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On the Integrated Design of Existing Multi-storey Residential Building and Integral Solar Water Heater

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Solar energy is a kind of renewable and clean energy. The application of solar water heaters in buildings is one of the ways to effectively solar energy. Through the detailed analysis of the composition and characteristics of solar water heaters, and with integral solar water heaters as the main research object, this paper mainly studies how to integrate solar water heaters and existing multi-storey residential buildings and puts forward the design principles for integrating multi-storey residential buildings and integral solar water heaters, hoping to lay a theoretical foundation for the design of green residential buildings and heating transformation of existing residential buildings.

1. Introduction

For a long period of time, applying green and clean energy such as solar energy in buildings was just a dream that solar energy companies, photovoltaic enterprises, designers and engineers had. The application of clean energy like solar energy in buildings can not only create a green, low-carbon and healthy living environment, and make every household live more comfortably, but also bring about the benefits of energy efficiency, thus it is of great significance to the realization of the national sustainable development strategy (Gu et al., 2001). Nowadays, the living environment of mankind is getting worse, and the energy is getting scarcer, leading to intensified contradictions in energy consumption and serious structural imbalances. Therefore, how to develop and apply the energy efficient solar energy products has become a hot issue now, and how to turn such products into accessories of residential buildings has also been a focus of the current research.

The integration of solar energy and buildings has its own characteristics (Wang et al., 2016): First, the integration of solar energy applications and the environment and the combination of buildings, technologies and aesthetics together turn solar energy products into building components, which better facilitates the integrated design; second, solar energy products can be made into roofing materials, such as solar tiles, so as to incorporate modern science and technology into traditional building finishes; third, solar energy products can be integrated with roofs and facades. For flat roofs, the products can be of overhead type, and for slope roofs, solar equipment can be mounted on the surface, and on the facades, they can be placed on the balconies, walls between windows and windowsill walls; fourth, the technology is comprehensive, involving multiple fields like solar thermal applications, architectural modeling and construction design, pipeline layout and lightning protection facilities.

To put it simple, the goal of the “integrated design” is to reduce costs and increase benefits, so that every household can use solar water heaters (He and Jiang, 1993; Ding and Zhang, 2003). In the integrated design schemes for residential buildings, solar water heaters can be coordinated with the residential buildings, which helps achieve nice appearances, rational and efficient use of space, optimized structures, comprehensive utilization of various materials, light building load and low total cost. In summary, from the internal structure to the external appearance, a building can be organically integrated with the solar water heating system.

2. Classification and characteristics of solar water heaters

Solar water heater is a kind of collector that converts solar energy into renewable energy and at the same time heats water. Solar water heater involves a wide range of technologies and is being applied in more and more

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countries (Fan, 2009). Solar water heater commonly used in residential buildings are usually divided into two types: integral solar water heaters and detachable solar water heaters. Both types of water heaters generally have auxiliary heat sources. When the water temperature in the water heater is lower than the set temperature (for example, 50°C), the auxiliary heat source will be activated so as to maintain hot water supply around the clock. At present, a solar water heater for residential use and sold on the market is generally made up of a collector, a storage tank, brackets and other accessories (Su, 2003).

2.1 Characteristics of solar water heaters

(1) Anti-freezing performance: usually a solar water heater is equipped with an anti-freezing device used to unfreeze the frozen pipelines, but this will not only delay the use of the water heater, but also easily shorten its useful life. The user must determine whether to turn on the anti-freezing device according to the weather forecast, especially in cold areas in the north, where the anti-freezing device must be kept on all winter.
(2) Life expectancy: according to both domestic and international engineering experience, the service life of a plate type solar water heater is about 20 years, that of a wall-mounted one is 10 to 15 years, and that of an all glass vacuum tube one is 15 years. However, in reality, the life expectancy is generally less than 20 years.
(3) Adaptability to buildings: if solar water heaters are less adaptable, then during the design of a building, the installation locations of solar water heaters need to be taken into consideration and collaboration is required from the government, residents, developer, solar water heater manufacturer, building designers and construction workers.
(4) Price: there are solar water heaters of various brands on the market, with the prices ranging from low to high. Some may be priced at RMB 3,000 to 4,000 Yuan and some may be over RMB 10,000 Yuan. Users are very cautious about installing solar water heaters and few actively responds to the government's calls. The reasons are that most users have doubts about the quality of solar water heaters and that the media are also reporting all kinds of problems with solar water heaters. Only if the prices of solar water heaters are lowered, will residents think about installing them in their homes.

