An Initial Concept Design of an Innovative Flat-Plate Solar Thermal Facade for Building Integration

X. Zhang, J. Shen, T. Yang, L. Tang
Department of Architecture and Built Environment, University of Nottingham, Ningbo, China

Y. Wu
Department of Architecture and Built Environment, University of Nottingham, UK

ABSTRACT: Compared to the conventional solar thermal collectors, Solar Thermal Façade (STF) is a prevalent implementation by incorporating a solar thermal collecting device into building façades. It has been greatly driven by a desire for aesthetic architecture, a practical demand for improved indoor thermal performance, and the simultaneous aspiration for on-site energy/thermal generation in a building. The proposed flat-plate STF is an optimal choice in both heat transfer performance and façade intension, in addition with a high-tech expression, easy design assortment with the metal window frame and the exposed metal load-bearing section, flexible profiles and expressive textures. Meanwhile, it can provide a domestic hot water (DHW) solution for a typical 3-member family apartment in a high-rising residential building in Shanghai, China. This paper aims to present a comprehensive study of STF building integration design from multi-angles of technical, functional, constructive and formal aspects based on the proposed STF system.

1 INTRODUCTION

In order to achieve the global carbon emission target, the high fraction of locally available renewable energy sources in energy mix will become necessary in addition to a significantly reduced energy demand. Solar energy is one of the most important renewable sources locally available for use in building heating, cooling, hot water supply and power production. Truly building integrated solar thermal facade systems can be a potential solution towards the enhanced energy efficiency and reduced operational cost in contemporary built environment.

According to the vision plan issued by European Solar Thermal Technology Platform (ESTTP), by 2030 up to 50 % of the low and medium temperature heat will be delivered through solar thermal (ESTTP 2009). However currently, the solar thermal systems are mostly applied to generate hot water in small-scale plants. And when it comes to applications in field of solar space heating, large-scale plants in urban building projects, hotels and local heating networks, the insufficient suitable-and-oriented roof of most buildings may dictate solar thermal implementation. For a wide market penetration, it is therefore necessary to develop new solar collectors with feasibility to be integrated with building components. Such requirement opens up a large-and-new market segment for the STF system, especially in future district or city- level energy supply.

STF is defined as the "multifunctional energy facade" that differs from conventional solar panels in that it offers a wide range of solutions in architectural design features (i.e., colour, texture, and shape), exceptional applicability and safety in construction, as well as additional energy production. It has flexible functions of heating/cooling buildings, providing hot water, power generation and improving the insulation and overall appearance of buildings. These STF technologies would boost the building energy efficiency and literally turn the envelope into independent energy plant, creating the possibility of solar-thermal deployment in high-rise buildings.

2 WORKING PRINCIPLE OF TYPICAL SOLAR THERMAL FACADE SYSTEM

The typical STF system is schematically shown in Figure 1. The system normally comprises a group of modular STF collectors that receive the solar irradiation and convert it into heat energy, whereas the heating/cooling circuits could be further based on the integration of a heat pump cycle, a package of absorption chiller, modular thermal storage and system controller.

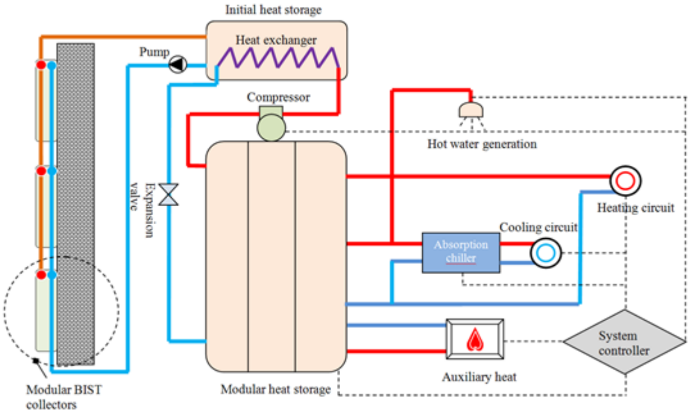

Figure 1: Schematic of modular solar thermal facade system for building services

In case of unsatisfied weather conditions, a back-up/auxiliary heating system is also integrated to guarantee the normal operation of system.

In the typical solar thermal facade system, the overall energy source is derived from solar heat, which is completely absorbed by the modular STF collectors. This part of heat is then transferred into the circulated working medium and transported to the preliminary heat storage unit, within which heat transfer between the heat pump refrigerant and the circulating working medium will occur. This interaction will decrease the temperature of circulating medium and enables it absorbing heat in the facades for next circumstance.

