Resources, Conservation & Recycling 174 (2021) 105823

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Are you an energy saver at home? The personality insights of household energy conservation behaviors based on theory of planned behavior

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ARTICLE INFO

Keywords:
Personality traits
Five factor model
Energy-saving behavior
Pro-environmental behavior
Theory of planned behavior
Building energy modeling

ABSTRACT

Personality traits play an important role in pro-environmental behavioral heterogeneity. This study aims to explore the effects of Big Five personality traits on the energy-saving behavior of residents based on the extended theory of planned behavior (TPB). We employ the k-means algorithm to cluster 1119 respondents in Xi'an, China by their personality characteristics into four groups: (1) the positives, (2) the temperates, (3) the conservatives, and (4) the introverts. The research observes significant heterogeneity of energy-saving behavior among the four resident groups. We examine the behavioral pattern of each resident group, and the analysis indicates that TPB attributes bridge personality traits and household energy-saving behaviors. The extended TPB factors explain the best performance on household energy-saving intention and behaviors of the positives. Besides, the results present the different effects of psychological factors on the energy-saving behaviors of different resident groups. The positive and temperate groups' energy-saving intention is more sensitive to subjective norms, while perceived behavior control plays a more critical role in other groups. This study could broaden the scope of pro-environmental behavior research and advance knowledge by untangling the intertwined relationship between personality traits and household energy-saving behavior. The findings can contribute to occupant typology development, which is important to capture the diverse energy effect of occupant activity in building energy simulation research as well as differential energy-saving intervention setting in residential buildings to achieve sustainable development goals.

1. Introduction

The residential sector is one of the most important energy consumers, contributing 27% of global energy consumption and 17% of carbon emissions (Nejat et al., 2015). Although the overall carbon emissions have decreased globally during the COVID-19 epidemic (Liu et al., 2020a; Tollefson, 2020), the residential sector has dramatically consumed more energy than before (Rouleau and Gosselin, 2021). This increase comes from the long-term home-stay of residents under the extensive home office and remote learning mode (Klemeš et al., 2020). In addition to the common energy-saving methods, such as energy-efficient building services (Li et al., 2013; Shi et al., 2016) and sustainable materials (Weng et al., 2020), sufficient empirical observations have evidenced that energy-saving interventions can reduce household energy consumption by 10%–30% (Allcott and Rogers, 2014; Hafner et al., 2020; Schwartz et al., 2015; Xu et al., 2021). Also, the behavior-driven energy-saving strategy requires less capital and time investment than other methods. Thus, promoting residents' energy-saving behaviors seems a promising sustainable development strategy in the residential sector (Allcott and Rogers, 2014).

The research community has developed various theories to explain the psychological process of household energy-saving behavior and explored the critical factors in this process (Fornara et al., 2016; Wang et al., 2018a; Wittenberg et al., 2018). Among them, the theory of planned behavior (TPB) and its extensions are the most widely-used models in pro-environmental behavior studies (Liu et al., 2020b; Ru

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https://doi.org/10.1016/j.resconrec.2021.105823
Received 25 February 2021; Received in revised form 16 July 2021; Accepted 22 July 2021
Available online 10 August 2021

et al., 2018; Wang et al., 2014). Several existing research has confirmed that the core factors in TPB (i.e., attitude, subjective norms, and perceived behavior control) can well predict household energy-saving behavior (Abrahamse and Steg, 2011; Ru et al., 2018; Wang et al., 2014). These studies have significantly contributed to residential energy behavior intervention (Hafner et al., 2020; Schwartz et al., 2015).

Some studies have reported the heterogeneity of residents' energy use behavior as well as psychological attributes (Allcott and Rogers, 2014; Ma et al., 2013; Mi et al., 2021; Poškus, 2020; Sütterlin et al., 2011). For example, Ma et al. (2013) observed that even similar households in the same community have significant differences in energy consumption habits. Besides, Poškus (2020) and Mi et al. (2021) suggests that the heterogeneous effect of psychological attributes on residents' pro-environmental behaviors. These heterogeneities lead to uncertainty about the effectiveness of energy interventions and policies in the residential sector. Personality traits refer to an individual's stable perception, thinking, and behavior patterns (Fiske, 1949), and are recognized as the originals of these heterogeneities (Brick and Lewis, 2016; Farizo et al., 2016; Poškus, 2020; Wang et al., 2021). Previous studies have discussed the role of personality traits in energy-related behaviors in office buildings (Hong et al., 2020; Schweiker et al., 2016). However, its underlying working mechanism and the critical factors in this process are still unclear.

To bridge this research gap, this study aims to explore the role of Big Five personality traits in household energy-saving behavior process with the extended TPB. This study has two main contributions. First, this research empirically evidences that personality traits are meaningful to explain the individual heterogeneity in household energy-saving behavioral patterns. Second, the study employs the extended TPB to explain how personality traits influence household energy-saving behaviors and expand the research paradigm of pro-environmental behavior studies. We emphasize the influence of interaction between personality traits and psychological attributes on residents' household energy-saving behavior potential and preferences. This and further experiments would build up a basis for a typology of residential building occupants. The findings would contribute to not only modeling occupant behavior in the building energy simulation but also the design and implementation of differential information interventions to promote residents' energy-saving behaviors.

The rest of this paper is structured as follows: Section 2 is literature review. We first clarify the definition and classification of household energy-saving behavior, then review the pro-environmental behavior studies employing extended TPB and personality trait theory. Section 3 is methodology, where we show the questionnaire design, the data collection process, and the data analysis methods. The fourth section presents and compares the analysis results. Section 5 not only discusses the analysis results, but also highlights the implication and limitations of this study. The conclusion is then drawn in Section 6.

2. Literature review

2.1. Household energy conservation behaviors

Occupant behavior is the original of building energy consumption: buildings consume energy to provide them with a comfortable environment and meet their needs (Hu et al., 2017). Promoting energy-saving behaviors has been a promising strategy for sustainable development (Cao et al., 2016; Paone and Bacher, 2018; Zheng et al., 2014). This section reviews the definations and classifications of household energy conservation behaviours in previous research. Trotta (2018) defined household energy-saving behavior as "the daily and habitual practices of households that focus on specific reductions in energy use" (Trotta, 2018). Urban and Ščasný (2016) defined it as "a one-dimensional class of behavior defined by its ultimate goal of energy conservation" (Urban and Ščasný, 2016). Based on the above studies, the defination of household energy-saving behavior can be concluded as a collection of pro-environmental behaviors aimed at reducing energy consumption, such as electricity conservation behavior (Wang et al., 2018b) and energy-efficient system adoption (He and Veronesi, 2017).

There are two common household energy-saving behavior classification methods: (1) by scene; and (2) by nature. The first method classifies household energy-conservation behaviors according to the scenes where they occur (Chen et al., 2013; Wang et al., 2020). For example, Wang et al. (2020) categorized 16 household energy-saving behaviors into four scenes: kitchen, living room, bedroom and bathroom. Chen et al. (2013) analyzed bedroom, living room and kitchen energy behaviors respectively. The method pays more attention to environment characteristics rather than the purpose of behaviors. The second method focuses on the purpose and nature of energy consumption (Zheng et al., 2014). For example, several studies divided energy-saving behavior into three groups: (1) heating, ventilation, and air conditioning (HVAC), (2) lighting, and (3) domestic hot water use (Caputo et al., 2013; Pérez-Lombard et al., 2008). The energy consumption of those systems accounts for more than 50% of the total household energy consumption (Pérez-Lombard et al., 2008). In addition, several researches added sustainable cooking behavior into this framework (Hager and Morawicki, 2013; Yu et al., 2011). American families consume 6.9×10^8 GJ energy on cooking (Heller and Keoleian, 2000). However, this classification structure can hardly cover all types of household energy-saving behaviors. For example, some studies have pointed out the critical role of high-efficiency electrical appliances in household energy conservation (Busic-Sontic et al., 2017; Davis, 2011). Thus, timely equipment maintenance and purchase energy-efficient appliance are also household energy-saving behavior (Ali et al., 2019). To include those behaviors, Yue et al. (2013) divided 13 energy-saving behaviors into three categories: (1) direct energy conservation, (2) promoting appliances' energy efficiency, and (3) promoting energy-saving by interpersonal interactions. In addition to the mentioned classifications, there is also a few studies divide the building occupant energy behavior based on energy resources, such as electricity, natural gas, petroleum product, coal and renewable energy resources (Fujii, 2006). However, this method can hardly reflect the characteristics of behavioral process and is only employed in some aggregate research.

Based on the above literature, this study classifies energy-saving behaviors into six categories by their natures: (1) eco-friendly building services operation, (2) sustainable use of appliances, (3) kitchen energy-saving behavior, (4) saving domestic hot water, (5) household energy-efficiency investment and (6) interpersonal interaction for energy conservation. The first category focuses on sustainable built environment adjustment and concerns the behaviors avoiding unnecessary building services operation. For example, residents can turn off unnecessary lighting and ventilation systems and set sustainable air conditioning temperatures to reduce energy consumption (Liu et al., 2020a; Yue et al., 2013). The second category pays attention to reducing unnecessary use of home appliances, such as allowing computers to enter energy-saving mode and unplugging appliances that are not in service (Jareemit and Limmeechokchai, 2017; Meier et al., 2004). The third category focuses on energy use in the cooking process, such as reusing the waste heat and reducing gas consumption (Hager and Morawicki, 2013). The fourth category is sustainable domestic hot water use behavior, such as avoiding waste in water heating, controlling bathing time, and choosing showers instead of baths (Wang et al., 2020). The fifth category covers household investment behavior for energy-efficient appliances and equipment. Replacing energy-consuming appliances and timely equipment maintenance can significantly reduce household energy consumption (Li and Just, 2018; Schleich, 2019). The last category focuses on promoting others' energy-saving behavior through human-to-human interaction, where residents can emphasize the importance of energy conservation and give others tips on saving energy (Yue et al., 2013).

Table 1 summarizes the definitions and typical cases of the six categories of household energy-saving behavior.

Table 1
Summary of six categories of household energy-saving behavior.

