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WILLINGNESS-TO-PAY FOR ENERGY-SAVING RETROFITS OF RESIDENTIAL BUILDINGS AND ITS INFLUENCING FACTORS: THE CASE OF THE PEARL RIVER DELTA, CHINA

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Abstract. In the 21st Century, the construction industry regards green building as an important breakthrough to achieve sustainable development, and energy-saving retrofits of residential buildings has been conducted globally with China no exception. In order to better understand consumers' attitudes and willingness-to-pay (WTP) for green retrofits and identify the shortcomings of the industry's development, this study designs a retrofit scheme and organizes a questionnaire survey to collect feedback of responds from the Pearl River Delta, China regarding their WTP for energy-saving retrofits of residential buildings and their decision factors. The study identifies a retrofit cost of $517.92 and found that 94.29% of respondents had the intention of green reconstruction. The results of a Pearson correlation analysis and one-way ANOVA show the professional background of respondents and their WTP to be negatively correlated, while education level, perceived value, perceived behavior control, and feelings of the surrounding reference group are positively correlated with participants' expected inputs. Of all the factors considered, the level of education and feelings of the surrounding reference group influence budget most significantly. The findings will help property developers and the government to design better marketing strategies and launch corresponding policies, thereby promoting the development of the green building industry.

Keywords: residential buildings, energy-saving retrofit, WTP, influencing factors, cost estimation, correlation analysis.

JEL Classification: R11.

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Introduction

With the rapid development of science, technology, and economy in the 21st Century, such non-renewable resources as coal, oil, and natural gas are facing becoming exhausted (Hu, 2014). People now pay increased attention to such problems as resource shortages and energy crises (Zhang, 2011). Urbanization is developing rapidly in China under the social background of building a moderately prosperous society; however, the rapid expansion of cities has also led to a rapid increase in resource and energy consumption (Li, 2016; Building Energy Research Center of Tsinghua University, 2020). As one of the giant industries with the largest energy consumption, the construction industry's energy-saving potential is self-evident (Zhang, 2011; Hu, 2014). Since China's existing buildings are younger than those of more developed countries, the renovation of buildings in western countries started much earlier than in China (Huang, 2014). As early as the middle of the 20th century, developed countries in Europe and America, such as the UK, France, and the U.S. had already started research and renovation work in terms of improving the thermal performance of building structures and the energy efficiency of equipment. The real estate industry in China has experienced large-scale development over the past two decades, as a result, work on the renovation of existing buildings has started relatively late. Although the government has started to retrofit public buildings from the north to the south of the country and is promoting the construction of green buildings over a large area, there has been little work carried out, or attention paid, in the green retrofits of residential buildings. At present, the country's stock of residential buildings is huge, with more than 60% completed before 2000 (China State Council, & National Population Census, 2011). The lack of seismic and energy-saving design at that time has resulted in all having high energy consumption (Zhang et al., 2018; Zhao et al., 2016; Wang et al., 2020). Therefore, research into the energy-saving retrofit of residential buildings is of great significance for the future sustainable development of the country's construction industry and society. At the same time, some studies consider that encouraging the voluntary participation of the public in an energy-saving campaign will help achieve national carbon emissions reduction targets. Moreover, based on previous research into consumer willingness-to-pay (WTP) in different industries, a number of socioeconomic factors, such as income, educational level, and occupation have been found to have an impact on consumer intentions and WTP, hence there may be some factors that have a positive influence on people's WTP for green retrofits (Ozor et al., 2013; Kwak et al., 2013; Rahman et al., 2017; Sehreen et al., 2019; Karytsas et al., 2019). This study can help in understanding the consumer wishes for residential energy-saving retrofits and increase people's understanding of the green building industry, encourage consumers to actively buy green buildings, and participate in green retrofits (Koo & Hong, 2018).

Since the concept of green building was first proposed in 2003, green building construction has been promoted all over the country, and many high-quality green buildings have emerged. However, as a new term, "green building" and "green retrofit" have been misunderstood by many consumers, with many thinking that the price of green building is very high, these kinds of buildings have not yet widely appeared, green retrofit technology is pretentious, etc. (Hu, 2014; Zhang, 2011). In response, the present study aims to deepen consumer understanding of the green building industry and the effectiveness and budget of the retrofit through the calculation of the renovation cost involved, and provide theoretical guidance for future housing design and retrofits. Combined with the concept of the green retrofit of buildings, the Customer Perceived Value theory and Theory of Planned Behavior, the analysis and research into consumer WTP, and its influencing factors, will help designers and developers have a deeper understanding of consuming psychology so as to adopt more targeted scheme designs and marketing strategies according to consumer needs and preferences. It will also help provide the government with a deeper understanding of consumer opinions and the views of industry, and find deficiencies in the development of the industry, to enable the implementation of suitable measures or corresponding policies to promote the development of the green building industry, which may help to better address the challenge of globe warming and reach the goal of an emission peak and carbon neutrality.

The paper offers a new perspective to analyze consumers' concerns and attitudes over green retrofits by a factor analysis of the influencing factors and quantifying the cost of retrofitting. A brief review of the current situation and common measures for the energy-saving retrofits of residential buildings as well as studies of WTP is presented. Section 2 describes the methodology used including the design of the questionnaire, followed by Section 3 detailing the retrofit scheme and how the cost calculations are made. Section 4 gives the results of the data analysis, cost calculations of the retrofits, and consumer WTP as well as the key influencing factors involved. The last Section conclude the paper with suggested policy implications, a proposed future research agenda, and highlighting the limitations of the study.

1. Literature review

1.1. Current situation of energy-saving retrofits of residential buildings in developed countries

The energy crisis caused by the outbreak of the Middle East war in the 1970s, and the sharp fluctuations in oil prices caused by the Gulf War and the Iran-Iraq War, brought about the realization in developed countries that energy is essential to national stability and future development (Xu, 2005). Scholars were also aware of the importance of energy-saving technology in building retrofits and began to analyze and study related technologies, starting the worldwide building energy-saving movement. At the same time, energy-saving work on buildings in developed countries was also carried out during this period (Yu et al., 2012). Relevant research has become more specific since the turn of the 21st Century, and the research results have been successfully applied to practice. At present, developed countries promote energy-saving retrofits as improving the thermal performance of buildings, improving the energy efficiency of energy consumption systems and equipment in buildings, developing new energy, etc. At the social level, the United States has adopted a market-based approach, using tax breaks and other marketing tools to increase the citizens' motivation to retrofit. European countries such as the United Kingdom and France have introduced a range of economic incentives such as subsidies, low interest loans, tax breaks, etc., and develop strict, detailed, and practical policies and regulations to help retrofit buildings. In addition, Germany has set quantitative requirements for energy consumption, and established a system of energy efficiency certificates for buildings, whereby developers are required to provide consumers with proof of the energy consumption of their homes for their reference and to ensure that it meets legal requirements (Ma, 2015; Xu & Ding, 2014; Zheng, 2018; Lu, 2020).