Meanwhile in the heat pump cycle (compressor-condenser-expansion valve-evaporator), the liquid refrigerant will be vaporized in the heat exchanger, which, driven by the compressor, will be subsequently converted into higher-temperature-and-pressure, supersaturated vapour, and further release heat energy into the tank water via the coil exchanger (condenser of the heat pump cycle), leading to temperature rise of the tank water. Also, the heat transfer process within the coil exchanger will result in condensation of the supersaturated vapour, which will be downgraded into lower-temperature-and-pressure liquid refrigerant after passing through the expansion valve. This refrigerant will undergo the evaporation process within the heat exchanger in the initial heat storage again, thus completing the heat pump operation. When the water temperature in tank accumulates to certain level, then water can be directly supplied for utilization or under-floor heating system. For the cooling purpose, additional appliance of absorption chillers should be coupled with.

3 CATEGORIES OF SOLAR THERMAL FACADE TECHNOLOGIES

The solar thermal facade can be classified into air-, hydraulic- (water/heat pipe/refrigerant) and PCM-based types according to heat transfer medium. Air based type is characterized by lower cost, but lower efficiency due to the air's relatively lower thermal mass. This system usually uses the collected solar heat to pre-heat the intake air for purpose of building ventilation or space heating. Hydraulic-based STFs are most commonly used building integrated solar thermal devices that enable the effective collection of the striking solar radiation and conversion of it into the heat for purpose of hot water production and space heating. The PCM-based type is usually operated in combination with air, water or other hydraulic measures that enable storing part of the collected heat during the solar-radiation-rich period, and releasing it to the passing fluids (air, water, or others) during the solar-radiation-poor period to achieve a longer period of STF operation. In general, the economical air type is good at anti-freezing/boiling and non-corrosive with simple structure but lower in heat capacity and with potential leakage and noise. Cost effective water type performs well in cold climates for its higher specific heat, but potential mineral deposits, possible leakage, freezing, corrosion and overheating is unavoidable. As compared, higher efficient refrigerant type is both smaller in storage volume and fluid volume, but its limitations lie in higher cost and unbalanced liquid distribution. Heat pipe type shows compact and super highest heat exchange ability while being low in hydraulic and thermal resistances, but the higher vacuum degree is a limitation in processing. PCM type aims to improve thermal comfort and building envelop with diversity building integration methods. Its disadvantages are difficult operation with complex behavior, diverse affection factors and sensitive heat injection. Therefore, further selection of these solar thermal facade technologies should be carried out depending on different application scenarios.

4 CONCEPTUAL DESIGN OF AN INNOVATIVE SOLAR THERMAL FAÇADE SYSTEM

The proposed STF system is designed to provide DHW for a typical 3-member family apartment in a high-rising residential building in Shanghai, China. This system is expected with lower cost, higher efficiency, façade integrative and aesthetical appearance to provide an alternative to an existing roof-mounted, conventional wall-hung evacuated-tube or flat plate solar water heating system.

4.1 *Relevant standards for STF design*

First of all, there are several relevant standards for STF design. European Standards EN 12975-1, EN 12977-1 and EN12978-1 specify the requirements related to the product itself containing high temperature resistance, exposure, external thermal shock, internal thermal shock, rain penetration, impact resistance and mechanical load. And EN 12975 standard is updating to address the global concerns in evaluating the conventional and advanced solar thermal products (Zhang 2015). In addition, the solar thermal facade should provide protection from external conditions, as solar irradiation temperature, humidity, precipitation and wind in order to achieve an acceptable indoor thermal comfort (Roecker 2009) (Probst 2008). Additionally, there are statutory instruments, directives and standards for the facade application to possess the construction, hydraulic and hygiene characteristics. The integration constrains has illustrated in Figure 2.

Figure 2: Integration constrains for STF

4.2 *Choose of absorber material*

With regards to the material selection of the innovative solar thermal façade, it is cohered with the metal for its hi-tech appearance, strong intention and highly prefabricated feature inspired from the roll-bond absorber. The most popular constructive metals are steel, aluminium, copper, titanium-zinc and bronze. As a potential building component, the material should also pay special attention to the most common and significant physical phenomena. Thermal dilation is a movement that can be accommodated by appropriate forms of jointing and assembly. The corrosion is an alternation on the surface appearance of majority metals from environmental influences that requires higher maintenance costs. Meanwhile, the connection between water pipe and metal absorber also need to avoid a regenerative anti-corrosion layer which changes the appearance with the time, such as copper or a contact between a third group, such as iron and steel. In a consequence, stainless steel seems to be an optimal choice with combinations in both heat transfer performance and façade intension.

