Rev. Int. Contam. Ambie. 38 (Sustainable Architecture and Urban Environment) 111-120, 2022
https://doi.org/10.20937/RICA.54466

TRANSFORMATION-BASED DESIGN METHOD FOR THE INTEGRATION OF GREEN RESIDENTIAL BUILDINGS AND SOLAR THERMAL COLLECTORS

Método de diseño transformativo para la integración de colectores solares térmicos en edificios residenciales verdes

Wang RUOZHU, Ma RUTING, Qian YONGMEI* and Tian WEI

Jilin Jianzhu University, Changchun, 130118, China.

*Author for correspondence: 654675316@qq.com

(Received: June 2021; accepted: September 2021)

Key words: dwelling unit, detail design, solar water heaters, integrated design

ABSTRACT

This study investigates integrated application of solar thermal collectors (STCs), as green renewable energy, on the design of green residential buildings (GRBs). With the gradual increase of residential buildings, the use of solar thermal energy has become the main popularization and application mode for the integration of residential buildings and solar energy. Additionally, this study presents applicable solutions using the transformation-based design method to expand the functions of STCs through the integrated design of STCs and GRBs, thus laying a strong theoretical foundation for promoting the integrated design of solar water heaters and GRBs.

Palabras clave: unidades de vivienda, diseño en detalle, calentadores solares de agua, diseño integrado

RESUMEN

Este estudio investiga la aplicación integrada de colectores solares térmicos (CST), como energía renovable verde, en el diseño de edificios residenciales verdes (ERV). Con el incremento gradual de los edificios residenciales, el uso de la energía solar térmica se ha popularizado como modo de aplicación para la integración de la energía solar en dichos edificios residenciales. Adicionalmente, este estudio presenta soluciones aplicables con el uso del método de diseño transformativo para expandir las funciones de los CST a través del diseño integrado de CST y ERV, con lo que proporciona un fuerte fundamento teórico para la promoción del diseño integrado de calentadores solares de agua en ERV.

OVERVIEW

The environmental pollution induced by the burgeoning development has become a major issue today (Karagiorgas et al. 2006). Through the proper use of solar energy, the massive energy consumption in residential buildings and the heavy pollution caused by conventional energy sources can be remarkably improved (Chaithanakulwat 2019). Additionally, the solar energy contributes significantly to the improvement of energy issues, the environment, and the standard of living of human beings, and the realization of the social sustainable development. Northeast China is defined as Class III region in terms of solar energy resources, with the annual amount of solar radiation of over 5000 MJ/m^2 (Benramdane et al. 2019, **Table I**). Thanks to the well-developed industries in Northeast China, the solar energy industry in this region plays a leading role in its line across China based on Chinese construction design specification. As a result, solar water heaters have been extensively mounted in numerous residential buildings in Northeast China. Changchun, which lies in the middle portion of the Northeast China Plain, is a representative city in Northeast China (Guellai et al. 2019).

The solar water heaters in Changchun, primarily installed by residents on the roofs, are scattered irregularly on the roofs of low- rise and multistory buildings, and vary greatly in size, color, material, and model. As population grows, there must be a growing demand for high-rise residential buildings in the future, because most solar thermal collectors (STCs) can be only installed on large roofs rather than narrow roofs (Wang et al.2020a). Based on the development of solar energy application in northeast China, this study analyzes issues regarding the installation of solar water heaters and the appearance of green residential buildings (GRBs): the method for integration of solar water heaters and the appearance of GRBs is analyzed from the aesthetic aspect, and the solar water heater is used as an architectural design element to achieve synchronous design and construction; on the precondition of ensuring the functions and efficiency of STCs, the functions of STCs (e.g., protection, appearance design elements, thermal insulation, and sun shading) are fulfilled; the structural processing of key parts in the integrated design of solar water heaters and the appearance of GRBs is performed, so as to provide a cost-effective, applicable, safe and feasible method for installations and construction of STCs on the roofs of GRBs, improve the residential performance, and reduce the cost of installations (Ding 2013). Based on the three aspects, this study explores applicable strategies for the integrated design of GRBs and solar water heaters in Changchun and implements the synchronous design of solar water heaters and GRBs. Moreover, promoting the integration process of solar water heaters and GRBs can not only realize the design of component and improve the integration of solar water heaters and GRBs, but also accelerate the integrated development of solar buildings.