Category	Definition	Example	References
Eco-friendly building services operation	Behaviors of avoiding unnecessary building services operation.	Sustainable air conditioning temperature setting.	(Alshahrani and Boait, 2019)
		Close windows when heating and cooling systems operate.	(Wang et al., 2020)
		Turn off lighting system when not necessary.	(Du and Pan, 2020; Yue et al., 2019)
Sustainable use of appliances	Behaviors of reducing unnecessary or unreasonable use of home appliances.	Set computers on energy-saving mode.	(Jareemit and Limmeechokchai, 2017)
		Unplug the appliances when not in service.	(Du and Pan, 2020; Wang et al., 2020)
Kitchen energy-saving behavior	Energy conservation behaviors in cooking process.	Reuse waste heat to save energy in cooking.	(Hall et al., 2013)
		Reduce the flame when boiling starts.	(Wang et al., 2020)
		Cool down hot food before storing in the fridge.	(Wang et al., 2020)
Saving domestic hot water	Behaviors of saving energy by reducing domestic hot water waste.	Take a shower rather than a bath.	(Wang et al., 2020)
		Control the showering time.	(Wang et al., 2020)
		Only heat the amount of water that you need.	(Singh and Yassine, 2018)
Household energy-efficiency investment	Investment behaviors aimed at improving household energy efficiency	Purchase energy-efficient appliance and product.	(Ali et al., 2019; Yue et al., 2019)
		Timely equipment maintenance for satisfactory energy efficiency.	(Ali et al., 2019; Tan et al., 2017)
Interpersonal interaction for energy conservation	Behaviors of promoting others' energy-saving behavior through human-to-human interaction	Sharing household energy-saving experience.	(Yue et al., 2019)
		Encouraging others' energy-saving behavior.	(Yue et al., 2019)

2.2. Extended theory of planned behavior

Theory of Planned Behavior (hereinafter referred to as TPB), as one of the most frequently used psychological models that connect people's beliefs and behaviors, has been adopted in many studies to explain pro-environmental behavior (Tan et al., 2017; Tonglet et al., 2004; Wang et al., 2021). The TPB model, as shown in Fig. 1, is built on the postulate that individuals make rational decisions to conduct certain behaviors referring to the available information and knowledge. Three factors, namely attitude, subjective norms, and perceived behavioral control (hereinafter referred to as PBC), comprise the model to explain an individual's intention to engage in a specific behavior (Ajzen and Madden, 1986).

To be specific, attitude derives from a person's salient behavioral beliefs. It reveals a person's overall estimation of whether the behavior result is favorable. For example, residents who value environmental protection are more likely to perform household energy-saving behaviors (Liu et al., 2020a). Subjective norms refer to the normative beliefs and consist of a person's perceived behavioral expectations concerning whether the significant others think he/she should engage in the behavior. Subjective norms manifest the influence of social or external pressure on behavioral intention, and this influence mainly comes from essential referent individuals or groups. For example, an employee might refuse to set the air conditioner temperature higher due to concerns about colleagues' feelings (Lo et al., 2014; Obaidellah et al., 2019). Students may comply with their teachers' or parents' expectations to engage in energy-saving behaviors because of their expectations (De Leeuw et al., 2015). PBC is conceptualized as the critical contribution of the TPB (Ajzen, 1991). The concept refers to the value-laden difficulty or convenience level of behavior perceived by an individual and reflects whether people enjoy a sense of control towards the behavior. Low convenience is recognized as an important reason people avoid engaging in household energy-saving behaviors (Liu et al., 2020a; Nie et al., 2019).

The TPB model concludes that given an appropriate level of perceived behavioral control over the behavior, an individual will be expected to form the intention to perform that behavior when the opportunity arises (Ajzen, 1985; De Leeuw et al., 2015). Several works have traced the direct influences of the three TPB factors on intention. Their research findings confirmed the significant role the three TPB factors play and claimed intention to be a vital proxy for explaining pro-environmental behaviors (Ali et al., 2019; De Leeuw et al., 2015). Nevertheless, there still lacks theoretical coherence. Critics have asserted that, under certain circumstances, the attitude had little discernible effect on intention (Chiou, 1998). Although Nie et al. (2019) found subjective norm is the strongest driving force of "caring-use" energy-saving behaviors, some studies had difficulties identifying its impacts (Gao et al., 2017; Lim et al., 2016; Liu et al., 2020a). Moreover, Ru et al. (2018) highlighted the fact that the role of subjective norms may become smaller or disappear if taken into account additional factors, such as personal norms. The same goes for PBC, which was believed to have no significant effect on behavior (Paul et al., 2016).

Many studies have employed the extended TPB that adds personal norms as an attribute (see Fig. 1) since 2000s (Chen, 2016; Tan et al., 2017). Personal norms reflect the individual's perceived moral obligations and responsibilities for certain behaviors. A myriad of empirical studies has verified the positive contribution of personal norms to pro-environmental intentions. Tan et al. (2017) conducted a questionnaire survey on energy-efficient household appliance purchases in Penang, Malaysia, covering 210 consumers. The findings suggest that personal norms significantly influence purchase intention. Chen (2016) analyzed 728 online survey responses and found that personal norms can effectively predict the intention to reduce carbon emissions. A recent Indian study surveyed 326 consumers from 57 dealers and found the positive impact of personal norms on adopting electric vehicles (Shalender and Sharma, 2021). Sufficient research findings show that the extended TPB model that includes personal norms has higher explanatory power (Chen, 2016; Du and Pan, 2020; Harland et al., 1999; Oteng-Peprah et al., 2020). For example, Harland et al. (1999) revealed that adding personal norm increase the interpretive power of four environmental relevant behaviors on the basis of original TPB from 16% to 47%. Also, Oteng-Peprah et al. (2020) found that the explanatory ability of TPB for pro-environmental behavior had raised between 54% and 59% by adding the personal norm.

2.3. Personality basis of pro-environmental behaviors

The connotation of personality traits rests on the idea that people imply consistency and stability in terms of feelings and emotional patterns in various situations and over time (Cobb-Clark and Schurer, 2012). It represents the basic dimensions on which people differ (Matthews et al., 2003). As thus, personality traits can be adopted to explore the mechanism of different choices made by different people in the same situation and investigate the stable individual differences when people

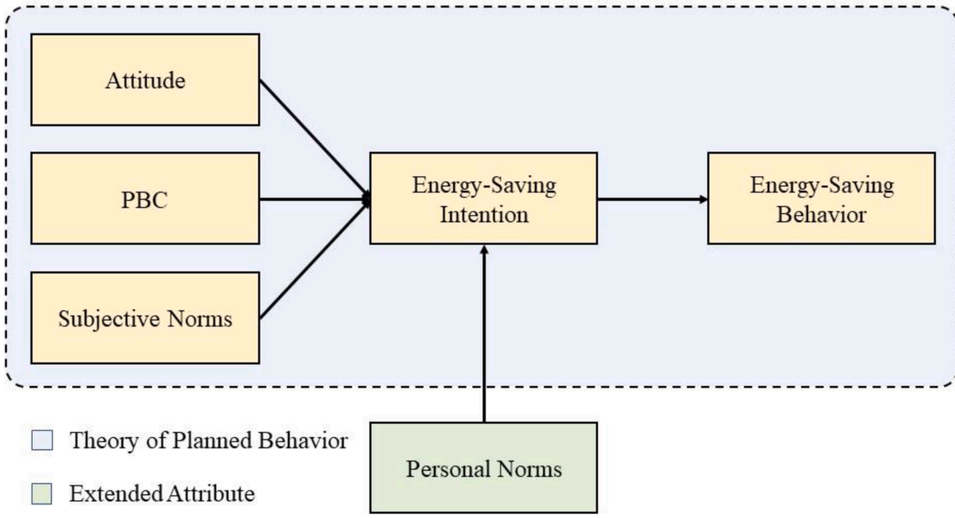

Fig. 1. The theoretical framework of the extended TPB.

conduct similar behaviors.

The Big Five model (also called the Five-Factor Model, FFM) promoted by Fiske (1949) is a widely accepted personality trait model. There are five labeled personality traits in the Big Five model: Extraversion, Agreeableness, Conscientiousness, Neuroticism and Openness (Matthews et al., 2003; McCrae and Costa, 1989). Extraversion reflects an individual's energetic engagement, sociability, as well as assertiveness (Wilt and Revelle, 2009). Extroverts are active and often invigorated by the breadth of activities. Agreeableness reflects people's compassion and empathy (Roccas et al., 2002). Agreeable individuals present a higher motivation to be helpful and cooperative. Conscientiousness is characterized by high self-discipline levels, respect for duty, and desire for achievement (Hirsh and Dolderman, 2007). Conscientious people are careful, dutiful, and hot on punctuality. Neuroticism refers to "the tendency to experience negative emotions, such as anger, anxiety, and depression" (McCrae and Costa, 1989) and is so-called emotional instability. Neurotic people are vulnerable, impulsive, dysphoric, and always haunted by inner conflict and depression. Openness indicates the degree of intellectual curiosity, abstract thinking, and a preference for novelty and individual variety (McCrae and Costa, 1989) and is related to productive cognitive flexibility (DeYoung et al., 2005). People scoring higher in openness are more likely to positively embrace new ideas and experiences and change the world with new methods.

Several studies observed the significant relationship between Big Five personality traits and pro-environmental intention and behaviors (Akhtar, 2019; Klein et al., 2019; Kvasova, 2015; Roos et al., 2020; Wang et al., 2021). Wang et al. (2021), for example, found that openness, agreeableness, and conscientiousness positively influence household energy-saving while neuroticism showed a negative impact. Roos et al. (2020) surveyed 1812 urban and rural residents in Sweden and found that openness and agreeableness positively contribute to public transport taking behavior. Akhtar (2019) analyzes feedback from 572 individual investors and reports the significant link between personality traits and green share investment in emerging economies. Besides, Klein et al. (2019) investigate the impacts of openness on political orientation and pro-environmental behaviors. Also, Kvasova (2015) found that all Big Five personality traits except openness positively contribute to sustainable tourism behaviors. There is also research link personality traits with green hotel visiting (Verma and Chandra, 2018) and green installation in rural families (He and Veronesi, 2017). While these studies have evidenced the effect of personality on pro-environmental behavior, its working mechanism is still unclear. Thus, personality traits are only considered as control variables (Lange et al., 2014; Yang et al., 2020).

A few studies bridged personality traits and pro-environmental behavior with attitudes (Brick and Lewis, 2016; Soutter and Mõttus, 2020; Wang et al., 2020). Wang et al. (2020) employed attitude to link Big Five personality traits and both household and office energy-saving intentions. The results suggested that agreeableness positively affects both attitudes while the effects of neuroticism were negative. Besides, Soutter and Mõttus (2020) also illustrated two empirical cases to analyze the impact of personality traits on pro-environmental attitude. Poškus and Žukauskienė (2017) and Wang et al. (2021), argued that the effect of personality traits on other psychological factors had been ignored, and suggested that TPB attributes can explain the impact of personality traits on students' recycling and household energy-saving intention heterogeneity. However, there is a lack of research on the comprehensive effect of personality on household energy-saving behavior and its underlying psychological process. The influence of personality heterogeneity on the psychological mechanism of various household energy-saving behaviors is valuable to be explored.

