be used by policymakers to identify priority groups for potential energy saving policies.

From the survey study in chapter 5, it was found that the heating and cooling hours and duration are the main determinants of final energy consumption. Thus, it is needed to test the impact of behavioural measures of adjusting heating and cooling hours through simulation analysis. It was indicated in chapter 4 that a single-zone simulation with smart meter data can not only reduce the simulation complexity, but also capture the occupancy diversity which cannot be taken into consideration by the traditional simulation method. Thus, this section uses the single-zone simulation method to test the impact of the behavioural measures that relate to the determinants in energy use as identified in the survey study.

Figure 7.3 displays the plan layouts of the small and large flats where smart meters were installed, also shown in section 7.2. There are two layouts for the 126 flats: 62 cases with a small floor area of 45 m^2 and 64 cases with a large floor area of 60 m^2.

Figure 7.3. Plan layout of each flat type: small (left), large (right)

(Source: online, http://www.shcngz.com/pages/house_info.aspx?houseid=4)

EnergyPlus was used for the single-zone simulation. Based on the methods applied in previous research, several unknown parameters were assumed to meet the minimum requirements or designed values in the building standards JGJ134-2010 (MOHURD, 2010): 1) U-value of 1 W/m^2K for wall and U-value of 2.8 W/m^2K for window; 2) glazing area of 30% of external wall; 3) air conditioners are used for heating and cooling, with cooling COP of 2.3 and heating COP of 1.9; 4) heating temperature of 20°C and cooling temperature of 26°C, with air change rate of 1 ACH; 5) heating period from 1 December to 28 February and cooling period from 15 June to 31 August.

As mentioned before, the definition of occupant behaviour in Chinese regulation is simple, which cannot represent an actual occupant profile and leads to a huge performance gap between the actual energy consumption and simulated results. For instance, Table 7.6 shows the definition of occupancy profiles in the hot summer and cold winter region in China. Several field survey and questionnaire studies have been carried out to understand more about occupant behaviour in residential buildings in China.

Table 7.6. Definition of occupancy profiles based on Chinese regulation in hot summer and cold winter region

Parameters	
Set temp. in winter	18°C
Temp. in summer	26°C
Air change rate	1 ACH
COP for cooling	2.3
COP for heating	1.9
Internal heat gain	4.3 W/m^2
Heating period	1 Dec to 28 Feb
Cooling period	15 Jun to 31 Aug
Wall U-value	0.8 to 1 W/m^{2}K

(Source: MOHURD, 2010)

Table 4.2 demonstrates the simulation design in section 7.5, also shown in chapter 4. The original actual annual demand of each household was collected from smart meter data. There were two plan layouts of recorded households. The traditional multiple-zone simulation (step 1) with assumptions from the Chinese standards was simulated in EnergyPlus at first for comparison, in two simulations of the two plan layouts with the assumptions as mentioned in the building standards. A single-zone simulation with the original occupancy patterns extracted from the smart meter data (step 2) was simulated in EnergyPlus, for 126 simulations of the 126 profiles of the two plan layouts. In step 3, two behavioural measures from survey study were tested through single-zone simulation, including (a) adjusting heating and cooling temperature and (b) reducing heating and cooling hours, in the 126 simulations of 126 profiles of the two plan layouts for each behavioural measure.

Table 4.2. Simulation design

Step	Notation	Occupancy schedule
(0)	0	Actual annual demand of each household: 126 values
(1)	1-small 1-large	Multiple-zone simulation with Chinese standard, JGJ134-2010: 2 simulations
(2)	2-small 2-large	Single-zone simulation with original occupancy profiles: 126 profiles and 126 simulations
(3)	3-small-a 3-large-a	Quantify effect of behavioural measure (a) set temperature for air conditioners: 126 profiles and 126 simulations
(3)	3-small-b 3-large-b	Quantify effect of behavioural measure (b) air conditioning hours: 126 profiles and 126 simulations

(Source: by Author)

For step 2 and step 3, two original profiles of the small and large flats were first generated in EnergyPlus, and then Matlab was used to rewrite and generate new IDF profiles for each household. The two original profiles in small and large were generated as a single-zone with the same plan layout as Figure 7.3, and the assumptions were from the Chinese standard, shown in Table 7.6. In other words, the original step 2 model can be regarded as the step 1 model but without the internal partition. In Shanghai, the transition seasons provide a baseline of electricity consumption without cooling or heating, representing the electricity consumption of domestic appliances of that specific households. Therefore, by subtracting the baseline electricity consumption from the electricity consumption in winter and summer, electricity used for heating and cooling could be obtained. To extract the heating and cooling profiles from actual daily profiles for each household, the following calculations were run automatically in Matlab. First, the average electricity use at each hour of the day in June (transition season) was calculated for each household. Second, the average electricity use at each hour of the day in July (cooling season) and December (heating season) were calculated. Third, the average electricity use in the transition season were subtracted from the average electricity use in the cooling season and the heating season to calculate the average heating and cooling use for each household at each hour of the day. After three steps, three schedules could be obtained for each household, including average electricity consumption at each hour of the normal day, average heating consumption at each hour of the winter day and average cooling consumption at each hour of the summer day. These schedules were used as parameters in EnergyPlus of occupancy schedule, heating schedule and cooling schedule for each household. The two original simulation profiles (small flat and large flat) were rewritten in Matlab by using the special profiles for each household. For instance, if a household is in a small flat, the new IDF profile is generated by changing the occupancy, heating and cooling schedules of the original profile of the small flat, but other parameters are not changed, such as the internal temperature.

Step 3 examines the effect of behavioural measures through single-zone simulation. According to the survey results in chapter 5, the parameters of (a) set temperature for heating and cooling and (b) heating and cooling hours, were identified as two primary determinants that affect the electricity consumption of each household. Thus, section 7.5.3 tests how much electricity can be saved by adjusting these two primary input parameters in the simulation. Table 7.7 lists the behavioural measures tested in this section. In particular, for measure (b), it says "switch off the air conditioner when not necessary". In Matlab, this was manipulated to set the HVAC schedule as "0" if the average heating and cooling profiles were smaller than 0.2 kWh (which means that heating and cooling was not used frequently at this hour of the day on normal heating or cooling days). The input parameters were rewritten in Matlab to generate IDF files automatically for a single-zone simulation in EnergyPlus with "group simulation" function.

Table 7.7. List of behavioural measures

	Measures	Saving target
(a)	Set temperature	Heating temp from 20 to 18 °C; Cooling temp from 26 to 28 °C
(b)	HVAC hour	Switch off the air conditioner when not necessary* (in Matlab, it was manipulated to set the HVAC schedule as "0" if the average heating and cooling profiles are smaller than 0.2 kWh)

(Source: by Author)

7.5.2 Simulation of original profiles (step 2)

To illustrate the usefulness of using smart meter data to capture occupancy variation and the accuracy of a single-zone simulation with smart meter data, traditional multiple-zone simulations with assumptions from the building standards (step 1) for the small and large plan layouts were also simulated in EnergyPlus. From the simulation, the annual electricity consumption was 4206 kWh for a small flat and 6623 kWh for a large flat.

Multiple simulations have been conducted in EnergyPlus to investigate the effect of variation in occupancy pattern on energy demand prediction. A single-zone simulation using the original profiles extracted from the smart meter data (step 2) was simulated in EnergyPlus, in 126 simulations of the 126 profiles of the two plan layouts. Figure 7.14 compares the actual annual electricity use from the smart meter data (step 0) (orange dot) with the predicted annual demand from the single-zone simulation using the actual profiles (step 2) (blue dot). When the actual annual demand is small, the predicted annual demand is relatively small. The simulation result is positively related to the input profiles, as the input schedule is extracted from the actual electricity demand. Further, the large variation in measured occupancy patterns also leads to a large variation in energy demand prediction. The predicted annual demand ranges from 2000 kWh to 5500 kWh for the small layout, and ranges from 4000 kWh to 6000 kWh for the large layout. The variation is in a factor of 3–4. All the predicted results were higher than the actual measured data. The difference may result from other unknown and stochastic parameters such as assumptions in building fabrics, but this study aims to explore the influence from energy use behaviour and will not investigate other uncertain parameters.

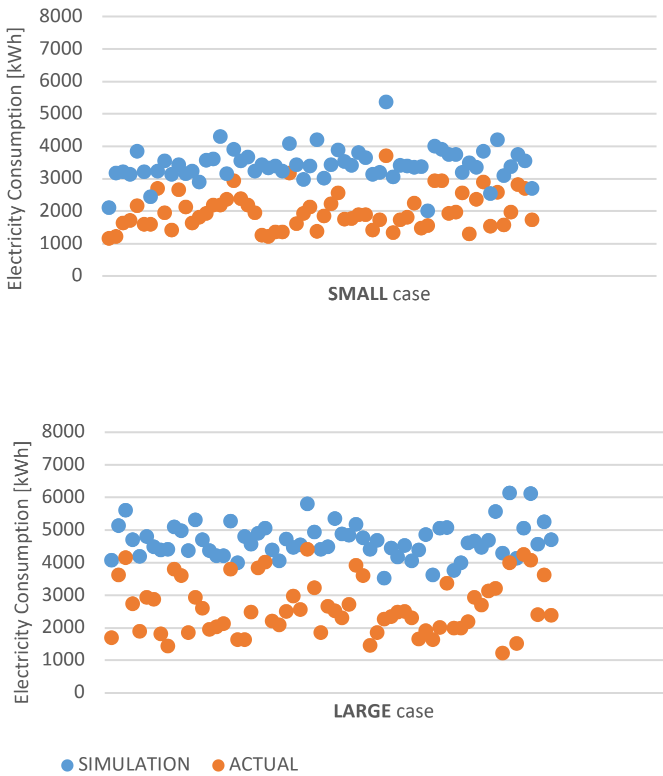


Figure 7.14. Single-zone simulation (step 2) in small (top) and large (bottom) layout, compared with actual data

(Source: by Author)

The differences between the actual consumption and simulation results are from many reasons. Firstly, building materials and other parameters were assumed based on minimum requirement of the Chinese standard, which will lead to a performance gap. Secondly, the electricity use at each hour of the day cannot be fully transferred to occupancy patterns, as some appliances such as fridges would constantly use electricity when occupants are not at home. The limitations of this simulation method are acceptable, as section 7.5 aims to test the energy saving potential of two behavioural measures and behavioural parameters are the main variables to assess. The reason of why to simulate single-zone models in 126 times is to test the energy saving potential of two behavioural measures in a range of energy use behaviours.

7.5.3 Simulation of behavioural measures

Section 7.5.3 quantifies the effect of behavioural measures. Figure 7.15 shows the actual annual electricity consumption from the smart meter data (step 0), the simulation results of the original profiles (step 2), and the simulations of the two energy saving measures (step 3-a and 3-b). Figure 7.16 shows the annual electricity saving potential with the two behavioural measures. In general, each behaviour measure has an energy saving potential of 20% on average, with great variations. The behavioural measure of (a) adjusting heating and cooling temperature, was more useful in the larger floor area household. The behavioural measure of (b) reducing heating and cooling hours, had a similar average value in terms of the energy saving percentage in both small and large floor area households, but the larger floor area household showed a larger variation in terms of the energy saving percentage.

