Research on the Adaptability Design of Smart House Based on Residential Demand

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Abstract
With the development of Internet of Things technology and the wide application of multimedia information technology and intelligent control mechanisms, great changes have taken place in people's living environment and lifestyle. In the prevention of COVID-19, higher requirements are put forward for current living quality. The application of smart home systems can help to upgrade the quality of the living environment into the intelligent era, but its intelligence is mostly reflected in the addition of unilateral multi-functions and the centralized control of the system. There is a lack of system analysis and design of residential intelligence that meets the actual needs of the users. Qualitative investigation and correlation analysis are used in this paper. Firstly, Taking the residential needs based on temporal and spatial behavior as the starting point, the functions and performance of smart home system products in the market are classified and summarized. Secondly, a correlation system is further established among residential behavior, residential needs and smart home systems. Finally, the paper takes the project of "24 • 35 housing home" in the 2021 International Solar Decathlon Competition as an example, and proposes adaptive design strategies for smart houses from three aspects: structural form, flexible space design and smart home scene setting. Based on the development of the Internet of Things and the background of new residential demand, this paper provides reference basis and optimized direction for the construction of smart homes and improvement of living quality.

Keywords
Living demand, Smart house, Adaptive design

1 Introduction

With the rapid development of society, economy, and technology, people's lifestyles have undergone tremendous changes, and there are higher requirements for the quality of the living environment. At the same time, the outbreak of the new crown epidemic has caused people to face their parents, lovers, children, work, study, and entertainment every day in their long-term home life. The needs of healthy and comfortable living environment, safety and convenience, and flexible space have never been so important. However, the existing traditional residential space in my country is difficult to respond flexibly to the dynamic changes in residential demand in the 35-year residence cycle.

During the fight against the epidemic, smart sensing equipment based on face recognition and other technologies in the community realized sensorless traffic in the community, reducing the contact

within the community property; the smart elevator realized zero touch between the residents and the elevator buttons; zero-touch smart appliances based on information interaction and remote operation technologies not only effectively prevent the spread of viruses but also facilitate people's lives.It can be seen that the development of the Internet of Things technology and the wide application of multimedia information technology and intelligent control technology have promoted the iterative upgrade of the quality of living space to a certain extent. The article combines the application of residential intelligent equipment with residential adaptive design, and systematically proposes a smart residential adaptive design strategy that adapts to changing residential needs.

2 Smart house

2.1 Research status

In domestic and foreign research, there are many vocabulary similar to smart home, such as smart house, home automation, etc. Among them, the Massachusetts Institute of Technology in the United States defines intelligent housing as an adaptive and predictive intelligent service system.Its goal is to connect various information-related communication equipment, household appliances and home security devices in the home to a home intelligent system through home bus technology, and then conduct centralized or remote monitoring, control and family affairs management, and maintain the harmony and coordination between these family facilities and the residential environment."Research on Intelligent Design Strategies of Ecological Houses" (Xihang Yan 2012) proposes intelligent optimization strategies from the aspects of residential planning and design, envelope structure, building materials, ventilation, solar energy utilization and rainwater recycling. Shen Zhenjiang(2018) built an intelligent index system for smart houses through the exploration of the origin of smart houses and the discrimination of green concepts, including four aspects of respecting users, responding to climate, energy saving and water saving, and high efficiency and intelligence. From the perspective of ageing, Wu Jianxin(2017) proposed that the intelligent system should be integrated and standardized with the interior design and decoration of age-appropriate houses, highlighting the characteristics and trends of comprehensive functions, reasonable application, easy operation and access. Using the 2018 sdc entry "Habitat 2.0" as a research platform, Jiao Sen(2020) studied the realization path of his zero-energy smart house from two aspects: energy-saving technology and intelligent system. And through the energy consumption monitoring and energy management system for its sustainability evaluation research.

In the field of architecture, most researches on smart buildings are carried out from the perspective of building technology from two perspectives: the intelligent control of the indoor physical environment and the optimal design of the home energy system.There is a lack of research from the perspective of combining smart home systems with architectural design.which is based on the needs of users' living behaviors.