2.2 Classification and characteristics of solar collectors

(1) Plate solar collector
A plate solar collector, a basic component for solar low-temperature heat utilization, has always been the dominant products in the world solar market (Wang et al., 2015). A water heater consisting of plate solar collector components is called a plate type solar water heater. A plate solar collector mainly consists of a transparent cover, absorber plates, thermal barriers and a shell, as shown in Figure 1.
Plate solar collector is one of the most common types of collectors. It is featured with simple structure, stable operation and affordable price. In addition, it also has merits like strong bearing capacity, large heating area, great impact resistance and good thermal insulation performance. Therefore, it is one of the best choices for the integration of solar water heaters and buildings.

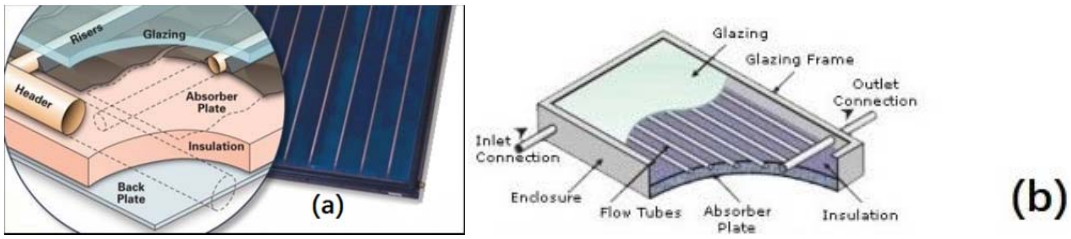


Figure1: Plate solar collector

(2) Vacuum tube solar collector
A vacuum tube solar collector is the solar collector that vacuates the space between the heat receiver and the transparent cover. The water heater consisting of vacuum tube solar collectors is the vacuum tube water heater, as shown in Figure 2.
By structural type, vacuum tube solar collectors can be divided into three categories: all glass vacuum tube solar collectors, heat pipe type vacuum tube solar collectors and glass-metal structured vacuum tube solar collectors. Currently, the most commonly used type is still the all glass vacuum tube solar collector.
An all glass vacuum collector tube is composed of two (inner and outer) concentric glass tubes. The selective absorbing film with low emissivity and high absorption rate is deposited on the outer surfaces of the inner and outer tubes and forms the heat receivers. The inter-space between the inner and outer tubes is vacuated and becomes high vacuum, with a shape like a slender thermos liner (Wang et al., 2015). It has a single open end,

which annularly seals the inner and outer glass tube nozzles; and the other end is closed into a hemispherical round head. The inner glass tube is supported on the outer glass tube by a spring support to buffer the stress from the thermal expansion and contraction of the inner tube. The spring card is equipped with a getter, which, after it is evapotranspired, can absorb the gas generated during vacuum operation and maintains the vacuum in the tube, as shown in Figure 3.