In another aspect of the unglazed absorber type, the proper mechanical joining is the important link to guarantee a good thermal bond through processing techniques (Kalogirou 2004). The modern manufacturing techniques of cutting, folding, stamping and welding introduced by industry enable a super thin the full flow-through stainless steel absorber.

4.3 *Configuration of the innovative STF*

The basic configuration of the innovative STF is showed in Figure 3. The thermal absorber is made up by two parallel thin flat-plate metal sheets, one of which is extruded by machinery mould to formulate arrays of mini corrugations, while another sheet remains smooth for attaching building wall. A laser-welding technology is applied to join them together, forming up the built-in turbulent flow channels. Such unique compact structure engenders not only high heat transfer capacity but also convenience in rapid assembly and installation. If several absorbers are connected together as a complete larger area of building facade the question of the connecting arrangement arises. Therefore, a flexible connection arrangement scheme is proposed through two sets of inlet and outlet around the four corners of the flat plate panel. Basically, there are three kind of arrangements as parallel, series and combined.

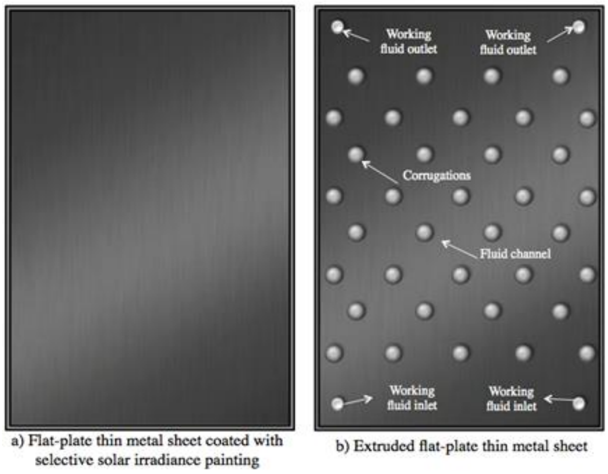

Figure 3 Elementary diagram of the innovative super thin flat-plate metal solar absorber

In the case of parallel connection, all the distributing and collecting header pipes are connected as illustrated in Figure 4. In the case of series connection, all the absorbers are connected successively as illustrated in Figure 5. And in the case of combined connection, the absorbers in each group are in parallel connection first, then multiple groups are connected in series, making it possible to combine the advantages of both connection principles as illustrated in Figure 6.

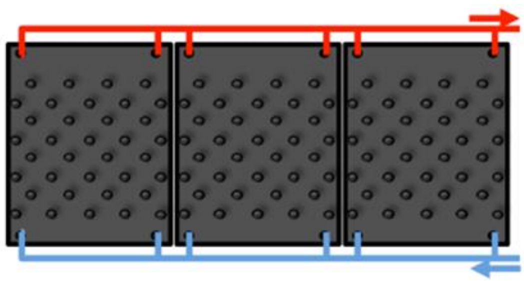

Figure 4 Parallel connection arrangement of the proposed STF

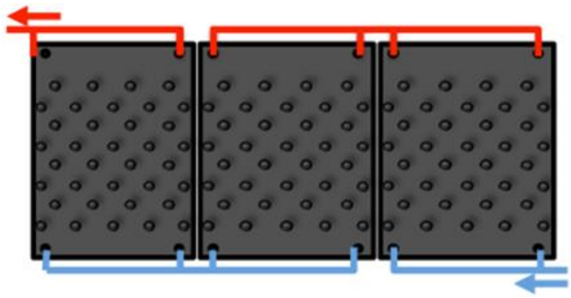

Figure 5 Series connection arrangement of the proposed STF

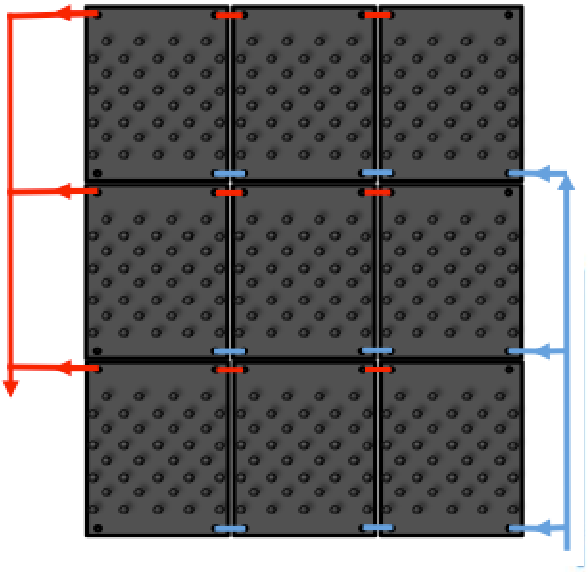

Figure 6 Combined connection of the proposed STF

Figure 7 demonstrates the conceptual application design of the solar thermal façade. It can be seen that the whole system is simply in structure with main stainless steel solar absorber, accessorial metal profiles, piping and insulation.