2.2 Smart home system

The application of the smart home system in the residential space came into being under the background of diversified and rapid development of residential demand.It uses integrated wiring technology, network communication technology, security technology, automatic control technology, audio and video technology to effectively integrate home living facilities. And using residential space as a platform, through the collection and analysis of user behavior data, to provide users with green, healthy, comfortable and efficient personalized life services.

At present, many smart home companies can be roughly divided into two categories. One is traditional home appliance manufacturers and Internet giants represented by Huawei, Haier, Midea,

and Honeywell, which focus on the intelligent upgrade of large home appliances and the establishment of integrated intelligent systems; the other is represented by Xiaomi, Focusing on the introduction of smart single products, it is committed to the intelligent development of small home appliances.The research selected smart home products of Huawei, Haier, Midea, Honeywell and Xiaomi as the research subjects, and conducted research on the products launched by various manufacturers in the field of smart home.

According to the practical functions of smart home products, they can be divided into four categories, namely, security systems, smart home appliances and their control systems, environmental control systems, and health care systems (Figures 1 and 2). The article summarizes the smart products and their functions in each category, as shown in Table 1:

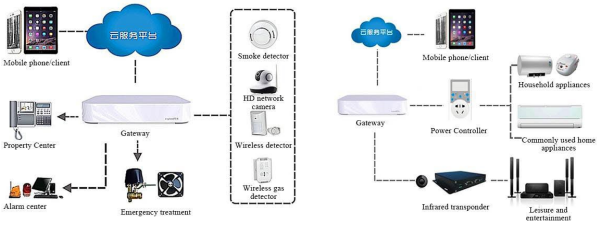

Figure 1: Security system and smart home system appliances and their control system

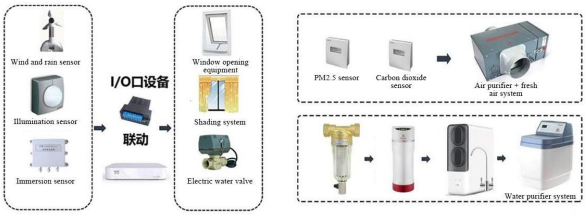

Figure 2: Environmental control systems and health care system

Table 1: Types of smart products

Types	Products	Function description
Security system	Smart door lock	Face recognition, fingerprint recognition and unlock
	Smart doorbell, cat's eye	24-hour monitoring of abnormal entrances, short video notifications on mobile phones, remote visual voice change intercom on mobile phones
	Sensor/Alarm	Temperature sensing, natural gas alarm sensor detects the danger signal of fire or gas leakage in time to warn
Smart home appliance and its control system	Smart refrigerator	Food management function: understand the internal food quantity and shelf life, and remind users of the food information in the refrigerator through the Internet and mobile phone interconnection; Intelligent control function: digital temperature control is conducive to food preservation, multiple adjustment modes to adapt to different user needs, and time-sharing to keep electricity; Entertainment functions: audio and video, games, online shopping, etc.
	Smart washing machine	Ultraviolet ray sterilization; intelligently put detergent and softener, accurately control the dosage to avoid detergent residue; automatically remind after washing, remote control by mobile phone.
	Smart kitchen appliances	Mobile phone remote control. Set up smart linkage between electrical appliances according to user behavior habits.
	Smart bathroom appliances (smart toilet, water heater, bath heater, magic mirror, smart body cleaner, etc.)	Magic Mirror: Record daily health status. When the health indicators are abnormal, it provides timely warning, pushes health advice and health recipes, and has the entertainment function of audio playback. Smart toilet: Automatically senses the flip cover, and automatically flushes away from the seat. Smart water heater: Smart linkage, and intelligently adjust the water temperature according to the user's habits.
	Smart curtain motor	It can be controlled by voice or mobile phone.
	Smart home appliances	Including smart AI speakers, sweeping robots, etc.
	Switch/gateway	Wireless induction control/network interconnection
Environmen tal Control System	Smart lighting	Centralized control to realize the lighting switch of each space in the room; intelligent dimming; set the home mode or away from home mode, one-key control

	Smart air conditioner	Actively monitor and control the indoor temperature and start the automatic cleaning function at the right time, without human manipulation; one-button setting, the air conditioner is comfortable and energy-saving.
	Sensor/Air Conditioning Companion	Sensing indoor light, temperature, humidity to link the start and stop of air conditioners or other corresponding equipment
Health care system	Fresh air purification system	Sensors are linked with air purifiers and other equipment to promote indoor air circulation, remove harmful substances such as PM2.5, dust, and bacteria in the air, and purify the air; remote operation
	Intelligent water purification system	Real-time monitoring and filtering of incoming and outgoing water quality; automatic alarm for operation failures; intelligent networking; support for remote control of flushing and standby by mobile phones.