3. Methodology

3.1. Data collection

The researchers conducted a questionnaire survey in Xi'an, China, and collected self-reported data from the respondents. Xi'an is the capital of Shaanxi Province and one of the most historical cities in China. There are two reasons for choosing Xi'an as the research location: (1) The per capita energy consumption of Shaanxi (i.e., 3245 kgce) is close to the national average level of China (i.e., 3325 kgce) in 2018, which makes Xi'an a widely-employed case in studies on urban energy use in China (Cai and Jiang, 2008; Chen et al., 2011; Zhao et al., 2020). (2) Xi'an is a typical representative of the fast-growing cities in China (Yang and Li, 2019; Zhao et al., 2020). The researchers invited 3000 households in the urban area to participate in the survey. Due to the COVID-19 epidemic, the questionnaire for this study was conducted online. Previous research has confirmed the feasibility of online questionnaires (Liu et al., 2016a.; Santiago-Cruz et al., 2021). With assistance from local community service staff and volunteers, the researcher first sent the invitation to the *Huzhu* (i.e., registered representative of the household) of the selected families by SMS. After obtaining consent, the researchers would send them the link (QR code) to the questionnaire. The respondents can fill out the questionnaire anonymously and all their personal information are protected during the data collection and management process. A total of 2276 responses were received in this study, of which 1119 were valid. Table 2 shows the respondent profile.

Table 2 indicates the respondents' demographic information,

Table 2
Respondent profile.

Demographics Information		Number	Percentage
Gender	Male	629	56.211
	Female	490	43.789
Age	Below 18	36	3.217
	18 to 30	279	24.933
	31 to 40	374	33.423
	41 to 50	335	29.937
	51 to 60	78	6.971
	61 to 70	14	1.251
	Above 70	3	0.268
Education level	Secondary school or below	17	1.519
	High school or Equivalent	75	6.702
	Polytechnic College or Equivalent	246	21.984
	Undergraduate or Equivalent	694	62.020
	Postgraduate or Equivalent	78	6.971
	PhD or Equivalent	9	0.804
Marital status	Unmarried	527	47.096
	Married without children	164	14.656
	Married with children	428	38.248
Household Income level (CNY per year)	Less than 50,000	342	30.563
	50,000 ~150,000	313	27.971
	150,000 ~ 200,000	201	17.962
	200,000 ~ 250,000	111	9.920
	More than 250,000	67	5.987
	Not applicable	85	7.596
Occupation	Management	305	27.256
	Technical	438	39.142
	Service	177	15.818
	Self-employed or Student	189	16.890
	Others	10	0.894

including age, education, income, marital status, and occupation. Among the respondents, 629 males (i.e., 56.211%) are more than females (i.e., 490, 43.789%), which is in line with local demographic characteristics. The household income of the interviewed population matches the local statistics. The median age of the population is between 31 and 40, which closes to the local population's age characteristics (mean = 35). However, since most of Huzhus are adults, the proportion of respondents under 18 is relatively small (36, 3.217%). Also, the proportion of elderly respondents over 60 is relatively low (3, 0.268%). The internet-based data collection approach is a potential cause for this result. The balanced occupational statistics of the respondents reflect the situation of residents. More respondents are working in technical positions (39.142%), while 15.818% of respondents work in the service industry.

3.2. Measures

The questionnaire employed in this study has four parts: (1) typical household energy-saving behaviors, (2) psychological factors affecting energy-saving behaviors, (3) five factor personality traits, and (4) sociodemographic information.

The first part focuses on household energy-saving behavior reported by residents. The researchers classified typical household energy-saving behaviors into six categories based on the literature review (see Section 2.1 for details). In the questionnaire, the researcher provided the definitions and cases of each type of energy-saving behavior and invited the respondents to judge these behaviors' frequency in their lives. Appendix A shows the content of the first part of the questionnaire. The second part uses 14 items to measure the main factors in the extended TPB: attitude, subjective norms, PBC, personal norms, and intentions. Appendix B summarizes the items in the second part of the questionnaire. The researcher disrupted these items' order in the questionnaire. The third part uses the Mini-IPIP (Chinese) developed by Donnellan et al. (2006) to collect the respondents' personality characteristics. Mini-IPIP is a standard FFM test scale with 20 items (Donnellan et al., 2006). Previous research has proved the validity and cross-cultural applicability of Mini-IPIP (Li et al., 2012; Shou et al., 2016). Therefore, Mini-IPIP has been widely employed in pro-environmental behavior research (Dalvi-Esfahani et al., 2020; Kvasova, 2015; Milfont and Sibley, 2012; Verma et al., 2017). The fourth part records the subjects' personality statistics: gender, age, education, income, marital status, and occupation type. The first two parts use the five-point Likert scale. The first part measures the behavioral frequency of the subjects in the (never = 1, rarely = 2, sometimes = 3, often = 4, always = 5) and the second part focuses on the degree of agreement with the statements (completely disagree = 1, disagree = 2, neutral = 3, agree = 4, completely agree = 5). Besides, the third part employs the seven-point Likert scale (completely disagree = 1, disagree = 2, slightly disagree = 3, neutral = 4, slightly agree = 5, agree = 6, completely agree = 7).

After completing the questionnaire design, the researchers conducted two pilot experiments. The first experiment invited 20 professionals in energy research, psychology, community service, property management, and the second experiment covered 55 residents. The researchers invited all respondents to provide comments and then revised the questionnaire accordingly. In addition to 46 regular items, the researcher also added five trap items (i.e., two groups of the same questions and one item requiring the respondents to choose the certain answer) to eliminate invalid responses.

3.3. Data analysis

The research employs a three-step approach for data analysis. Fig. 2 illustrates the detailed stages of data analysis.

The first step focuses on the psychological pattern of all respondents, where the study employs measurement modeling to exam the validity of the theoretical framework and factors and structural equation modeling (SEM) to explore the psychological patterns of the overall model. SEM is an analysis method of establishing, estimating, and testing causality. It has the advantages of multiple regression analysis, path analysis, and other methods to reveal the effect of influencing factors on the unified model and the relationship between factors (Hair et al., 2020). SEM integrates the method of factor analysis and path analysis and can simultaneously examine the relationship between observed variables and latent variables. Thus, SEM has been widely used in pro-environmental behavioral science (Chen and Tung, 2014; Ru et al., 2018; Tan et al., 2017; Wan et al., 2014; Wan and Shen, 2015; Wang et al., 2021).

The second step is to cluster the respondents according to their personality characteristics. The study employs the Hierarchical-K-means approach for clustering (Wang et al., 2015; Xu et al., 2015). This approach first determines the number of clusters with Ward's method and Squared Euclidean distance. Then, the study applies the k-means algorithm for clustering analysis. Some researchers have proved that the method is valuable in exploring the personality traits affecting environmentally friendly behavior in school and office buildings (Hong et al., 2020; Poškus and Žukauskienė, 2017). Xu et al. (2015) suggest that the approach can achieve better compactness and distinctiveness in the corresponding clustering results.

The third step concentrates on group analysis to compare the psychological and behavioral characteristics as well as the psychological pattern that affects household energy-saving behavior of different clusters. Within this process, the study first conducts one-way analysis of variance (ANOVA) to exam whether extended TPB factors and household energy-saving behavior have significant differences base on the cluster analysis result. ANOVA is one of the most commonly used statistical methods in the social sciences. It is used to test the significance of the difference in the mean of the dependent variable and determine the factors that will affect the experiment results (Kaufmann and Schering, 2014). Then, a comparison of TPB attributes and household

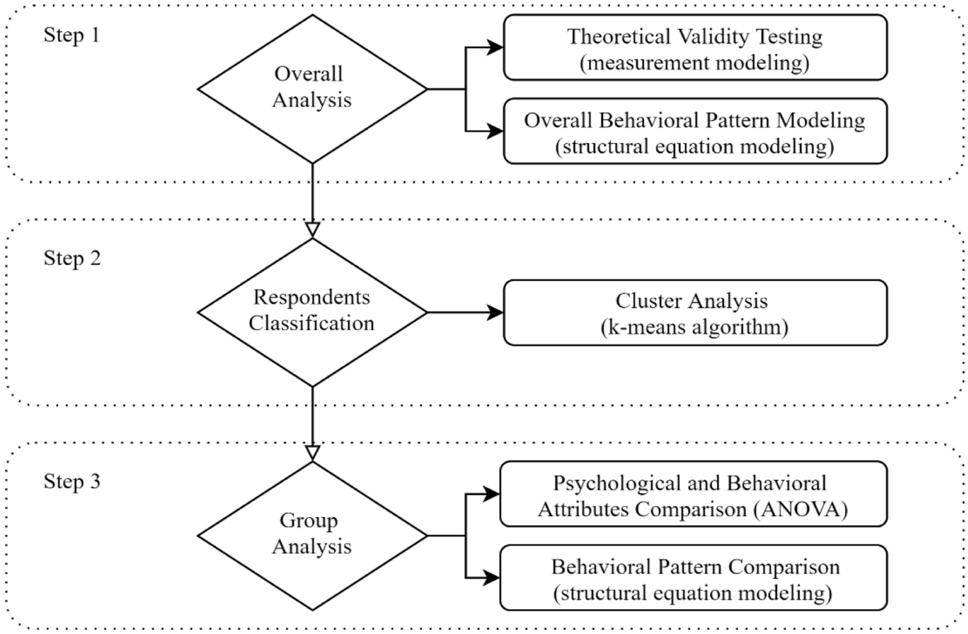

Fig. 2. Data analysis flow.

energy-saving behaviors is executed to find out the differentia of each cluster. Secondly, the study conducts SEM on analysing the psychological and behavioral patterns of each cluster's respondents and compares the characteristic of each cluster with the overall model to explore the behavioral features of different clusters.

The study employs SmartPLS 3.0 for SEM and SPSS 23 for ANOVA and clustering analysis.

4. Results

4.1. Overall analysis

The research analyzes household energy-saving behavior and other factors that affect behavior in the overall analysis. The SEM comprises the measurement and structural models. The study first administers the measurement model to determine the reliability and validity of constructs and items and establishes a structural model to evaluate whether the hypothesis is verified and relevant.

