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Optimizing the Configuration of a Compact Thermal Facade Module for Solar Renovation Concept in Buildings

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Abstract

Solar concepts show potentially an improved cost-performance (energy) ratio when applied as the integrated parts of building renovations. This paper reported a compact solar thermal facade (STF) module with the internally extruded flow channel suiting for solar renovation concept in buildings. A few of impact factors were considered for the parametric study in order to optimize the STF's configuration for various applications through the validated simulation model. The overall research results are expected to be useful for further improvement in the thermal performance of solar renovation measures.

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Keywaords: Solar; Thermal facade; Configuration; Renovation

1. Introduction

Building sector is currently responsible for more than one third total primary energy consumption and the equivalent total carbon emission. As most of the existing buildings have poor energy performance, renovation of existing buildings to achieve the energy-efficiency standards will represent a large proportion of the building construction duties and contribute to the corresponding primary energy saving target. The biggest challenge in building renovation is to increase the cost-performance ratio. To achieve

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this, it is necessary to reduce renovation costs and also to increase energy performance of the renovated components at the same time. Effective solutions thus need to be developed, demonstrated, and replicated.

Integrating of solar thermal module with building facade components represents a promising solution to tackle the above challenge. The solar thermal façade (STF) module is defined as the “multifunctional energy facade” that differs from conventional solar panels or construction materials as it offers a wide range of solutions in the architectural design features (i.e., colour, texture, and shape), exceptional applicability and safety in construction, as well as additional energy production. There are a series of demonstration projects displaying how synergic collaboration between the solar thermal module and the building facade can be within the STF applications [1]. Diverse directions with miscellaneous motives have led to a lot of different STF building integration variations [2-5]. Typical strategies can be assigned to dissimulation into building envelope, special placement, and modular building component design. Furthermore, it can be found that majority of new building project belongs to solar house, passive house or even net zero energy building design, while renovation projects provide a new direction of functional transformation instead of sole repairing. More focuses have been put on threatening resource shortage, comfort living environment, as well as position architectures themselves in the niche market. It is worthy mention that as an innovative choice of multifunctional building envelope, STF has superiority in reducing costs by combined functions of solar absorption and building covering, and improving the energy performance of buildings via reduction in energy load and generation of certain amount of energy simultaneously. It is usually modularized to be adaptable to both individual and mass renovation solutions.

This paper proposes a compact metal STF module featured with simple structure, low cost, high feasibility in building renovation as displayed in Fig.1 (a). The STF module is made up by two stainless steel sheets, one of which is extruded by machinery mould together to formulate arrays of pin-fin corrugations, while the another sheet working as the absorbing surface remains smooth and can be coated into optional colour or texture according to different requests. Such STF can be employed as shading or rainscreen as an advanced building envelop to buffer the overall building energy load and delivery of solar thermal energy. It also has feasible functions in heating/cooling the building, providing hot water, power generation and improving the insulation and overall appearance of building, as illustrated in Fig. 1 (b). In order to optimize the configuration of such a STF, seven impact factors will be considered for the parametric through the validated simulation model. It is expected that the research result could be useful for further design of such STF in various building renovation scenarios.

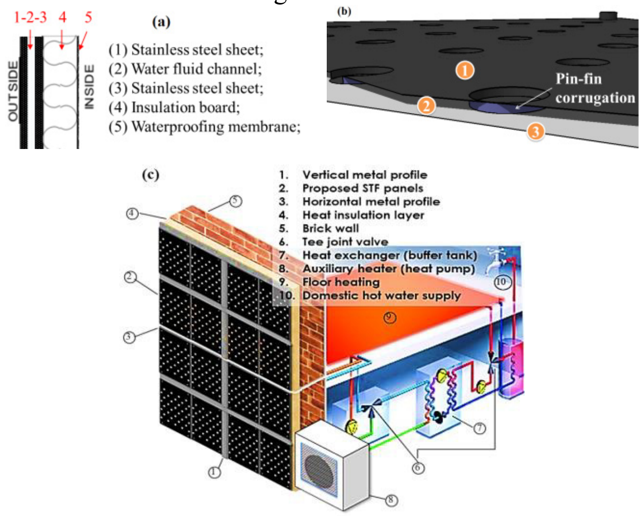

Fig. 1 (a) Schematic design of the proposed STF; (b) flow channel of the STF; (c) conceptual wall renovation with the STF

2. Parametric Analysis by the Validated Simulation Model

The STF's thermal performance is a factor that depends upon its several design parameters, i.e., colourful paint types, pin-fin diameter, number of pin-fin rows, pin-fin length, vertical distance between fin rows. In order to optimize the design configuration for better operating performance, a series of parametric analysis are carried out on basis of the validated simulation model developed by the authors, which was conducted for the operating performance exploration of the proposed STF [6]. Therefore, a set of operational parameters has been achieved for the controlled environment conditions, i.e. equivalent solar radiation of 500 W/m^2, air temperature of 20℃, air velocity of 1 l/min, water mass flow rate of 1 l/min and inlet water temperature of 30℃.