3 The adaptability of the residence

The adaptability of the house, that is, the housing ability to adapt or respond to various changes brought about by different conditions or personal needs through the use of design forms or means under the premise of no major physical structural changes in the building(Lin Wang 2017).In "Adaptive Design of Living Space",Beisi Jia(1988) divides adaptability into functional adaptability and structural adaptability, and proposes to improve the overall quality of the residence through the design of function and space, the use of simple technology, and the structural adaptability design.Leupen(2006) believes that the durable structural system of the residence has constituted an internal variable frame system. Therefore, the formation of a polysemous space that can carry multiple functions in the basic spatial organization can enhance the adaptability of the residence.Liu Yang(2017) pointed out in his thesis "Micro-change Design of Open Houses" that the full use of multi-directional contact spaces with high accessibility can realize the flexibility of the suite. Rabeneck (2018)proposed that flexible space division equipment can be used to subdivide the space, further realize the reconfiguration of the same space at different times, and meet the changing living needs of users. For example, the 2018 IF Award Winning Works Bigger +,it meets the different needs of users in a limited space through changes in interior decoration, flexible furniture, and smart home applications.

With the widespread application of networks, smart home systems and intelligent control technologies in residences, through the linkage of intelligent devices, the ingenious use of virtual and personalized life scenes created by the environment such as sound and light,so as to meet the individual needs of users for living space.To a certain extent, this weakens the clarity of space division. On the basis of meeting the living needs, it enhances the flexibility of living space division.At the same time, this gradual approach to technological lifestyle has also improved the environmental quality and economic efficiency of the living space.

4 Living demand based on spatio-temporal behavior

4.1 Spatio-temporal behavior

The occurrence of residential behavior is directly related to residential space and time. Residential behavior permeates every part of life. Japanese resident scholar Yoshisaka Takashi classified the daily activities of the people, and proposed three types of life. He called reproduction, excretion, recuperation, foraging, and maintenance of physiological and life needs behaviors as the first life; he called housework, production, exchange, consumption and other material activities to maintain and serve basic physiological needs as the second life ; The art, entertainment and thinking activities such as performance, creation, games, and ideas are called the third life [11].

4.2 Living demand

Living demand is the need to provide convenience and security for the occurrence of residential behavior on the basis of the current living standard. With the continuous improvement of material living standards, people’s living needs have reached a higher standard. The article summarizes the housing needs into four aspects: living safety, comfortable environment, convenient living, and low carbon and energy saving. In the 35-year family growth cycle of a family, the needs and desires of the occupants are constantly changing, which means that the building needs to have flexible spatial adaptability to respond to the changes in a timely manner.

4.3 Relevance system of living demand, living space, and smart home system

As the carrier, the residential space carries the occurrence of people's living behaviors, and at the same time satisfies the basic living needs. With the progress of society and the continuous improvement of living standards, people's requirements for living quality are gradually escalating, and traditional living space is not enough to meet new living needs. In the application of the smart home system, according to the needs of users in different spaces, different intelligent scenarios are created in the way of smart interconnection between products, so that the current new needs of living can be better met.(Figures 3)