Although solar water heaters and GRBs are on a massive scale in China, their integration requires long-standing efforts (Wang et al .2020b). The inadequate planning for residential projects leads to the low efficiency and multiple potential safety hazards of solar water heaters and the unaesthetic integration of solar water heaters and GRBs (**Fig. 1** and **Fig. 2**).

Fig. 1. Water leakage of water tank.

TABLE I. THE COMPENSATED AREA RATIO RS OF STCs.

Changchun										Latitude 43º54' longitude 125º13' Altitude 237 m									
Dip angle \ Azimuth	East	–80	–70	–60	–50	–40	–30	–20	–10	South	10	20	30	40	50	60	70	80	West
90	52%	56%	59%	63%	66%	69%	72%	74%	75%	75%	75%	74%	72%	69%	66%	63%	59%	56%	52%
80	57%	61%	66%	70%	73%	77%	80%	82%	83%	84%	83%	82%	80%	77%	73%	70%	66%	61%	57%
70	62%	67%	71%	76%	80%	83%	86%	89%	90%	90%	90%	89%	86%	83%	80%	76%	71%	67%	62%
60	67%	72%	77%	81%	85%	88%	91%	94%	95%	96%	95%	94%	91%	88%	85%	81%	77%	72%	67%
50	72%	76%	81%	85%	89%	92%	95%	97%	98%	99%	98%	97%	95%	92%	89%	85%	81%	76%	72%
40	76%	80%	84%	88%	91%	94%	97%	98%	100%	100%	100%	98%	97%	94%	91%	88%	84%	80%	76%
30	80%	83%	86%	89%	92%	95%	97%	98%	99%	99%	99%	98%	97%	95%	92%	89%	86%	83%	80%
20	83%	85%	87%	89%	91%	93%	95%	96%	96%	96%	96%	96%	95%	93%	91%	89%	87%	85%	83%
10	84%	86%	87%	88%	89%	90%	91%	91%	92%	92%	92%	91%	91%	90%	89%	88%	87%	86%	84%
Horizontal plane	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%	85%

Fig. 2. Scattered STCs on roofs.

Most residential solar water heaters in China, which are primarily evacuated tube solar water heaters, are installed by residents on the roofs of low-rise or multistory residential buildings, with the water tank placed on the upper part of STCs (Xue, Q. M. Yang, C. J. Wang 2014). Since most solar water heaters are installed by residents, they vary greatly in scale, shape, color and texture, and are irregularly placed. Additionally, pre-embedded rod pieces are not available on the roofs, causing many potential safety hazards from the solar water heaters; the exposed water tank can lead to the reduced efficiency of hot water and increased difficulties in the maintenance (Zhang 2010).

The above-mentioned issues received tremendous attention from the Government of China, and the solar energy industry has joined hands with multiple real estate agencies to explore the methods for integration of solar water heaters and GRBs.

TRANSFORMATION-BASED DESIGN METHOD

The study investigates the architectural aesthetic design with a focus on the architectural expression method, so that STCs can be integrated with the GRBs as the components and design elements (Xue 2016). There are three approaches to add new elements: becoming the extended elements of the original elements; producing the transformation effect through integration of the original elements; imitating and completely replacing the original elements.

Transformation is the process of changing from one form, state or characteristic to another (Wang et al.2020c). It can be broadly understood as the transformation from one object to another, and it is applicable to non-objective things. In the architectural design, the method of "transformation" is between "extension" and "replacement". "Extension", which is the extension of the original components or order, means starting a practice from scratch; "replacement" means the complete replacement of the original components in terms of function, followed by the presentation of the components in a new form (Wang and Gong 2011). The transformation methods are commonly used for detail design or macro-planning.

