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Design of Solar Water Heater and Residential Building Integration Based on Chemical Energy Conversion Mode

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The new roof solar water heater is to convert renewable energy sources by chemical energy conversion mode. Under the premise that the roof meets the installation requirements of solar water heater, water heater can be integrated with the roof. The integrated or split-type solar water heater can be installed on pitched roof or flat roof. If the roof doesn't meet the requirements, water heater can be either installed on the window-sill walls horizontally or walls between windows vertically, which can not only meet the water needs of users, but also enrich the building elevation and beautify the environment. A variety of feasible schemes of solar water heater and building integration are provided for the existing residential heating house reconstruction, which is beneficial to the utilization and popularization of solar water heater.

1. Introduction

In the warm house project, most of the existing multi-storey residential buildings are brick-concrete structure with the wall thickness of 370 mm or 490 mm. The storey height of the existing multi-storey buildings is 2,700 mm or 2,800 mm, the height of window-sill wall is 1,300 mm, the width of wall between windows is 1,200 mm-1,500 mm, and the height of parapet wall is 600 mm, which provides sufficient size to install solar thermal collector (Bianco et al., 2017). Most balconies of existing multi-storey residential buildings are not closed, and most balcony fences are made of 60-mm-thick red bricks or lattice fences. These balconies are transformed into closed balconies to increase the use area of the room, so such balcony fences can't be used to install solar water heater (Yang, 2000). In addition, most roofs of the existing multi-storey residential buildings are flat. However, it remains to be studied whether the flat roof has enough area for solar water heater and whether the flat roof can bear the weight of water heater. For the existing multi-storey residential buildings that are transformed from flat roofs into pitched roofs, their roofs are colored steel plates which can't bear the weight of solar water heater.

2. Integrated design of solar water heater and roof

2.1 Integrated design of solar water heater and pitched roof

2.1.1 Integrated solar water heater

For the installation of integrated solar water heater on the pitched roof of the existing multi-storey residential buildings, the water heater can be installed on the roof combined with the slope of the roof. During installation process, protective measures shall be adopted, and the original roof sloped of the building shall be used as much as possible, and the facilities for people to climb up shall be left for later maintenance (He and Jiang, 1993). Before installing the water heater, the bearing capacity of the roof shall be considered first, and the original construction drawings of the residence shall be proofread and re-checked again. The installation of solar water heater on the pitched roof will great affect the appearance of the residence, so it is necessary to choose the water heater with the same model and color as the residence (Dubey and Tiwari, 2010).
However, it is more difficult to construct and maintain the integrated solar water heater on the pitched roof. At present, the common installation methods in the multi-layer building of pitched roof are flat ridge type, ridge top overhead type, straight slope type and overhanging eave type (Fan, 2009). Although some multi-storey

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residential buildings are installed with solar water heaters, their specifications, appearance and colors are not uniform and their placement positions are disorderly and irregular, which has obvious shortcomings.
(1) In order to integrate solar water heater with pitched roof better, the solar water heater should be set on the south-facing pitched roof in the way of straight slope overhead type or straight slope ridge top type.
(2) The slope of the pitched roof of the existing multi-storey buildings has been determined and the best inclination angle of the water heater receiving sunlight is about ±5° of local latitude, so it is necessary to fully consider the installation inclination angle of solar water heater.
(3) After proofreading and calculation roof, the required area of solar water heater and the data of their arrangement on the pi.tched roof (length X width) are determined. When the water heater is installed on the pitched roof, several suitable elevation proportions should be designed and other factors, such as construction conditions should also be taken into consideration (Su, 2003; Masci et al., 2018).
(4) According to the characteristics of integrated solar water heater, the pipelines can be arranged at the suspended ceiling under the roof, and the upper and lower water pipes can be arranged in the staircase and connected with the pipelines in the kitchen and toilet. They can also be arranged along the wall to enter the house from the balcony, but the exposed pipelines should be conducted heat preservation and corrosion protection and hidden as much as possible.