1.2. Overseas research into consumer WTP for green buildings

In the context of increasing environmental pollution and energy scarcity, studies regarding WTP are conducted in different countries and different sectors around the world, mainly examining people's WTP for environmental health and secure energy supplies (Masud et al., 2015; Al-Amin et al., 2020). The consumers' view and WTP for green buildings emerge as a critical question for adaptation policy-making in promoting the development of the green real estate industry, therefore, much research has been conducted into their willingness to buy green buildings and the influencing factors involved. Portnov et al. (2018) and Ofek and Portnov (2020), for example, have conducted in-depth studies in Israel of the acceptable green building price premium of different stakeholders and the factors affecting their WTP. He et al. (2019) used a joint selection model and two-step clustering algorithm to study customer willingness to pay for green housing attributes and identified the attributes that were most attractive to all target customers and feature groups. From the point of view of the whole life cycle of architecture, Liu et al. (2019) used the potential class regression method to analyze the heterogeneity of the preferences of the residents. Zalejska-Jonsson's (2014) Swedish survey was conducted of the declarative and rational WTP of owners and tenants living in traditional buildings and environmentally friendly green buildings with low energy consumption to understand their differences in opinions. Banfi et al. (2008) used the selection experiment and the logit model based on fixed effect to evaluate the willingness of tenants and owners of Swiss residential buildings to pay for energy-saving measures. Golbazi et al. (2020) conducted a survey of the comfort and perceived quality of the indoor environment of U.S. university students living in green dormitories, to reveal their WTP to live in green buildings after graduation. Park et al. (2013) used a joint analysis and ranking method to test consumers' marginal WTP to determine the monetary value they are willing to pay for different environmental performances in Seoul, South Korea.

1.3. Studies of the livable renovation of buildings or the WTP for green buildings in China

Chinese studies are mainly concerned with the WTP for the promotion and development of green buildings, the influencing factors involved, and the livable renovation measures of buildings. Taking cities such as Changsha, Hangzhou, Suzhou, Wuxi, Lanzhou, and Jinan as examples, some studies have carried out binary logistic regression analysis, structural equation modeling, multi-group model statistical methods, Analytic Hierarchy Process, etc., to analyze consumer willingness and influencing factors (Hu, 2014; Huang, 2014; Li, 2016; Lu, 2019; Yang & Li, 2014; Zhong, 2017). Taking Xi'an as an example, Yang et al. (2018) has systematically discussed the influence path and mechanism of resident willingness to support the green retrofit of residential buildings from the point of view of internal psychological factors and external factors. Similarly, taking Beijing as an example, Zhang et al. (2015) used the two-stage survey method to ask the respondents' WTP for green buildings before and after informing them of the indoor environment and comfort index of green and non-green housing.

1.4. Research into energy-saving renovation measures of residential buildings in China

There have been various Chinese studies of energy-saving retrofits of existing residential buildings according to the climatic characteristics of different building thermal design zones. Some expound on the connotation of a livable retrofit of residential buildings and establish the special and key retrofit technologies in hot summer and cold/hot winter areas in terms of functional retrofits, safety retrofits, energy-saving retrofits, environmental retrofits, etc., (Wang et al., 2020; Zhang et al., 2018). Based on a field investigation and measurement of the thermal environment of typical village and town houses, Li (2012) has analyzed the methods to reduce building energy consumption and improve the indoor thermal environment quality of villages and town houses in the Pearl River Delta (PRD) region under the background of rapid urbanization, while Wang and Yu (2010) analyzed energy-saving measures in terms of overall planning and design, structural materials, and systems, as well as the thermal performance of exterior structures. Yang (2017), Zhao et al. (2016), and Li (2014) combine the current situation of building energy conservation in China with the climatic characteristics of hot summer and warm winter areas, briefly analyzing energy-saving renovation technologies from the aspects of peripheral structure, air-conditioning systems, and lighting systems, to provide a scientific basis and technical reference for the promotion of suitable technologies. Starting from the energy saving building envelope and heating metering, Zuo (2017) provides technical support for the practical application to the northern heating areas of existing building energy saving from the aspects of external walls, windows, doors, and roofs. Wang et al. (2019) and Zhang et al. (2013) focus on existing residential buildings in cold regions to simulate building energy consumption for different types and thicknesses of insulation materials, proposing energy-saving retrofitting techniques for existing residential buildings in cold regions in terms of external windows, external walls, roofing, heating, etc.

The review of the above literature shows that Chinese research into green retrofits of buildings is more focused on investigating the current situation from such macro-level social aspects as technical measures, policy plans, and economic evaluation. The WTP of household subjects at the micro level is relatively ignored, with research into people's WTP for energy-saving renovation of residential buildings in the 22 million population PRD region particularly absent. Compared with Chinese domestic research, foreign studies concerning the promotion of green buildings or green retrofit of buildings focus more on the price premium and quantifying the extra cost or price proportion that consumers are willing to pay.

2. Methodology

Face-to-face interviews were conducted with potential recipients of energy-saving retrofits of residential buildings in a small-scale pilot study to determine a reasonable survey area and verify the rationality of the numerical interval settings of the questions, supplement some of the question options, and modifying ambiguous questions before the main survey. The 10 respondents were all residents of the PRD region, including university students, newcomers to the workplace, veterans, and retirees, with an age range of 20–60 years old, to ensure that the questions set would be understood by all types of people. The main survey was conducted by an online questionnaire and the data was analyzed by One-way ANOVA and Pearson correlation analysis.

2.1. Sample size and sampling technique

Of the target sample size was 200, 162 completed questionnaires were received, of which 140 met the established requirements. The test statistics showed reliability of the questionnaire to be high and the data having strong correlations, which was therefore suitable for further factor analysis. In this study, data were collected by an online structured questionnaire through the Wenjuanxing (WJX) platform (https://www.wjx.cn/, a professional online questionnaire survey platform). The interviewees were selected using random sampling from the PRD including: Guangzhou, Foshan, Zhaoqing, Shenzhen, Dongguan, Huizhou, Zhuhai, Zhongshan, and Jiangmen.