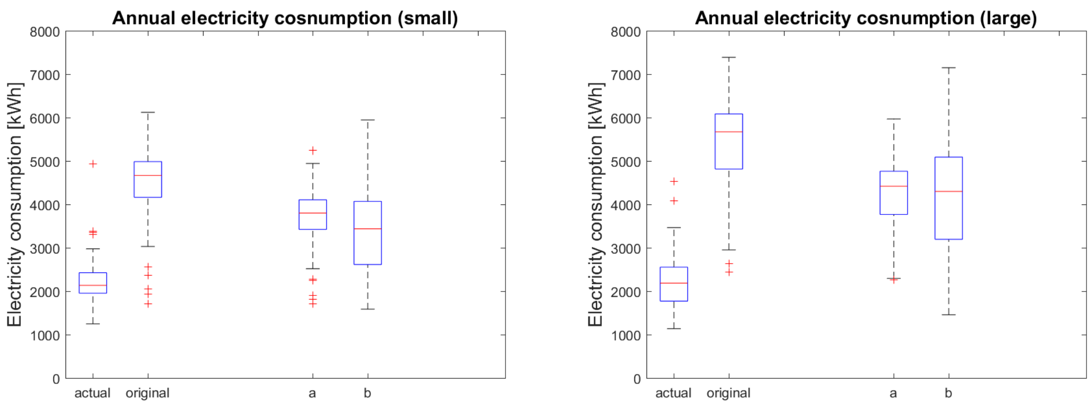


Figure 7.15. Annual electricity consumption (kWh) tested with two behaviour measures: (a) adjusting temperature and (b) reducing heating and cooling hour

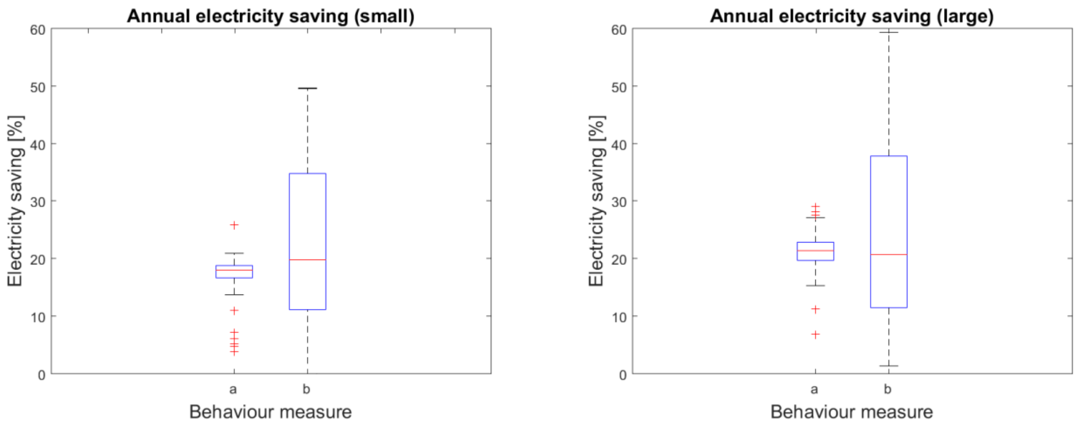


Figure 7.16. Annual electricity saving by two behaviour measures: (a) adjusting temperature and (b) reducing heating and cooling hours

(Source: by Author)

From the single-zone simulation of 126 cases, the behavioural measure of changing heating temperature from 20 to 18 °C and cooling temperature from 26 to 28 °C could help to save about 18% of electricity for small flat residents and save about 21% of electricity for large flat residents on average each year, in a range from 15%–28%, with the larger flat has a relatively higher average value. The behavioural measure of reducing heating and cooling hours could help to save about 20% of electricity annually. The combination of these two measures could help to roughly 40% electricity in the domestic sector, which is a huge potential. If the smart meter is installed at home with a display guidance of switching off air conditioners at an appropriate room temperature, this measure could help to save a large amount of energy but without sacrificing occupants' thermal comfort.

7.6 Summary of the analysis of smart meter data

Chapter 7 used smart meter data from Shanghai residential buildings as a case study to explore actual electricity use patterns, and to explore the information that could be obtained for policy design. Section 7.2 provided an overview of the data, which reflects the great variation in occupancy patterns, varying by a factor of six even for residents living in similar apartments with similar demographic variables. It also suggests that there are differences in seasonal electricity consumption such that the electricity use in winter is more than twice that during summer, and that electricity use in summer and winter is higher than in the non-air-conditioning period. The use of electricity in summer is more random when compared to winter profiles, which shows the variation of occupancy patterns in daytime in summer.

In the analysis of smart meter data based on each individual household, it was found the level 1 consumers have relatively low base load, which suggests the occupants do not use air conditioners for most days in winter or summer. Among all households, the average electricity consumption in winter and summer is 200-300 kWh per month, while the average electricity consumption in non-air-conditioning month is about 150 kWh per month.

The analysis based on all recorded days of all households, with 47045 readings in total, suggested that profiles in C1 and C2, which may be categorised as low energy consumers, distinguished by relatively evenly distributed low electricity consumption levels. In contrast, for profiles in C7, C8 and C9, which may be categorised as high energy consumers, present double peaks, with a low peak in the morning and a high peak in the evening. For profiles in C3, C5 and C10, which may be also categorised as high consumers, occupants have high night-time electricity use due to air conditioning. The characteristics from the clustering analysis could be used by policymakers to identify priority groups for energy saving policies, which will be discussed in chapter 8.

A single-zone simulation with smart meter data was used to explore how much electricity could be saved by adjusting the determinants identified in chapter 5. It was found both of the two behavioural measures (which can bring level 2 consumers closer to level 1 patterns) have a potential energy saving of 20% on average, with wide variation. The behavioural measure of (a) adjusting heating and cooling temperature performed better in the larger floor area household, and the measure of (b) reducing heating and cooling hours showed similar average values in energy saving percentage, but had wider variation for the large floor area household.

Chapter 8 summarises the findings from the three empirical studies, and proposes potential policy instruments for domestic energy saving.

Chapter 8 – CONCLUSIONS

8.1 Introduction

This research aims to understand energy use behaviour, the reasons behind practices, occupants' attitude toward smart meters and related energy saving policies, and the information that could be extracted from smart meter data to aid in policy design, in the context of urban households in Shanghai. This thesis also aims to explore occupants' attitudes toward different policy instruments and to propose energy saving policies specifically designed for young urban households. Furthermore, this thesis explores the applicability of using the theory of planned behaviour (TPB) to understand occupants in the context of domestic energy use and energy saving policies.

In this chapter, section 8.2 summarises key findings from three empirical studies. Section 8.2.1 explains energy use patterns and attitudes identified in the survey study and answers research question 1. Section 8.2.2 lists findings about the motivations and norms of energy saving from the interview study and answers research question 2. Section 8.2.3 summarises findings from the analysis of smart meter data and answers research question 3. Section 8.3 answers research question 4 about policy recommendations for domestic energy saving in the context of urban households in Shanghai, China. Section 8.4 explains findings from the theoretical dimension of applying the theory of planned behaviour (TPB) and mixed methods approach in the context of domestic energy use behaviour. Section 8.5 discusses the new contribution of this thesis to the field of study. Section 8.6 indicates the limitations of this research and provides suggestions for future research.

8.2 Findings from empirical studies

8.2.1 Energy use patterns and attitudes

According to the review of existing studies on domestic energy use behaviour in China (chapter 3), three research gaps were identified: 1) the lack of a theoretical framework to understand the link between attitudes and behaviour; 2) the lack of mixed methods research that crosses disciplines using a socio-technical approach to address the complexity of energy use behaviour, especially in the Chinese context; and 3) the lack of research on smart meters and data-mining studies that explore occupancy patterns in China. Further, it was identified in the pilot studies (section 4.5) that there is a great gap between the estimated and actual energy use in Chinese households, thus it is important to explore the diverse energy use characteristics.

The survey study was designed to better understand the factors that affect domestic energy use behaviour and attitudes, in response to research question 1. Figure 8.1 summarises the findings from the survey study in relation to demographics (R1) and attitudes (R2).

Chapter 5 reported the survey results. There were 341 respondents in total, with 240 samples in level 1 (<3120 kWh), 67 samples in level 2 (3210–4800 kWh) and 34 samples in level 3 (>4800 kWh), based on the 3-level progressive electricity pricing system in China. This reflects the structure of the electricity pricing system in which level 1 was designed by the government to cover 80% of all consumers, and both level 1 and level 2 were designed to cover 95% of all consumers.

The average annual electricity bill was 1408 RMB (164 GBP) for level 1 consumers, 2420 RMB (283 GBP) for level 2 consumers, and 4102 RMB (480 GBP) for level 3 consumers. It can be seen that the average value of the annual electricity bill for level 1 and level 3 consumers varied by a factor of three. According to the results in Table 5.4 and Figure 5.2 (see section 5.2), level 3 high consumers are more likely to have a higher income level and are more likely to live in newer houses with a larger floor area.

Among the eight occupancy parameters analysed in section 5.2 (heating and cooling hours per day, set temperature, start month and stop month), heating and cooling hours were the most influential factor in high electricity consumption. According to the survey results in Table 5.5 and Figure 5.3 (see section 5.2), level 3 consumers had longer average heating and cooling hours and had a higher percentage in the early start period and later stop period in average seasons. These characteristics are summarised in Table 5.5, which shows that while the level 1 consumers were using heating or cooling on average 4.75 hours per day, level 3 consumers were using them for 10 hours per day.