Regarding the residential design, transformation methods are primarily used for detailed design. Since GRBs represent the repeat design of each dwelling unit, designers conduct the transformation-based design with the single story as the unit, and seek changes (e.g., changes in bay windows and balcony) from an overall perspective (**Fig. 3** and **Fig. 4**). Individual changes are accomplished through regularly reducing or adding specific components, to add a sense of rhythm. The transformation methods are usually adopted at the bottom and top of GRBs to change the appearance through enriching the facades of the buildings, thereby avoiding the monotonous appearance.

Transformation of STCs towards awnings in rooftop gardens

Rooftop gardens can be traced all the way back to the Sumerian ruins around 4000 BCE. Over the next 1500 years, the Babylonians built the Hanging Garden of Babylon, thereby elevating the artistic form of rooftop gardens to a new height (Spalding-

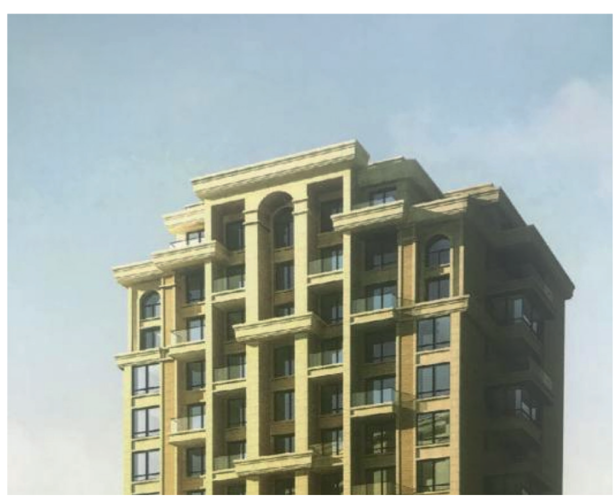

Fig. 3. Semicircular arc-shaped windows at the top.

Fig. 4. Unique appearance created through changes in bay windows.

Fecher et al. 2002). After many years of development, rooftop gardens play a variety of roles and become a new landscape on buildings with flat roofs. In modern architecture, rooftop gardens can beautify the environment, purify the air, improve the local microclimate, enrich the ur-ban pitching landscape, compensatethe green space occupied by buildings, and remarkably increase the urbangreen coverage rate. Therefore, rooftop gardens are worthy of vigorous promotion. In regions where it is not very hot in summer, rooftop gardens are the excellent places to cool off in the shade and enjoy the leisure time, and a growing number of rooftop gardens are built on the flat roofs of GRBs (**Fig. 5**). Among GRBs, rooftop gardens are commonly seen on villas and low-rise and multi-story residential buildings, with a high utilization rate. However, rooftop gardens are rarely seen on small high-rise and high-rise residential buildings, with a low utilization rate because of the low elevation of the buildings. In rooftop gardens, a variety of ground cover plants, wooden cooling racks, tables and chairs for rest, and parapets for creating space are commonly available. With the continuous improvement of the quality of GRBs, there is an increasingly number of designs for rooftop gardens, the locations of the gardens are not subjected to a corner of the roof, and more than one rooftop gardens can be provided on the roof. The presence of materials with excellent and sophisticated properties help to tackle many structural issues and enables rooftop gardens to be not subjected to the height of buildings. Additionally, rooftop gardens, which are being developed towards the courtyard, are necessary for high-end residences. A rooftop garden can be built in one place, or multiple rooftop gardens can be built in every corner of the roof. The independent design is not used for rooftop gardens, instead, the design for integration of rooftop gardens and elements on the roof (e.g., staircase, computer room, and parapet) is implemented.

In the design of rooftop gardens, the awning remains the representative element and the most active element. The awning, located at the highest point of the roof, plays a leading role in the overall planning of rooftop gardens, and the determination of centralized and decentralized designs is dependent on the awning. Moreover, the awning is the only component that can be seen on the flat ground and is the component that is most easily related to STCs. The texture of the awning is very similar to that of the evacuated tube thermal collector. Therefore, an applicable top bracket can be designed after replacement of the

Fig. 5. Different types of rooftop gardens.

awning on the cooling rack with the evacuated tube thermal collector and the determination of area and size of the collector. Besides, the awning can be designed to be close to the tube well, so that the water pipe can be directly placed in the room through the tube well, and the water tank can be placed in the kitchen or washroom. In the design of awnings, the angle of inclination of the awning at the top of the cooling rack should be determined using the pre calculated optimal angle of inclination of the STC, to obtain the maximum annual solar radiation and reduce waste and cost.