2.2. Design of the questionnaire

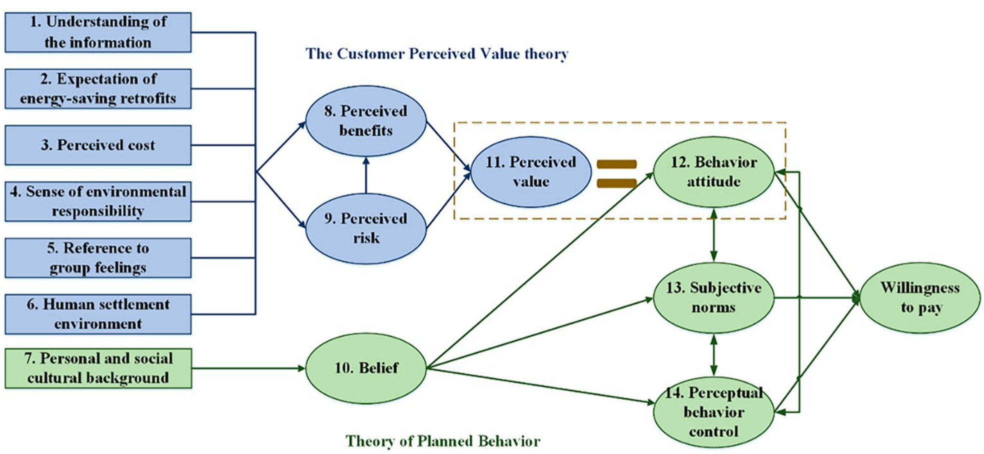
The questionnaire was divided into three parts, comprising (i) an introduction to the design scheme and cost calculation results as detailed in Section 3, (ii) the respondents' personal information and socio-economic attributes (i.e., gender, age, education level etc.), and (iii) the respondents' WTP for energy-saving retrofits and the influencing factors involved. Combined with the decision-making model, which will be illustrated in more detail in Section 2.3, the questions concern the respondents' understanding of green buildings, their willingness to invest in a retrofit, and the demand, expected return, and perception of risk involved.

2.3. Construction of the decision-making model of resident WTP for energy-saving retrofits of residential buildings

Resident WTP for energy-saving retrofits of residential buildings is affected by the subjective wishes of the owners and various external factors: it is closely related to the owner's interests and comfort of the living environment, which requires the investment of much time, energy, and money. This study establishes WTP on the premise that the owner accepts the monetary and non-monetary costs associated with the retrofit. Moreover, the safety and function of the building meet the requirements of continuing use and energy-saving retrofits. Customer Perceived Value theory and Theory of Planned Behavior is introduced, with 14 factors influencing the owners' WTP for energy-saving retrofits of residential buildings identified through literature review, and an associated decision-making model is constructed (Figure 1). The explanation of the influencing factors is as follows:

(1) Understanding of the information refers to the owners' understanding of the cost of the renovation plan, the amount of their own funds, as well as government subsidy policies or social publicity endeavors and other information.

(2) The expectation of energy-saving retrofits is whether the construction quality, comfort, and energy-saving effect of the house can meet the owners' expectations.
(3) Perceived cost includes capital cost and non-capital cost (i.e., time, energy, economic cost, and other additional efforts) spent by the owner when determining the products.
(4) The sense of environmental responsibility represents the responsibility the owner can feel for the maintenance of the environment.
(5) Reference to group feelings refers to the impact of publicity and comments on people's energy-saving transformation attitude and payment decisions made by their neighbors, relatives, and friends, or on social media before and during the decision-making period.
(6) Human settlement environment refers to the living environment of the house itself and the living experience caused to the residents.
(7) Personal and social cultural background refers to decision makers' personality, accumulated experience, age and gender, cultural background and other factors that may indirectly affect their behavior, attitude, subjective norms, perceived behavior control, and ultimately their behavior intention.
(8) Perceived benefits are the expectation of the owner to reap the benefit from the payment decision.
(9) Perceived risk is the concern of owners in the process of payment decision making.
(10) Belief is the tendency of people's own thoughts, consciousness, and behavior. It is the self-confidence that the individual can achieve the desired effect after the adoption of a certain behavior.



Note: Kim et al. (2007), Huang and Wang (2013), Luo and Zhu (2016), and Sang et al. (2019) all believe that attitude represents the feeling of an individual after the comprehensive evaluation of a product or behavior, which is similar to perceived value, and can be used to explain intentioned behavior by replacing consumers' attitude. Therefore, when combining the Customer Perceived Value theory with Theory of Planned Behavior, perceived value equates with the behavior attitude.

Figure 1. Decision-making model of resident WTP for energy-saving retrofits of residential buildings

(11) Perceived value is the subjective trade-off and evaluation of the benefits and risks that owners can perceive after the building energy-saving transformation. It may be equal to the amount of money paid by consumers, or all the returns that consumers can obtain.
(12) Behavior attitude refers to the external activities produced by people under the influence of subjective and objective factors, as well as the tendency to evaluate and act on things according to their own values and morality.
(13) Subjective norms refer to the social pressures and influences when the owner makes a payment decision.
(14) Perceptual behavior control refers to the individual's perception of the difficulty in adopting a certain behavior (decision making), which reflects the individual's perception of the factors that promote or hinder that behavior.

3. Retrofit scheme and cost calculation

3.1. Background of the research area

The PRD region is in the central and southern part of Guangdong Province, covering the nine cities of Guangzhou, Foshan, Zhaoqing, Shenzhen, Dongguan, Huizhou, Zhuhai, Zhongshan, and Jiangmen. It is an important economic center in China and one of the three major urban agglomerations with the largest population, strongest innovation ability, and strongest all-round strength in China.

The PRD region is in the south subtropics and has a subtropical marine monsoon climate, with abundant rainfall and sufficient heat. It is a hot summer/warm winter area according to the building climate demarcation (Figure 2) and the IV area according to the building thermal design (Figure 3). The three-dimensional climate characteristics of this region are obvious. Most areas are warm in winter and cool in summer, with distinct dry and wet seasons. There are thunderstorms and fog all the year round, the annual range of air temperature is small, the daily range is large, the sunshine is less, and the solar radiation is strong. While architectural designs must fully meet the requirements of heat protection, ventilation, and rain protection in summer, no winter cold protection and heat preservation measures are needed.

3.2. Current situation of regional housing

3.2.1. Housing design

Most residential buildings in the PRD are tower blocks, with several households surrounding a group of public vertical elevators to form a building plan with roughly the same length and width. This kind of architectural form means the orientation of the building often needs to be tilted to take care of the lighting needs of several apartment types, so buildings do not usually face north and south. Compared to the spray-painted walls in north China, the facades of many buildings in southern China are pasted with ceramic tiles, while the roofs are mostly reinforced concrete. Due to the humid climate, the first floor of the building is mostly overhead, designed as a garage or the owner's activity place. Most balconies are not closed to ensure an open and ventilated environment.

