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Active Solar Thermal Facades (ASTFs): From concept, application to research questions

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ABSTRACT

The aim of the paper is to report a comprehensive review into a recently emerging building integrated solar thermal technology, namely, Active Solar Thermal Facades (ASTFs), in terms of concept, classification, standard, performance evaluation, application, as well as research questions. This involves the combined effort of literature review, analysis, extraction, integration, critics, prediction and conclusion. It is indicated that the ASTFs are sort of building envelope elements incorporating the solar collecting devices, thus enabling the dual functions, e.g., space shielding and solar energy collection, to be performed. Based on the function of the building envelopes, the ASTF systems can be generally classified as wall-, window-, balcony-and roof-based types; while the ASTFs could also be classified by the thermal collection typologies, transparency, application, and heat-transfer medium. Currently, existing building and solar collector standards are brought together to evaluate the performance of the ASTFs. The research questions relating to the ASTFs are numerous, but the major points lie in: (1) whole structure and individual components layout, sizing and optimisation; (2) theoretical analysis; (3) experimental measurement; and (4) energy saving, economic and environmental performance assessment. Based on the analysis of the identified research questions, achievements made on each question, and outstanding problems remaining with the ASTFs, further development opportunities on this topic are suggested: (1) development of an integrated database/software enabling both architecture design and engineering performance simulation; (2) real-time measurement of the ASTFs integrated buildings on a long-term scheme; (3) economic and environmental performance assessment and social acceptance analysis; (4) dissemination, marketing and exploitation strategies study. This study helps in identifying the current status, potential problems in existence, future directions in research, development and practical application of the ASTFs technologies in buildings. It will also promote development of renewable energy technology and thus contribute to achieving the UK and international targets in energy saving, renewable energy utilization, and carbon emission reduction in building sector.

Contents

Abbreviations: ASTFS, Active Solar Thermal Facades; BIM, building information modeling; CFD, computational fluid dynamics; CPD, construction products directive; CPR, construction products regulation; CPBT, cost payback time; DHW, domestic hot water; EC, embodied carbon; EE, embodied energy; EPBD, energy performance of buildings; EPBT, energy payback time; FMEA, failure modes and effects analysis; FYFS, first year fuel savings; LCA, life cycle assessment; NPV, net present value; O&M, operational and maintenance; PCM, phase change material; PV, photovoltaic; PV/T, photovoltaic/thermal; PVD, physical vapour deposited; STC, solar thermal collector; SWHS, solar water heating system; TISS, thickness insensitive spectrally selective; TSTC, transparent solar thermal collector; TSSS, thickness sensitive spectrally selective; UTSC, unglazed solar thermal collector; VTC, vacuum tube collector

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1. Introduction

It has been well known that global energy demand is continuously growing, and buildings are consuming one third of the total energy supply in developed countries and one-fourth in developing countries [1]. Reducing energy demand and making good use of renewable energy are considered to be the major route towards the low energy and sustainable future, in particular, for building sector.

Solar technologies have been well explored for many years, and solar photovoltaic (PV), solar thermal and hybrid photovoltaic/thermal (PV/T) are regarded as the most feasible renewable solutions to building application. Solar thermal, as the most mature technology among all currently available solar technologies, is proved to have relatively higher solar conversion efficiency, 2 to 4 times higher than that in PV systems [1]. Furthermore, the solar thermal technology, owing to the wide range of application and massive scale production at global level, can obtain a much shorter payback period compared to its lifetime [2].

In the UK, space heating consumes a large amount of energy. The Digest of the UK Energy Statistics 2013 indicated that 148.2 million tonnes of oil equivalent was consumed annually in domestic house sector, of which 66% was used for space heating and 17% for hot water production [3]. The cost of heating is around £33 billion in the UK each year, which was higher than that for transporting and for power generation as well. In this regard, '*The Future of Heating: A Strategic Framework for Low Carbon Heating in the UK*' was recently published to address this particular challenge and to plan a vision for future energy with particular emphasis of secure supply of low carbon and renewable energy [4]. In this report, the solar driven water heating system was predicted to have a potential to provide around 70 to 90% of total energy required for hot water generation and supply [5,6]. In 2011, around 131 GWh of domestic hot water was delivered by the solar systems, which significantly reduced the gas and electrical uses in the UK [7]. In Europe, there was around 10 GW_{th} ('th' stands for 'thermal') of solar thermal systems in operation in 2005. This capacity is expected to grow to 200 GW_{th} by 2030, of which up to 50% will be used for delivering the low and medium temperature water [8]. Apart from hot water production and space heating, solar thermal was also used to drive air conditioning systems for buildings, which could be operated at water temperature of 90 °C or above [9]. According to the *Government's Renewable Heat Premium Payment* scheme, solar thermal will be an important heat source, which will provide a major support to develop the sustainable cities and towns, boost the UK economy and create a low carbon future.

Compared to conventional solar thermal equipment, 'Active Solar Thermal Façade' (ASTF) is a new building integrated solar thermal product, which allows integration of a solar thermal collecting device into a building envelope element (e.g. wall, window, shading, or roof), thus creating both the shielding and solar energy collecting functions for the façade. Recently, many types of ASTFs have been found in market and applications of these ASTFs have also been discovered in various buildings globally. Although many works have been carried out in the ASTFs, certain levels of ambiguity still remains in several aspects: (1) type and classification; (2) advantages and disadvantages;