However, some awnings may be designed to be the horizontal awnings because of modeling, causing the STC attached on the awnings to fail to be placed at the optimal angle of inclination. For STCs that are unable to be placed at the optimal angle of inclination due to insufficient conditions, the optimal angle of inclination should be obtained using the compensated area ratio R S of STCs. According to statistics, the R S for the horizontal plane is 85%, and it can be substituted into the formula AB=A S+A S(1-RS) to obtain AB=1.15 × A S, namely, if the calculated total area of the original STC is expanded by 1.15 times, the relationship between appearance and cost should be measured using the economic benefit analysis.

The integration of STCs and the awning in the rooftop garden features multiple advantages. For example, the similar texture enables the original awning to give full play to its role (**Fig. 6**); the colors (i.e., dark blue and grey) of the evacuated tube thermal collectors are in sharp contrast with the warm color of wood and the light color of metal, thus enhancing the sensory impact of colors; the integration of the flat-plate thermal collector and the glass canopy of the terrace can lead to the special lightand shadow effects, thereby avoiding the monotony; when integrated with the glass canopy, dark-color STCs can form real elements through the contrast between virtual and reality, while when integrated with wooden or the tile-roof awning, cool-color STCs can form virtual elements. In summary, it is feasible to integrate STCs and the awning in rooftop gardens, noticeably improving the appearance of GRBs and the dwelling quality in GRBs.

Transformation of STCs towards dormers

A dormer, also known as a lucarne, is a form of roof window (**Fig. 7**), which is typically set vertically on a sloping roof for lighting and ventilation at the top of the house. The dormer at the top of the buildings that we see now was initially pronounced in accordance with the homophonic pronunciation of Shanghai dialect for the English word “ROOF”. Since 1843, when Shanghai was opened as a treaty port, many British people came to Shanghai, and promoted development of British architectures in Shanghai. Since the United Kingdom is in a cold region in Northern Europe, the building roofs are generally designed in the form of pitched roofs or spires, to reduce the snow load on the buildings. Since the 1920s, Shanghainese built an attic between the second floor and the roof through leveraging the advantages of the high space and pitched roofs on the second floor of their Shikumen houses due to the increased housing difficulties in Shanghai. To facilitate the lighting and ventilation of the attic, they opened windows called “dormer” on the roofs. A dormer is an active element on the pitched roof, its dark-color smooth texture is in sharp contrast with the warm-color tiled pitched roof, and the pitched roofs based on the combination of reality and virtuality make the “fifth facade” of GRBs more out- standing. However, the area and number of dormers are subjected to the size of the room. If the ratio of “virtual” elements is small, the pitched roofs cannot be brightened up, making the

Fig. 6. The awning with the evacuated tube thermal collector installed.

Fig. 7. Different types of dormers.

roof look unwieldy and affecting the composition (**Fig. 8**). However, this can be tackled using the flat-plate thermal collectors, because the color, texture, and smoothness of the col- lectors are nearly the same as those of glass. Therefore, the collectors can be integrated with dormers, to expand the scale of virtual elements on the pitched roofs, make the roofs simple, and brighten up the overall composition.

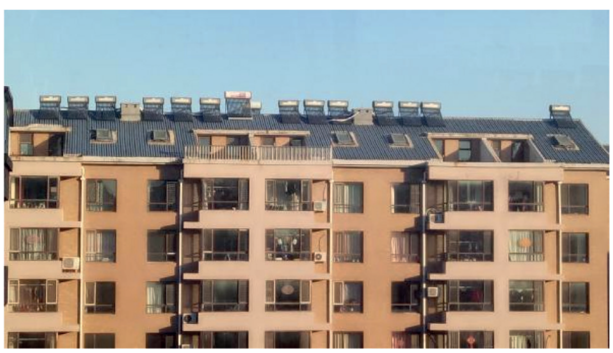

Fig. 8. Scattered solar thermal collectors on the pitched roof.