Figure 2. Zoning map of building thermal design in China
(source: Thermal Design Code for Civil Building)

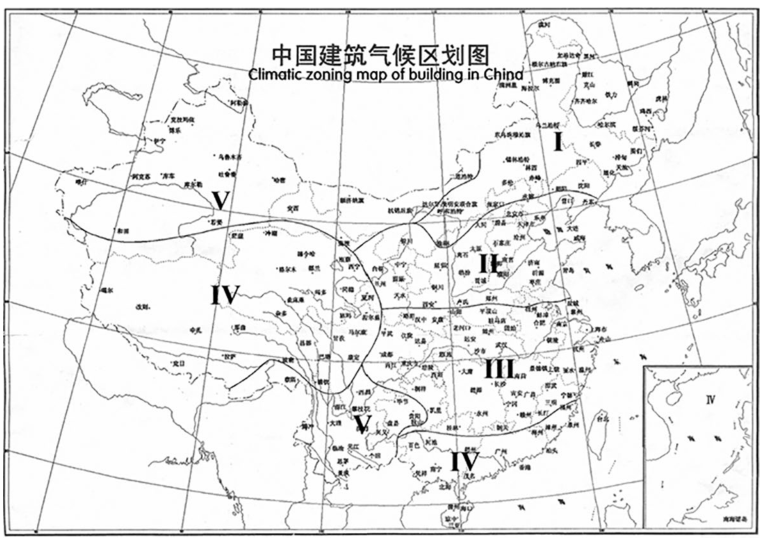


Figure 3. Climatic zoning map of buildings in China
(source: Building Climate Demarcation)

3.2.2. The selection of reformed household type

CRIC is a leading real estate big data application service provider in China, with information covering 387 cities across the country, serving more than 95% of the top TOP100 real estate enterprises. It provides a comprehensive solution of online and offline information services for the government, enterprises, and property buyers. Combined with the statistical data of the real estate industry of CRIC in the past five years, a typical household type is selected as the application case of cost calculation.

The data show that, in the new housing market, whether in first- and second-tier cities or third- and fourth-tier cities, the sales of 100–120 m^2 three-room apartments are the most prevalent. In the second-hand market in the past five years, there are a similar number of transactions for two- and three-room apartments, with a strong demand for both. In key monitoring cities, most transactions involve apartments less than 120 m^2, with the demand for 70–90 m^2 particularly strong. Therefore, a unit type with an area of approximately 100 m^2 is selected for this study as this is the most representative for the scheme design and cost calculation.

3.2.3. Technical measures for energy-saving retrofits

The State Council of the People's Republic of China (2008) define energy-saving retrofits of buildings as activities to implement the enclosure structure, heating system, heating and refrigeration system, lighting equipment, and hot water supply facilities of existing buildings that do not meet the mandatory standards for energy conservation of civil buildings. Combined with the regulations and the technical measures commonly adopted in the industry, this study expounds the technical measures of energy-saving retrofits of residential buildings through the following six aspects.

3.2.3.1. Wall reconstruction of buildings

This involves (i) installing thermal insulation materials on the inside of the enclosure structure for internal thermal insulation, or using appropriate thermal insulation materials for external thermal insulation treatment of the external wall to improve the total thermal resistance of the external wall and isolate the cold and heat in the external environment; (ii) installing a sunshade panel on the outside of the wall for external shading to reduce the wall's exposure to sunlight, or sunlight entering the room: due to the strong solar radiation in this area, the thermal reflection material is smeared onto the outer wall to transfer the solar radiation heat to the external environment using the reflection and emission of the coating, which can effectively prevent the heat from entering the room and producing a good thermal insulation effect; and (iii) planting such green climbing plants as Parthenocissus on the wall to form a natural barrier to absorb and isolate solar radiation, reduce the heat absorption of the peripheral structure, and help beautify the surrounding environment.

3.2.3.2. Reconstruction of windows and the design of lighting and ventilation

The thermal insulation performance and air tightness of windows are relatively poor, which is the weakest part of building thermal insulation. This may not only affect the indoor thermal environment, but also increase air conditioner energy consumption. Therefore, it is very important to improve the thermal performance of the outer window. Double or multi-layer glass, heat reflection glass, Low-e glass, or a heat insulation film can be used to degrade the heat transfer coefficient and radiation transmittance of the outer window, which can also be used to reduce temperature difference, heat transfer, heat loss, and radiation heat absorption of windows.

The building layout can effectively guide the flow of natural wind between building blocks, strengthen indoor natural ventilation, improve indoor comfort, and reduce air conditioner energy consumption (Li et al., 2020). The ups and downs of the terrain can be used to improve the residential structure, orientation of the building, distance between houses, and try to adopt a north-south layout as far as possible. For the main room, as its area is usually slightly larger than other rooms, it is suggested to set up at least two external windows in the room to obtain better ventilation and lighting, and a rain shield outside the window to avoid ventilation obstruction caused by closing the window on rainy days. The use of sunshades or curtains can reduce the amount of solar radiation entering the room and effectively reduce indoor temperature to reduce air conditioner use and save energy. Attention should be paid to the window size – avoiding reduced comfort due to an excessive window area, resulting in excessive indoor lighting, dazzling light, local solar radiation, high regional temperature, etc.

3.2.3.3. Roof reconstruction

At present, most residential buildings have a flat roof structure, which receives a large amount of solar radiation under sunlight over time and transfers a large part of the heat into the room, resulting in a rise in indoor temperature, affecting comfort and increasing energy consumption. Therefore, the following retrofit measures can be taken: (i) transforming the flat roof into a water storage roof, using the evaporation and heat absorption of water to reduce the roof's temperature; (ii) adopting a "flat slope" design and embedding thermal insulation materials inside, improving the waterproof performance of the roof and enhancing the thermal insulation effect; (iii) providing green plants on the roof to form a barrier to isolate heat and reduce the temperature fluctuation on the inner and outer surface of the roof; and (iv) smearing heat insulation materials to reduce heat entry.

3.2.3.4. Balcony reconstruction

This can be achieved by selecting tight, glass doors with a strong thermal insulation effect for the open balcony to help isolate cold air or heat from the outside, transforming an open balcony into a closed balcony, using insulation windows, and adding thermal insulation materials into balcony panels.

3.2.3.5. Other aspects

The hot summer/warm winter PRD climate is suitable for the growth of green plants all year round. Using three-dimensional greening on the roof and outer wall can help strengthen the thermal insulation of the enclosure structure, reduce the inner surface temperature of the wall/roof, and reduce air conditioner cooling capacity in summer. Also possible is to transform the air conditioner system and lighting system, replace old high energy consumption equipment, adopt frequency conversion air conditioners and LED lamps with high energy efficiency and low energy consumption, and make good use of ventilation and lighting design to reduce the use of air conditioners and lighting.

3.2.4. Retrofit scheme

Climate conditions play an important role in building energy performance, since the primary energy demand is usually based on the relationship between the internal and external environment of a building (Mac Uidhir et al., 2020). Choosing suitable sustainable retrofit measures may directly influence the expected energy savings created by a specific retrofit, so it is necessary to conduct a case-specific localized study to maximize the energy saving effect involved (He et al., 2021). The PRD region's summer is hot and lasts a long time, with tropical storms and typhoons, strong winds, and torrential rain. Due to the large solar height angle, little sunshine, and strong solar radiation, buildings need to be protected from the sun in the west in their architectural design and planning, with careful attention paid to the provision of sunshade, flood control, rain protection, moisture protection, etc. The focus of energy conservation of buildings is on improving the quality of the indoor thermal environment and reducing air conditioner energy consumption in summer (Deng et al., 2016; Fu & Hou, 2002; Liu et al., 2020; Zhao et al., 2016). One approach to this is by focusing on heat insulation during the day and cooling at night in summer. However, there has been little research into energy-saving renovation technology of buildings by improving the thermal insulation performance of external walls and roofs.