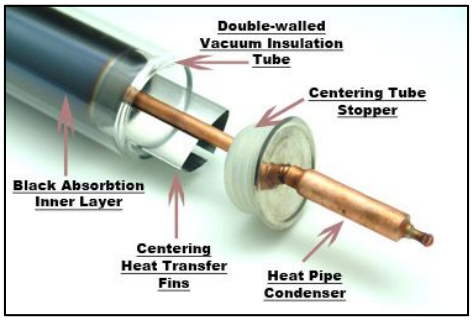


Figure 2: All glass vacuum tube

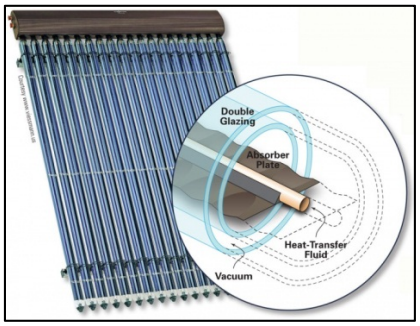


Figure 3: Vacuum tube solar collector

(3) Phase change energy storage type solar collectors

A phase change energy storage type solar collector, also called a tankless solar collector, refers to a solar water heater that fills the collector tubes with high-performance PCM (phase change energy storage) material through the concentric casing type parallel structure to achieve real-time heat storage; in other words, this heater uses “PCM material” instead of “water” as the heat storage medium. The solar water heater is modularized and tankless and can be integrated with and adapted to buildings, which is a revolutionary breakthrough from the traditional solar water heater. A PCM collector is just a heat pipe pressure-bearing solar collector (Gan, 2006; Yang, 2000), as shown in Figure. 4.

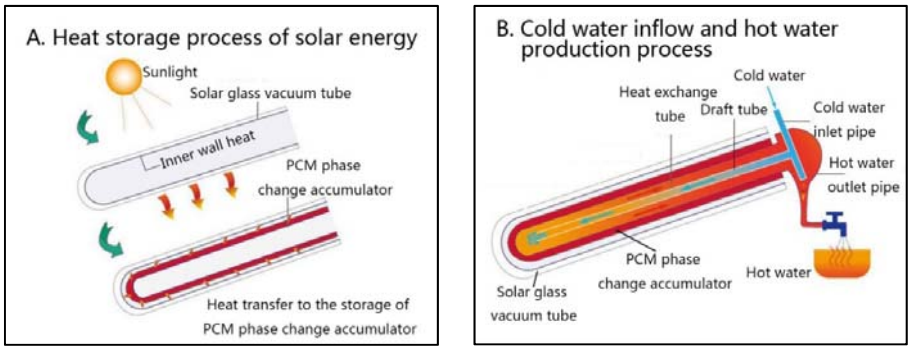


Figure 4: Operation principle diagram of phase change energy storage type solar energy water heater

Product advantages: Without the large water tank like in the general solar water heater, this equipment is very suitable for being installed on a wall or balcony of a multi-storey residential building, and it is highly efficient in heat collection, easy to operate and use, safe and stable without potential hazards. The pipelines are connected in parallel, so if several pipelines fail, the entire system will still function and supply hot water around the clock.

3. Integrated design of integral solar water heater and multi-storey residential building

3.1 Building types suitable for integral solar water heaters

In the integrated design of solar water heaters and various buildings, especially in terms of appearance, the major things to take into account are the installation locations and methods of the solar water heaters. The storage tank and other attachments may also need to be taken into account, but they will not have significant impacts on the architectural appearance.

An integral solar water heater is a compact in-line solar water heater. In terms of the position of the building, this type of solar water heater is mostly installed on the roof of the building. From the perspective of the heater

structure, the collector and the storage tank of the integral solar water heater are inseparable, so no matter on which part of the building the water heater is installed, it will affect the appearance of the building. Therefore, it is not easy to integrate the integral solar water heater with the building. Currently, the common practice is to mount the integral solar water heater on a flat roof or a slope roof, as shown in Table 1. For example, a flat roof can be carpeted with the heater to fully utilize the roof area. One or more rows of solar energy equipment can be added on the roof, which enriches the roof form; if it is installed on a slope roof, as it is connected with the storage tank, the collector cannot be placed along the roof, but needs to be installed with additional components and even on the roof ridge. This not only reduces the wind resistance, but also greatly affects the appearance of the building. However, such installation method is still commonly applied, especially in low-rise or multi-storey buildings.

Table 1: Integral solar water heater installed on the roof

Figure of Project		
Position installed	Slope roofs of residetials	Flat roofs of residetials

The integral solar water heater has many limitations. In public buildings, usually this type of water heaters are not used, partly because public buildings are of many shapes and have high requirements for their appearances; on the other hand, for the integral solar water heater itself, the water storage tank is undoubtedly a big limitation as it cannot be hidden. For this reason, residential buildings which do not have high requirements for appearance become the preferred carriers for integral solar water heaters. What is more, usually they can only be installed on the proofs and nowhere else in the buildings. Therefore, it is still an urgent problem as how to better integrate the integral solar water heaters with buildings.

