Solar Energy 135 (2016) 408–422

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Review and analysis of solar thermal facades

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ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form 31 May 2016
Accepted 2 June 2016

Keywords:
Solar thermal collector
Solar thermal facades
Facade integration

ABSTRACT

Harnessing solar energy to provide for the thermal needs of buildings is one of the most promising solutions to the global energy issue. Exploiting the additional surface area provided by the building's façade can significantly increase the solar energy output. Developing a range of integrated and adaptable products that do not significantly affect the building's aesthetics is vital to enabling the building integrated solar thermal market to expand and prosper. This work reviews and evaluates solar thermal facades in terms of the standard collector type, which they are based on, and their component make-up. Daily efficiency models are presented, based on a combination of the Hottel Whillier Bliss model and finite element simulation. Novel and market available solar thermal systems are also reviewed and evaluated using standard evaluation methods, based on experimentally determined parameters ISO 9806. Solar thermal collectors integrated directly into the facade benefit from the additional wall insulation at the back; displaying higher efficiencies then an identical collector offset from the facade. Unglazed solar thermal facades with high capacitance absorbers (e.g. concrete) experience a shift in peak maximum energy yield and display a lower sensitivity to ambient conditions than the traditional metallic based unglazed collectors. Glazed solar thermal facades, used for high temperature applications (domestic hot water), result in overheating of the building's interior which can be reduced significantly through the inclusion of high quality wall insulation. For low temperature applications (preheating systems), the cheaper unglazed systems offer the most economic solution. The inclusion of brighter colour for the glazing and darker colour for the absorber shows the lowest efficiency reductions (<4%). Novel solar thermal façade solutions include solar collectors integrated into balcony rails, shading devices, louvers, windows or gutters.

1. Introduction

Over one third of all energy consumption is associated with buildings, about half of this energy is used for space heating/cooling and hot water preparation (IEA, 2013). These loads are primarily served through the burning of fossil fuels resulting in concerns of climate change and environmental degradation. Alternative, sustainable methods of meeting these loads are required. The application of solar thermal technology can reduce or eliminate fossil fuel requirement to provide for a building's thermal needs (Peuser et al., 2010; Baños et al., 2011).

Traditionally Solar Thermal Collectors (STCs) are mounted on frames that are attached to the roofs of buildings. Facade integration of renewable technologies exploits a larger proportion of a building's surface area for energy generation. Transpired solar collectors, based on heating air between layers of the facade are increasingly common (Shukla et al., 2012). Facade integration of photovoltaic technologies is today commonplace and the state of the art is well documented (Cerón et al., 2013). Facade integrated solar thermal collectors, hereafter, termed Solar Thermal Facades (STFs), are less common. Authors have reported a paucity of STF product options that are aesthetically pleasing or widely commercially available (Cappel et al., 2014; Farkas and Horvat, 2012; Probst and Roecker, 2012). STFs include STCs that are integrated into the weather line of the building (DOMA Solartechnik, 2015; S-solar, 2015; Winkler Solar, 2015) or are attached proud of the façade as, for example, balcony rails (Ji et al., 2015; Schweizer Energie, 2015; Yang et al., 2013b; Zhai et al., 2008) or louvers (Abu-Zour et al., 2006; Palmero-Marrero and Oliveira, 2006; Zhai et al., 2008). These solutions generally derive from common roof attached solar thermal collectors, configured in alternative orientation, colour, casings and forms.

Increasing the usable building surface area for energy production is particularly beneficial for buildings with low roof to envelope ratios (Chow et al., 2006, 2005; O'Hegarty et al., 2015; Shi

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http://dx.doi.org/10.1016/j.solener.2016.06.006
0038-092X/

et al., 2013). Additionally, other components of building services compete for roof space. STFs replace building cladding elements and their associated embodied energy (Greening and Azapagic, 2014; Lamnatou et al., 2015; Maurer et al., 2015a). However, vertically orientating the STCs reduces the annual solar yield per m^2 of collector (by approximately 26% in Dublin) when compared with an optimally tilted surface (Fig. 1).

Locating the collectors vertically reduces solar gains in the summer, which can reduce the risk of the system over heating and subsequently damaging the collector, pump and expansion vessel (DGS, 2010; Peuser et al., 2010). A brief introduction to STCs and their components is first presented to further understand STF advantages and limitations.

2. Solar thermal collectors and their components

This work categorises STCs into five core technology types, which most STFs derive from; (A) Unglazed Collectors (UC), (B) Glazed Flat Plate Collectors (FPC), (C) Massive Solar Thermal Collectors (MSTC), (D) Evacuated Tube Collectors (ETC) and (E) Concentrated Solar Collectors. Simplified section cuts and plan drawings of each collector (A–E) are shown in Fig. 2. This classification aims to capture STFs that replicate standard roof attached solar thermal systems, as well as novel, and bespoke designs, that are adapted from these technologies for façade integration. The collectors are reviewed with reference to five core components ((1) cover, (2) absorber, (3) heat transfer fluid network, (4) insulation, and (5) fixings and framing systems). Components (1–4) are indicated in Fig. 2.