There are multiple methods for making different types of dormers, such as the dormers with the windows embedded on the pitched roof (**Fig. 9**). Since no shelter is available, STCs can be designed to be installed around the windows, and the size of the windows should be expanded in terms of texture. Additionally, the matte characteristics of STCs results in changes in the internal details of the system for integration of STCs and the windows under the condition of unified overall style. **Fig. 10** and **Fig. 11** show the structural details. Attention should be devoted to not damage the waterproof membrane and thermal insulation on the roofs, pipelines can be placed in the pipes along the roofs to enter the dwelling houses, and the water tank can be conveniently installed in the kitchen or washroom.

Fig. 9. The effect diagram for transformation from STCs to embedded dormers.

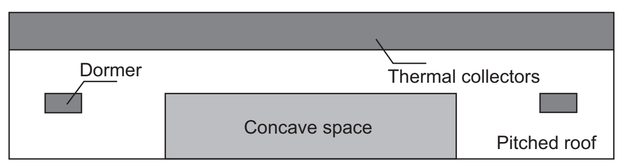

Fig. 10. The order of virtual elements for pitched roofs without integrated design.

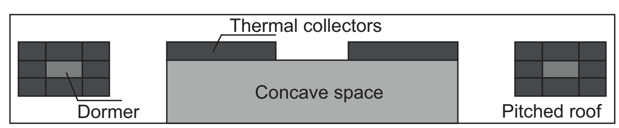

Fig. 11. The order of virtual elements for pitched roofs based on integrated design.

For dormers protruding from the roof, the design for the installation of STCs around the windows is not feasible because of the shielding. In this case, STCs can be placed on the double slopes over the bay window or the pitched roof over the dormer (**Fig. 12**).

If the overall colors of the roof are cool colors (e.g., blue), STCs should be integrated into the roof back- ground without affecting the original pattern; If the overall colors of the roof are warm colors (e.g.,

Fig. 12. The diagram effect for transformation from STCs to the couple roof with dormers.

red), STCs should stand out in the background to form a contrast. Such method has great limitations. First, the available area of the pitched roof over the dormer is very small. Second, the heat-collecting efficiency of the east-west facing STC is low, and the area compensation should be performed. In summary, this method is most applicable to hot water compensation for residents on the ground floor, and it should be used together with other combined methods for solar water heaters for supplementary designs.

Third, the design for the currently popular high-rise attic is adopted. Currently, designers pursue the spatial mobility, and prefer to integrate the living room and the high-rise attic. Since windows in the living room are used for lighting, dormers at the top of slope are not necessary, resulting in the monotony of the south-facing slope. Although some dormers are available in the south-facing bedroom, the pitched roof cannot be brightened up because of the limited number of dormers. As mentioned above, the texture of flat-plate thermal collectors is very similar to that of glass, and both are virtual elements. Therefore, the method for transformation from the thermal collectors to the dormers should be used together with the aforementioned method, so as to form a false dormer, thus brightening up the monotonous order of the whole roof (**Fig. 13**).

Fig. 13. The diagram effect for transformation from STCs to protruding dormers.

Among the three methods, the first method is independently applicable to dwelling houses with embedded dormers rather than high-rise dwelling houses because of the limited roof area and number of dormers. The combination of the second and third methods is a complementary practice, which is intended to compensate the area of STCs of residents on the ground floor. Therefore, the second and third methods are applicable to all dwelling houses with pitched roofs. Briefly, the three methods aim at brightening up the roof order to avoid the rigidness and monotony of the roof.