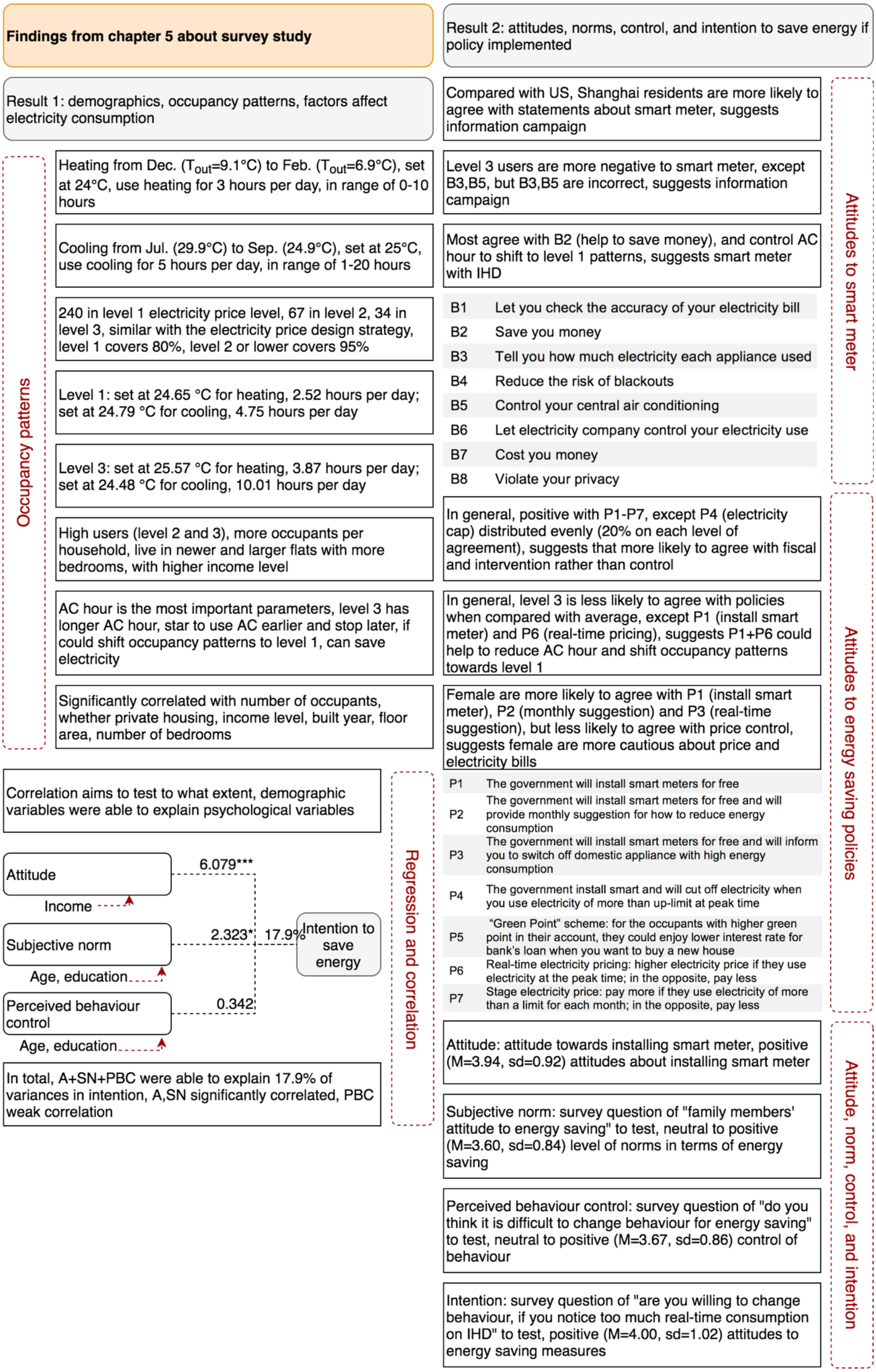


Figure 8.1. Findings from the survey study

According to the survey results, the annual electricity bill ranged from 420–6000 RMB (48–682 GBP) per household, varying by a factor of 14 times, with the average annual electricity bill being 1875 RMB/year (213 GBP/year). The average annual electricity use from the survey study was higher than the average level in Shanghai and China. The age of the respondents was younger than Shanghai average, due to the survey distribution method being through the Internet. Correlation analysis showed that annual electricity use was significantly correlated with the number of occupants, income level, built year, floor area, and the number of bedrooms. Similar to the behavioural research by Hu et al. (2017), Lin et al. (2016) and Feng et al. (2016) (see section 3.2), income level was highly related to the domestic energy use level, and the energy use increases with higher income levels even in new energy efficient housing.

The survey study also explored occupants' attitudes toward smart meters. It was found that most respondents agreed with the statements about smart meters and were positive, but some of the understandings of smart meters and what they do were not correct (such as the belief that a smart meter could tell them how much electricity each appliance used). Compared with the survey results from U.S. households (Krishnamurti et al., 2012), Shanghai residents are more likely to agree with the descriptions about smart meters. However, the misunderstanding about the capabilities of smart meters may affect participants' motivation for behavioural change if they realise that some functions cannot be achieved through the smart meters. This suggests that an information campaign is required if the government intend to implement a roll-out of smart meters. The survey study also examined occupants' attitudes toward energy saving policies related to smart meters, grouped in fiscal, communication, and control policy instruments. It was found that respondents were more likely to agree with fiscal and communication instruments (such as installing smart meters with energy saving suggestions) rather than control instruments (such as energy use caps). This observation, that more command and control instruments are likely to be less acceptable, is not surprising and has similarly been observed in the Western context.

It was also shown that among the seven proposed energy saving policies, level 3 consumers were more likely to accept the policy of a smart meter with real-time electricity pricing. As average heating and cooling hours were high for level 3 consumers, the installation of smart meters with real-time pricing information can be useful in reducing peak-time electricity use specifically in the case of high consumers, supported by the high level of acceptance of smart meters at home.

The influence from socio-psychological variables (attitude, subjective norm, and perceived behaviour control) were tested in section 5.3.6 using the theoretical framework of TPB discussed in chapter 4. It was found that these three variables were able to explain 17.9% of the variance in intention to save energy with potential policy instruments, in which attitude and subjective norm were significantly related to the intention to save energy, but the perceived behaviour control reflected relatively weak correlation. With the help of correlation analysis, it was found that income level was correlated with the attitude toward smart meter policies (Table 5.12), thus indirectly affecting the intention to save energy. In addition, age and education level affected the socio-psychological variables of subjective norm and perceived behaviour control, affecting the intention to save energy with potential policies.

8.2.2 Motivations and norms

Five occupants among the survey respondents were selected for in-depth interviews to understand their motivations and norms further. Figure 8.2 illustrates the key findings from the interview study. The semi-structured interviews revealed that, even within the target group of young highly-educated urban households, occupants' behaviour, attitudes, and values are extremely diverse. Based on their attitudes, norms and control, two types of energy consumers were identified by the interviews: "comfort-driven" consumers and "conscious" consumers.

Figure 8.2 shows that even though the five interviewees were in similar demographics (aged 27–29, master's degree educational level, middle income level, live in urban Shanghai), their attitudes, norms, control and consumption were diverse. In terms of what made the "conscious" consumers different from the "comfort-driven" consumers, the educational background strongly influenced norms, as these three "conscious" consumers (Alex, Chris, Dora) graduated with environmental science, engineering, and law majors. The two "comfort-driven" consumers (Belle, Emma) graduated with business and accounting majors, with the knowledge of economic models.

Findings from chapter 6 about interview study

	Characteristics of "comfort-driven" consumers	Characteristics of "conscious" consumers
Attitude, norm and control	1) They prioritise comfort, work hard for a better living standard, and don't want to sacrifice thermal comfort 2) They think electricity bill is cheap compared with income level 3) They think it is hard and inefficient to spend effort in energy saving; and electricity is a merchandise, no right to restrain their use - Belle: "*Electricity is a merchandise, I paid more for what I used. Why do you want to restrain me?*" 4) They think electricity is a necessity with their lifestyle, and would not change use in response to price - Emma: "*Electricity is a necessity, I would not consider to spend time to save it.*" In general, negative attitude, weak norm and lack of control	1) They think it is our duty to save energy - Alex: "*My major is environmental science, which equipped me knowledge of energy saving.*" Dora: "*When I started to pay the living expenses, I started to realise I need to saving energy.*" 2) They never mention it is hard to save energy, but they would try to save energy if thermal comfort could be maintained - Chris: "*I would like to consider energy saving if thermal comfort could be maintained.*" In general, positive attitude, strong norm and intention about control. (e.g. both Alex and Dora mentioned to maintain AC temperature at 26°C as they heard from social media that 26°C is the most energy saving temperature setting in summer)
Impact factors	1) Influence from parents, subjective norm 2) Impact from education background: Belle and Emma all from major of business and accounting, and their main concern is thermal comfort rather than social responsibility; Alex and Chris from environmental science and engineering background 3) From income level: the electricity bill is too cheap, less than 10% of income, and maximum variation is less than 100 RMB 4) Influence from the change of social structure (e.g. getting married)	
Knowledge about policies	Belle: limited knowledge and negative attitude, she pointed out the policy of switching off AC after 6:00pm in office, and she didn't know other policies Emma: limited knowledge and negative attitude, she pointed out the rubbish recycling policy and peak-and-valley electricity pricing, but the pricing system has no effect, as "*I don't care about electricity price*"	Alex: general knowledge but negative attitude, he pointed out the energy saving advertisement in underground station, and the peak-and-valley electricity pricing, but would not consider to use electricity in valley price due to it will affect his daily rountines Chris: general knowledge but negative attitude, mentioned the peak-and valley electricity pricing, but would not consider when use electricity in valley price due to the inconvenience Dora: general knowledge and positive attitude, mentioned the policy to promote electric cars, one-hour blackout activity in her office, and the peak-and-valley electricity pricing, and she will consider to use electricity in valley, and said "*if I can save money without any inconvenience, it would be better to do so*"
Policy suggestions	Belle: energy-efficient appliance and solar hot water system, as it is hard to reshape behaviour, but can save energy from higher appliance efficiency Emma: no suggestion, as "I don't have any suggestion as I think it's inefficient to spend time and sacrifice thermal comfort for energy saving"	Alex: broadcast energy saving policies to the whole country (information publicity), advertisement of energy saving on Alipay (information publicity), and the reward and restrain system, with consumption comparison system on IHD Chris: punishment system for the factory who manufacture inefficient appliance Dora: social comparison system between peers or within the community Chris and Dora: consumption visualisation system, with red, yellow and green bar on IHD

Figure 8.2. Findings from the interview study

Secondly, influence from family members played a vital role in energy use attitudes and behaviour. Alex mentioned his parents were very energy-saving when he was a child, though they saved electricity for economic factors. Chris and Dora indicated they often discussed the monthly electricity bill with partners if the consumption was too high. Dora highlighted that her energy use behaviour was influenced by her husband. Educational background and influence from family members were therefore identified as factors that shape occupants' energy use attitudes that underlie their behaviour patterns and heating and cooling seasons.

Based on the results from section 6.2.4, the occupancy patterns of "conscious" consumers differ from those of "comfort-driven" consumers, which makes a difference in their energy use. In general, the lifestyle of Belle and Emma (the "comfort-driven" consumers) was more energy-consuming. The average cooling hours per day for the interviewees was about 6–7 hours, except for Belle ("comfort-driven" consumer), who used 9 hours AC for cooling on average if she stayed at home. Five interviewees used similar amount of hours for heating per day compared with cooling hours, except Chris ("conscious" consumer), who used 6 hours for cooling but used 3 hours for heating on average. There were also differences in how they related to possible policy instruments and a sense of entitlement among "comfort-driven" consumers, summarised by Belle: "*Electricity is a merchandise, I paid more for what I used. Why do you want to restrain me?*".

8.2.3 Smart meter data analysis

Finally, smart meter data was used to extract occupancy profiles from quantitative smart meter data from a group of young urban households in Shanghai. The sample was different from the sample used for the survey and the interviewees, but represented the same socio-demographic group. Their conditions of living in identical houses allowed for an equal comparison that eliminated the impact of the building fabric. Figure 8.3 presents the figures from the analysis of smart meter data and the following sections present detail explanation of these figures.