The methodology is that while keeping all other design and operating parameters constant, changing one configuration parameter each time led to a variation in the STF thermal performance accordingly. And the relevant heat transfer processes in the STF module will eventually achieve through the energy balance at the steady state condition and each part of the STF will establish a certain temperature in operation. The detailed algorithm can be assessed through authors' previous work [6].

2.1. Impact of colourful coatings/paints

After determining the stainless steel as the STF material, the correlation between the colourful coatings/paints and the STF thermal performance is given in Fig. 2 while remaining the other design and operating parameters the same. Ten different coatings/paints were considered to be applied for the STF's front colours [2]. By inputting their characteristic values, like absorptance and emittance, into the established simulation model, their respective impact on the STF thermal performance could be observed. The selective black chrome reached the best performance with the highest thermal efficiency (nearly 70%) and the lowest heat loss coefficient (about 13.17W/m^2-℃) due to its high absorptance and low emittance. In contrast, the red paint (S-R-130-1) based STF achieved the worst thermal efficiency of less than 40% due to its highest emittance at 0.64. The rest paints have the equivalent impact to the STF's thermal efficiency in a reasonable range of 40%-60% with absorptance $\alpha \geq 0.76$ and emittance $\varepsilon \leq 0.4$. So it could recommend that the best colour choice is the selective black chrome while the other alternatives need to remain their absorptance and emittance values in the acceptable range as indicated above.

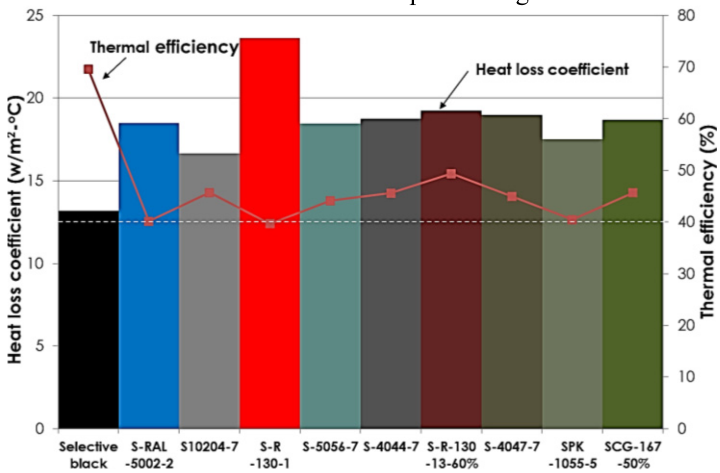

Fig. 2 Impact of colourful coatings/paints on STF thermal performance

2.2. Impact of pin fin diameter

By determining the selective black chrome as the initial STF coating colour, the correlation between the pin fin diameter and the STF thermal performance is illustrated from Fig. 3 if remaining the other design and operating parameters constant. The thermal efficiency, the fin effectiveness, the Reynolds number, the press loss and the heat removal factor all increased with the diameter of pin fins varying from 20 to 55 mm. It was because larger pin fins led to more turbulent flow across the fin bank as representing by the higher Reynolds numbers, which subsequently increased the heat transfer coefficient and the heat removal factor of the fluid as well as the fin efficiency (before the diameter of 40 mm). These impacts further raised up overall thermal efficiency of the STF module. In addition, the stronger turbulent flow resulted in the higher pressure drop when crossing the pin fin bank. On the other hand, the larger pin fin means the greater finned surface which thus enhanced the overall fin effectiveness but weakened the independent fin efficiency after the diameter was more than 40 mm (the dominant factor for the fin efficiency afterwards). In order to balance the overall thermal efficiency and the pressure loss of the fluid, an optimum/equilibrium range should be recommended. The pressure dropped significantly after the diameter of pin fins was over 40 mm while the thermal efficiency varied slightly all the time. As a result, the optimum range was determined from 25 to 40 mm in terms of the pin fin diameter.