The standard roof attached technologies ((A), (B) and (D)) differ in performance and appearance, but each follows a similar heat transfer process. Solar radiation incident on the collector is captured by its absorber (2), this heat is then transferred to the piping network (3) via conduction and finally to the working fluid by a combination of conduction and convection. As the collector temperature exceeds the ambient temperature, heat is lost by conduction, convection and radiation, and can be reduced by the inclusion of insulation backing (4) as well as a vacuum or air space between cover (1) and absorber (2).

Individual collector components are labelled: (1) cover, (2) absorber, (3) heat transfer fluid network (where light grey indicates inlet and dark is outlet) and (4) insulation.

2.1. Unglazed collectors

Unglazed Collectors (UC) (Fig. 2(A)) consist of a hydraulic piping system connected to, or forming an integral part of, an absorber layer that captures the solar radiation and transfers the heat to the circulating fluid. The UC may also include insulation at the back. High convective heat losses are characteristic of the UC due to the absence of a covering (Bonhôte et al., 2009; Tripanagnostopoulos et al., 2000), which reduces the collector's efficiency. Convective heat losses become proportionally significant when large temperature differences occur between ambient

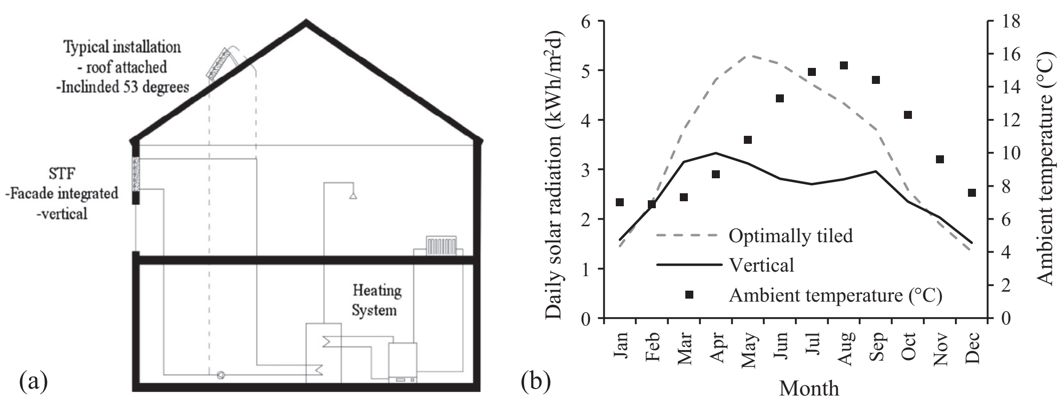

Fig. 1. (a) Typical roof mounted installation (53° optimal tilt) and solar thermal façade installation (vertical) where (b) displays annual profiles for the average daily solar radiation on the two surfaces in Dublin, Ireland (Latitude 53.35N; 6.26W). Data taken from (PVGIS, 2016).

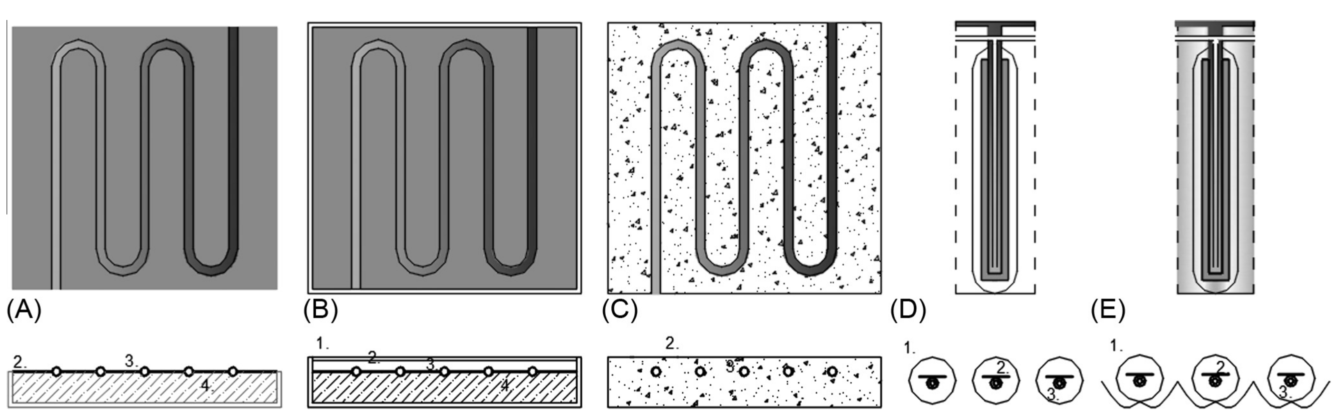

Fig. 2. Simplified section and plan drawings of example solar collectors: (A) Unglazed Collector, (B) Glazed Flat Plate Collector, (C) Massive Solar Thermal Collector, (D) Evacuated Tube Collector and (E) Concentrated Solar Collector.