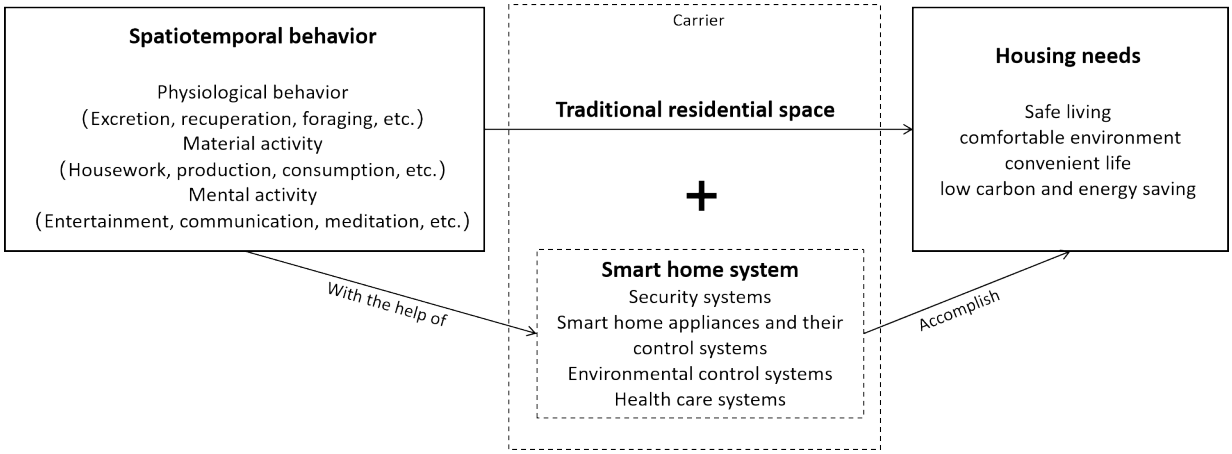

Figure 3. Relevance system of living demand, living space, and smart home system

The research uses the spatiotemporal behavior of young users in a day as a clue,and associates the security system(It is denoted by “ S ” in the table), smart home appliances and their control systems(A), environmental control systems(E), and health care systems(H) with the four categories of smart homes with residential behaviors and living spaces, and creates scenes, as shown in the table 2(Here we use S,A,E, and H to represent the four smart home systems).

Table 2**:** Smart home application scenario

Time	Behavior	Space	Smart home	Scene description	Advantage
6:00	Get up	Bedroom	A	The smart speaker wakes up the user on time and starts the wake-up mode at the same time. The curtain is linked and automatically opened.The smart full-length mirror will recommend suitable clothes according to the weather.The user tells the speaker that he wants to take a bath and reserve hot water...	Comfortable and convenient
	Wash	Bathroom	A	Smart speaker linkage smart water heater prepares hot water	Convenient

				according to the user's preferred water temperature. When the user comes to the bathroom to use the bidet, the exhaust fan is opened in conjunction to maintain ventilation, and the sunglasses automatically record the bidet monitoring data to help understand the physical condition. The hot water is ready,and you can start taking a bath...	
	Breakfast	Dining room	A	After washing, the coffee machine and toaster are controlled by voice, and you can start having breakfast.	Convenient
9:00	Leave home	Whole house	S + A + E	The whole house security system is activated. Lights an air conditioners are automatically turned off. The window sensor in the home automatically closes the window by sensing the weather change. Smoke detectors and alarms sense indoor abnormalities and send messages via mobile phones to inform users. It uses remote control to ensure safety and avoid losses.	Safe and energy saving
18:30	Come back home	Porch	S+E	When you get home from get off work, you can use your fingerprint to unlock the lock safely and activate the home mode. Then the lights at home will automatically turn on, and the air conditioner, air purifier and other equipment will automatically operate.	Safe and comfort
	Cook	Kitchen	A	In the kitchen, the smart refrigerator recommends recipes based on the stock of ingredients. When there are insufficient ingredients in the refrigerator, it proactively prompts users and can purchase ingredients online. Then the gas stove turns on the automatic linkage of the range hood. Everything is ready and the user can start eating.	Convenient
20:30	Casual	Living room	A + E + H	When comes to the living room after dinner, the user turns on the smart TV through voice control, and the night air purifier, air conditioner and other equipment automatically adjust the indoor state according to the weather changes...	Convenient and comfortable
22:30	Wash	Toilet	A	Before going to bed, choose your own customized bathing mode on the magic mirror and link the water heater at the same time. After the bath, you can put the dirty clothes in the washing machine. The washing machine automatically recognizes the material of the clothes and selects the appropriate washing mode.	Convenient
	Rest	Bedroom	A+S	The smart speaker receives instructions to close the curtains and lights, and turn on the security of the whole house. Gas, water, and electricity are adjusted to safe mode.	Safe and energy saving

5 Adaptable design strategy of smart house——take" 24·35 housing home" as an example

5.1 Project Overview

Solar Decathlon (SD) is a solar building technology competition initiated by the US Department of Energy with global universities as the participating units. "24 • 35 housing home" was designed as the entry of the Dalian University of Technology team under the background of the 3rd China International Solar Decathlon Competition in 2021.