Transformation of STCs towards windowsill walls

The design of modern residence focuses on the richness of facade modeling, regardless of Chinese-style, Western-style, classical, and modern residences. In this regard, the cool colors are commonly used to enhance the visual effects, to increase the sensation of depth and achieve the three-dimensional modeling. In Northeast China, the winter is long. Therefore, designers often adopt warm colors to reduce the sense of indifference created by buildings. However, many warm colors will make the buildings look unwieldy. In view of this, the appropriate color ratio can significantly optimize the dimension of buildings in terms of visual effects. Additionally, designers often use dark brown color for windowsill walls, connect the walls with the virtual elements (i.e., windows) to form vertical lines, and make the walls be in contrast with the peripheral warm-color materials to create a sensation of depth.

As mentioned above, the flat-plate thermal collector has a pitch-dark and blue texture and a glossy surface, and its texture is very similar to the dark-color texture of the windowsill wall. Therefore, the thermal collector can be embedded on the windowsill wall to achieve the expected visual effects without affecting the operations of the thermal collector. See **Fig. 14** and **Fig. 15** for specific practices.

With respect to the size, the length should be in coordination with the length of the window. The window is 0.3 m in width, and the south-facing windows are relatively large, most of which are 1.8 m in width and very few of which are 2.1 m in width. According to the current residential development trend, windows with a width of 1.5 m will be not very commonly seen. According to the demand for at least 1.96 m2 of a thermal collector per household, a thermal collector should be at least 1.09 m in width, if a window is 1.8 m in width, and a thermal collector should be at least 0.94 m in width if a window is 2.1 m in width. However, since the thermal collector is placed on the wall at 90º, the compensated area

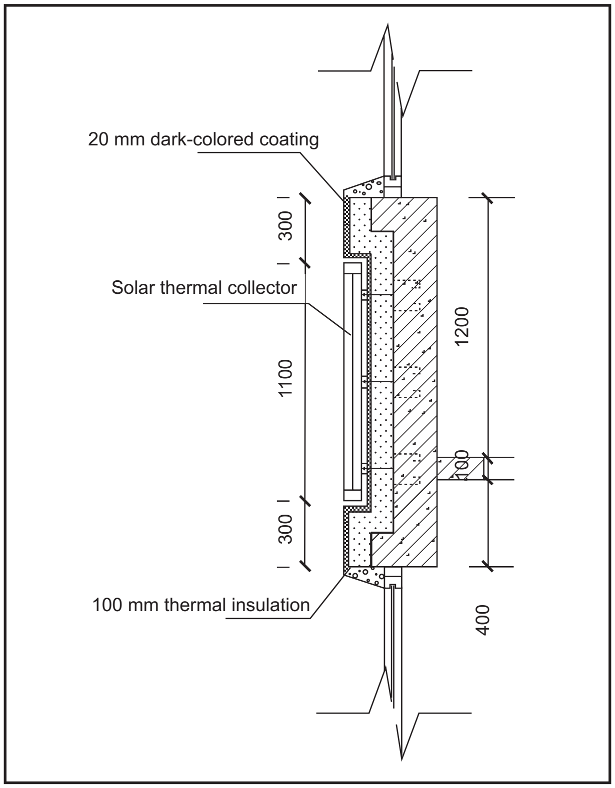

Fig. 14. The practices for embedded thermal collector and related parameters.