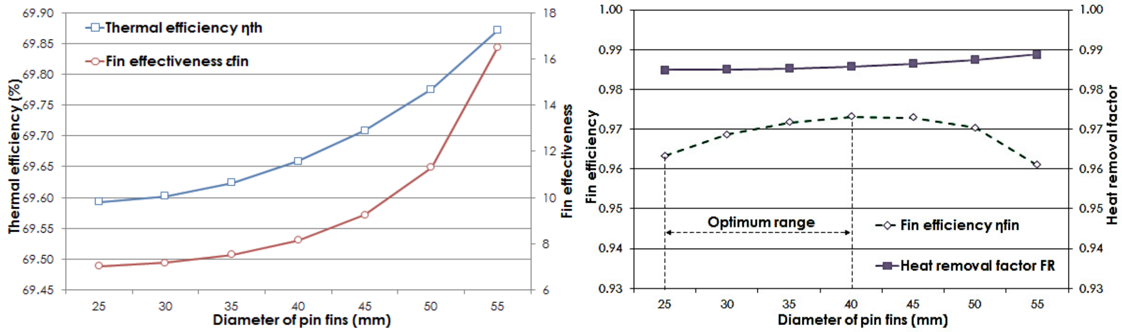

Fig. 3 Impact of pin fin diameter on STF thermal performance

2.3. Impact of number of pin fin rows

While remaining the other design and operating parameters the same, the correlation between the number of pin-fin row and the STF thermal performance is presented from Fig. 4.

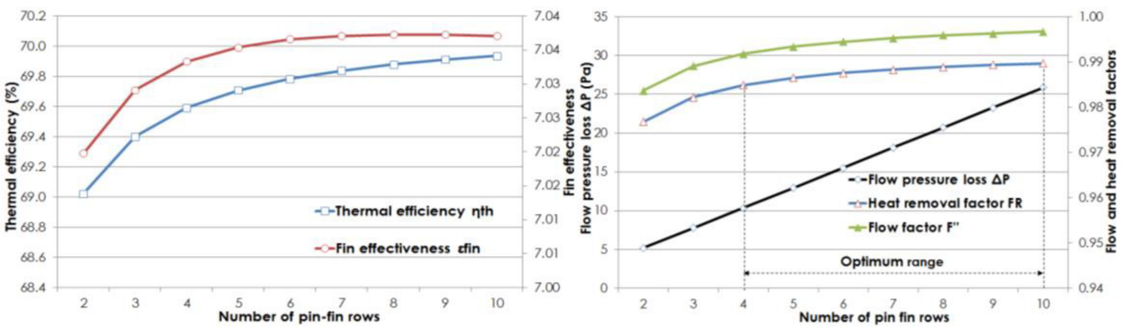

Fig 4 Impact of number of pin fin rows on STF thermal performance

It was found that all the main performance indicators, like thermal efficiency, fin effectiveness, fluid flow factor, heat removal factor, and pressure loss, increased with the number of pin-rows varying from 2 to 10. This phenomenon was because more rows of pin fins enlarged the heat exchanging surface area between the fluid flow and the fins. The fully heat exchange process therefore increased the total amount of heat transfer from the fins to the fluid shown in the form of the increasing thermal efficiency. These positive impacts also applied to the fin effectiveness, the fluid flow factor, and the heat removal factor. In contrast, the increased pin fin bank resulted in the higher pressure drop for the fluid. The increasing number of pin fin rows only strengthened on the other parameters slightly, like fin efficiency, Reynolds number and heat transfer coefficient of fluid. In order to balance the pressure loss and the other thermal performance, an optimum range was recommended from 4 to 10 in terms of the number of pin fin rows.

2.4. Impact of pin fin length

While remaining the other design and operating parameters the same, the correlation between the pin fin length and the STF thermal performance is presented from Fig. 5. It was found that the thermal efficiency, fluid flow factor, and the heat removal factor increased with the length of pin fins varying from 0.5 to 5 mm. This phenomenon was because longer pin fins enabled more surface space for the fluid flow to remove heat and therefore increased the total amount of heat transfer to the fluid. These positive impacts also applied to the fin effectiveness at the beginning (before 2.5 mm) while the reduced the fin efficiency became dominant to drop down the overall fin effectiveness (after 2.5 mm) showing a longer fin was much less effective. In the meanwhile, the variation of the pin fin length didn’t have too much effect on the other parameters, like Reynolds number and pressure loss. In order to balance the fin efficiency and the fluid flow factor as well as the fluid heat removal factor, an optimum/equilibrium range was recommended from 2.4 to 2.7 mm in terms of the pin fin length. An optimum length of 2.5 mm was found if it was from the overall fin effectiveness point of view.