"24 • 35 housing home" aims to design and build a solar smart house that can meet the needs of users 24 hours a day and the living needs of households with a life cycle of more than 35 years. The article will take "24 • 35 housing home" as an example, and propose adaptive design strategies for smart houses from two perspectives: adaptive design of living space and application of intelligent equipment, to meet the residential needs of safe living, comfortable environment, convenient living, low carbon and energy saving.

5.2 Adaptive design of living space

5.2.1 "Nine-Rectangle-Grid" space prototype

The plan extracts the courtyard space in Zhangjiakou's traditional architecture, and at the same time takes the shape of " Nine-Rectangle-Grid" space as the prototype, At the same time, the plan is based on the shape of the "Nine-Rectangle-Grid" space, using the central symmetry, modularity, unique hierarchical structure and construction (variability and flexibility) of the " Nine-Rectangle-Grid" space to cope with the changing living needs of long-term residential life. (Figure 4.5)

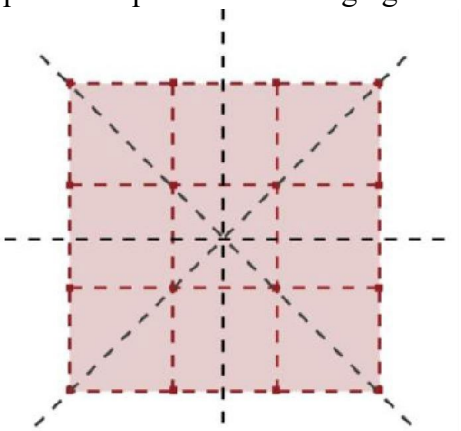

Figure 4. "Nine-Rectangle-Grid" Space Prototype space

Figure5. Plan layout and flexible

5.2.2 Assembled modular structure system

The plan adopts a prefabricated modular structure system. The main structure of the project uses a steel frame structure.The whole is divided into six modules, and the living space on the ground floor is composed of two 3.6*11.5*3.35 modules and one 3.9*11.5*3.35 module placed side by side. There is a truss structure equipment layer module on the upper part, which realizes the centralized distribution of equipment pipelines and liberates the open large space at the same time.In the plane layout, all functional rooms are arranged flexibly with 3.6*3.9 and 3.9*3.9 as the basic units, forming a spatial layout with the living room as the center and surrounding rooms for other functions. On the one hand, it echoes the traditional courtyard layout of Zhangjiakou with a courtyard as the center. On the other hand, it forms a highly accessible multi-directional space layout.Through the disassembly and deformation of functional modules, it can meet the changing living space needs of the family in different periods.

5.2.3 Flexible space design

After the outbreak of the COVID-19 and knowing that it may be necessary to prepare for long-term epidemic prevention, the plan designed a flat epidemic combined with a room to respond to this special life needs. This room considers the lifestyle during the epidemic and the general period. In normal conditions, the external exit of the isolated room is closed, and the entrance streamline is unified. The bathroom can be used as a family public bathroom, the door separating the room and the living room can be opened normally, and the flexible locker can be used as a partition wall at the same time so that the room can be used as a normal guest room or study (Figure 6). During the epidemic, the external exit of the isolation room was opened, the door between the isolation room and the living room was closed, and the flexible locker moved completely separated the isolation room from the living room. The independent decontamination space and bathroom were only used by the isolation room, and the quarantined people flowed. The line is independent of the other members of the family. (Figure 7)