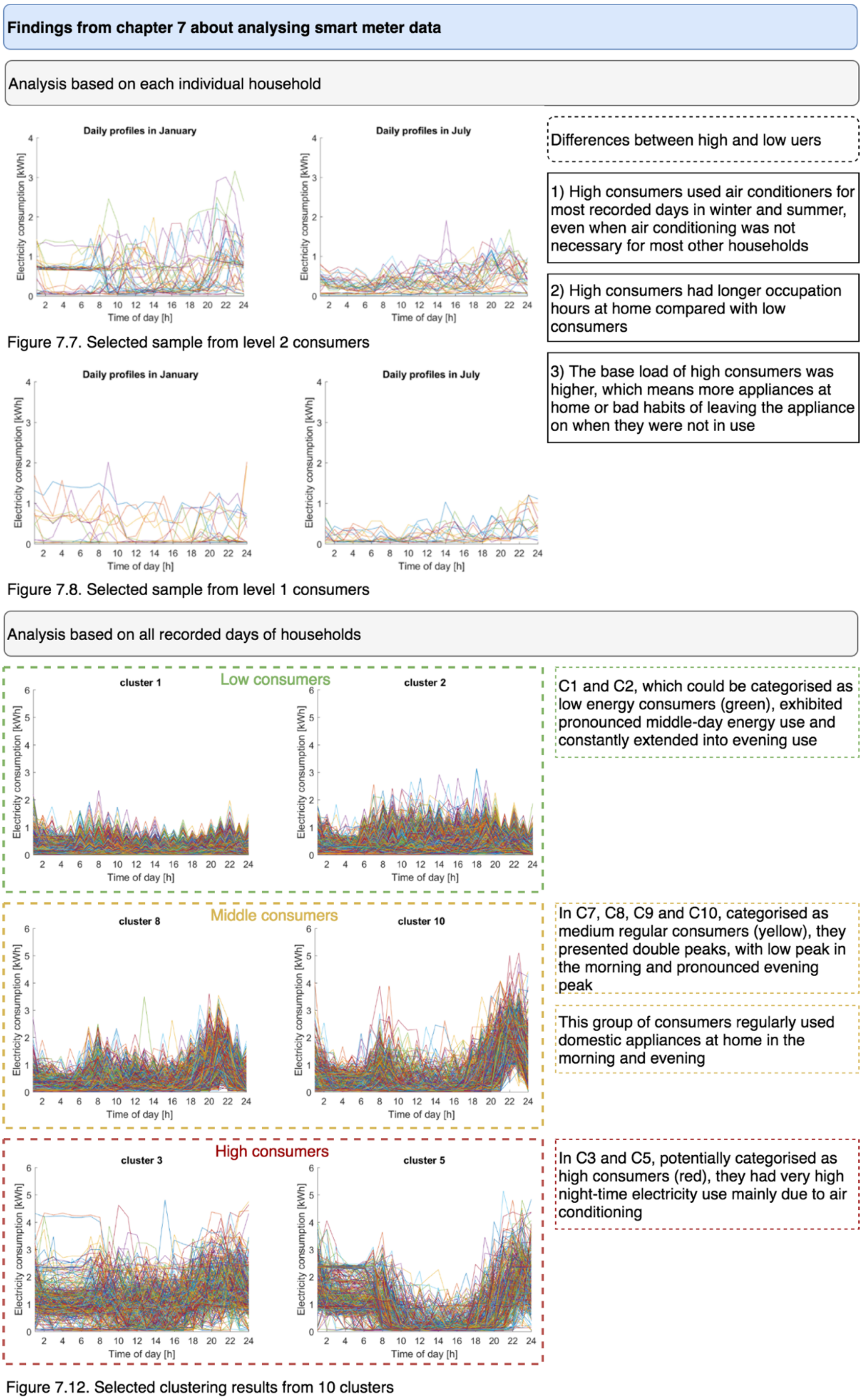


Figure 8.3. Key figures from the analysis of smart meter data

Section 7.3 analysed the smart meter data based on each individual household. The average profile of each household is summarised in Figure 8.3. The samples from level 1 and level 2 consumers (based on the 3-level electricity pricing system) were selected for analysis to explore the differences between the two levels of consumers. To compare the daily profiles of high (level 2) and low (level 1) consumers, the differences were identified as stemming from the following reasons: 1) high consumers used air conditioners for the most recorded days in winter and summer, even when air conditioning was not necessary for most other households; 2) high consumers had longer occupation hours at home compared with low consumers; and 3) the base load of high consumers was higher, which means more appliances at home or bad habits of leaving appliances on when they are not in use. Furthermore, even within the same level of consumers and in a similar socio-demographic group in identical houses, the occupancy profiles showed diversity.

The analysis in section 7.4 was based on all recorded days of all households, with 47,045 readings in total. Cluster analysis of all readings can provide information for demand-side management (Figure 7.12). The load profiles of C1 and C2, when compared with other clusters, were identified by a relatively low and evenly distributed energy use level. C1 and C2, which could be categorised as low energy consumers (green), exhibited pronounced energy use in the middle of the day, which constantly extended into evening use. In contrast, C7, C8, C9 and C10, categorised as medium regular consumers (yellow), presented double peaks, with a low peak in the morning and a pronounced evening peak. This group of consumers regularly used domestic appliances at home in the morning and evening. In addition, C3 and C5, potentially categorised as high consumers (red), had very high night-time electricity use mainly due to air conditioning. The analysis of the smart meter data presented a potential approach to identifying and characterising different energy use patterns, which could be used to identify priority groups and to aid in tailored policy design. For example, the rollout of smart meters could provide massive amounts of energy use data from which energy use characteristics could be extracted, such as the peak and valley periods of energy use, or to assess the potential for solar electricity.

8.3 Policy recommendations

Policy suggestions were discussed based on findings from the survey, interview and smart meter data analysis to address the energy use in group of young urban households in China, with the underlying aim of keeping them as level 1 consumers: 1) smart meter with in-home display; 2) dynamic real-time pricing system; 3) review, reward and restrain feedback system; and 4) higher standards for buildings and appliances.

Smart meters with in-home display

The survey study in chapter 5 explored occupants' attitudes toward smart meters and their acceptance of energy saving policies. The Chinese young urban consumers' positive perceptions of smart meters suggest that the government can install smart meters for the target groups, but it should take care of any potential misunderstanding about smart meters. As expected, the survey respondents were more likely to agree with the policy instruments of fiscal and communicative instruments, rather than consumption or price control. Compared with the study by Krishnamurti et al. about occupants' attitudes toward smart meters in U.S. households, the survey results from this thesis suggest that the young Chinese households were more likely to agree with the installation and information provided by the government. It also suggests that an information campaign is crucial in the promotion of domestic energy saving and behavioural change.

Installing the smart meter with an in-home display could help to address heating and cooling temperature and air conditioning hours, and try to keep household energy use patterns closer to level 1 consumers. The single-zone simulation in section 7.5 showed that changing the indoor temperature and reducing air conditioning hours could both help to save 20% energy. The cluster analysis in section 7.4 also showed the potential for the government to obtain data to understand actual electricity consumption and electricity grid peaks to help with policy design. A cluster analysis of smart meter data could therefore help to identify target groups for each policy instrument to make the policies more effective.

However, based on the review of existing studies, the information shown on the display is meaning less for users in China, and there is a lack of information feedback system to promote behavioural change by smart meter with displays (Du et al., 2017). In the interview study in chapter 6, three out of five interviewees indicated their interest in smart meters with in-home displays. They further suggested a visualisation system for current electricity use and electricity price with an RBG bar, in which green represents energy savers and low electricity prices, yellow represents normal users and medium electricity prices, and red represents intensive users and high electricity prices. They believed it would be more straightforward to pay attention to the current use and electricity price with colour signs.

Dynamic electricity pricing system in conjunction with smart meters

The survey study in chapter 5 showed that occupants were more likely to have lower requirements for indoor temperature if they started to use heating later and accepted a higher temperature in summer with a shorter cooling period. This suggests that the government could increase the electricity price during transition months (typically in May) especially for level 3 consumers, so that the electricity bill is high when level 3 consumers start heating and cooling earlier than most households. In conjunction with pricing, the government could also send information to all energy users about when it is appropriate to start using heating or cooling.

When asked about potential energy saving policies, level 3 consumers were more likely to accept the policy of smart meter installations with real-time electricity pricing. Reflecting the occupancy patterns of each group in chapter 5, the average heating and cooling hours were extremely high for level 3 consumers. If smart meters were installed with in-home displays showing real-time energy use and prices, which were progressive for critical months when some households use cooling and heating earlier, and some do not, then level 3 consumers could be more likely to turn off air conditioners or other appliances to save energy, bringing occupancy patterns closer to level 1 consumers and reducing electricity use. From the correlation analysis of the demographic variables and actual energy use, the consumers with higher income level are more likely to have higher electricity consumption. How to encourage the high-income group to reflect to the electricity price would be a challenge, with the opinion of "*we earn more so that we can live in a better way*" proposed by a "comfort-driven" consumer. It was summarised from the interviews that the "comfort-driven" consumers prioritise thermal comfort more than energy saving and believe the electricity bill is cheap compared to income level, so they don't pay attention to save energy or money as "*it is inefficient to do so*". Thus the fiscal and communicative instruments are ineffective for this target group. As a result, a restrain system proposed by a "conscious" consumer might be more powerful for this type of consumers.

In addition, the electricity price in China is relatively cheap when compared with the income level. From the interview study, two "comfort-driven" consumers mentioned "The electricity bill varies less than 100 RMB per month, which is so small compared to the income level. Do you think the residents with the income level of higher than 40,000 RMB would care about their electricity bill?" A previous research by Ouyang et al. (2009) suggested to increase the energy prices to promote higher energy efficiency in China. It is supported by Wang et al.

(2017)'s research which proposes that the electricity price should be designed differently for different provinces with different average income level. As a fiscal policy instrument, more appropriately designed electricity pricing system could help to promote domestic energy saving by motivating behavioural change.

Review, reward and restrain feedback system

As mentioned in the interview chapter 6, on the top right side of the electricity bill sheet (which was obtained from one interviewee), there is a barcode which allows the consumers to scan and pay the bill through the mobile application Alipay, which is operated by ALIBABA, the largest e-commercial company in China. Figure 8.4 presents the sample pages and functions in Alipay.

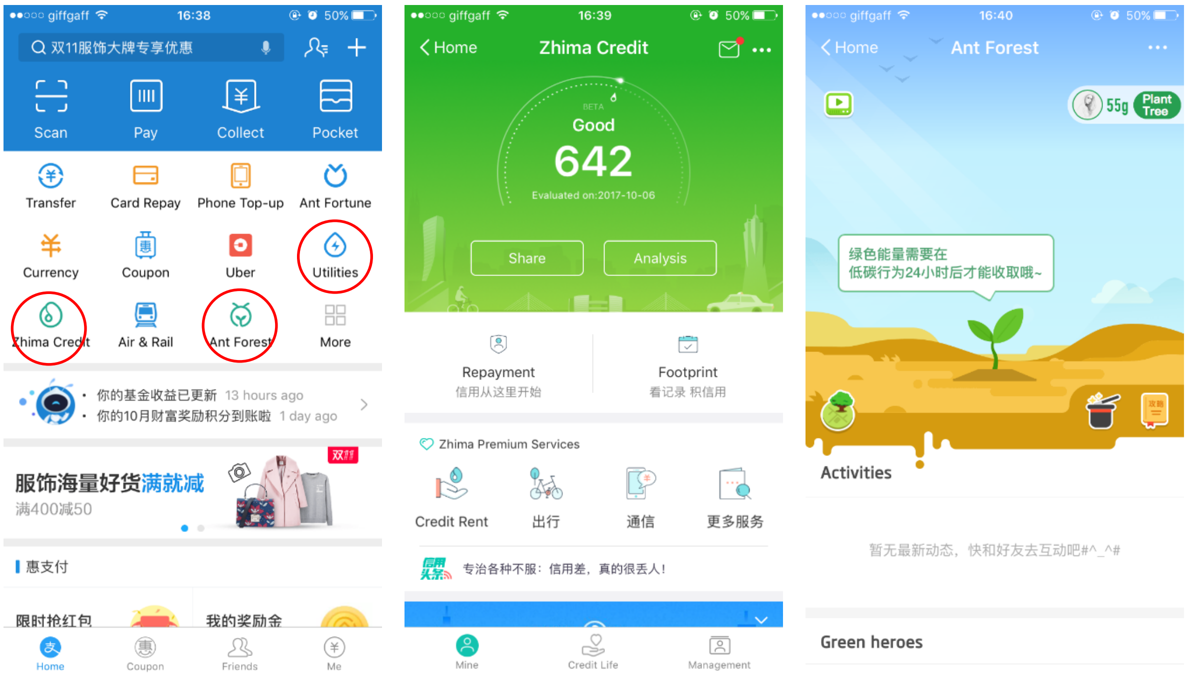


Figure 8.4. Sample pages and functions in Alipay

(Source: by Author)