2.1.2 Spilt-type solar water heater

For installation conditions and suggestions on implementation of split-type solar water heater, please refer to the integrated solar water heater, as shown in Figure 1.

Figure 1: Installation way of split-type solar energy water heater on the roof

The arrangement method of split-type solar thermal collector on the pitched roof is less limited and split-type solar thermal collector can be arranged flexibly, mainly paying attention to the placement position of the collector. The south-facing slope surface of the pitched roof should have enough area to install the collector. It is not suitable to install the collector if the roof has too many dormers or intersections. The roof with complete slope surface is the most suitable for installing the split-type water heater]. The water storage tank can be installed at the appropriate position of the suspended ceiling and the staircase of roof layer. The pipelines can be laid horizontally and the water storage tanks are centrally arranged. The water heater system with centralized household forced circulation is adopted. The hot and cold water in the upper and lower water pipes continuously flows to ensure that users can use hot water at any time without waiting for the retained cold water in the pipeline, otherwise it is easy to waste water. In addition, the water heater system with decentralized household forced circulation is adopted, that is, the water storage tank can be installed in the house of each floor, and the water in the water storage tank can be heated by the upper and lower water pipes by means of moving medium, and the heat conduction medium can be recycled all the time without waste of water resources. Households can also control the water temperature by themselves, which can also ensure access to hot water at any time.

2.2 Integrated design of solar water heater and flat roof

Integrated water heater is less limited on flat roof than on pitched roof, and is relatively easy to install and maintain later [11]. For flat roof, aisle shall be reserved for inspection and maintenance. The bearing capacity of the roof shall also be considered, and the original construction drawings of the house shall be re-checked and verified. At the same time, the number of multi-storey residential households should be accounted to determine the number of water heaters installed on the roof. Although the installation of solar water heater on flat roof has little influence on the elevation of the house, we still need to select the water heater with the same model and color as the house.
The problem existing in installing solar water heater on flat roof is the same as that on pitched roof, that is, water heaters are placed in disorder, the model and specification are not uniform, the water storage tank

pipelines are exposed, and there is potential safety hazard.
(1) The fore-and-aft clearance should be paid attention to when installing the water heater on the flat roof and shall not be sheltered, and the heating condition of 4 h for collector should be satisfied.
(2) The arrangement form may use the array type as long as the water heater with the same model is placed in order. However, in view of the safety of the structure, especially for a large number of installations, it is necessary to attach steel beams to the roof, and then fix the support of the solar water heater on the beams so as to avoid excessive concentrated load.
(3) Please avoid directly drilling and fixing the water heater on the roof as much as possible, otherwise, the insulation layer and waterproof layer of the roof will be destroyed, thereby causing the influence of leakage of the roof and non-insulation of the room.
(4) Water heater can form the natural pressure head on the roof, so pipelines can be selected flexibly, which can use both the top water type and the fall water type. In addition, the natural circulation type, the forced circulation type and the straight-flow type can be selected. In a multi-storey house, a separate system of decentralized heat supply and natural circulation can be selected.
Split-type solar water heater mainly considers the placement position of collector. Compared with integrated solar water heater, split-type solar water heater can place more collectors and raises lower requirements on installation inclination angle. As long as the roof has enough area, it can be placed. And the water storage tanks can be centrally placed in one place, for example, they can be located in the staircase or can also be installed separately.
The centralized heat collection and household water supply metering system adopts forced circulation water supply mode, which is favorable for freezing prevention and high solar energy utilization rate in northern area. Since the household uses the storage tank by itself, the auxiliary heat source can be added so that 24-hour hot water supply can be guaranteed. The centralized heat collection and household water supply metering system is easier to integrate with the residence because the water storage tank is arranged separately without hiding the water storage tank.
The centralized heat collection and centralized water supply metering system is easy for maintenance and management due to the centralized equipment, which occupies fewer building area and is convenient to use. However, the pipeline arrangement is complicated and the heat loss is large. That the initial investment is low, recovery period is short, and maintenance cost is low can also guarantee 24-hour hot water supply, so it is also popular with developers, solar energy manufacturers and designers.