In practice, inherent designs such as exterior walls and roofs cannot be redesigned by the owners themselves, and the thermal insulation of the roof only has an impact on residents living on the top floor, so the retrofit measures are only briefly described in the upper section, as these parts can greatly meet energy-saving requirements after the unified renovation of the building. We have selected a typical household in the PRD region for the energy-saving retrofit study, and the design drawing of the retrofitted room is shown in Figure 4. The retrofits of the present study focus on improving the quality of the thermal environment in summer and reducing air conditioner energy consumption. Specific measures include: (i) renovating exterior windows: replacing old windows with low radiation (Low-e) glass windows with better thermal insulation and light transmission, and pasting heat insulation film onto glass in such non-main lighting areas as where there is severe sun exposure or toilets to reduce heat entry into the dwelling to improve its thermal insulation performance and privacy; (ii) replacing the glass door that connects the balcony and the living room with a hollow toughened glass

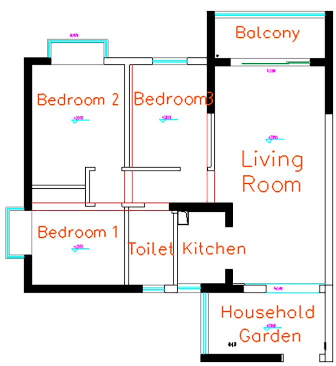


Figure 4. Design drawing of a residential household in Shenzhen
(source: A Shenzhen decoration company)

door with good sound insulation, heat insulation, and tightness, which can effectively isolate the heat and moisture from the outside, and reduce the loss of air to the outside when the air conditioner and fan are in operation; (iii) adopting sunshade and rain protection measures: providing a practical endurance board rain shed canopy over the bedroom window (floating window) and balcony window to reduce the amount of ultraviolet, sunlight radiation, and rain spatter to improve ventilation; (iv) enclosing the balcony; (v) replacing old high energy consumption household appliances with new higher energy efficiency products; and (vi) increasing the number of green plants on the balcony to form a natural heat barrier to reduce heat gain into the room and improve air quality.

3.2.5. Cost estimation

The latest prices of building materials in Guangdong Province in January 2021 were collected from the Zaojiatong website one month before the questionnaire was distributed, with the average prices of all the suppliers in the website used for cost estimation.

A rough estimation (Table 1) was made of the door and window area according to the size of the opening (Table 2). It is assumed that the doors and windows are made at the construction site, rather than purchasing them premade. The calculation includes accessories but only considers the increased cost caused by different glass materials as the other accessories required for making doors and windows will not be different due to the change of glass materials.

Table 1. Incremental cost of energy-saving retrofits

Item	Unit price of modified materials	Quantity	General cost	Retrofit cost	Incremental cost
Windows	\$15.25 / m^2	20 m^2	\$116.02	\$305.00	\$188.98
Seal the balcony	\$15.25 / m^2	9 m^2	\$52.21	\$137.25	\$85.04
The door between balcony and living room	\$14.93 / m^2	7 m^2	\$40.61	\$104.51	\$63.90
Sunshade (rain shield) board	\$5.70 / m^2	4 m^2	\$0	\$22.80	\$22.80
Cost			\$208.84	\$569.56	\$360.72

Table 2. Opening size (source: The design drawing)

Item	Calculation of engineering quantity	Size (Width m × Height m)	Area (m^2)
Household garden window	Calculated in m^3 and in terms of area according to the size of the opening as shown in the design drawing.	2.04×2.20	4.488
Kitchen window		0.77×1.30	1.001
Toilet window		0.71×1.30	0.923
Bedroom 1 window		0.57×1.87×2+1.55×1.87	5.0303
Bedroom 2 window		0.56×1.87×2+1.83×1.87	5.5165
Bedroom 3 window		1.15×1.30	1.495
Balcony		3.65×2.37	8.6505
Door connecting the balcony to the living room		2.63×2.3	6.049

The specific size of the sunshade is related to the required sunshade effect and, as the specific size and orientation of different windows are different, we roughly set the size of the rain shed canopy to extend 10 cm from each edge of the window.

Air conditioners are one of the most common electrical appliances in the PRD region, and its energy consumption greatly affects total energy consumption. Moreover, air conditioners with higher energy efficiency can save more electricity, but are also more expensive to buy. The product comparison function of the JD.com online Mall website is used to compare the prices of air conditioners with the same brand, similar model functions, and different energy consumption levels – indicating that an air conditioner with higher energy efficiency levels will cost at least \$31.44 more, and the price difference between some brands can even reach a \$157.20. Normally, the bedroom and living room are each equipped with one air conditioner, so if the owner considers the energy efficiency factor when buying, the cost of a three-room household model may increase by at least \$157.20.

4. Results and discussion

4.1. Estimation of WTP

The results in Table 3 show that more than 90% of the respondents intend to have a green retrofit. Their willingness is mainly focused on transforming to a one- or two-star green building, with only 17.14% willing to go to the highest level. This shows that, although they are willing to carry out the energy-saving retrofits of green buildings, there are reservations in terms of the cost and effect of the retrofit, and a sizeable portion are unwilling to retrofit directly to the highest-level buildings, at least in the short term. As Table 4 shows, the WTP amount is fairly evenly distributed, with the largest number of people willing to pay \$786 – 1572/100 m^2 floor area, while the least people are willing to pay more than \$1572/100 m^2. Overall, the potential recipients' WTP for green building renovation is still considerable.

Table 3. Interviewees' distribution table of retrofit stars and WTP

Star level		
Star level	Number of valid samples (copies)	Percentage
Traditional (non-green)	8	5.71%
One-star	53	37.86%
Two-star	55	39.29%
Three-star	24	17.14%
WTP		
Budget	Number of valid samples (copies)	Percentage
Less than \$786/100 m^2	48	34.29%
\$786 - 1572/100 m^2	55	39.29%
More than \$1572/100 m^2	37	26.43%

Note: Green buildings are divided into three levels: three-star > two-star > one-star. The higher the level, the higher the level of green certification.

Table 4. Data sheet of residents' WTP

WTP price range	Frequency	Frequency of positive WTP	Cumulative frequency of positive WTP	Frequency of non-negative WTP	Cumulative frequency of non-negative WTP
Unwilling to transform	8	–	–	5.71%	5.71%
Up to \$786 / 100 m^2	46	34.85%	34.85%	32.86%	38.57%
\$786 – 1572 / 100 m^2	52	39.39%	74.24%	37.14%	75.71%
Over \$1572 / 100 m^2	34	25.76%	100%	24.29%	100%
Total	140	100%	–	100%	–

Note: Data are rounded to retain two decimal places.