4.1.1. Measurement modeling

This section presents the convergent validity (CV) and discriminant validity (DV) test results to verify the reliability and effectiveness of the construction model and item. Fig. 3 illustrates the evaluation criteria of measurement modeling.

The CV examination aims to evaluate the correlation between different items within the same category. The test examines three indices: (1) Cronbach's alpha, (2) Composite Reliability (CR), (3) Average Variance Extracted (AVE), and (4) standardized outer loading. Cronbach's alpha and CR reflect internal consistency and reliability. Cronbach's alpha value is expected to be larger than 0.5 (Leontitsis and Pagge, 2007) and CR is expected to be no less than 0.7 (Afthanorhan, 2013). AVE represents the comprehensive explanatory ability of latent variables for all measured variables. The cut-off value of AVE is 0.5 (Afthanorhan, 2013). Standardized outer loading (also called factor loading) shows the correlation coefficient between the latent and observed variables. Afthanorhan (2013) recommended that the factor loading value of each item should be higher than 0.5. Table 3 summarizes the CV test results.

According to Table 5, all constructs satisfy the CV requirements. Cronbach's alpha values varied from 0.552 to 0.713, and the above constructs and items will be retained for structural modeling. The scope of factor loading is between 0.538 and 0.692 and the AVE value ranged from 0.538 to 0.692, which are greater than 0.5. Therefore, the result indicates that the measurement model has sufficient convergent reliability.

The DV test evaluates whether a construct varies from the model's remaining constructs. This study employs the Heterotrait-Monotrait (HTMT) ratio for the DV examination. HTMT is a standard for

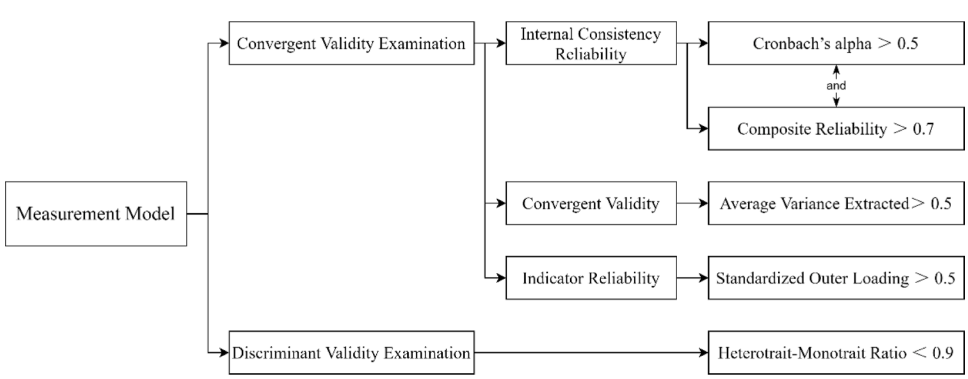

Fig. 3. The evaluation criteria of measurement modeling.

Table 3
The CV test results.

Construct	Items	Standardized Outer Loading	Cronbach's Alpha	Composite Reliability	AVE
Attitude	ATT-1	0.761	0.638	0.804	0.577
	ATT-2	0.777			
	ATT-3	0.741			
PBC	PBC-1	0.563	0.552	0.767	0.538
	PBC-2	0.781			
	PBC-3	0.889			
Subjective Norms	SN-1	0.823	0.555	0.818	0.692
	SN-2	0.840			
Personal Norms	PN-1	0.780	0.603	0.787	0.553
	PN-2	0.715			
	PN-3	0.733			
Intention	I-1	0.799	0.713	0.839	0.636
	I-2	0.847			
	I-3	0.743			

evaluating the validity of the discrimination between structures. It is suggested that the HTMT ratio should maintain the level of no more than 0.9. Appendix C illustrates the DV test results and shows the results satisfy the requirement.

4.1.2. Overall structural equation modeling results

The study conducts the structural modeling with bootstrapping estimation at a 90% confidence interval and with 5000 samples to explore the statistical correlation between latent variables. The Table 4 and Fig. 4 summarizes the structural modeling results.

The structural modeling results suggest that all four psychological factors significantly contribute to household energy conservation intentions. Among them, PBC ($\beta = 0.418$, $p < 0.001$) is the most important predictor. Also, attitude ($\beta = 0.324$, $p < 0.001$) plays an important role. The modeling results show that normative factors have a smaller effect on household energy-saving intentions. It is worth noting that household energy-saving intentions significantly impact the six energy-saving behaviors. In particular, energy-saving intentions have a more substantial positive impact on sustainable electrical appliance use ($B_{Appliances}$, $\beta = 0.532$, $p < 0.001$), household energy-saving investments ($B_{Investment}$, $\beta = 0.493$, $p < 0.001$), and encouraging others to save energy ($B_{Interaction}$, $\beta = 0.443$, $p < 0.001$).

4.1.3. Respondent classification

According to the respondents' personality characteristics, the study uses the Squared Euclidean distance and the Ward's linkage method to determine the number of clusters as four. Then, the study conducts k-means clustering to divide the respondents into four categories, which are further defined as (1) Positive (the positives, $N = 169$), (2) Temperate (the temperates, $N = 229$), (3) Conservative (the conservatives, $N = 391$), (4) Introverted (the introverts, $N = 330$). Standardized data is used to display the results of cluster analysis. Fig. 5 illustrates each respondent group's standardized personality characteristics. The study then performs one-way ANOVA to provide a statistical validity test of the clustering analysis results. The ANOVA results (see Appendix D) verify that different groups' personality characteristics are significantly different.

The four clusters' respondents have different characteristics and performance of big five personality traits. Positive people have the highest score in most personality components: conscientiousness (i.e., 1.534), agreeableness (i.e., 1.407), openness (i.e., 1.375), and extraversion (i.e., 0.850). They have the lowest neuroticism score (i.e., −1.607), which suggests their highest emotional stability. Positive respondents have higher self-discipline and friendliness than others, and they usually have no persistent negative emotions. Temperate people's Big Five Personality Traits' overall performance is relatively balanced, and their personality trait scores are higher than the average. The extent of neuroticism (i.e., 0.755) and extraversion (i.e., 0.555) is relatively great within the Big Five personality traits. The Temperate individual is highly perceptive and likes to communicate with others actively, but their emotions are reacting strongly with life experience changes. Conservative people have a high score on neuroticism (i.e., 0.117), while its other Big Five personality traits are below average. For example, openness (i.e., −0.946) and conscientiousness (i.e., −0.748) are lower than average obviously. It seems that conservative people get used to the routine and preservation and easy to influence by the external environment. The cluster of introverted has higher neuroticism (i.e., 0.160) and openness (i.e., 0.143) and lower agreeableness (i.e., −0.519) and extraversion (i.e., −0.711). Therefore, people in the cluster seem to have passive emotion regulation and response but willing to accept new perspectives. However, pressure can easily lead to unstable sentiments. In a word, the scores of Big Five personality traits for positive and temperate people are above average, while conservative and introverted individual scores are below average. The information of big five personality traits of each cluster can be found in Appendix D. Besides, the descriptive statistics of personality information, TPB attributes and household energy-saving behaviors of each cluster are shown in Appendix E.

Table 4
The path coefficients in the overall structural model.

Tested Relationship	Original Sample	Standard Deviation	T Statistics	P Values
Attitude → Intention	0.324	0.027	11.949	0.000***
PBC → Intention	0.418	0.030	14.054	0.000***
Subjective Norms → Intention	0.143	0.026	5.580	0.000***
Personal Norms → Intention	0.052	0.021	2.559	0.011*
Intention → B_{BS}	0.300	0.033	9.090	0.000***
Intention → $B_{Appliances}$	0.532	0.026	20.743	0.000***
Intention → $B_{Kitchen}$	0.396	0.028	14.040	0.000***
Intention → $B_{Hot\ Water}$	0.327	0.031	10.615	0.000***
Intention → $B_{Interaction}$	0.443	0.028	16.034	0.000***
Intention → $B_{Investment}$	0.493	0.029	16.794	0.000***

4.2. Group analysis

4.2.1. Psychological and behavioral attribute comparison

The study compares the psychological and behavioral characteristics of each cluster by ANOVA analysis (results see Appendix D). Appendix E

The ANOVA results show significant differences in the five TPB attributes of the four clusters. Fig. 6. represents the TPB elements' detailed circumstance of four clusters. The result indicates that each TPB components of the positive people got the highest score (attitude = 0.346, PBC = 0.413, subjective norms = 0.572, personal norms = 0.433 and intention = 0.311). Temperate people's all TPB attributes are the second-highest (intention = 0.234, attitude = 0.207, personal norms = 0.204, PBC = 0.167 and subjective norms = 0.102) and greater than the average. The Conservative's TPB score has a low performance but relatively balanced. Their PBC (i.e., −0.017) is close to the average while the other four components (ATT = −0.118, subjective norms = −0.120, personal norms = −0.052, intention = −0.110) below average. The five TPB attributes of Introverted are unbalanced and the lowest among all clusters. The PBC score (−0.308) and personal norms (−0.302) of Introverted are extraordinarily lower than the other three elements. In general, the TPB components' score gradually decreases from high to low following the sequence of Positive, Temperate, Conservative, and Introverted. The one-way ANOVA results (see Appendix D) verify the significant differences in psychological factors

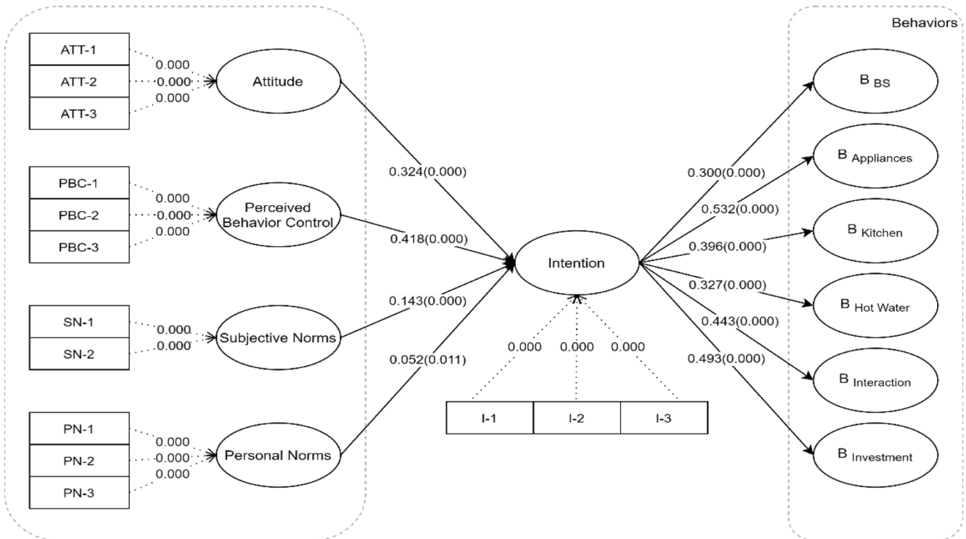

Fig. 4. The overall structural modeling results.