3. Study on integrated design of solar water heater and elevation in the reconstruction of multi-storey residential warm houses

For some existing multi-storey houses, that installation position of solar water heater is not reserved at the beginning of the scheme design. The roof part can only be used for the top floor households. If the middle floor households want to use solar water heaters, they can only install them on the elevation, as shown in Figure 2, which completely damages the original building elevation. In addition, disorderly installation not only may damage the original building envelope, but also will damage the urban landscape and block texture.

Figure 2: Installation of solar water heater on an elevation

Figure 3: Installation of solar water heater on the wall between windows and window-sill wall

The installation position of solar water heater on the wall can be divided into wall between windows and window-sill wall, as shown in Figure 3. In the warm house project, the wall between windows of the multi-storey building is used to arrange, and the solar thermal collector can be as high as the adjacent windows. The balcony and window of the multi-storey building have certain regularity, so the installation of solar water heater can enhance the horizontal line sense on the elevation of the building. In the same way, the sense of longitudinal line on the elevation of the building can be enhanced by installing solar collector on the window-sill wall with the same width as the window.

In the warm house project, most of the balcony fences of the existing multi-storey buildings are not load-bearing, and expansion bolts are needed in the installation process. However, most balcony fences are made of 60-mm-thick red bricks, so the expansion bolts are not suitable for installing the solar thermal collector. Thus, the best place to install the collector on the south-facing elevation of the building is the window-sill wall and the wall between windows.

The pipeline design of solar water heating system should conduct proper arrangement first to meet the normal operation of the system. When the pipeline is arranged outdoors, it is better to set it up in hiding so as not to affect the appearance of the residence. At the same time, heat preservation treatment should be done well. When the pipeline is arranged on the elevation, the color of the pipeline shall be consistent with the color of the elevation. The pipeline shall be insulated with rock wool and polyurethane when passing through the wall. Distributed household water storage system should be adopted for solar water heater on the elevation of multi-storey buildings. Mechanical circulation or natural circulation can be selected for water supply circulation according to specific conditions. Mechanical circulation and indirect system can be preferred. As each household can manage the decentralized system by itself, problems appearing to one household system will not affect the use of other households. In the decentralized system, water heater is installed in each household, which will not damage the original structure of the building. The collector can be uniformly and orderly installed on the elevation, and the water storage tank can be hidden in toilet and kitchen, which is very suitable for the integrated design of solar water heater and the existing multi-storey residence.

3.1 Integrated Design of solar water heater and window-sill wall

3.1.1 Design of collector on window-sill wall

In the warm house project, the solar collector can be installed on the window-sill wall. The height of the window-sill wall is about 1,300 mm, so there is enough space to install the collector. The load of the wall body is enough to bear the collector, and the horizontal line sense of the external wall can be strengthened to enrich the whole elevation. That the solar collector is placed in the window sill can form sunshade component. The water storage tank can be placed indoors so that the solar thermal collector can not only act as the sunshade device in summer, but also solve the problem of the installation space, which makes effective use of the space. For fixation of the solar thermal collector, the elevation of the existing residence can be fixed by using expansion bolts without destroying the insulation layer.

The window-sill wall is connected with the ground, so many objects on the ground will shelter the solar thermal collector, which will affect the heat collection efficiency and will easily cause damage to the collector itself and become a safety hazard. Therefore, it is better to place the solar thermal collector on the window-sill wall between the first floor and the second floor of the building while the solar thermal collector on the top floor can be placed on the parapet wall.

3.1.2 Design of water storage tank and pipeline

Take Scheme B as an example, the collectors of the top floor house hold are installed at the parapet wall, and the collectors of the first floor are installed on the window-sill wall of the first and second floors, so the position of the water storage tank is lower than that of the collector. Therefore, the method of forced circulation is required. The water storage tanks can be placed horizontally or vertically near the collectors according to requirements and indoor arrangement.