From the interview study, a "conscious" consumer suggested to promote energy saving on the platform of Alipay, as almost every households in Shanghai use Alipay to pay monthly bills. Alipay is an application on the mobile phone, operated by ALIBABA, the most famous e-commerce company in China. On the Alipay homepage, there is button named "Utilities", with the function of paying electricity, gas and water bills. The users can check the electricity bill for each month in the past when their house account number is connected with the Alipay account. On the Alipay homepage, there is a button named "Zhima Credit" (Figure 8.4 middle), with the function of recording users' credit system when the payment is conducted by Alipay. Zhima Credit was designed to calculate credits for each individual with a financial credibility indicator and compliance mechanism, for example recording tax filings and driving demerits (Ming, 2017). It was designed for developing a nationwide social credit system, and provided multiple benefits for users with high credit. For instance, users with enough credits can wave the deposits for car rental or flat rental, and users with higher credits could have priority access for airport security checks. On the homepage, there is a bottom named "Ant Forest" (Figure 8.4 right), with the function for tracking individuals' carbon footprint. Ant Forest allows users to collect "energy points" through their actions in the real world that can be used to grow virtual and, ultimately, real trees. Alipay and the cooperated environmental NGOs have planted 10.25 million trees, equivalent to 1.22 million metric tons in CO_2 emission reduction by 9 September (Xinhua, 2017).

As suggested by one interviewee, experience could be learnt from the Alipay platform that, the government could develop a smart platform for energy use feedback system. As "smart city" and "digital-twin" are the hot topics in China, the Chinese government is highly possible to provide funding in developing the smart platform. The platform could be designed as the only official online system to pay the monthly bills, so that every households will install this application on their mobile phone. The feedback system can record the monthly electricity use of each household during past years. In the review system, if the households' consumption is higher than the record value, the feedback system will send a notification. If the consumption over the next several months still be high, the feedback system will set a remark in the credit system. As proposed by a "conscious" consumer, a restrain system should be established for the high-income households who ignore the increased price and continuously use too much electricity. The credit system of driving licence could be taken as an example showing that it is hard to change the residents' behaviour shortly through education but the restrain system is more powerful. On the other side, if the consumption reduced, the feedback system will issue the users with higher scores in the credit system. With the proposed system, households could gain benefits in other areas by lowering energy use, such as having priority in airport security checks ("Zhima credit" in Alipay is trying to promote this benefits now). For "comfort-driven" users with intensive patterns, savings in the energy bill are unlikely to make them change behaviour for energy saving, but they might be motivated if incentives were given in other important areas which could improve their living quality. In addition, the information feedback system could also establish a game as "Ant forest" in Alipay. For residents with more green points, the platform would plant trees with their name on the trees in the dessert. By visually showing the growing process of the trees in the feedback system, the users could be motivated by the thoughts of "*if I save a little more, I can plant a tree on the dessert*" and improving the impact from social norm variables.

Stricter standards for buildings and appliances

As indicated in the interview chapter, "comfort-driven" consumers are less interested in smart meters and less likely respond to fiscal and communication instruments, such as dynamic pricing and feedback systems. The policy instruments listed above may work more with "conscious" consumers, but regulation policy instruments may be required to address the target group of "comfort-driven" consumers. They themselves suggested the promotion of energy-efficient appliances as a potential policy instrument. In addition, based on the review of studies in section 3.2.1, the technical solution could help to achieve 20% in domestic energy saving (Guo et al., 2018). The energy saving from the improvement of building components should also be considered.

As mentioned in section 2.4, China implemented the national standards for appliances, named "Administration Regulation on Energy-Efficiency Labelling". Table 2.4 lists the energy efficiency grade specification for air conditioners in 2010. The table shows that the minimum allowable values of energy efficiency ratio (EER) were 3.6 (up to 4.5 kW), 3.5 (4.5–7.1 kW), and 3.4 (above 7.1 kW) for each category of for a split-unit air-conditioner. Within the 2006 version of Japan's Top Runner Program, that eliminates the most inefficient products in the market and sets the high performing products as a new minimum standard, the target EER values for a split-unit air-conditioner were 3.23 (up to 4 kW), 3.23 (4–7 kW), and 2.47 (above 7 kW). The 2006 level of the Japan's Top Runner standard was stricter than China's 2010 level. If a similar policy was to be implemented in China, where the most energy efficient appliance in the market would be set as the lowest standard after ten years in the market, this could shift domestic appliances toward becoming more efficient, and greatly improve the energy performance of the appliances.

Zhou et al. (2018) compared the building energy simulation of five buildings in Tianjin, China with the buildings designed based on the German standards (WSVO-1995, EnEV-2002 and

EnEV-2009) and summarised that the annual heating energy consumption will be reduced by 14.9%, 21.9%, and 36.1% respectively, compared with case building designed based on the step three building energy efficient standard (65% saving compared to the pre-1986 benchmark mentioned in section 2.4.1) in Tianjin. Therefore, stricter building standards could be applied in the context of China to improve building energy efficiency. Even though some researchers revealed that occupants' energy use behaviour would be more energy intensive if they move into the building with better performance (Majcen, Itard and Visscher, 2015), the improvement of building components is still important with the large energy saving potential. Some residents may think their building is more energy efficient and tend to use appliance more frequently or maintain the room at a more comfortable temperature. However, with the development of the society, people in China are more focused on improving the living standard rather than energy saving. It means that the energy use behaviours are shifted towards more intensive if occupants can earn more money, even if they live in the same building as before. The upgrade of building components and domestic appliances could help to relieve the burden of intensive energy use. The post-occupancy evaluation system is also suggested to take the behavioural impacts into considerations, as from the single-zone simulation in section 7.5, 20% of energy saving potential could be achieved by changing the set temperature for space conditioning or reducing the air conditioning hours, individually. Apart from that, education of energy saving behaviours should be provided to the occupants living in more energy-efficient buildings.

8.4 Effectiveness of theoretical framework

Following the literature review of social psychological models, the theory of Planned Behaviour (TPB) was selected in chapter 5 as the theoretical foundation in this thesis. This research aimed to explore how useful the TPB is for understanding energy use behaviour in the context of domestic energy use in China. The variables in TPB were used in the design of the survey and interview questions.

In the survey study, in order to test the factors that affect intentions to save energy under potential energy saving policies, each question that addressed each variable (attitude, subjective norm, perceived behavioural control and intention to save energy) was designed to explore the relationships between socio-psychological variables. According to the regression analysis, three socio-psychological variables (attitude, subjective norm, and perceived behavioural control) were able explain 17.9% of the variance in intention to save energy with potential policies. Respondents with more positive attitudes toward smart meter policy and more restraint in subjective norm from family members were more likely to change their behaviour toward domestic energy saving if these policies were implemented. According to the correlation analysis, it was found that socio-demographic variables could partly explain the variation in the socio-psychological variables in TPB. The socio-demographic variables of age and educational level showed good explanatory power of the psychological variables of subjective norm and perceived behavioural control. The socio-demographic variable of family income level had the best explanatory power of attitudes toward smart meter policies.

The application of TPB in this thesis was helpful in exploring further variables that affect the intention to save energy other than attitude, such as norms that can be shaped by educational or family background or perceived control. The survey results showed that, with the help of correlation analysis, income level was correlated with the attitude toward smart meter policies, so that it indirectly affected the intention to save energy with potential policies. Age and educational level affected the socio-psychological variables of subjective norm and perceived behaviour control, indirectly affecting the intention to save energy with potential policies. Thus, the use of TPB was also helpful in identifying target groups with certain demographic variables for specific policy instruments.

In the design of the semi-structured interviews, the components in of TPB were adopted to understand the motivations behind energy use and how their attitudes and norms had shaped behaviour. The application of TPB in this thesis not only considered attitude as a variable, but also took the subjective norm and perceived behavioural control into consideration in the qualitative analysis, which helped to develop a wider angle of understanding of the motivations and drivers of energy saving intentions. Compared to the lack of theoretical framework in existing behavioural studies in China that have a very practical focus (see chapter 3), the application of TPB in this thesis could address the research gap of the lack of knowledge about the links between behaviour and attitudes.

8.5 Contribution to the field of study

The literature review in chapter 2 identified a lack of policy instruments to address domestic energy use behaviour in China. This thesis adopted the Theory of Planned Behaviour (TPB) in the occupant survey and interviews, and combined it with quantitative smart meter data clustering as a mixed methods approach to address this research gap. According to the review of the limited number of studies on energy use behaviour in China, as mentioned in chapter 3, most existing studies use a single method. The mixed methods in this thesis helped with understanding not only occupancy patterns and behavioural pattern clusters, but also occupants' motivations and norms for energy saving among young urban households in China. The application of TPB in the survey and interviews illustrated that TPB is useful in exploring occupants' attitudes and behaviour in this research context.

This thesis has revealed the great diversity of occupants' behaviour and attitudes, even within the similar socio-demographic group of Shanghai urban young households. This thesis has identified the heating and cooling patterns as a main variable in energy use intensity and the income level as a key variable in determining the patterns. It has also addressed the urgent need to keep as many consumers as possible as level 1 consumers, as this research shows that with the increased income level they are likely to grow into level 3 consumers with their consumer habits and higher comfort expectations. This thesis demonstrates the importance of behavioural measures to address domestic energy use behaviour in energy saving policies, in addition to improvements in building components and appliances. This thesis has used regression and correlation analysis to explore the factors that affect domestic energy use and the intention to save energy. The results could be used to design more effective policies for each target group instead of a blanket policy for all households.

This paper explored the embedded reasons behind energy use behaviour and attitudes. From the interviews, two groups were identified as "comfort-driven" and "conscious" consumers. It was summarised that family influence, change of social structure, educational background and income level were influential in affecting the psychological variables and shaping energy use behaviour. Among them, educational background showed a great impact on the psychological variable of attitudes (A) and affected behaviour, and the family influence shows some impact on the psychological variable of subjective norms (SN) and affected behaviour.

This thesis has also revealed the fact that energy use profiles based on smart meter data can increase knowledge about actual energy use patterns in China, that according to the pilot study differ greatly from the simulated results where assumptions are based on Western occupancy patterns. In the context of China, there is a lack of analysis of energy use data in the design of energy saving policies or building regulations. This thesis has revealed that with the help of energy use data, policy design could be more precise, which might make it more practical for specific cities located in different climate zones and for different occupant groups. This can provide accurate and valuable data support for the government to set reasonable energy efficiency policy and promote building energy saving work.

This paper explored how useful the TPB is for understanding energy use behaviour in the context of domestic energy use in China. The variables in TPB were used in the design of the survey and interview questions. Three psychological variables in TPB were able explain 17.9% of the variance in intention to save energy. The application of TPB was helpful in exploring further variables that indirectly affect the intention to save energy, such as norms can be shaped by educational or family background.