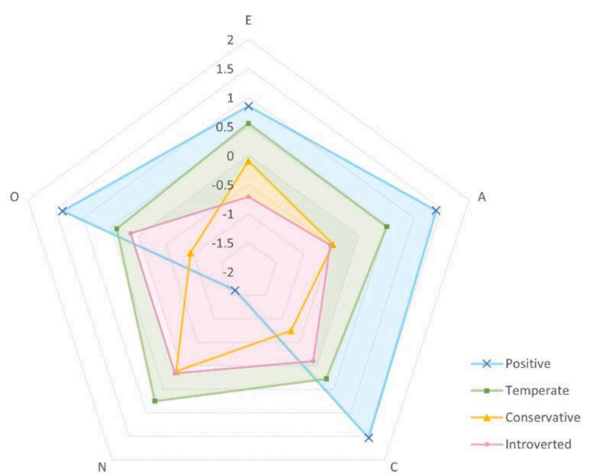

Fig. 5. The personality characteristics of each cluster note: E refers to extraversion, A refers to agreeableness, C refers to conscientiousness, N refers to neuroticism, and O refers to openness.

between groups.

Fig. 7 indicates the performance in household energy-saving behaviors of Building Services, Appliances, Kitchen, Hot Water, Interaction and Investment of four clusters.

The results revealed that all the positive individual's self-evaluated behavior scores are significantly higher than the average. They report the highest score of $B_{Investment}$ (0.537), $B_{Kitchen}$ (0.455), $B_{Interaction}$ (0.388), B_{BS} (0.357), $B_{Hot\ Water}$ (0.304) and the second-highest score of $B_{Appliances}$ (0.065). It means that Positive people have good energy-saving potential. The self-reported behaviors score of the cluster of Temperate is above average. Temperate people inform the highest $B_{Appliances}$ (0.167) and the second-highest score of the remaining household energy-saving behaviors (B_{BS} = 0.081, $B_{Kitchen}$ = 0.041, $B_{Hot\ Water}$ = 0.039, $B_{Investment}$ = 0.302). In contrast, people in the other two clusters present low performance of household energy-saving behavior. The scores of most behaviors of Conservative people are below average, except for $B_{Appliances}$ (0.016). The behavior scores on most energy-saving behaviors reported by Conservative residents are below average. Their self-assessed behavioral scores on $B_{Kitchen}$ (−0.069) and $B_{Investment}$ (0.537) are the lowest among all respondents. Introverted people hold a below-average level of all behaviors. They report an approached average $B_{Kitchen}$ (−0.030) while the other household energy-saving behavior is the lowest level of all respondents (B_{BS} = −0.160, $B_{Appliances}$ = −0.168, $B_{Hot\ Water}$ = −0.172 and $B_{Interaction}$ = −0.182). To sum up, positive and temperate individuals prefer to conduct majority energy-saving behaviors, while conservative and introverted people are more passive in most behaviors.

4.2.2. Group behavioral pattern comparison

The study performed structural modeling analysis on four clusters to evaluate their household energy-saving behavior process. The result shows that attitude, PBC, and subjective norms have essential effects on intention in all clusters. Howsoever, the influence of personal norms on intention is distinct in the four clusters. Besides, the clusters present significant differences between the impact of energy-saving intention on different household energy-saving behaviors. Table 5 compares the structural modeling results (i.e., path coefficients, standard deviation, t statistics and p-value) in different respondent groups.

Fig. 8 summarizes the structural modeling results of the positive group. The results suggest that attitude (β = 0.388, p < 0.001) and subjective norms (β = 0.332, p < 0.001) have a higher impact on household energy-saving intention of the positives than that of the others. However, the correlation between their PBC and intention is the smallest (i.e., β = 0.219, p < 0.013) among the four resident clusters and personal norms (β = 0.028, p = 0.717) present an insignificant relation with household energy-saving intention. Moreover, the correlations between household energy-saving intention and behaviors of the positives are weaker than the overall levels (see Table 5): $B_{Appliances}$ (β = 0.421, p < 0.001), $B_{Hot\ Water}$ (β = 0.226, p < 0.001) and $B_{Investment}$ (β = 0.408, p < 0.001). Additionally, different from that of the other clusters, the positives' energy-saving intention presents insignificant impacts on the other two behaviors (B_{BS}, β = −0.034, p = 0.610; $B_{Kitchen}$, β = 0.007, p = 0.949).

Fig. 9 summarizes the structural modeling results of the temperate group. The influence of attitude (β = 0.341, p < 0.001) and subjective norms (β = 0.155, p = 0.005) on intention of temperate individuals are beyond that of the overall levels (see Table 4). However, the effect of PBC (β = 0.323, p < 0.001) is lower than the result of overall (β = 0.418, p < 0.001). The relationship between personal norms and intention is insignificant (β = 0.026, p = 0. 587) for the temperates. Moreover, the temperate residents' energy-saving intention has a significant correlation with the most behaviors. Especially, the correlation between energy-saving intention and hot water saving behavior ($B_{Hot\ Water}$, β = 0.354, p < 0.001) is stronger than the overall analysis result (i.e., β =

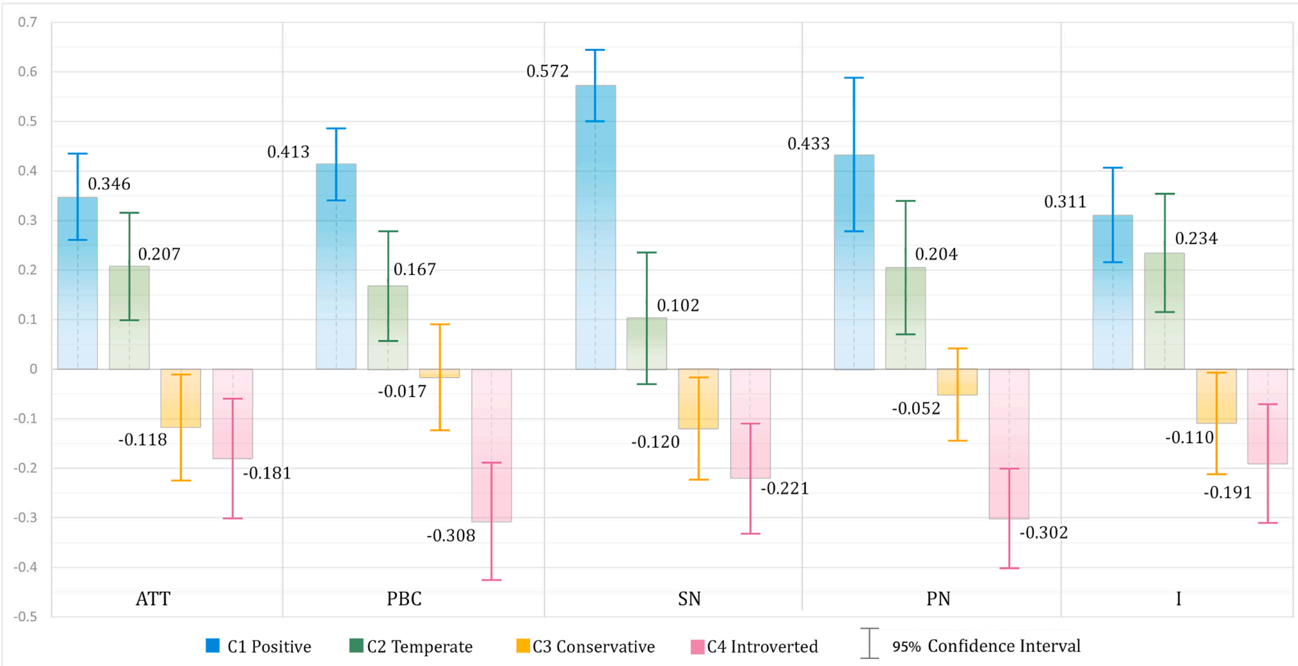

Fig. 6. The Comparison of Each Cluster's TPB Attributes Note: *ATT* refers to attitude, *SN* refers to subjective norms, *PBC* refers to perceived behavior control, *PN* refers to personal norms, *I* refers to intention. Mean equals to 0 for each attribute in Fig. 6.

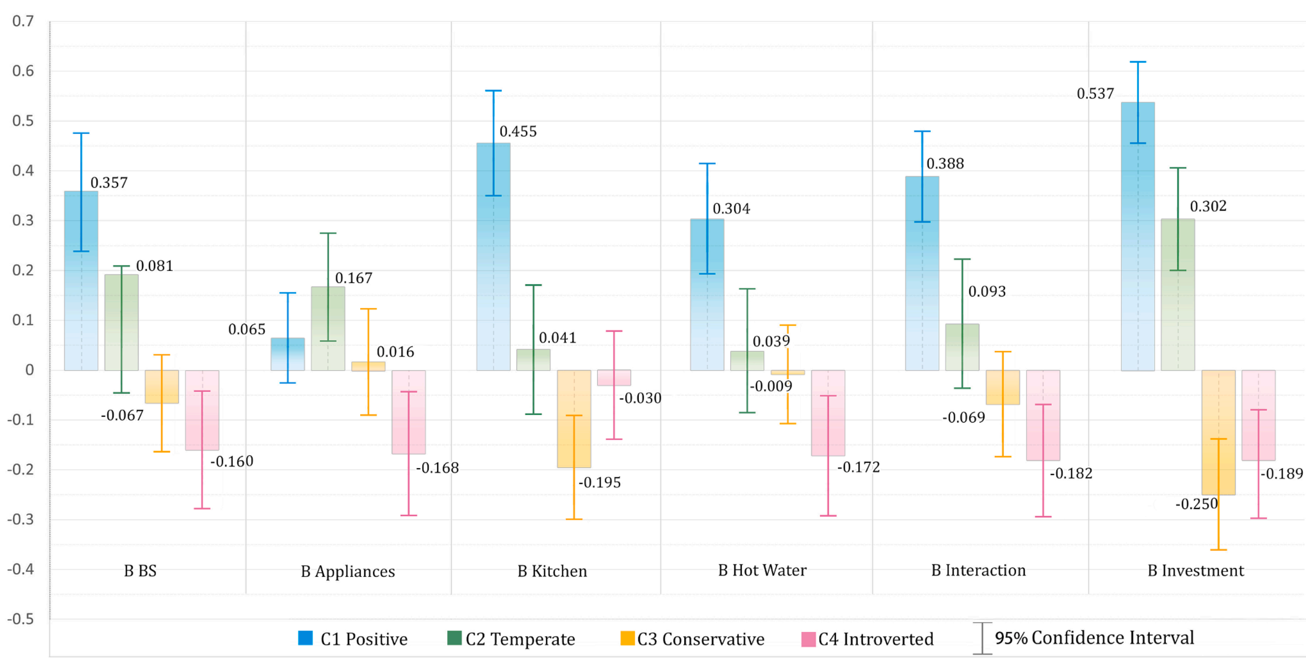

Fig. 7. The Comparison of Each Cluster's Behavioral Characteristics Note: Mean equals to 0 for each behavior in Fig. 7.