The installation of pipelines shall be based on the principle of proximity. Heat preservation shall be done at the opening of the wall so as to avoid cold bridge. The pipeline shall be laid regularly and orderly, and the location of the pipelines indoors shall be hidden so as to facilitate maintenance.

3.2 Integrated design of solar water heater and wall between windows

3.2.1 Design of collector on the wall between windows

In the warm house project, the south-facing elevation of the existing multi-storey buildings can be installed with solar thermal collector on the window-sill wall as well as on the wall between windows. The width of the wall between windows is about 1,200 mm-1,500 mm. There is enough space to install the solar thermal collector, and the load of the wall is enough to bear the collector. The installation of the collector on the wall between windows can increase the vertical line sense of the elevation, and won't affect the lighting.

(1) Determination of azimuth angle of collector

The lighting analysis of the wall between windows can refer to the calculation formula of the window-sill wall. The solar thermal collector installed in wall between windows is assumed to be a flat plate collector with a size of 2,000 * 1,000 * 80 mm. The width of the wall between windows is about 1,200 mm-1,500 mm in the existing multi-storey buildings. Therefore, the flat plate collector can only be placed vertically. Collectors are not installed on the first floor and 9 collectors are installed on second to sixth floors with a total length of 14 m. The

vertical projection length L_2 of each collector on the wall is about 1,555.6 mm. According to the formula, the installation inclination angle of collector is about 85°. Since the collectors are continuously placed together, they will cause shade at any time. Moreover, the optimum installation angle of solar thermal collector in Changchun is 48.72°, so it is not suitable to install flat plate collectors with inclination angle vertically on the wall between windows. Similarly, the vacuum tube solar thermal collector should not be placed horizontally on the wall between windows, and should be placed vertically. As the vacuum tube collector can be installed vertically on the wall, that is, the installation inclination angle of the collector is 90°, it can be continuously placed on the elevation. In order to get more sunshine, the horizontal projection line of the collector can have a proper angle with the wall, namely the best azimuth angle so as to ensure the heat collecting efficiency of the collector. The angle range is 0°-30° or -30°-0°. In order to meet the integrated design of collector and elevation, the azimuth angle should be 0°, that is, the collector should be directed to the south.

(2) Area estimation of collector

The collectors installed between the windows are mainly vacuum tube type. The collector is set by estimating the area of the collector so as to ensure that there is enough space in the elevation. The area of the collector is determined by the solar energy collection amount and the local solar radiation amount.

In the study, the formula for determining the standard area of collector provided by the solar energy manufacturer is adopted:

Standard area = number of family members × 0.5 m^2

By this formula, the actual area of the collector can be determined.

Calculated by a family of three people, the required area of the collector is 1.5 m^2. The area of vacuum tube collector provided by the solar water heater manufacturer is about 1.6 m^2, which can meet the needs of hot water in daily life.

(3) Design of plane and elevation

The existing multi-storey residential buildings in Changchun generally have 52 households with three households on one floor, and each household has five rooms. The balcony can't be placed with collector, so collector can only be placed on the wall between windows on both sides of the balcony. There are a total of 6 floors with 18 households. Thus, the wall between windows must be installed with 9 solar thermal collectors to meet the needs of all households.

Vacuum tube collector can be selected for the wall between windows. According to the size of vacuum tube collector provided by the manufacturer, two schemes are designed. Scheme A All collectors are only placed vertically side by side and in a single row on the elevation. No collector is installed on the first floor. From the second to fifth floors, collectors are placed vertically side by side, and collectors are placed on the sixth floor in a single row to ensure that there are enough collectors on the wall between windows to correspond to each household. After the collector is added, the vertical structure of the elevation becomes rich in three dimensions, strengthening the vertical rhythmical image of the elevation. In terms of color, the color of the collector itself is black and blue, which can form a good contrast with the original color of the elevation so that the elevation looks more beautiful and fashionable with a strong sense of science and technology.