This paper also came up with three energy saving policy suggestions for reducing domestic energy use. The smart meters could be installed for households with higher income level, as they are more likely to have higher consumption level and more positive attitudes towards smart meter. For high energy consumers, higher energy pricing in transition months for heating and cooling could be applicable. For the "conscious" consumers, smart meters with real-time displays plus monthly suggestions of how to save energy was identified as an effective instrument. Besides, the energy use credit and feedback system might be useful to tackle the attitudes of "comfort-driven" consumers, where benefits in other areas such as fast security checks or motivation gams of visually seeing trees growing up, could be a motivator for them to save energy. If policy-makers are fully aware of these possible changes, they can better forecast energy demand and make fact-based decisions on energy saving policy design.

8.6 Limitations and future recommendations

There are several limitations in this research. The first limitation is the sample size. In chapter 5, the sample used in the survey study is limited to a relatively young population due to the online questionnaire data collection method, since old people in China have limited knowledge of and access to the internet. This limitation is acceptable, as the aim of chapter 5 is to identify the factors that affect occupants' attitudes and behaviour with a focus on young urban residents and relatively young respondents are more preferred. In chapter 6, there are five participants interviewed, in which it cannot represent the selected samples of urban households in Shanghai. This limitation is acceptable, as the aim is not to generalise the findings from the interview study, but to explore further information for the target group of young urban highly-educated residents. In chapter 7, due to the limited smart meter data available in China, the sample of valid smart meter data used for analysis is limited to 126 flats with limited demographic information. In addition, it could be better if the survey studies could be done for the monitored occupants. However, the demographic information of the monitored households was waved for privacy purpose and it is not possible to find them. In the future, it is highly recommended that the survey and interview studies could be done for the same group of monitored occupants. As the sample size is limited in this research, more samples should be obtained to obtain constructive research results in the future. This reflects the gap in energy use data available in China. With the development of smart infrastructure in China, more stable electricity use data could be obtained to explore the occupancy patterns and provide further important information for demand-side management.

The second limitation is the limited information of building construction materials, domestic appliances and room orientations for the single-zone simulation analysis. The model was built by using the assumption based on the minimum requirement of building codes, which will lead to a large performance gap. This limitation is acceptable in this thesis, as section 7.5 is aiming to test the energy saving potential of two behavioural measures with the variance input of energy use patterns of 126 monitored households. It reflect the limited public available data of building information for research purpose. In the future, if similar research would be done, it could be better if detail building construction information could be obtained for the monitored households so that the simulation model could be calibrate more.

The third limitation is the research design of the mixed-method research approach. This thesis uses three empirical studies to explore the complexity of energy use behaviour in a full angle. In the design of three empirical studies, it seems that the survey and interview studies are more related but the analysis of smart meter data is not that closely related. This limitation is from the differences in the samples of three studies (smart meter data sample is not surveyed). The analysis of smart meter data in this thesis aims to test the information could be extracted from the smart meter data and the energy saving potential of using air conditioners more precisely. It contributes to a deeper understanding of energy use patterns and energy saving potentials from behavioural change, thus it is not useless. In the future, it would be better if the monitored households could be surveyed and interviewed, many interesting research could be done with adequate information for the same group of sample. For instance, by combining the results of occupants' willingness to respond to information on the smart meter display (from survey study) and the energy saving potential of each behavioural measures simulated by occupants' energy use patterns extracted from smart meter data (from single-zone simulation), how much electricity could be saved for this group of people can be calculated. In addition, by combining the results of respondents' demographic variables and their energy use practices such as temperature settings (from survey study) and the energy use characteristics of each households and the groups they belong to based on daily profiles (from cluster analysis), correlations might be detected between the cluster groups they belong to with the demographic variables of occupants and more precise energy saving policies and demand-side management strategies could be designed for target groups classified by the demographic variables.

The forth limitation is the lack of connection of technical solution between these behavioural solution. Based on the review of existing policies in China in section 2.4, domestic energy saving policies are mainly focused on the improvement of building fabrics and appliances, with the lack of consideration on behavioural factors. At same time, many researchers indicated that about 20% of energy saving could be achieved by improving energy use behaviour. Thus, behaviour is identifies as a key to achieve the 60–65% energy saving goal by 2030 in the domestic sector. From the review of energy saving potential from the improvement of building fabrics and domestic appliances in section 3.2.1, about 20% of energy could be saved with the improvement of building components and appliances, and 36% of energy saving potential could be achieved if the German EnEV-2009 standard could be applied. As multiple studies have been on the technical solutions of building fabrics, this research only focuses on the behavioural solutions. In the future, simulations could be done for technical solutions only, behavioural solutions only, and the combination of technical and behavioural solutions, to test the effectiveness of technical and behavioural solutions for more effective policy design.

The fifth limitation is the limited findings regarding four energy saving initiatives. According to the cross analysis of three empirical studies, different policy instruments were recommended for different type of users. For instance, for "conscious" consumers, smart meters with in-home displays, dynamic electricity pricing system and review, reward and restrain feedback systems were suggested. For "comfort-driven" consumers, stricter standards for buildings and appliances were suggested. However, in this research, it only proposed four policy initiatives, but how fruitful of those policies was not tested such as how much electricity could be saved if the smart meter with in-home display was installed for level 3 consumers. In addition, the details of how the dynamic electricity pricing system is designed and how the review, reward and restrain system might be operated are not explained. In the future, the detail proposal of 1) how the smart meter data could be used for demand-side management and how the feedback information could be designed to achieve a high policy effectiveness; 2) how the dynamic electricity pricing system can be designed to target on high energy users with the consideration of residents' acceptance of higher electricity price; 3) how the review, reward and restrain system could be designed to promote the energy saving awareness of "comfort-driven" consumers; and 4) how useful of each single policy initiative and the embedded barriers within them can be expanded and explored further as four PhD/MPhil research topics.

For similar behavioural studies in the future, it is hard to say which research method is more useful. As mentioned before, the combination of mixed methods could contribute to more fruitful findings and more precise policy design. This section lists five limitations identified in the research process and proposes suggestions of how to improve the method of data collection or data analysis and what could be done better. This section also indicates four research topics for future research.

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Appendix A
Behavioural survey questionnaire for Shanghai residents

Behavioural study for Shanghai residents

The survey had multiple-choice, rating-scale, and open-ended questions about smart meters, in-home energy displays, demand response pricing programs, and electricity use. Thanks for your participation.

Socio-demographic information

1) Respondent's age?
   a) =<20
   b) 20-30
   c) 30-40
   d) 40-50
   e) 50-60
   f) >60
2) Respondent's gender?
   a) Male
   b) Female
3) Education level?
   a) High school or lower
   b) Undergraduate
   c) Postgraduate
4) Family annual income?
   a) 0-10 ten thousand RMB
   b) 10-20 ten thousand RMB
   c) 20-30 ten thousand RMB
   d) 30-50 ten thousand RMB
   e) More than 50 ten thousand RMB
5) Number of occupants at home?
   a) 1
   b) 2
   c) 3
   d) 4
   e) 5 or more
6) Private or rental housing?
   a) Rental
   b) Private
7) Do you need to pay electricity bill?
   a) No
   b) Need to pay

Buildings, appliances and consumption

1) Number of bedrooms?
   a) 1
   b) 2
   c) 3
   d) 4 or more
2) Building construction year?
3) Total floor area?
4) Annual electricity consumption in electricity bill?
5) How many air conditioners at home?
   a) No
   b) 1
   c) 2
   d) 3
   e) 4
   f) 5 or more
6) Air conditioner in bedroom
   a) No
   b) Yes
7) Air conditioner in lounge
   a) No
   b) Yes
8) Air conditioner in study
   a) No
   b) Yes
9) Electrical water heater
   a) No
   b) Yes
10) Gas water heater
    a) No
    b) Yes
11) Solar water heater
    a) No
    b) Yes

Energy use behaviour

1) Average heating temperature?
2) Average operation hours of air conditioners in winter (h)?
3) Heating start period?
   a) October
   b) November
   c) December
   d) January
   e) Other
4) Heating stop period?
   a) January
   b) February
   c) March
   d) April
   e) Other
5) Average cooling temperature?
6) Average operation hours of air conditioners in summer (h)?
7) Cooling start period?
   a) May
   b) June
   c) July
   d) August
   e) Other
8) Cooling stop period?
   a) August
   b) September
   c) October
   d) December
   e) Other

Attitude towards smart meter
("1=strongly disagree" to "5=strongly agree")

1) Smart meter can let you check the accuracy of your electricity bill
2) Smart meter can save you money
3) Smart meter can tell you how much electricity each of your appliances is using
4) Smart meter can reduce the risk of blackouts
5) Smart meter can control your central air conditioning
6) Smart meter can let electricity company control your electricity use
7) Smart meter can cost you money
8) Smart meter can violate your privacy

Attitude towards energy saving policies
("1=strongly unwilling to accept" to "5=strongly willing to accept")

1) The government will install smart meters for free
2) The government will install smart meters for free and will provide monthly suggestion for how to reduce energy consumption
3) The government will install smart meters for free and will inform you to switch off domestic appliance with high energy consumption
4) The government install smart and will cut off electricity when you use electricity of more than up-limit at peak time
5) "Green Point" scheme: for the occupants with higher green point in their account, they could enjoy lower interest rate for bank's loan when you want to buy a new house
6) Real-time electricity pricing: higher electricity price if they use electricity at the peak time; in the opposite, pay less
7) Stage electricity price: pay more if they use electricity of more than a limit for each month; in the opposite, pay less

Norms, control and intention to save energy

1) Family members' attitudes towards energy saving and sustainability
    1) Strongly unwilling to
    2) Unwilling to
    3) Normal
    4) Willing to
    5) Strongly willing to
2) Do you think it is difficult to change behaviour to save energy at home?
    1) Very difficult
    2) Difficult
    3) Normal
    4) Easy
    5) Very easy
3) Are you willing to change behaviour for energy saving if you notice too much real-time electricity consumption on the in-home display?
    1) Strongly unwilling to
    2) Unwilling to
    3) Normal
    4) Willing to
    5) Strongly willing to
4) Which behaviour measure are you willing to consider when you notice high real-time consumption? (yes/no)
    a) Switch off air conditioners
    b) Change time to use washing cloths
    c) Change time to wash dishes
    d) Change time to heat up water
    e) Change time to use kettle
    f) Change time to take shower

Appendix B
Semi-structured interview questions for Shanghai residents

Site observation

1) How many air conditioners?
2) How many rooms?
3) Shadings?
4) Appliances?
5) Bathroom heater?
6) Electricity meter?
7) Any other special things?

Energy use behaviour

8) Comfort standard? Which room used most? Do you often feel warm?
9) Heating/cooling period?
10) How to maintain indoor temperature? Temperature setting?
11) How do you operate this appliance (walking around)?
12) Do you often open window? For ventilation? Why? How long?
13) Do you close window when using the AC?
14) How to use the AC? Do you switch off AC when leaving the room?

Attitudes and norms

15) How do you rate yourself, in terms of sustainability?
16) Do you feel concerned about consumption?
17) Are you aware of the climate change?
18) Do you think we should save energy?
19) Do you recycle?
20) Do you drive to work or use the public transportation?

Factors that affect practices

21) How practices changed during your life time?
22) Do you think your parents' energy use habits affect your daily routines?
23) Does the electricity price affect your electricity use behaviour?
24) Do you discuss electricity price at home?
25) Do you look at Energy Label when buying appliances?
26) What do you think can help you save energy use?
27) How do you often pay the electricity bill? Every month?
28) Do you check the electricity meter often?
29) Do you think the information could influence your energy use behaviour?