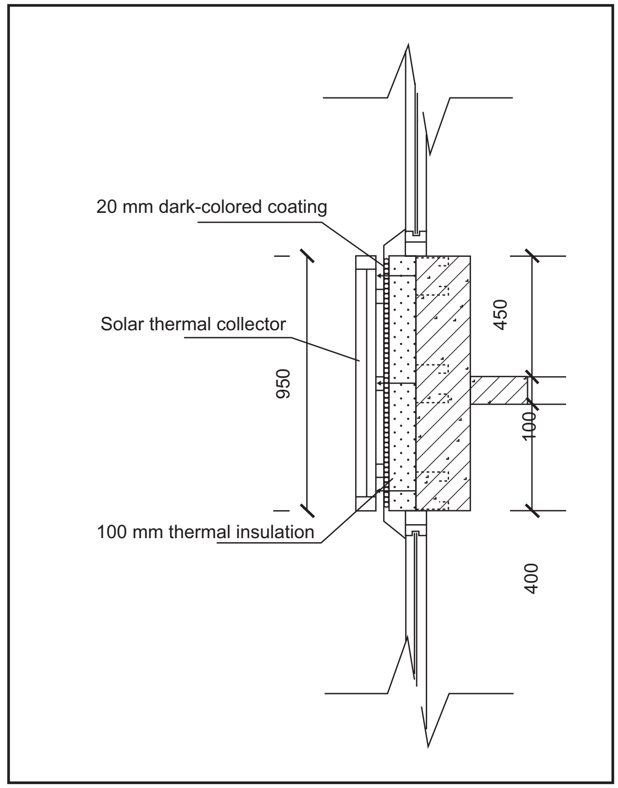

Fig. 15. The practices for surface-applied thermal collector and related parameters.

should be calculated according to the requirements. After area compensation, the area of the thermal collector is 2.45m2, and the corresponding widths are 1.36 m and 1.17 m respectively. Therefore, the size is too large to achieve the expected visual effects.

In this regard, if the flat-plate thermal collector is replaced with the evacuated tube thermal collector, the hollowed texture of the evacuated tube thermal collector can expose the rear wall, thereby forming hidden visual effects. Seen from the appearance, the evacuated tube thermal collector seems to be hidden in the windowsill wall and integrated with the building (**Fig. 16**).

The advantages for transforming the thermal collector to the windowsill wall lie in the continuity of the original order of the building, improvement of the visual effects through colors, the integration of the thermal collector into the residential building, and the formation of the hidden effects due to the unique hollow texture of the evacuated tube thermal collector.

Transformation of STCs towards shutters

Currently, shutters occupy an awkward position in high-end residences because they are unable to play the role of sun-shading boards, and thus become a symbolic symbol. In view of this, STCs and shutters can be integrated to maintain the original texture

Fig. 16. The diagram effect for transformation from STCs to window sill walls.

order of shutters while enabling STCs to play their roles (**Fig. 17** and **Fig. 18**).

Fig. 17. The diagram effect of modern high-end residence with integration of STCs and shutters

Fig. 18. The diagram effect of classical high-end residence with integration of STCs and shutters.

The specific method is that the width of the south-facing window should be reduced as much as possible to reduce the width of STCs, to obtain an appropriate length-width ratio. Additionally, STCs are located on both sides of the windows and directly laid on the walls (**Fig. 17**), and some moldings can be designed based on STCs and windows to strengthen their integrity.

The advantage for transforming STCs towards shutters lies in transforming the novel elements of STCs into the original elements of the building to exert their new functions. This method is applicable to many styles of high-end residences including modern residence.

Nowadays, thanks to highly developed science and technology, shutters have lost their original purpose of existence. People can adjust the indoor lighting thanks to venetian blinds that can be adjusted automatically. Such venetian blinds are easy to operate and are safe, thus they can replace shutters to meet all technical requirements. The authors have interviewed many residents who are not architects, and when they were asked what they think about villas, the three words that appeared most often were pitched roof, spiral staircase, and shutters. Thus, they have become a symbolic component which may be given a special value of the times.

In the end, although the shutters have lost their original function, they still often appear in modern villas. Consequently, the integrated design of solar heat collection facilities and shutters can be adopted. The texture of vacuum tubular heat collection equipment is very similar to that of shutters, so that the equipment can be arranged on both sides of the windows of high-end residences as shutters. This design not only retains the symbolic significance of shutters for high-end residences, but also plays a new role in heat collection.

CONCLUSIONS

This study focuses on the aesthetic form of the integration of GRBs and STCs in the cold region using the transformation-based design method. Based on the characteristics, texture, material, and element properties of STCs as well as the component characteristics for the appearance of GRBs, this study proposes the transformation-based design method. Since the previous structural method is adopted, there is a high feasibility.

Transformation-based design method: in the architectural design, the method of "transformation" is between "extension" and "replacement". "Extension", which is the extension of the original components or order, means starting a practice from scratch; "replacement" means the complete replacement of the original components in terms of function, followed by the presentation of the components in a new form. Transformation means the change of the original appearance or intrinsic properties of objects and identification of other functions of STCs.