0.327, $p < 0.001$). However, the correlation between intention and other energy-saving behaviors ($B_{Appliances}$, $\beta = 0.446$, $p < 0.001$; $B_{Interaction}$, $\beta = 0.404$, $p < 0.001$; $B_{Investment}$, $\beta = 0.371$, $p < 0.001$) is smaller than the overall levels (see Table 4). Furthermore, it is worth noting that intention shows no significant relationship with B_{BS} ($\beta = 0.143$, $p = 0.068$).

Fig. 10 summarizes the structural modeling results of the conservatives. The analysis finds the effects of the conservatives' attitude ($\beta = 0.359$, $p < 0.001$) and subjective norms ($\beta = 0.144$, $p < 0.001$) on energy-saving intention surpass the result of overall analysis. Similar with that of the temperatures, the impacts of their PBCs ($\beta = 0.387$, $p < 0.001$) are lower than the overall level. Different from the other three clusters, conservative people's personal norms ($\beta = 0.073$, $p = 0.036$) shows a significant impact on household energy-saving intention. All six behaviors significantly reflect the energy-saving intention of the conservatives and the effects of intention on most behaviors, e.g., B_{BS} ($\beta = 0.375$, $p < 0.001$), $B_{Appliances}$ ($\beta = 0.563$, $p < 0.001$), $B_{Interaction}$ ($\beta = 0.537$, $p < 0.001$), $B_{Investment}$ ($\beta = 0.548$, $p < 0.001$), are the highest levels among all clusters.

Fig. 11 summarizes the structural modeling results of the introverts. The results show that PBC ($\beta = 0.512$, $p < 0.001$) is the most critical

Table 5
The structural modeling results for group analysis.

Cluster	Path	Original Sample	Standard Deviation	T Statistics	P Values
Positive	Attitude → Intention	0.388	0.074	5.218	0.000***
	PBC → Intention	0.219	0.088	2.495	0.013*
	Subjective Norms → Intention	0.332	0.067	4.928	0.000***
	Personal Norms → Intention	0.028	0.077	0.362	0.717
	Intention → B_{BS}	−0.034	0.066	0.510	0.610
	Intention → $B_{Appliances}$	0.421	0.062	6.790	0.000***
	Intention → $B_{Kitchen}$	0.007	0.106	0.063	0.949
	Intention → $B_{Hot\ Water}$	0.226	0.098	2.292	0.022*
	Intention → $B_{Interaction}$	0.192	0.112	1.712	0.087#
	Intention → $B_{Investment}$	0.408	0.081	5.039	0.000***
Temperate	Attitude → Intention	0.341	0.059	5.743	0.000***
	PBC → Intention	0.323	0.057	5.649	0.000***
	Subjective Norms → Intention	0.155	0.056	2.782	0.005**
	Personal Norms → Intention	0.026	0.047	0.543	0.587
	Intention → B_{BS}	0.143	0.078	1.826	0.068#
	Intention → $B_{Appliances}$	0.446	0.082	5.412	0.000***
	Intention → $B_{Kitchen}$	0.255	0.080	3.196	0.001**
	Intention → $B_{Hot\ Water}$	0.354	0.075	4.702	0.000***
	Intention → $B_{Interaction}$	0.404	0.072	5.581	0.000***
	Intention → $B_{Investment}$	0.371	0.065	5.700	0.000***
Conservative	Attitude → Intention	0.359	0.045	8.016	0.000***
	PBC → Intention	0.387	0.045	8.603	0.000***
	Subjective Norms → Intention	0.144	0.041	3.552	0.000***
	Personal Norms → Intention	0.073	0.035	2.095	0.036*
	Intention → B_{BS}	0.375	0.051	7.319	0.000***
	Intention → $B_{Appliances}$	0.563	0.047	11.999	0.000***
	Intention → $B_{Kitchen}$	0.437	0.041	10.708	0.000***
	Intention → $B_{Hot\ Water}$	0.240	0.050	4.808	0.000***
	Intention → $B_{Interaction}$	0.537	0.041	13.066	0.000***
	Intention → $B_{Investment}$	0.548	0.037	14.776	0.000***
Introverted	Attitude → Intention	0.308	0.041	7.497	0.000***
	PBC → Intention	0.512	0.046	11.077	0.000***
	Subjective Norms → Intention	0.094	0.046	2.056	0.040*
	Personal Norms → Intention	0.068	0.038	1.782	0.075#
	Intention → B_{BS}	0.315	0.059	5.378	0.000***
	Intention → $B_{Appliances}$	0.547	0.032	16.899	0.000***
	Intention → $B_{Kitchen}$	0.464	0.049	9.420	0.000***
	Intention → $B_{Hot\ Water}$	0.384	0.052	7.319	0.000***
	Intention → $B_{Interaction}$	0.351	0.050	7.079	0.000***
	Intention → $B_{Investment}$	0.412	0.062	6.616	0.000***

Note: #: $p < 0.10$; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

driven factor of introverts' household energy-saving intention and its impact is significantly stronger than the overall analysis results (see Table 5). In contrast, their attitude (β = 0.308, $p < 0.001$) and subjective norms (β = 0.094, $p = 0.040$) show the lowest levels among the four clusters. For introverted householders, intention has significant correlations to all six energy-saving behaviors: its effects on B_{BS} (β = 0.315, $p < 0.001$), $B_{Appliances}$ (β = 0.547, $p < 0.001$), $B_{Kitchen}$ (β = 0.464, $p < 0.001$), $B_{Hot\ Water}$ (β = 0.384, $p < 0.001$) are higher than the overall levels (see Table 5). However, its influence on $B_{Investment}$ (β = 0.408, $p < 0.001$) is slightly below the overall analysis result (β = 0.493, $p < 0.001$).

5. Discussion

This study clusters the respondents into four groups to reveal their personality characteristics and household energy-saving behavioral patterns. Different resident clusters show significant differences in household energy-saving behaviors and psychological variables. The results report that positive householders have the best performance in energy-saving behavior, consistent with previous pro-environmental studies' conclusions (Brick and Lewis, 2016; He and Veronesi, 2017; Hirsh, 2010). Positive residents have stronger adaptive personality traits: higher agreeableness, openness, and emotional stability. These characteristics promote their energy-saving attitudes, subjective norms, and PBC levels (Wang et al., 2021).

Conservative householders have better scores on psychological factors and perform better in most household energy-saving behaviors than introverted residents, albeit they have the lowest openness and conscientiousness. Their relatively higher extraversion and agreeableness provide an explanation: compared with introverted residents, conservative residents are more concerned about others' feelings and are more likely to develop empathy (Tang and Lam, 2017), which can positively affect pro-environmental behaviors. Therefore, conservative residents show better performance in sustainable building service use and encouraging others' energy-saving behaviors. Yet, introverted residents perform better in household energy-saving investment and kitchen energy-saving behaviors. The introverts have a higher openness level, reflecting that they are more open to novel energy-saving concepts and equipment. This echoes previous research which claimed that people with higher openness tend to install energy recycling (He and Veronesi, 2017) and distribut solar energy recovery systems (Busic-Sontic et al., 2017).

Some studies point out that personality traits might bridge intention and behavior (Sheeran, 2002). However, only a few studies shed light on the impacts of intention on household energy-saving behaviors from the personality perspective. This research has carried out a preliminary exploration of this issue. The results indicate that conservative

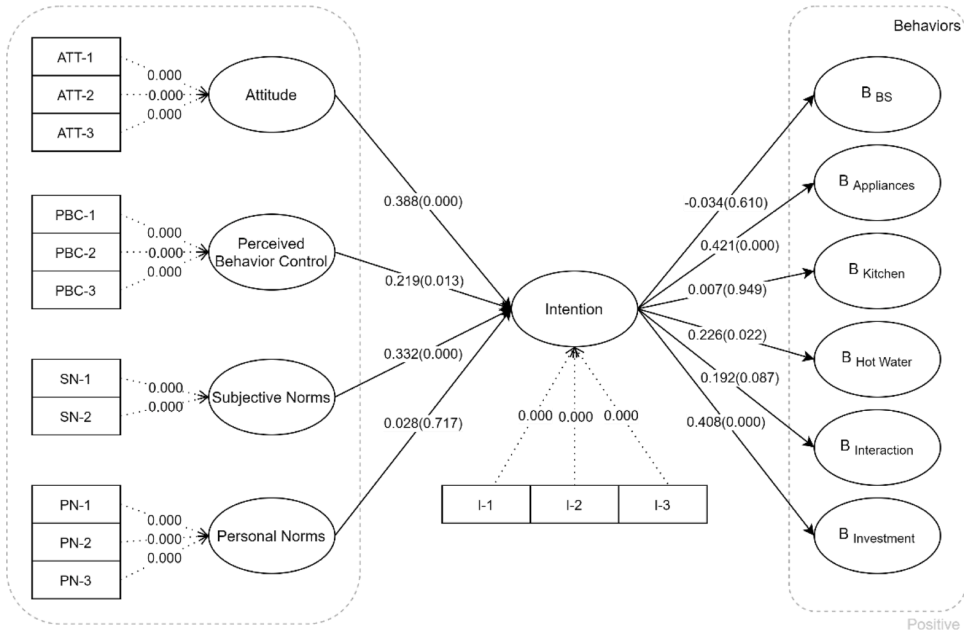

Fig. 8. Summary of structural modeling of the positive group.