The average WTP for energy-saving retrofits of residential buildings in the PRD is estimated according to the following formula:

$$E\left(\mathrm{WTP}\right)_{positive} = \sum\nolimits_{i=1}^{n} \theta_i P_i, \tag{1}$$

where θ_i denotes the willing price, P_i frequency of the corresponding price, and n refers the number of interval types to pay the willing price. In this study, $n = 3$.

Since the WTP price set in the questionnaire is a range, the price of each range is defined as its mean value for convenience in the calculation process: that is, an unwilling retrofit is defined as \$0, less than \$786/100 m^2 is defined as \$393/100 m^2, \$786–1572/100 m^2 is defined as 1179/100 m^2, and more than \$1572/100 m^2 is defined as \$1965/100 m^2. The mean value of WTP, E(WTP) is \$1107.57/100 m^2. Since 5.71% of the interviewees in the sample pay \$0 then, in order to reflect the economic significance of non-negative WTP considering its impact on average WTP, the Spike model is used to adjust the WTP. The formula is

$$E\left(\mathrm{WTP}\right)_{non-negative} = E\left(\mathrm{WTP}\right)_{positive} \times (1 - P_{\mathrm{WTP}=0}), \tag{2}$$

which is \$1044.33/100 m^2.

Combining the positive WTP distribution (Figure 5) and the non-negative WTP cumulative frequency distribution (Figure 6) gives a median WTP approximately in the range of \$786–1572/100 m^2, closing to the left end of the interval, which is close to the calculated result of average WTP. Therefore, the calculated results are taken to be reasonably accurate.

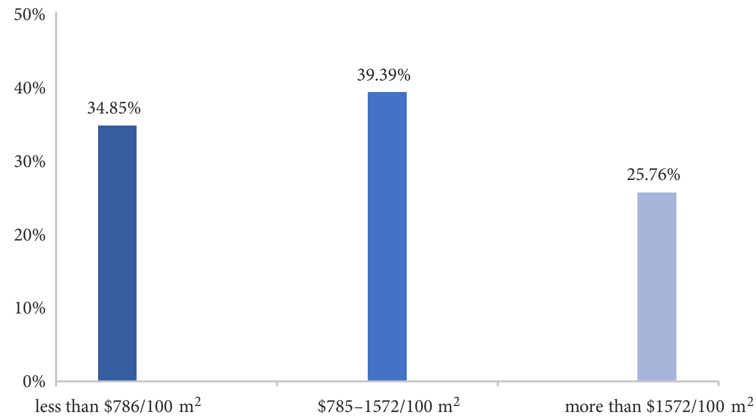


Figure 5. Distribution of positive WTP

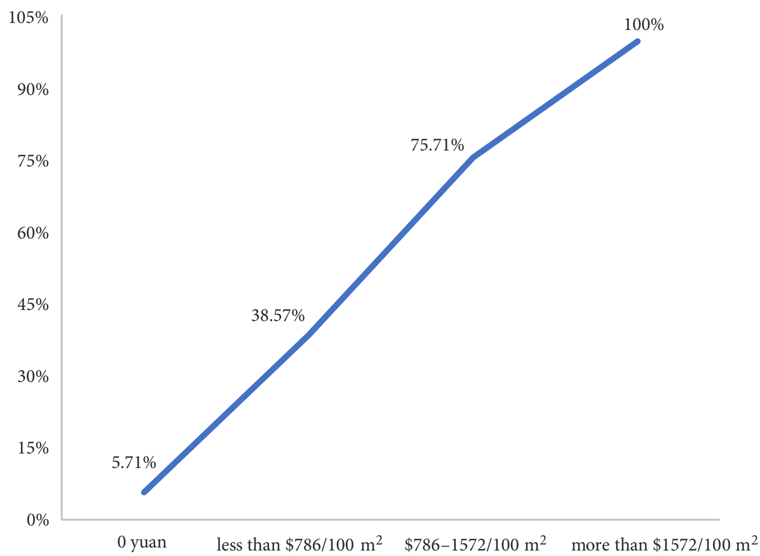


Figure 6. Cumulative frequency distribution of non-negative WTP

4.2. Identification and analysis of factors affecting WTP

4.2.1. Correlation analysis

Tables 5 and 6 contain the Pearson correlation coefficients for the main factors influencing residents' WTP and expected investment, showing that, at the 5% significance level, the respondents' professional background is negatively correlated with their WTP, and their perceived value (behavior attitude) as well as perceived behavior control are positively correlated with their expected input. At the 1% significance level, the respondents' education level and the feelings of the reference groups around them are positively correlated with their expected input.

Table 5. Pearson correlation analysis 1

		Gender	Age	Residential location	Education	Monthly income	Professional background	Occupa-tion	Year of construction	Housing property right	Decoration time	WTP	Budget
Gender	Pearson correlation	1											
	Significant (bilateral)												
Age	Pearson correlation	0.122	1										
	Significant (bilateral)	0.151											
Residential location	Pearson correlation	–0.006	–0.093	1									
	Significant (bilateral)	0.947	0.276										
Education	Pearson correlation	–0.152	–0.389**	–0.086	1								
	Significant (bilateral)	0.072	0.000	0.313									
Monthly income	Pearson correlation	0.098	0.649**	-0.061	-0.030	1							
	Significant (bilateral)	0.251	0.000	0.477	0.725								
Professional background	Pearson correlation	0.041	–0.063	0.005	0.051	–0.015	1						
	Significant (bilateral)	0.629	0.458	0.955	0.552	0.864							
Occupation	Pearson correlation	0.042	–0.265**	–0.009	–0.160	–0.536**	–0.060	1					
	Significant (bilateral)	0.625	0.002	0.911	0.058	0.000	0.481						
Year of construction	Pearson correlation	0.037	–0.080	0.219**	0.132	0.093	0.092	–0.003	1				
	Significant (bilateral)	0.664	0.346	0.009	0.119	0.273	0.281	0.974					
Housing property right	Pearson correlation	0.041	0.094	0.059	–0.247**	–0.070	0.014	0.083	–0.051	1			
	Significant (bilateral)	0.630	0.267	0.488	0.003	0.411	0.874	0.331	0.546				
Decoration time	Pearson correlation	0.015	0.120	–0.028	–0.101	0.026	–0.095	0.013	0.074	0.016	1		
	Significant (bilateral)	0.858	0.158	0.742	0.235	0.756	0.263	0.877	0.387	0.847			
WTP	Pearson correlation	0.037	0.150	–0.063	–0.083	0.107	***–0.212****	–0.061	0.013	–0.031	0.011	1	
	Significant (bilateral)	0.668	0.077	0.456	0.332	0.209	***0.012***	0.477	0.874	0.715	0.898		
Budget	Pearson correlation	–0.139	–0.101	–0.082	***0.227*****	0.003	–0.052	–0.149	–0.031	0.028	0.059	–0.042	1
	Significant (bilateral)	0.101	0.236	0.337	***0.007***	0.975	0.540	0.079	0.717	0.744	0.488	0.624	

Note: ** and * indicate a significant correlation at 0.01 level (bilateral) and 0.05 level (bilateral), respectively;
The italic bold term shows that there is a significant correlation between the two variables.