Knowledge and attitude to policies

30) Do you think we should save energy?
31) Do you know any energy saving policies in Shanghai?
32) What are the important factors affect your behaviour under energy policies?
33) Do you know smart meters?
34) Do you think smart meters with in-home display can help you save energy? Why?
35) Will you consider to change behaviour to save energy with proposed energy saving policies?

Appendix C
Ethical Approval to conduct the interviews granted by the Ethics Committee of the School of Humanities and Social Sciences

SHSS Research Ethics Committee 2015/16 Application Form

UNIVERSITY OF CAMBRIDGE

SCHOOL OF THE HUMANITIES AND SOCIAL SCIENCES

Application for ethical approval of a research project
To be completed by the applicant

REFERRAL
Prior to applying to the School Research Ethics Committee, your project must have already been submitted to your Department/Faculty Ethics Committee. If they recommend that your project is referred to the School REC, your Department/Faculty Administrator will then forward this form to HSS REC. *Please do not complete or submit this form unless your Department/Faculty Ethics Committee or Department Administrator has asked you to do so.*[*]

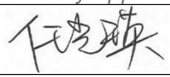
Title of the study
Exploring effective energy saving policies in domestic sector through encouraging behavioural change: Shanghai as a case study

Primary applicant	
Notes: The primary applicant is the name of the person who has overall responsibility for the study. For student projects, this will be the main supervisor	
Primary applicant:	*Dr Minna Sunikka-Blank*
Student name:	*Guangying Ren*
Department affiliation:	*Senior Lecturer*
Notes: If you don't have a departmental affiliation, please email cshssethics@admin.cam.ac.uk in the first instance, to receive guidance on how to proceed.	
Contact email address:	*mms45@cam.ac.uk*

Co-applicants
Notes: List the names of all researchers involved in the study. Include their departmental affiliations, appointment or position held and their qualifications. Please expand the form as necessary to complete this section.
Guangying Ren *PhD Candidate* *gr350@cam.ac.uk*

Start and end dates of the study	
Research start date:	*14/09/2017*
Research end date:	*14/10/2017*

[*]Some departments will use this form for their own review

Signatures of the study team	
Notes: The primary applicant and all co-applicants must sign the form. For research students, the supervisor will be the primary applicant and their signature is also required. Electronic signatures are acceptable.	
Signature:	
Position:	*Primary applicant*
Signature:	
Position:	*Co-applicant*

Date of Application:	*13/09/2017*

Appendix D
Participant information letter (in both English and Chinese version)

Request for participation and interviews with Shanghai residents

Cambridge University Department of Architecture

Dr Minna Sunikka-Bank and Guangying Ren

Dear participants,

We would be very grateful for your participation and assistance in conducting a research project for the Department of Architecture, Cambridge University.

In this project we want to exploring effective energy saving policies in domestic sector through encouraging behavioural change: Shanghai as a case study. Our team member Guangying Ren would like to visit you and talk to you about your energy use behaviours and energy saving attitudes. He would then like to interview you for up to 45 minutes, recording the interview on a digital audio recorder. We would later transcribe relevant parts of the interview and use sections of this in academic publications and presentations.

In order to protect your privacy and conform to privacy laws, we would strictly observe the following rules.
1. Anonymity: Your identity will be unknown to all but the two researchers on the project, Dr Minna Sunikka-Blank and Guangying Ren. Any information we use from the visit and/or interview will be anonymised. Names, occupations and other identifying characteristics will be changed; addresses left blank; any descriptions of homes will be altered so that identification is not possible.
2. Protection of data: The digital recordings and all notes taken will be stored securely and be accessible only to Dr Minna Sunikka-Blank and Guangying Ren. The data will not be accessible to the line managers of these two researchers, nor to any other personnel within or outside of their institution. After the research project is completed, including the writing of relevant publications, all this data will be destroyed.
3. Purpose use only: The information and data will be used for the findings of this research project only, and will not be used for any other project, current or future. The findings of this research project may be published as academic articles in scientific journals and/or book chapters; as lectures and presentations for academic conferences and teaching; and in non-academic publications reporting on the findings which have been, or are being, published in academic articles, books and presentations.
4. Right to withdraw: If you agree to participate in this project, you may withdraw at any time, including after the visit and interviews. In that case, from that moment on the data pertaining to you will no longer be used, and all such data being held will be destroyed.

We hope very much that you will agree to participate in this research project. We look forward to being in touch with you again in the near future.

Thank you and good wishes,

Dr Minna Sunikka-Blank
Guangying Ren

受访同意书

尊敬的参与者，

非常感谢您对剑桥大学建筑系研究项目的参与和协助。本受访同意书提供给您一些信息，请尽可能仔细阅读以下内容。它可以帮助您了解该项研究以及为何要进行这项研究，研究的程序和期限 。请您仔细阅读，如有任何疑问请向研究人员提出，并请研究人员给予解释，直至您对本项研究完全理解。

1）研究项目名称：关于上海地区住宅建筑行为节能政策的研究
2）主要研究者和调查员：Minna Sunikka-Blank；任光瑛
3）项目背景和研究目的：
4）研究简介：

我的博士研究课题是关于上海地区住宅建筑行为节能政策的研究。希望通过社会科学研究方法，基于计划行为理论，探索有效的行为节能政策。我的研究主要分为四个部分：文献调查、问卷调查、半结构化访谈和智能电表数据分析。希望能通过整合分析各部分的数据，提出有效的关于行为节能的政策建议。

5）研究过程：

如果您愿意参加该研究，我们将会询问您的用电习惯，您对于节能政策的态度，和您对于智能电表的认知。该过程为访谈形式，大概需要占用您 45 分钟的时间。

6）个人信息及记录的保密：

如果您决定参加本项研究，您参加本研究及在研究过程中的个人资料将严格保密。所有研究组成员都被要求对您的身份信息保密，可以识别您身份的信息将不会透露给研究组以外的成员，除非获得您的许可。该研究结果发表时，将不会披露您个人的任何信息。

7）可以自愿选择参加研究或中途退出研究：

是否参加研究完全取决于您的意愿。如果您对本研究有任何疑问，您可以向研究人员提出来。您也可以拒绝参加此项研究，或在研究过程中的任何时间退出本研究，这都不会影响您和研究人员之间的关系，不会影响您的权益。

8）联系人：

在研究过程中，如果您有任何与本项研究有关的疑问或不理解的事情，或如果您认为在参加本研究中您受到非公正对待，您随时可向负责该研究的人员提出。

联系人：任光瑛；微信：guangying_ren

非常感谢您百忙之中的支持！

Appendix E
Sample of informed consent form

INFORMED CONSENT FORM
受访同意书

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.
我确认我已阅读并理解研究信息表，并有机会提出问题。 ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.
我知道我的参与是自愿的，我可以随时没有理由自由退出。 ☐

I agree to take part in the above study.
我同意参加上述研究。 ☐

	Yes 是	No 否
I agree to the interview being audio recorded. 我同意这次访谈被录音。	☐	☐
I agree to the use of quotes in publications. 我同意我的言论被引用。	☐	☐
I request anonymity. 我要求匿名。	☐	☐

Name of Participant 受访者姓名	Date 日期	Signature 签名
Guangying Ren Name of Researcher 研究员姓名	Date 日期	Signature 签名

Appendix F
Pilot study 1: sample buildings in building performance simulation

Sample 1a: pre-1990 notional dwelling

The case household is located in Shuguang no.4 community, Jiangdong City, which was built in 1984. There are 5 stories of that building, and the case household is located on level 3. Figure F.1 shows the external appearance. The indoor temperature was set as 16-28°C. The window to wall ratio was around 30% according to estimation, installed with single glazing steel frame window. The total area of that room is around 76.12 m^2. The energy intensity of this household was around 12.49 kWh/m^2 per year, based on information collected from actual electricity consumption data.

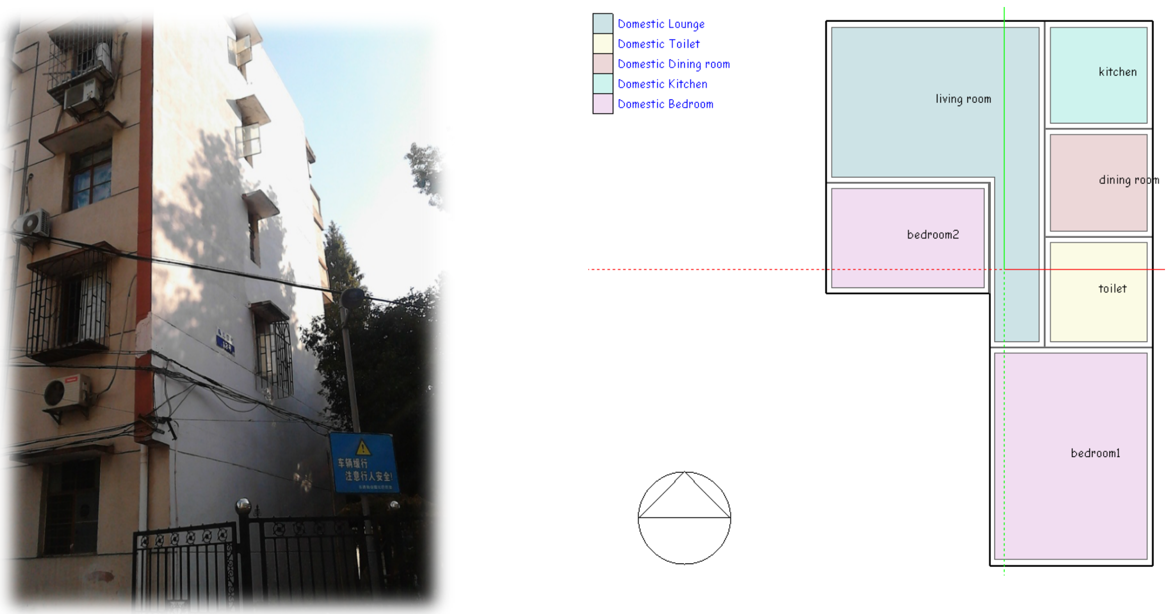


Figure F.1. External appearance (left) and plan layout in DesignBuider (right) of sample 1a

As construction material was hard to know, the construction material was simulated according to the residential building regulations of the built year of this building, shown in Table F.1. The air change rate was assumed as 3.5 for the 1984 built residential buildings. The lighting and air-conditioning schedule in simulation used the default setting in DesignBuilder. The results will be shown in Table F.2. The predicted energy intensity of 105.78 kWh/m^2 per year was far different from actual intensity of 12.49 kWh/m^2.

Table F.1. Construction material for sample 1a

	Structure	U-value [W/m^{2}K]	R-value [m^{2}K/W]
Wall	100mm brickwork 13mm plaster	2.215	0.452
			Transmittance
Window	3mm clear glazing	3.835	0.821

Table F.2. Simulation results of sample 1a

	Electricity [kWh]	City Cooling [kWh]	City Heating [kWh]
Heating	0	0	2546.81
Cooling	0	3923.02	0
Interior Lighting	594.12	0	0
Interior Equipment	553.91	0	0
Water Systems	0	0	433.74
Total End Uses	1148.04	3923.02	2980.55
Energy intensity	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]
	15.08	51.54	39.16
Total	105.78		

Sample 2a: 1990-2000 notional dwelling

The case household is located in Yinxing community, Jiangdong City, built in 1993. There are 7 stories of that building, and the case household is located on level 2. Figure F.2 presents the external appearance. The indoor temperature was assumed as 16-28°C in simulation. The window to wall ratio was assumed as 30% in simulation, installed with the double glazing aluminium frame window.