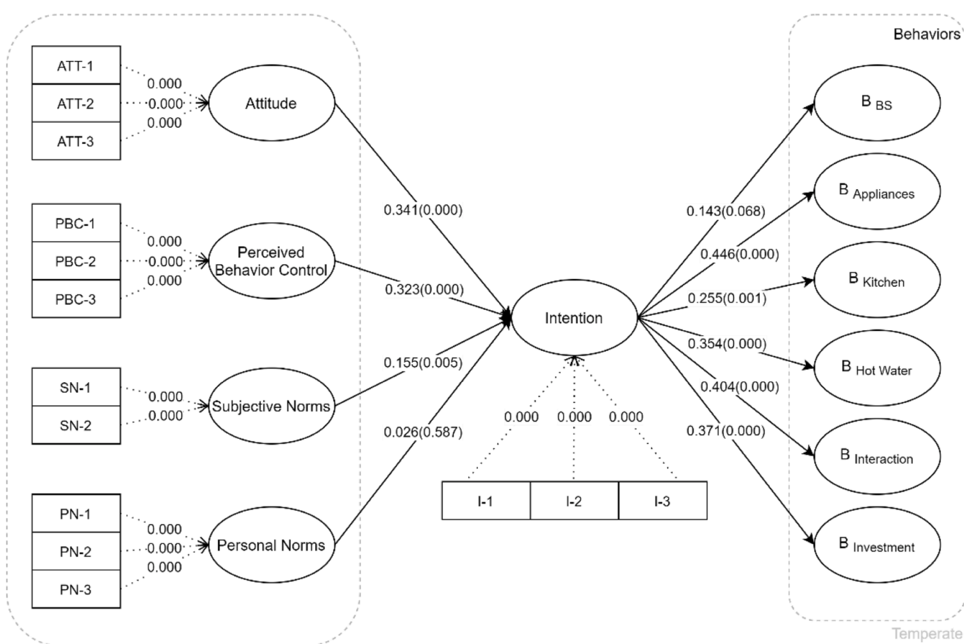

Fig. 9. Summary of structural modeling of temperate group.

householders' energy-saving behaviors are most affected by their energy-saving intentions, followed by introverted residents. However, the impacts of intention on energy-saving behaviors are smaller in positive and temperate groups. In line with Maier et al., (2012), the differences between clusters evidence that the interaction between personality traits and energy-saving intention affects household energy-saving behavior. Although the introverts and the conservatives hold relatively lower scores in energy-saving performance, their sensitivity to intentions increases their potential for behavioral intervention: achieving the goals only requires a smaller change in energy-saving intention than the others.

This study explored the role of different psychological factors in residents' household energy-saving behaviors. Based on these findings, research communities can formulate targeted behavioral intervention strategies to promote household energy-saving behaviors. We found that among different types of residents, the impact of attitudes on household energy conservation intentions maintains at a high and similar level. Therefore, interventions such as energy conservation education to improve residents' household energy-saving attitudes apply to almost all residents. Interestingly, the analysis results suggest that residents with weaker adaptive personalities (i.e., the conservative and introverted groups) are more sensitive to PBC. These residents hold relatively lower extroversion and agreeableness and present more self-centered (Hirsh and Dolderman, 2007). Thus, their behaviors and decision-makings are more likely to be affected by non-volunteering behavioral control (Wang et al., 2021). Practitioners would consider reducing the perceived behavioral difficulty of conservative and introverted residents through PBC-based interventions, such as issuing energy-saving tips. In contrast,

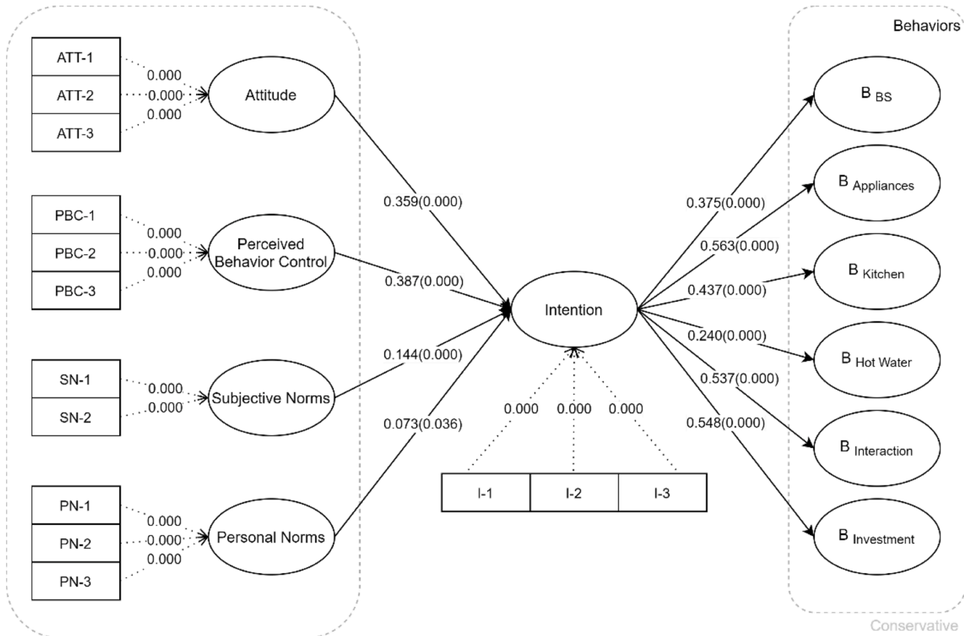

Fig. 10. Summary of structural modeling of conservative group.

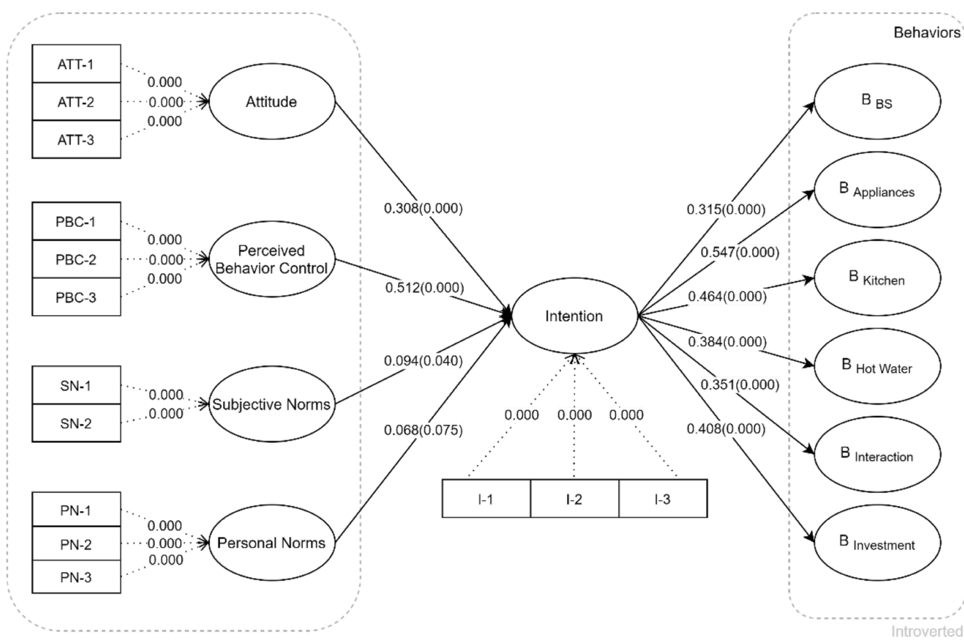

Fig. 11. Summary of structural modeling of introverted group.

residents with more adaptable personalities, such as positive and temperate, are more sensitive to subjective norms. These residents are more extroverted and agreeable and therefore have more external control elements (Poškus, 2017; Poškus and Žukauskienė, 2017). Property managers may consider reminding them to pay attention to their family members' and neighbors' feelings to promote their household energy-saving behaviors. However, research has found that personal norms play a limited role in household energy-saving behavior. In summary, in addition to attitude, the study demonstrates that subjective norms and PBC can also bridge personality traits and pro-environmental behavior intention.

The research calls for attention to personality traits in pro-environmental behavior and bridges three critical research gaps. First, the findings empirically evidence the impact of personality characteristics on household energy conservation. Unlike most works on "green personalities" (Kvasova, 2015; Ruci et al., 2018; Wang et al., 2020), this study compares personality traits' impacts on several typical household energy-saving behaviors and explores the energy-saving behavioral preference from the personality perspective. Second, the study points out the differences in psychological factors that affect household energy conservation among different residents. Most previous studies employ attitude to bridge personality traits and pro-environmental intention or behavior (Soutter and Mõttus, 2020; Sun et al., 2018; Wang et al., 2020). This study, however, emphasizes that personality traits can influence household energy-saving behavior through PBC and subjective norms as well. Therefore, this research contributes to a more comprehensive understanding of personality traits' influence. Modeling occupant behavior has been a challenge in both individual- and urban-scale building energy simulation (Happle et al., 2018; Hong et al., 2020). The findings of this study provide a psychological explanation for the behavioral heterogeneity in residential buildings, which might contribute to the occupant typology development in building energy research (Schweiker et al., 2016). The study can complement previous conclusions from the perspectives of architects, engineers and designers, such as the International Energy Agency's Energy in Building and Communities Program (IEA-EBC) Annex 53 (Yoshino and Chen, 2016), 66 (IEA, 2017) and 79 (IEA, 2021). Third, the research found that psychological factors' roles might change according to residents' personality characteristics. The findings suggest that personality traits can not only affect TPB attributes directly but also influence how they work. While only a few studies (Dalvi-Esfahani et al., 2020) in the research community have focused on this phenomenon and considered its role in actual behavioral interventions.

There are some limitations to this study. First, due to limited resources, this study only involves urban residents in Xi'an, China. Residents in Xi'an and other regions may have differences in socioeconomic, demographic and cultural aspects. Therefore, the applicability of the findings in this article to other regions needs more in-depth exploration. Especially, further research may include investigating respondents living in both urban and rural areas better to understand the differences in and occupants' energy-saving behavior of the widespread area. Second, this study only invites one representative from each selected household to fill out the questionnaire in the data collection process. Therefore, further research would benefit from in-depth discuss the energy-saving behavior varying among family members. Third, due to the unexcepted COVID-19 epidemic, this study collected the data with an internet-based approach. This data collection method might exclude many non-internet users indeliberately, such as the elderly and the young residents. Therefore, future research would benefit from well-designed offline questionnaires to reduce missing data. Fourth, this study uses a self-report method to collect data. Respondents' self-perception may cause data discrepancies. In each part of the questionnaire, the researchers emphasized that "there is no right or wrong answer, only your thought matters" to minimize the impact of the respondent's socio desirability. Future research would obtain more accurate behavioral information through smart meters and big data. Besides, human personality traits are difficult to obtain in practice, and future research would benefit from the acquisition of big data and machine learning techniques.