Table 6. Pearson correlation analysis 2

		Understanding the information	Expectation of energy-saving retrofits	Perceived cost	Sense of environmental responsibility	Reference to group feelings	Human settlement environment	Perceived benefits	Perceived risk	Perceived value (behavior attitude)	Perceptual behavior control	WTP	Budget
Understanding the information	Pearson correlation	1											
	Significant (bilateral)												
Expectation of energy-saving retrofits	Pearson correlation	0.475**	1										
	Significant (bilateral)	0.000											
Perceived cost	Pearson correlation	0.782**	0.404**	1									
	Significant (bilateral)	0.000	0.000										
Sense of environmental responsibility	Pearson correlation	0.214*	0.382**	0.206*	1								
	Significant (bilateral)	0.011	0.000	0.014									
Reference to group feelings	Pearson correlation	0.272**	0.402**	0.336**	0.564**	1							
	Significant (bilateral)	0.001	0.000	0.000	0.000								
Human settlement environment	Pearson correlation	0.344**	0.394**	0.300**	0.568**	0.550**	1						
	Significant (bilateral)	0.000	0.000	0.000	0.000	0.000							
Perceived benefits	Pearson correlation	0.329**	0.496**	0.240**	0.637**	0.612**	0.642**	1					
	Significant (bilateral)	0.000	0.000	0.004	0.000	0.000	0.000						
Perceived risk	Pearson correlation	0.376**	0.250**	0.322**	0.353**	0.386**	0.409**	0.494**	1				
	Significant (bilateral)	0.000	0.003	0.000	0.000	0.000	0.000	0.000					
Perceived value (behavior attitude)	Pearson correlation	0.356**	0.405**	0.384**	0.653**	0.652**	.532**	0.679**	0.417**	1			
	Significant (bilateral)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000				
Perceptual behavior control	Pearson correlation	0.552**	0.372**	0.548**	0.433**	0.541**	0.492**	0.573**	0.322**	0.672**	1		
	Significant (bilateral)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
WTP	Pearson correlation	–0.080	–0.036	–0.033	0.140	0.068	0.051	0.005	–0.071	0.051	–0.015	1	
	Significant (bilateral)	0.348	0.676	0.699	0.099	0.427	0.551	0.953	0.404	0.550	0.860		
Budget	Pearson correlation	–0.064	0.051	0.014	0.086	***0.223***	0.024	0.048	–0.047	***0.181****	***0.178****	–0.042	1
	Significant (bilateral)	0.452	0.547	0.867	0.310	***0.008***	0.782	0.573	0.578	***0.032***	***0.035***	0.624	

Note: As Table 5.

4.2.2. One-way ANOVA

Tables 7 and 8 contain the result of the one-way ANOVA analysis of the two factors of WTP and the budget for the retrofit. Although the correlation analysis shows there may be a negative correlation between the non-professional background and WTP, further analysis shows this is not significant. On the other hand, the two variables of education level and reference group perception have a significant positive impact on the recipients' expected investment budget.

Table 7. Analysis of variance table of WTP and influencing factors

Factor	Sum of squares	df	Mean square	F	Significance
Gender	1.311	3	0.437	1.841	0.143
Age	7.777	3	2.592	1.450	0.231
Residential location	7.163	3	2.388	0.979	0.405
Education	0.854	3	0.285	0.528	0.663
Monthly income	13.867	3	4.622	1.050	0.373
Professional background	1.210	3	0.403	2.284	0.082
Occupation	12.378	3	4.126	0.866	0.461
Year of construction	0.193	3	0.064	0.083	0.969
Housing property right	1.446	3	0.482	0.948	0.419
Decoration time	0.034	3	0.011	0.012	0.998
Understanding the information	7.778	3	2.593	2.276	0.083
Expectation of energy-saving retrofits	0.345	3	0.115	0.124	0.946
Perceived cost	4.073	3	1.358	0.952	0.417
Sense of environmental responsibility	3.157	3	1.052	1.638	0.184
Reference to group feelings	3.884	3	1.295	1.551	0.204
Human settlement environment	0.875	3	0.292	0.351	0.789
Perceived benefits	0.832	3	0.277	0.466	0.706
Perceived risk	1.545	3	0.515	0.553	0.647
Perceived value (behavior attitude)	1.479	3	0.493	0.947	0.420
Perceptual behavior control	1.083	3	0.361	0.568	0.637

Table 8. Variance analysis table of influencing factors and energy-saving retrofit budget

Factors	Sum of squares	df	Mean square	F	Significance
Gender	0.858	2	0.429	1.795	0.170
Age	3.026	2	1.513	0.836	0.436
Residential location	3.434	2	1.717	0.701	0.498
Education	3.901	2	1.950	3.804	***0.025***
Monthly income	5.970	2	2.985	0.674	0.511
Professional background	0.109	2	0.055	0.298	0.742
Occupation	14.677	2	7.338	1.556	0.215
Year of construction	0.103	2	0.052	0.067	0.935
Housing property right	0.295	2	0.148	0.288	0.751
Decoration time	1.913	2	0.957	1.035	0.358
Understanding the information	1.052	2	0.526	0.446	0.641
Expectation of energy-saving retrofits	0.754	2	0.377	0.411	0.664
Perceived cost	0.704	2	0.352	0.244	0.784
Sense of environmental responsibility	2.125	2	1.062	1.646	0.197
Reference to group feelings	5.875	2	2.937	3.608	***0.030***
Human settlement environment	0.067	2	0.033	0.040	0.961
Perceived benefits	0.294	2	0.147	0.247	0.781
Perceived risk	0.542	2	0.271	0.291	0.748
Perceived value (behavior attitude)	2.384	2	1.192	2.336	0.101
Perceptual behavior control	3.069	2	1.535	2.489	0.087

Note: The italic bold term data is less than 0.05, which has a significant effect.

4.2.3. Mean value analysis

The mean value analysis shows the order of the average score of each factor to be Sense of environmental responsibility (4.32) > Perceived benefits (4.27) > Perceived value (behavior attitude) (4.195) > Reference to group feelings (4.11) > Human settlement environment (4.03) > Expectation of energy-saving retrofits (3.94) > Perceptual behavior control (3.84) > Perceived risk (3.64) > Understanding the information (3.05) > Perceived cost (2.99).

According to the sorting results, the respondents have a high level of agreement in the following factors: sense of responsibility, perceived benefits, perceived value, and reference to group feelings. Compared with the variables of the previous dimensions, the recipients' recognition of the expected effect of their renovated housing is weaker at between uncertainty and satisfaction and the score of the perceptual behavior control, perceived risk, and understanding the information are on the low side. On the other hand, the perceived cost score is the lowest, which is in the range of disagreement.