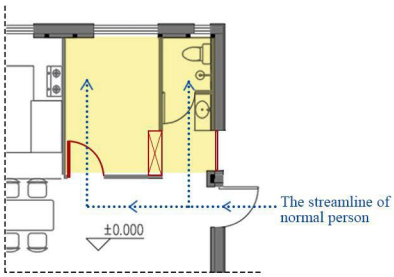

Figure 6. Spatial layout in general period

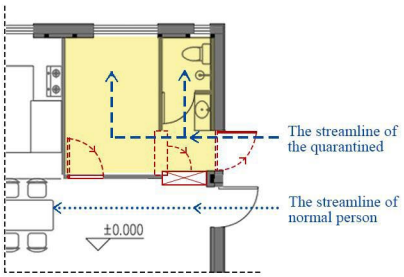

Figure 7. Spatial layout during the epidemic

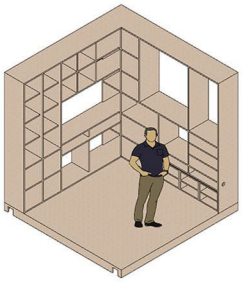

Figure 8. Flexible box

The design of the flexible box in the living room not only increases the diversity of the space, but also adds interest to the building (Figure 8). The residence must meet the changing living needs of users during the 35-year family growth cycle. The application of flexible partition walls can achieve flexible changes in the internal space layout on the basis of the unchanged residential structure frame, so as to adapt to different lifestyles at different stages of the family. In the plan layout, relatively private bedrooms and auxiliary spaces such as kitchen and bathroom are arranged along the west and north sides of "Nine-Rectangle-Grid". The living room is considered to be the center of family activities.The plan adopts an open large space form and puts a 2.4*2.4*2.4 movable box, as shown in the figure, which defines the bottom surface of the box and two adjacent sides. The two sides are given storage functions while dividing the space. In the process of the small box traveling in the space, the box and the living room boundary produce different combinations, enclosing or limiting the space effect of different feelings (Figure 9).

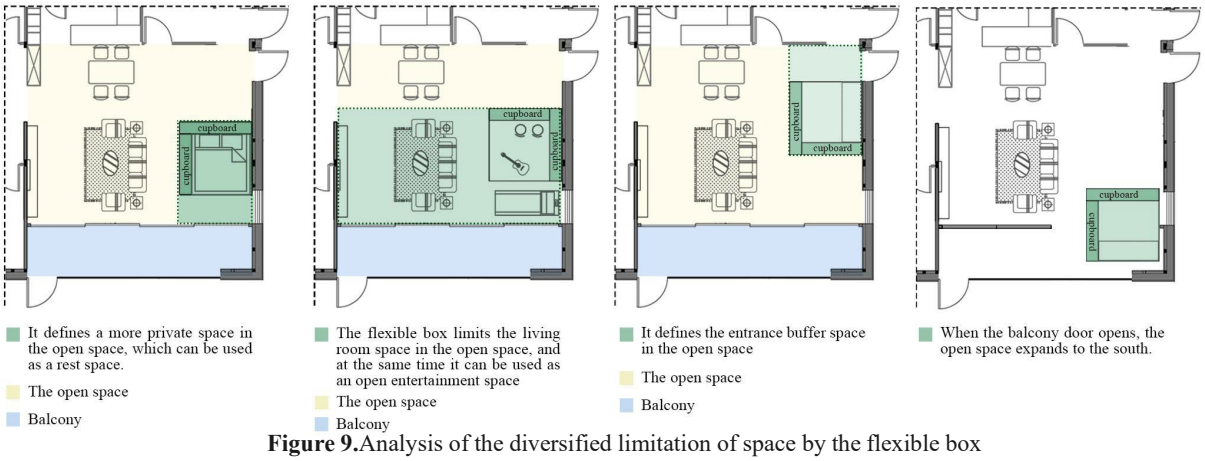

Figure 9. Analysis of the diversified limitation of space by the flexible box

The sliding double door between the living room and the balcony can be opened or closed according to the needs of use. When it is fully opened, the balcony space is released and the living room space expands to the south. When all of them are closed, the balcony can be used as an independent functional space equivalent to the Trumb wall.

The design of the kitchen space also takes into account the diversity of use requirements. When the family population structure is simple, the layout of the open kitchen and breakfast counter can be adopted. When the family population increases and there are higher requirements for the kitchen space and dining environment, the layout form of enclosed kitchen and dining table can be adopted.

5.3 Application and response of intelligent equipment

The solution is based on the correlation system of temporal and spatial behavior, living space, and smart home system, and creates different intelligent scenarios through the smart interconnection of smart home appliances,based on the user's needs in different spaces.Such as smart sleep, smart

access control, smart security, smart balcony, smart lighting, smart entertainment, etc. It can cooperate with the occurrence of all behaviors after people return home, and realize the current needs for living safety and convenience.(Figure 10).