6. Conclusion

This research explores personality traits' role in household energy-saving behavior. The study surveyed 3000 households in Xi'an, China, and collected 1119 valid responses. The study grouped the respondents into four groups according to their personality characteristics and the ANOVA analysis indicated the significant differences in energy-saving intention and typical behaviors among the four clusters. The positive residents performed best in most household energy-saving behaviors, while the introverted residents tend to gain lower scores among the four groups. Besides, the SEM analysis further examined the psychological patterns driving energy-saving behaviors among the four groups. The extended TPB factors explain the effect of personality traits on household energy-saving behavioral patterns: the groups that present better energy-saving performance tend to gain higher scores on the extended TPB factors. We also found that moral norms show a more significant influence on energy-saving intentions of the positive and moderate residents, while PBC plays a more critical role in the behavioral process of the other groups. The research findings would advance the typology development of the residential building occupant from a personality perspective. This would further contribute to capturing the complex energy effect of occupant activity for building performance simulation and urban-scale energy modeling. In addition, the findings might provide a reference for more effective intervention settings in residential energy-saving behavioral promotion schemes. The study calls on the research community to pay more attention to the roles of personality traits in pro-environmental behaviors and their applications in practices, which would power the sustainable development of the residential sector.

CRediT authorship contribution statement

Xuan Liu: Methodology, Software, Visualization, Writing – original draft. **Qian-Cheng Wang:** Conceptualization, Formal analysis, Writing – original draft. **Izzy Yi Jian:** Data curation, Visualization, Investigation, Resources. **Hung-Lin Chi:** Supervision, Writing – review & editing, Project administration. **Dujuan Yang:** Writing – review & editing. **Edwin Hon-Wan Chan:** Data curation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The researchers would like to thank all the families who participated in the survey and devoted their precious time. We take this opportunity to thank Guo Hansen, Xie Qiaopeng, and Wang Yixuan for their contribution and resources in the pilot experiment. Also, the researchers sincerely appreciate our local collaborators, especially the local community service staff and volunteers for their support in our data collection process. The researchers would also like to express their gratitude to the China Scholarship Council (CSC) and Cambridge Commonwealth, European and International Trust, which partially funded this research.

Appendix A Typical energy-saving behaviors in the questionnaire.

Code	Behavior Category
B_{BS}	Eco-friendly building services operation
$B_{Appliances}$	Sustainable use of appliances
$B_{Kitchen}$	Kitchen energy-saving behavior
$B_{Hot\ Water}$	Saving domestic hot water
$B_{Investment}$	Household energy-efficiency investment
$B_{Interaction}$	Interpersonal interaction for energy conservation

Note: The definition and examples in Table 1 is also presented in the questionnaire.

Appendix B Psychological attributes in the questionnaire.

Construct	Code	Item	Reference(s)
Attitude	ATT-1	Household energy-saving in my daily life is useful to protect the environment.	(Chen, 2016; Du and Pan, 2020; Ru et al., 2018; Wan et al., 2014)
	ATT-2	Household energy-saving is a wise action to reduce carbon emission.	
	ATT-3	Household energy-saving is valuable to alleviate energy shortage issues.	
Subjective Norms	SN-1	My families think that I should save energy at home.	(Nie et al., 2019; Ru et al., 2018; Tan et al., 2017)
	SN-2	People whose opinions I value would prefer my energy-saving behaviors at home.	
Perceived Behavior Control	PBC-1	I am confident that I have the knowledge and time for household energy-saving behavior.	(Alam et al., 2014; Dalvi-Esfahani et al., 2020; Wan and Shen, 2015)
	PBC-2	It is difficult for me to perform household energy-saving behavior.	
	PBC-3	It is completely up to me whether or not I save energy at home.	
Personal Norms	PN-1	I would feel guilty about not saving energy at home.	(Du and Pan, 2020; Gao et al., 2017; Ru et al., 2018; Tan et al., 2017)
	PN-2	Wasting energy at home goes against my moral principles.	
	PN-3	It is my moral obligation to perform energy-saving behavior at home.	
Intention	I-1	I am willing to engage in energy-saving behaviors at home.	(Du and Pan, 2020; Ru et al., 2018; Wan et al., 2014; Wan and Shen, 2015)
	I-2	I am willing to follow the suggestions and rules of the community energy-saving scheme.	
	I-3	I intend to make an effort to save energy at home.	

Appendix C The summary of DV assessment results.

	Attitude	PBC	SN	PN	Intention	B_{BS}	$B_{Appliances}$	$B_{Kitchen}$	$B_{Hot\ Water}$	$B_{Interaction}$	$B_{Investment}$
Attitude											
PBC	0.856										
SN	0.744	0.803									
PN	0.544	0.373	0.673								
Intention	0.839	0.837	0.797	0.466							
B_{BS}	0.335	0.404	0.205	0.25	0.355						
$B_{Appliances}$	0.558	0.631	0.613	0.335	0.628	0.256					
$B_{Kitchen}$	0.348	0.477	0.369	0.341	0.472	0.249	0.364				
$B_{Hot\ Water}$	0.307	0.31	0.261	0.296	0.388	0.176	0.293	0.326			
$B_{Interaction}$	0.387	0.523	0.505	0.45	0.522	0.218	0.436	0.389	0.318		
$B_{Investment}$	0.617	0.653	0.529	0.303	0.581	0.259	0.384	0.354	0.197	0.264	

Appendix D The ANOVA results of four respondent groups.

Items	F	P-value
Extraversion (E)	178.4	0.000***
Agreeableness (A)	384.562	0.000***
Conscientiousness (C)	494.05	0.000***
Neuroticism (N)	401.33	0.000***
Openness (O)	650.078	0.000***
Attitude	16.03	0.000***
PBC	23.529	0.000***
Subjective Norms	28.439	0.000***
Personal Norms	25.707	0.000***
Intention	15.816	0.000***
B_{BS}	8.55	0.000***
$B_{Appliances}$	4.163	0.002**
$B_{Kitchen}$	13.221	0.000***
$B_{Hot\ Water}$	6.571	0.000***
$B_{Interaction}$	10.398	0.000***
$B_{Investment}$	29.129	0.000***

Note: ***: $p < 0.001$.

Appendix E Descriptive Statistics of four respondent groups.

		Positive					Temperate					Conservative					Introverted				
		Mean	Max	Min	Med	SD	Mean	Max	Min	Med	SD	Mean	Max	Min	Med	SD	Mean	Max	Min	Med	SD
Big Five Personality Traits	E	0.850	3.125	−2.561	−0.466	1.107	0.555	3.125	−1.663	0.432	0.771	−0.092	1.928	−2.262	−0.167	0.732	−0.711	1.330	−2.561	−0.466	0.790
	A	1.407	2.680	−2.628	−0.504	0.684	0.510	2.415	−0.770	0.557	0.576	−0.468	1.619	−2.097	−0.504	0.735	−0.519	1.353	−2.628	−0.504	0.749
	C	1.534	2.527	−1.582	−0.042	0.535	0.283	2.270	−1.069	0.215	0.728	−0.748	0.986	−2.866	−0.812	0.592	−0.095	2.013	−1.582	−0.042	0.728
	N	−1.607	0.073	−1.449	0.073	0.765	0.755	2.610	−0.942	0.581	0.682	0.117	1.849	−1.956	0.073	0.633	0.160	2.357	−1.449	0.073	0.734
	O	1.375	2.419	−1.097	0.075	0.618	0.394	2.185	−1.097	0.310	0.707	−0.946	0.075	−2.503	−0.862	0.524	0.143	1.716	−1.097	0.075	0.608
TPB	Attitude	0.346	1.223	−3.648	0.141	0.578	0.207	1.223	−2.024	0.141	0.833	−0.118	1.223	−4.189	0.141	1.072	−0.181	1.223	−3.648	0.141	1.115
	PBC	0.413	1.160	−3.413	−0.212	0.478	0.167	1.160	−2.498	0.245	0.850	−0.017	1.160	−3.413	0.245	1.076	−0.308	1.160	−3.413	−0.212	1.098
	Subjective Norms	0.572	1.744	−3.580	−0.386	0.474	0.102	1.744	−4.112	0.147	1.020	−0.120	1.744	−3.047	0.147	1.037	−0.221	1.744	−3.580	−0.386	1.023
	Personal Norms	0.433	1.765	−3.082	−0.438	1.020	0.204	1.765	−3.082	0.443	1.034	−0.052	1.765	−3.522	0.002	0.938	−0.302	1.765	−3.082	−0.438	0.930
	Intention	0.311	1.066	−3.285	0.099	0.628	0.234	1.066	−4.735	0.582	0.917	−0.110	1.066	−3.768	0.099	1.028	−0.191	1.066	−3.285	0.099	1.106
Household Energy Saving Behaviors	B Building Service	0.357	1.062	−2.547	0.160	0.778	0.081	1.062	−2.547	0.160	0.979	−0.067	1.062	−2.547	0.160	0.979	−0.160	1.062	−2.547	0.160	1.089
	B Appliances	0.065	0.845	−3.627	−0.273	0.595	0.167	0.845	−2.509	0.845	0.833	0.016	0.845	−3.627	0.845	1.076	−0.168	0.845	−3.627	−0.273	1.147
	B Kitchen	0.455	1.249	−2.528	0.305	0.694	0.041	1.249	−2.528	0.305	0.997	−0.195	1.249	−2.528	0.305	1.049	−0.030	1.249	−2.528	0.305	1.003
	B Hot Water	0.304	1.147	−2.757	0.171	0.730	0.039	1.147	−2.757	0.171	0.956	−0.009	1.147	−2.757	0.171	0.997	−0.172	1.147	−2.757	0.171	1.112
	B Interaction	0.388	1.153	−2.762	0.174	0.599	0.093	1.153	−2.762	0.174	0.994	−0.069	1.153	−2.762	0.174	1.059	−0.182	1.153	−2.762	0.174	1.038
	B Investment	0.537	0.934	−2.800	0.001	0.536	0.302	0.934	−2.800	0.934	0.792	−0.250	0.934	−2.800	0.001	1.119	−0.189	0.934	−2.800	0.001	1.005

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