3.2 Design principles for integration of integral solar water heaters with multi-storey residential buildings

3.2.1 Design principles for installation on slope roofs

Due to many limitations, most of the integral solar water heaters mentioned above are installed on building roofs. Currently, installing them on the slope roofs of residential buildings is one of the best ways to integrate solar water heaters with buildings. Slope roofs of different styles and materials enrich the facades and add colors to the whole appearances of the buildings. The organic integration of integral solar water heaters with a slope roof not only adds hi-tech elements to the roof, but also turns the roof into the highlight of the whole buildings. However, such integration raises high requirements for roof insulation, water proofing, drainage and tile layout and brings challenges to construction, installation and maintenance. Therefore, the following principles should be followed in design:

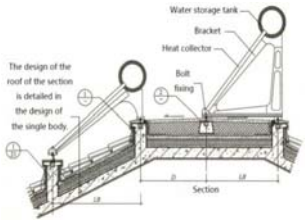
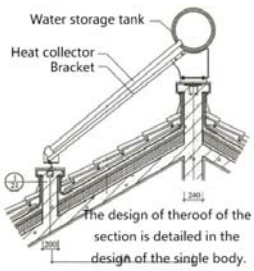
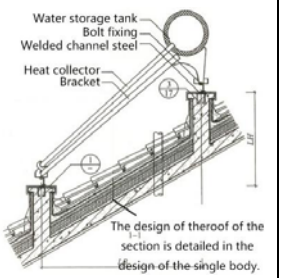
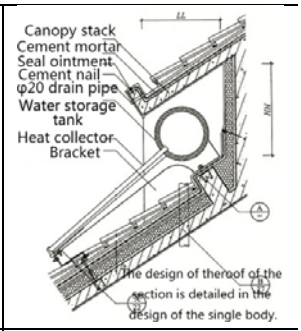
(1) Determination of roof slope: for new residential buildings, the angle of the slope roof should be set according to the best angle of the water heater to receive solar radiation. But the best installation angle of water heater changes with the season. In Changchun, more heat should be collected in winter and normal operation will be enough in summer. So the general principle for determining the roof slope is: the best angle for the roof slope of residential building should be the local latitude ±5°. In building design, the proportion of the facades should be adjusted according to the best installation angle of the water heaters, and the shape of the roof should be carefully designed to fit the roof slope.

(2) Location of the integral solar water heater on the slope roof. For slope-roof multi-storey residential buildings, the water heaters are usually installed on the south-facing roofs. During the architectural design, if the installation angle of the water heater is consistent with the slope of the roof, the solar water heater can be better integrated with the building. However, there is only a small installation area available on the slope roof. So installation of a water heater on a slope roof needs to make full use of the limited area facing south. The construction technology of the water heater mounted on the slope roof is more complicated and needs to take into account the impacts of roof insulation, water proofing, drainage and tile layout. After a series of factors

being taken into account, the installation location of the water heater on the slope roof can finally be determined.

(3) Layout of the integral solar water heater on the slope roof. The number of water heaters should be determined according to the number of households in each residential building. Then the area required for the water heaters can be calculated. After the water heater type is selected and the array dimensions are set, the layout design of water heaters on the slope roof should consider the proportion of the facades, especially the appearance design of the slope roof, which directly affects the overall appearance of the residential building. In new buildings, by the relationship between slope roof and water heater, the commonly used layout formsinclude flat ridge, downward overhead, ridge top overhead and overhanging types, as shown in Table 2.

Table 2: Installation of solar water heater on slope roof structure

			
The flat ridge type	The ridge top overhead type	Slope type (overhead)	Eaves type

The flat ridge type is to install a solar water heater on a slope roof with a flat ridge. The bottom of the heater is fixed at the support cast together with the structural layer and the prefabricated support, and below it lies the pre-embedded casing through the roof. Areas around the supports and casing should be well insulated, waterproofed and sealed with sealing materials to prevent roof seepage so as not to affect the life of households.