In response to the state policy of resource conservation and environmental protection, this study promotes the integration process of solar water heaters and GRBs, so as to effectively integrate solar water heaters and GRBs, enhance the aesthetic perception, give play to other architectural functions of solar water heaters and make them a part of GRBs, improve the efficiency and safety performance of solar water heaters, optimize components, standardize the modulus scale, save costs, and contribute significantly to promoting social sustainable development, elevating people's quality of life, and developing the circular economy.

In summary, with aesthetics as the principal factor and structure, technologies, and economic performance as the secondary factors, we can promote the integration process of GRBs and STCs in China through properly drawing on overseas experience from the perspective of architectural design, and expand the independent opening-up, so as to explore the applicable methods for integration of GRBs and STCs in China. From the aesthetic perspective, GRBs and solar water heaters should be designed synchronously to ensure the functions without affecting or while improving the overall aesthetics of GRBs. Finally, some examples regarding the successful integration of GRBs and solar water heaters should be used to provide references for the integrated design of solar water heaters and GRBs in Changchun.

ACKNOWLEDGMENT

Project of National Natural Science Foundation of China, 51478205.

REFERENCES

Benramdane M., Abboudi S. and Ghernaout M. (2019). Contribution to the simulation and parametric analysis of the operation of a solar concentration thermal installation. International Journal of Heat Technology 37 (2), 446. https://doi.org/10.18280/ijht.370210

Chaithanakulwat A. (2019). Design of solar-powered aeration system for shrimp ponds of farmers in thailand. European Journal of Electrical Engineering, 21 (6), 539. https://doi.org/10.18280/ejee.210608

Ding X. X. (2013). Research on the integration of solar hot water system and building in Changsha. Hunan University (2), 20.

Guellai F., Labed A., Moummi N. and Mahboub C. (2019). Measurement and analysis of thermal-hydraulic performance of curved and plate flat solar air heaters; a comparative study. Instrumentation Mesure Métrologie 18 (6), 553. https://doi.org/10.18280/i2m.180606

Karagiorgas M., Tsoutsos T., Drosou V., Pouffary S., Pagano T., Lara G. L. and Mendes J.M.M. (2006). Hotres: renewable energies in the hotels. an extensive technical tool for the hotel industry. Renewable and Sustainable Energy Reviews 10 (3), 198-224. https://doi.org/10.1016/j.rser.2004.09.012

Spalding-Fecher R., Thorne S. and Wamukonya N. (2002). Residential solar water heating as a potential Clean Development Mechanism project: A South African case study. Mitigation and Adaptation Strategies for Global Change 7, 135-153. https://doi.org/10.1023/A:1022854701442

Wang J. H. and Gong Z. R. (2011). Optimal selection of solar energy and heat pump for hot water. Water & Waste Water Information 2, 8.

Wang R. Zh., Qian Y. M., Wei T. and Jiang X. (2020a). Integrated design between energy-saving solar water heaters in high-rise residential building: a case study on Changchun, Northeast China. Journal of Environmental Protection and Ecology 21(4), 1265-1279.

Wang R. Zh., Qian Y. M., Wei T. and Jiang X. (2020b). Integration between energy-saving solar heating equipment and high-rise residential building. Journal of Environmental Protection and Ecology 4, 1697-1707.

Wang R. Zh., Qian Y. M., Wei T. and X. Jiang X. (2020c). A practical scheme for integrated utilization of passive solar heating in coastal high-rise residential buildings. Journal of Coastal Research 115, 438-442. https://doi.org/10.2112/JCR-SI115-123.1

Xue H. S. (2016). Experimental investigation of a domestic solar water heater with solar collector coupled phase-change energy storage. Renewable Energy 86, 257

Xue Y. B., Yang Q. M. and Wang C. J. (2014). Building solar energy utilization technology for series teaching materials of building environment and energy application engineering in general colleges and universities. China Building Materials Press.1st ed. Bei Jing, China, 323 pp.

Zhang C. (2010). Instance analysis of integrated design of solar hot water system and high-rise residential buildings-taking “Jingcheng Yuqin Bay” as an example. Construction technology.