3.2.2 Design of water storage tank and pipeline

The water storage tank is installed indoors. Whether the natural circulation system or the forced circulation system is adopted depends on the relative position of the collector.

The pipeline arrangement also adopts the principle of proximity, and the insulation treatment is done at the opening of the wall.

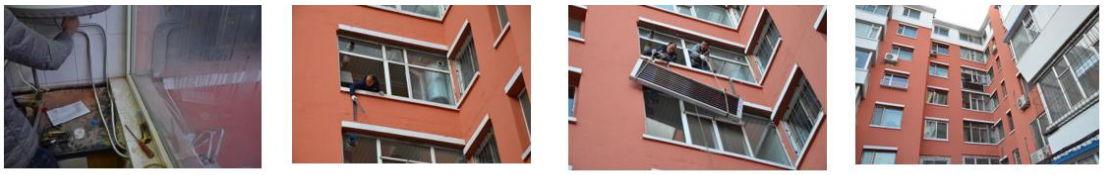
The water storage tank in the room can be combined with indoor layout and flexible use horizontal or vertical placement.

3.3 Demonstration of practical engineering on the basis of the experiment

The project is located in the Overseas Chinese Community of Chaoyang District of Changchun City. A household of three people in a building is taken as an example. The household has two halls, two rooms, a toilet and a kitchen facing south. This household originally uses gas water heater. The household now installs the solar water heater outside the kitchen and adopts vacuum tube collector. The water storage tank is placed above the collector in the mode of natural circulation. The collector type is U58 * 210/10 and the size is 2,213 m * 800 m * 92 m. The capacity of water storage tank is 100 L (2-3 people) and market price is about 7,500 yuan.

The field installation process of the solar water heater in Figure 4. The original gas water heater in the kitchen is removed, and the hole is punched on the wall that is knocked with expansion bolt. After the bracket is fixed, the water storage tank is hung. The window-sill wall is also perforated to install the pipeline and the collector support connected with the collector and the water storage tank. After filled with rock wool, the perforated

place should be foamed with polyurethane and the heat preservation treatment should be done well. The vacuum tube collector is hoisted from the ground floor to the sixth window-sill wall to complete the installation.



a) Water storage tank b) The collector support c) Vacuum tube collector d) Installation completed

Figure 4: Field installation process

4. Conclusions

(1) In the heating house reconstruction, the slope of the pitched roof of the existing multi-storey buildings and the optimum inclination of the solar thermal collector are not necessarily the same, which limits the type of the collector. Thus, we need to select suitable collector and installation method, which increases the difficulty of the reconstruction. The pitched roof structure, load, and area limit the number of solar water heater to be installed. If the number of water heater can't meet the needs of all users, solar thermal collectors can't be installed on the roof. The similar problems also exist in flat roof. It is impossible to consider installing collectors on a flat roof is a sufficient area for the installation of solar collectors is not ensured.

(2) Compared with the roof, the multi-storey residential elevation is more suitable for installing solar water heater. The elevation adopts split-type water heater so that the users of each floor can have independent hot water supply system without interfering with each other. This is also convenient for management and maintenance, and the damage to the envelope of existing buildings is minimal. The most important thing to be considered in installing the collector on the elevation is the style design. The rational and regular arrangement of the collector can make the overall style of the house more abundant.

(3) The advantage of installing solar water heater in the heating house reconstruction lies in environmental protection and energy saving, which is of great significance to the implementation of national sustainable development strategy and the use of clean energy. From common people, it is beneficial to using clean energy, reducing the impact of air pollution, smog and other disasters. This also improves people's living quality and quality of life. For the existing building itself, the installation of solar water heater makes it obtain appreciate, and improves its elevation, and enhances its appearance effect so that it is full of sense of science and technology, which plays a great role in improving the community environment and city appearance.

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