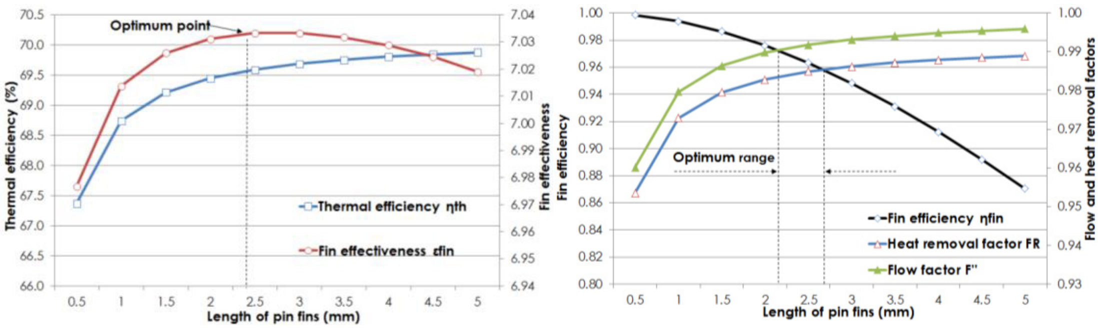

Fig. 5 Impact of pin fin length on STF thermal performance

2.5. Impact of vertical distance between fin rows

While remaining the other design and operating parameters the same, the correlation between the vertical distances of pin fin rows and the STF thermal performance is displayed from Fig. 6. It was found that the thermal efficiency, the fin efficiency, the flow factor, and the heat removal factor of fluid increased with the vertical distance between fin rows varying from 30 to 100. In contrast, the fin effectiveness, the Reynolds number, and the pressure loss of fluid varied in the opposite tend. This phenomenon was because larger vertical distance be-tween fin rows enlarged the heat exchanging space between the fluid flow and the fins, leading to more fluid passing through the fins. Such fully heat exchange process therefore increased the total amount of heat transfer from the fins to the fluid shown as the rising thermal efficiency. These positive impacts also applied to the fin effectiveness, the fluid flow factor, and the heat removal factor. On the other hand, the larger vertical distance between fin rows caused less turbulence of the fluid flow (lower Reynold number) and resulted in the lower pressure drop for the fluid. By considering the trends of the pressure loss and the other thermal performance indicators, an optimum range was recommended from 60 to 100 in terms of the vertical distance between fin rows.

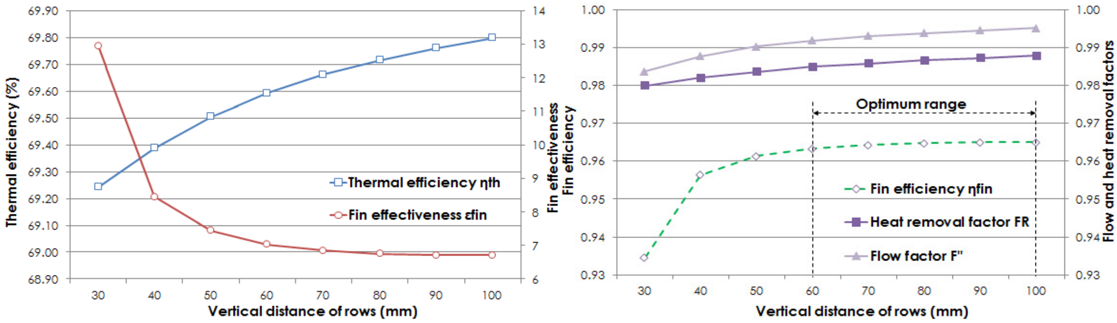

Fig. 6 Impact of vertical distance between fin rows on STF thermal performance

3. Conclusion

In order to achieve a higher thermal performance of STF, the simulation results recommend that: i) the alternative colour paints need to remain their characteristics in acceptable range (absorptance $\alpha \geq 0.76$ and emittance $\varepsilon \leq 0.4$); ii) the optimum range of the pin fin diameter was 25 to 40 mm; iii) the optimum range of the number of pin fin row was 4 to 10; iv) the optimum range of the pin fin length was 2.4 to 2.7 mm; and v) the optimum range of vertical distance between fin rows was 60 to 100. The research result shall be useful to improve thermal performance of solar renovation measures in energy-efficient buildings.

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