Figure 10.Smart home scene setting

The plan uses a floor radiant heating system and an air-conditioning system with independent temperature and humidity control. The air-conditioning system improves the comfort of the indoor environment by accurately controlling the indoor temperature and humidity parameters. The operating status and indoor parameters of the air conditioner can be connected to our smart phone via a wireless network. We can detect the condition of the indoor environment in real time, and easily control the air conditioner as required. At the same time, the fresh air system through air treatment, on the basis of ensuring the freshness of indoor air, it also reduces the load of the system through waste heat recovery to achieve the purpose of saving energy.

The application of intelligent equipment also helps residential houses realize intelligent control of energy.The plan further realizes green house production and energy independence through the use of solar energy.It applies a solar photovoltaic power generation system composed of solar cell components, storage batteries, charge and discharge controllers, inverters and other components(Figure 11,12), as well as the system of PVT photovoltaic photothermal integration to realize the simultaneous utilization of electrical and thermal energy(Figure 13).

Figure 11. Photos of PVT module on the roof

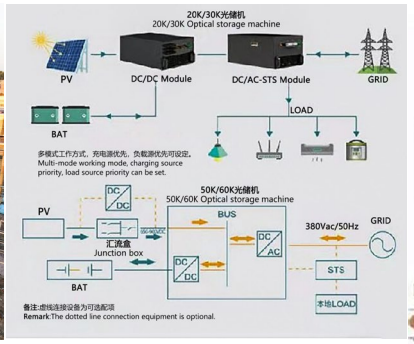

Figure 12.Photovoltaic power generation system

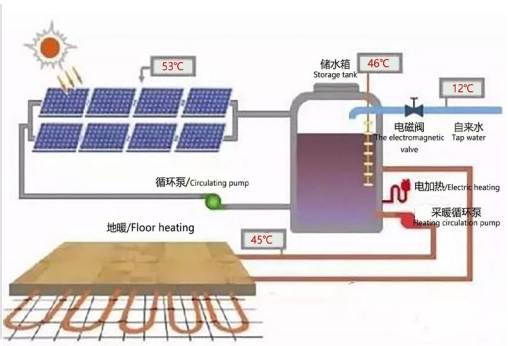

Figure 13. Photovoltaic heating system

In terms of the control of the house ' s electricity system,the electric energy generated by the photovoltaic array is charged by the charge and discharge controller to charge the battery or directly supply power to the DC load. In the case of no sunlight or insufficient sunlight, the charge and discharge controller controls the battery to supply power to the DC load. At the same time, the off-grid and grid-connected integrated inverter is used to convert DC to AC to supply power to the AC

load, while achieving automatic matching according to the end of power consumption, photovoltaic module power generation, energy storage and grid-connected grid conditions when off-grid.This further realizes the self-sufficiency of energy for the house.

The "24 • 35 housing home" project embodies the adaptive design of smart houses from three aspects: spatial structure, application of intelligent equipment and energy control. It satisfies the residential needs of the family in four aspects: safe living, comfortable environment, convenient life, low-carbon and energy-saving.

6 Conclusions and Further Research

This article is based on the background of the Internet of Things era and new residential needs, and uses the 3rd International Solar Decathlon Competition"24 • 35 housing home" as the design and research platform.The article proposes smart residential adaptive design strategies from three aspects: structural system, adaptive design of living space, and smart home scene setting based on temporal and spatial behavior. This provides a new direction for the system application of smart homes in residential spaces and the improvement of living quality throughout the life cycle of the family.

In today's rapid development of the Internet of Things, improving life with technology will become the mainstream way of life in the future.In the development of smart houses, it is also necessary to continue to track the behavior of family members in different periods, summarize the rules, and achieve iterative upgrades of living quality through the variable design of spaces, the creation of smart life scenarios, and the smart control of the home energy system.In the future promotion and application, the design can also form different sets of models through the disassembly and combination of internal functional modules,and it can be used in multi-story or high-rise residential design by adding traffic space and superimposing it vertically, thereby providing energy-saving and sustainable living environment in a high-density environment.

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