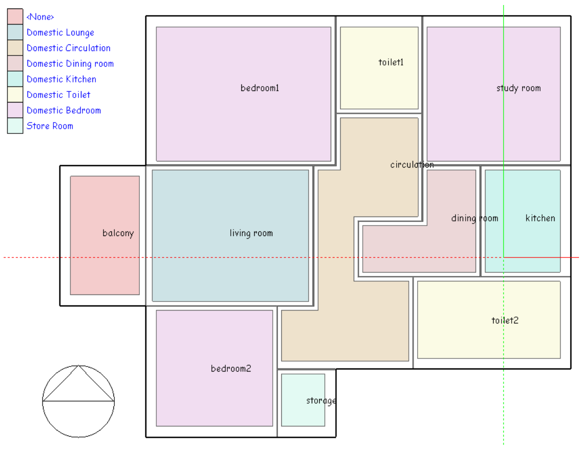


Figure F.2. External appearance (left) and plan layout in DesignBuider (right) of sample 2a

The average electricity consumption was around 180 kWh each month. In the heating period, the electricity demand was around 300 kWh; in the cooling period, electricity demand was more than doubled to 400 kWh. The total energy consumption each year was around 3827 kWh each year. Apart from the balcony, the total air-conditioned area is 97 m^2. Then the energy intensity was around 39.45 kWh/m^2 per year.

The standard for 1993 building is different from 1984 building. Thus, the construction material for the new-developed building is improved. As the material information was hard to collect, the buildings material was assumed as the lowest requirements of buildings built in that year, shown in Table F.3. The air change rate was assumed as 2.5 for the 1993 built residential buildings. The lighting and air-conditioning schedule was set using the default set in DesignBuilder. The simulation results will be shown in Table F.4. The simulated energy intensity of 106.60 kWh/m^2 per year is different from the actual use of 39.45 kWh/m^2.

Table F.3. Construction material for sample 2a

	Structure	U-value [W/m^{2}K]	R-value [m^{2}K/W]
Wall	100mm brickwork 25mm wood framing 100mm brickwork 13mm plaster	0.818	1.222
			Transmittance
Window	3mm clear glazing 13mm air 3mm clear glazing	1.960	0.821

Table F.4. Simulation results of sample 2a

	Electricity [kWh]	City Cooling [kWh]	City Heating [kWh]
Heating	0	0	2944.7
Cooling	0	5052.25	0
Interior Lighting	917.61	0	0
Interior Equipment	746.6	0	0
Water Systems	0	0	678.7
Total End Uses	1664.21	5052.25	3623.4
Energy intensity	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]
	17.16	52.09	37.35
Total	106.60		

Sample 3a: post-2000 notional dwelling

The case household is located in Riyuexingcheng community, Jiangdong City, built in 2003. There are 25 stories of that building, and the case household is located on level 19. Figure F.3 shows the external appearance of sample 3a. The indoor temperature was assumed as 16-28°C. The window to wall ratio was assumed as 30% in simulation. This new building was installed with the double glazing aluminium frame window.

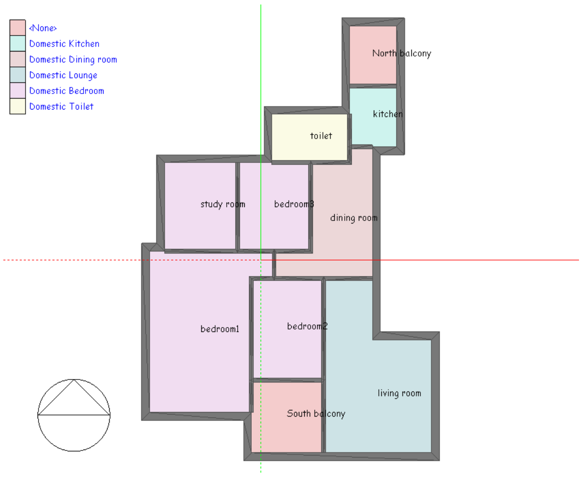


Figure F.3. External appearance (left) and plan layout in DesignBuider (right) of sample 3a

The average electricity consumption was 182 kWh each month, with the electricity bill of 88.54 RMB each month. In the heating period, the electricity demand was around 242 kWh, and in the cooling period, electricity demand was doubled to 364 kWh. The total energy consumption each year was around 182*6+242*3+364*3=2910 kWh each year. Apart from the North balcony and South balcony, the total air-conditioned area is 101.01 m^2. Then the energy intensity was around 28.81 kWh/m^2 per year.

The building construction material for the 2003 building is improved when compared with the old buildings mentioned before, also assumed as the lowest requirements of buildings built in that year, shown in Table F.5. The air change rate was assumed as 1.5 for the 2003 built residential buildings. The simulation results will be shown in Table F.6. The simulation energy intensity of 101.48 kWh/m^2 per year is different from the actual result of 28.21 kWh/m^2.

Table F.5. Construction material for sample 3a

	Structure	U-value [W/m^{2}K]	R-value [m^{2}K/W]
Wall	100mm brickwork 79.5mm XPS polystyrene 100mm brickwork 13mm plaster	0.350	2.856
			Transmittance
Window	3mm clear glazing 13mm air 3mm clear glazing	1.960	0.821

Table F.6. Simulation results of sample 3a

	Electricity [kWh]	City Cooling [kWh]	City Heating [kWh]
Heating	0	0	2300.88
Cooling	0	4861.85	0
Interior Lighting	1382.08	0	0
Interior Equipment	1270.8	0	0
Water Systems	0	0	433.74
Total End Uses	2653.57	4861.85	2734.62
Energy intensity	[kWh/m^2]	[kWh/m^2]	[kWh/m^2]
	26.27	48.13	27.07
Total	101.48		

Appendix G
Pilot study 2: behavioural survey in Ningbo

The questionnaire was handed out to randomly selected citizens Ningbo in September 2015 through Internet. The questionnaire consisted of five sections. The first section was about the demographics, including gender, age and family structure. The second section focused on the building information, including construction year, floor area, building type, room structure, occupancy patterns and annual electricity use. The third section of the questionnaire focused on domestic appliance ownership and energy use habits, including number of air conditioners in each room, and the habits of using lights and air conditioners. The forth section focused on heating practices in winter, including the heating period, set temperature for heating, average heating hour per day, indoor comfort level and peak electricity consumption in the coldest month. The fifth section was about cooling in summer, including the appliances used for cooling and the frequency of using them, cooling period, the highest acceptable indoor temperature, set temperature for cooling, average cooling hour per day, the frequency of opening windows, and the peak electricity consumption in the hottest month.

As a result, 153 responses were collected from the online survey. Due to the lack of important information from some respondents, 125 effective responses were selected out for further analysis. Among 125 effective responses, the average annual electricity use was 2432 kWh/year. Finally, 125 effective responses were grouped into high, middle and low users for comparison, based on their annual electricity consumption. Table G.1 presents the characteristics of energy use behaviour of each user cluster.

From the survey results, it shows incredibly diversity in cooling patterns in Ningbo households, for instance, the using of air conditioning varied from 2-20 hours per day in summer. The length of cooling season varied dramatically from 1-5 months. The large differences in energy demand between high and low user were mainly caused by two factors: 1) the number of appliances for each household, and 2) the way using of each appliance. In terms of energy use habits, high users were more likely to switch on air conditioner when they at home, but low user only switched on air conditioner in the bedroom when they feel unacceptably warm and switched it off immediately after feeling comfortable enough. In addition, high users were more likely to switch lights on when at home and sometimes forget to switch them off, but low users only switched lights on when they are needed.

Table G.1. Characteristics of the occupant electricity use by user cluster.

	High user	Middle user	Low user
Energy characteristics			
AVERAGE annual elec. consumption	5840 kWh	2146 kWh	840 kWh
Minimum annual elec. consumption	4500 kWh	1100 kWh	525 kWh
Maximum annual elec. consumption	10500 kWh	4400 kWh	1080 kWh
AVERAGE annual elec. intensity	42.8 kWh/m^2	20.71 kWh/m^2	12.24 kWh/m^2
Living room air conditioner ON			
Never switched on	0.0%	6.3%	33.3%
Switch on when feel uncomfortable	66.7%	84.2%	60.0%
Switch on when staying at room	33.3%	9.5%	6.7%
Living room air conditioner OFF			
Switch off when feel comfortable	40.0%	66.3%	80.0%
Switch off when leaving the room	60.0%	33.7%	20.0%
Bedroom air conditioner ON			
Never switched on	0.0%	2.1%	20.0%
Switch on when feel uncomfortable	46.7%	90.5%	73.3%
Switch on when staying at room	53.3%	7.4%	6.7%
Bedroom air conditioner OFF			
Switch off when feel comfortable	26.7%	52.6%	60.0%
Switch off before sleep	0.0%	2.1%	13.3%
Switch off at set time	0.0%	7.4%	13.3%
Switch off after awake	60.0%	32.6%	13.3%
Switch off when leaving the room	13.3%	5.3%	0.0%
Lights ON/OFF			
Switch lights on at home, sometimes forget to switch off	26.7%	20.0%	13.3%
Switch lights on when at a room	20.0%	26.3%	26.7%
Switch lights on when need	33.3%	35.8%	40.0%
Switch lights on when very need	20.0%	17.9%	20.0%
Frequency of using AC heating			
Everyday	6.7%	0.0%	0.0%
Frequently	66.7%	30.5%	6.7%
Sometimes	26.7%	54.7%	20.0%
Almost no	0.0%	13.7%	53.3%
Never	0.0%	1.1%	20.0%
Frequency of using AC cooling			
Everyday	40.0%	9.5%	0.0%
Frequently	60.0%	49.5%	0.0%
Sometimes	0.0%	34.7%	60.0%
Almost no	0.0%	4.2%	26.7%
Never	0.0%	2.1%	13.3%
Frequency of using cooling fan			
Everyday	6.7%	23.2%	13.3%
Frequently	53.3%	53.7%	20.0%
Sometimes	13.3%	12.6%	60.0%
Almost no	6.7%	4.2%	6.7%
Never	20.0%	6.3%	0.0%
Most common set temperature			
Heating in winter	22	20	most no heating
Cooling in summer	22	25 at lounge, 28 at bedroom	mainly at bedroom at 28
Average AC on hour per day	12	8	2

For heating in winter, the high users were likely to use air conditioner more frequently, while the low users used air conditioners less, even some of the low users never use air conditioner for heating, and sometimes an electric heater only. The low users were more likely to accept lower set temperature for heating with shorter heating period. For cooling in summer, the high users used air conditioners almost every day, but the low users almost never used air conditioning. Similar with winter, the low users were likely to accept higher set temperature in summer with shorter cooling period.

There are several key findings from this pilot study. Firstly, the old age group was likely to consume less energy. The young age group was likely to turn on the air conditioners for longer hours, operating with higher temperature in winter and lower temperature in summer. Secondly, the extreme diversity of energy use patterns makes it challenging to set input parameters in building energy simulation. Performance gap exists because of the lack of information in occupant behaviour, and it would result in the prebound effect that the occupant consumes less than simulated. After gaining more information of set temperature and schedule, it could help to mitigate the gap. Thirdly, according to correlation analysis, it was found that the floor area has a highest correlation with annual electricity consumption, followed by number of rooms and number of air conditioners.