4.2.4. Analysis of the characteristics of people with a high WTP

In this study, we define those willing to transform their residence into the highest three-star green building and willing to pay more than \$786/100 m^2 as people with a high WTP. A total of 13 samples were identified to meet the above conditions. The analysis of this group shows a higher education and higher income to be the significant characteristics. Approximately 85% of the respondents in the sample have at least a bachelor's degree. Except for those currently without a source of income, nearly 90% of the residents who meet the high WTP conditions have a monthly income of more than \$1383.39. Other variables are not considered to have significant characteristics because of the small differences in the number of people in each category. In addition, having housing property rights may also affect the residents' willingness to retrofit to some extent.

4.3. Discussion

As revealed from this study, the clearer the residents' perception of the benefits from green buildings, the more information is available for reference in the market for green building retrofits, the more positive retrofit information is given by the people around them, and the higher the level of education of potential recipients, the more they are willing to green retrofit their homes. Moreover, recipients with a higher education usually tend to have a higher expected investment. Similarly, recipients that receive more positive comments from their friends and salespeople around them, or experience more positive publicity from the government and developers, tend to increase their retrofit budget.

According to the data analysis, most respondents are willing to adopt green technology to carry out energy-saving retrofits in future housing reform. It is found that the residents have a very high degree of recognition of environmental responsibility and strong willingness to undertake the social responsibility of protecting the ecological environment. This may prompt them to carry out green renovation to reduce the environmental pollution caused by their dwellings. At the same time, they are also keenly aware of the development prospects of green buildings in the future, and it is because of the recognition of this new housing model that they are more willing to buy green buildings or make green retrofits. In addition, with the improvement of social living standards, the residents' living environment requirements are also increasing. They are willing to invest in a certain economic cost for a better living environment and recognize the possible benefits and existence values of their own investment. At the same time, residents also agree that the preferential policies of the government, social networks, and the evaluation of the people around them affect their retrofit decisions. Their understanding of the current pollution situation in the process of building development also leads them to be more willing to carry out green retrofits. However, the residents' understanding of the actual effectiveness of green retrofits is still weak: this is because they are unsure about some of the problems associated with their own decisions and are unclear whether they may encounter some practical difficulties in making retrofit decisions in the future. In addition, residents are still unfamiliar with the technologies related to green buildings. They do not know which technologies are truly green or the current popularity of green technology, and are worried about the ostentatious gimmicks of developers. A lack of thorough understanding of the relevant information, the necessity of retrofits and corresponding costs may cause some obstacles to their payment decisions, so the publicity and introduction in this aspect needs to be strengthened in the future.

Conclusions

This study considers the WTP and influencing factors of energy-saving retrofits of residential buildings in the PRD region from the point of view of recipients/potential recipients. A theoretical model is proposed of residents' retrofit decision-making from a combination of literature analysis, expert interviews, and questionnaire survey, and a housing renovation scheme and cost calculation is carried out, so they can have a better understanding of the likely results of a retrofit before making a decision. Finally, based on Shenzhen, a questionnaire survey was conducted in the PRD region to further identify the key factors affecting residents' WTP. The main research results and conclusions are as follows:

(1) The retrofit scheme involves the reconstruction of the two main parts of the window and balcony of an apartment, changing the material of the windows, adding sunshade awning, etc. According to real estate data provided by CRIC, the renovation plan was applied to a typical 3-room type of household of approximately 100 m^2 floor area, and the renovation cost calculated from the price of building materials published in the Zaojiatong website as $517.92.

(2) Analysis of the 140 valid questionnaires shows that 94.29% of the respondents intend to have a green retrofit, mostly on one or two stars. The amount of the renovation budget was fairly evenly distributed. In general, the residents have a strong desire for, and acceptance of, energy-saving retrofits, with an average budget of $1044.33/100 m^2.

(3) An in-depth analysis is made of the influencing factors involved using Pearson correlation analysis and one-way ANOVA. This shows the respondents' professional background to be negatively correlated with their WTP, while the perceived value (behavior attitude), perceived behavior control, the education level of the respondents, and the feelings of the reference groups around them are positively correlated with their expected input. Of these, a higher education level and having received more relevant positive evaluation and publicity is associated with a greater expected investment. A further finding is that the WTP of respondents or their families with a construction industry background is not positively affected, which points to the public's understanding of green retrofits being relatively poor. Even people working in related industries have little understanding of the topic: this, together with the necessity and urgency of green retrofits, indicates there is still a big gap in the popularization of green retrofits. However, with the improvement of social living standards, people's requirements for their own living environment are gradually increasing, and their strong awareness of environmental protection has made them fully identify with the current pollution situation in the process of building development. They are not only willing to invest a certain economic cost for a better living environment, but also recognize the possible benefits and existing value of their own investment, so they are

more willing to carry out a green retrofit. This desire will be even stronger with preferential policies from the government, or positive comments from social networks and people around them. The improvement of their own cultural and intellectual level will strengthen the desire as well.

Policy implications

As energy-saving retrofits of China's public buildings started earlier and were carried out more smoothly, the establishment and actual retrofit of various online monitoring platforms have achieved remarkable results. However, the implementation of energy-saving retrofits of residential buildings in the southern region has been accorded much less attention than northern areas, leaving the government to formulate and improve corresponding retrofit systems and policies according to the residential characteristics of hot summer/warm winter areas to strengthen retrofit endeavors by promoting and guiding the rapid and rational development of the green housing market in the south.

Most interviewees have a strong sense of environmental responsibility, a keen insight into the future trend of the green real estate industry, and a willingness to accept green retrofits, so the government and real estate developer can use mass media to play a vital role in widely publicizing the environmental friendliness and comfort of green building, and highlighting its ability to arouse consumer consumption desire. Since green housing is the long-term trend of future industry development and will become the mainstream feature of the future housing market, real estate developers should focus on developing green housing products and promoting the retrofit of green buildings to provide potential recipients with a variety of options. Appropriate strategies and initiatives such as subsidies and tax reductions need to be adopted to promote the development of green buildings and green retrofits. Moreover, it is also suggested to develop innovated renewal models in the future to promote the WTP for retrofits in the actual implementation process. Non-profit professional renewal organizations, college students, and other forces are encouraged to participate in the practice of energy-saving retrofits of residential buildings through the development of associated scientific research topics to provide professional plans and suggestions.

Limitations of the study

This study estimates the recipients'/potential recipients' WTP and influencing factors of energy-saving retrofits of residential buildings in the PRD region. Despite addressing the crucial aspects of this issue, there are still some limitations that need to be considered in the future. First, this study could not quantitatively calculate the energy saving costs in the retrofitting, which is an important element for future studies. Second, with reference to big data, a more typical household type is selected to calculate the renovation cost, however, there will be some differences in the houses designed by different real estate companies, and the cost of building materials will be different according to time and purchasing ways, so there will be some errors and limitations in the calculation results of the renovation cost. It is suggested to collect more samples in the future and conduct research over a longer time span and a wider and more comprehensive geographical range to enhance the universality of the results.

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