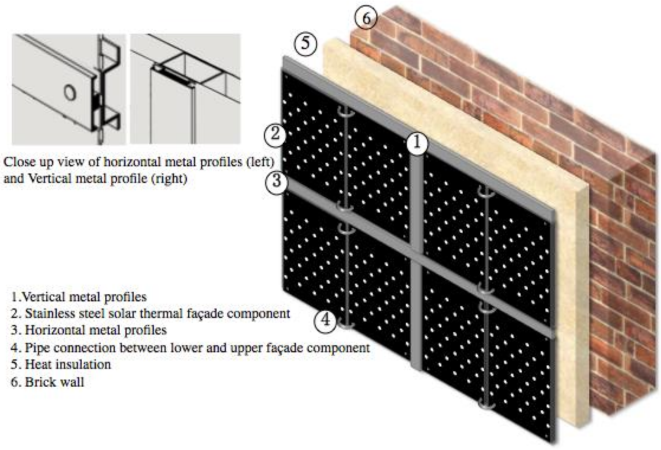

Figure 7 Conceptual design of the façade application with the close up view of horizontal and vertical metal profiles

4.4 *Reflexions of solar thermal façade applications*

The proposed STF system, shown in Figure 8 is simple in composition with a metal absorber, a circulating water pump and an insulated water tank. The stainless steel absorber is thin to integrate into building envelope as metal cladding panel converting the absorbed solar energy into thermal energy. Next, the absorbed solar heat is transported to the pipe coil in the insulated water tank through circulation water pump to exchange heat.

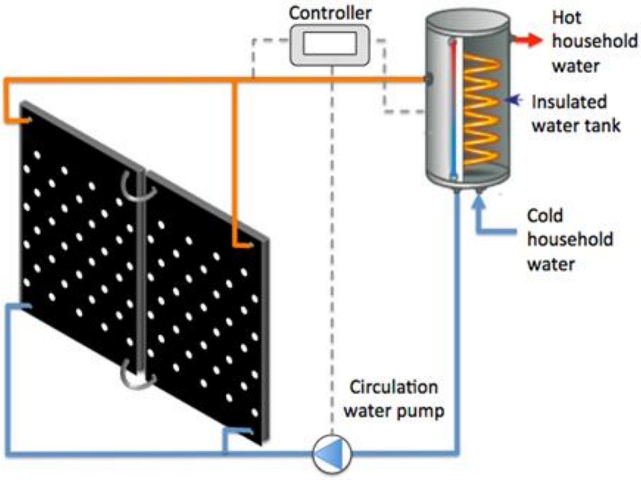

Figure 8 Conceptual system connections

5 CONCLUSION

This paper proposed the initial concept design of a metal cladding based STF technology that recently enjoys the popularity in building facade application for its high-tech expression, easy match with the metal window frame and the exposed metal load-bearing section, as well as flexible profiles and expressive textures. It inspires a promising direction for STF system owing to its simple structure, light and thin panel and optimal heat exchange performance. It is expected to break through the limitations of conventional STF, and achieve a broader market deployment.

6 ACKNOWLEDGEMENTS

The authors would acknowledge our sincere appreciation to the financial supports from the Ningbo Natural Science Foundation (2015A610039).

REFERENCES

Roecker C, Munari Probst M, de Chambrier E, Schueler A, Scartezzini J-L. Facade Integration of Solar Thermal Collectors: A Breakthrough. Berlin, Heidelberg: Springer Berlin Heidelberg; 2009. pp. 337–41.

Probst MCM. Architectural Integration And Design Of Solar Thermal Systems. PhD thesis of ÉCole Polytechnique FéDéRale De Lausanne; 2008.

ESTTP, 2009. Solar Heating and Cooling for a Sustainable Energy Future in Europe. European Solar Thermal Technology Platform.

Kalogirou S.A, 2004. Solar thermal collectors and applications. Progress in Energy and Combustion Science 30: 231–95.
Zhang X, Shen J, Lu Y, et al., 2015. Active Solar Thermal Facades (ASTFs): From concept, application to research questions, Renewable and Sustainable Energy Reviews 50: 32-63.