The ridge top overhead type is to install the integral solar water heater at the ridge top of the slope roof. Reinforced concrete support is cast on the ridge and the roof, and the water heater is bolted with the pre-embedded components in the support.

The overhanging type is to hide the water tank in the eave and place the collector outside the eave to make sure it can receive solar radiation. Below the water heater, the casing can be pre-embedded through the roof for drainage and load bearing. The overhanging design shows different layers and forms a unique architectural style.

(4) Maintenance. The staircase of the multi-storey residential building should be connected to the accessible roof, or the top of the staircase should be equipped with a dedicated installation/ maintenance manhole, and the slope roof should be equipped with reliable safety facilities to facilitate the installation and maintenance by professionals. For example, a safety ladder can be installed along the slope roof, or a hook can be anchored at the roof to connect the safety rope to ensure the safety of maintenance personnel.

(5) Consideration of comprehensive factors. When setting the slope roof for the integral solar water heater, one should fully consider the load of the water heater, weather and other safety factors to make sure it is perfectly safe.

3.2.2 Design principles for installation on flat roofs

Integral solar water heaters are mostly mounted on flat roofs, as this type of roof has no special requirements for the building orientation and collectors. On a flat roof, there is nothing that blocks the water heater from receiving solar radiation. The advantages of installing a water heater on a flat roof are that it is easy to install and that the area of the collector can be relatively large. For poorly-oriented buildings, installing water heaters on flat roof would be a good solution. The following design principles should be followed to install an integral solar water heater on a flat roof:

(1) Location of the integral solar water heater on the flat roof. For a building with a flat roof, there are much fewer restrictions for the installation of a solar water heater than on a slope roof, as the flat roof is not affected by the building orientation, the heat collection efficiency is high and the construction techniques are simple. It only needs to be ensured that the no less than 4 hours of sunshine is received by the collected on the flat roof every day. Therefore, the major thing to consider is how to place the collector. The front and back chambers of

the collector should not block each other, and should be kept at an adequate distance (including the operating distance for installation and maintenance) and arranged in order.
(2) Layout of the integral solar water heater on the flat roof. In new residential buildings, integral solar water heaters are often mounted in the overhead or array form.
The overhead form is a common way to integrate a solar water heater with a flat roof. It is to install the water heater on the metal support pre-embedded in the structural layer of the flat roof or on the reinforced concrete support cast together with the structural layer. The collector is fixed with the flat roof top by a support, and on both sides of and below the support, there should be drainage boards. The installation angle of the water heater can be calculated based on the local latitude. If the roof area is limited, the heater can be tiled across the roof, i.e. with an angle of 0° or nearly 0°.
(3) Maintenance. If there is any water heater installed on a flat roof, the roof should be equipped with a manhole for installation and maintenance. The surrounding areas of the water heater, the maintenance accesses, as well as the footwalk between the manhole and the water heater should be paved with rigid protective courses. Cement bricks can be laid to protect the waterproof layer.
(4) Consideration of comprehensive factors. The solar water heater needs to be fixed with a support or bearing on the roof. In architectural design, suitable roof embedded parts should be calculated and designed to install and securely fix the heater on the roof so that it will not be damaged by natural factors like wind or snow load.
(5) System selection. The water heater can form a natural pressure head on the roof, so piping system can be flexible – either from the top or bottom. The integral solar water heater itself adopts the natural circulation approach. In multi-storey residential buildings, usually the piping system is an independent one with decentralized heat-supply and natural circulation.

4. Conclusions

This paper introduces the application of solar water heaters in the existing multi-storey residential buildings, including the integrated design concept, the classification of solar water heaters and the applicable building types. By analyzing the characteristics of the collectors and the integral solar water heater, this paper proposes the design principles for the installation of integral solar water heaters on flat roofs and slope roofs, which provides a reliable theoretical foundation for the actual application of solar water heaters in the heating transformation of buildings. Hopefully, solar water heaters can be widely applied both in multi-storey residential buildings and heating transformation projects so as to promote the clean energy development in China.

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