Renewable and Sustainable Energy Reviews 51 (2015) 327–346

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Building integrated solar thermal collectors – A review

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ARTICLE INFO

Article history:
Received 15 January 2015
Received in revised form
11 May 2015
Accepted 1 June 2015

Keywords:
Solar energy
Building integration
Thermal collector
PV/T
Architecture
IEA Task 41

ABSTRACT

Among the solutions to the global energy problem, the utilisation of solar energy is, without a doubt, one of the most encouraging ecological avenues. In a solar thermal system, the solar thermal energy can be exploited via heating working fluid circulating through a heat collector. In this paper, the concept of the building integrated solar thermal collectors was briefly introduced, the applications of building integrated solar thermal collectors were presented and standards for assessing thermal performance of these solar thermal systems were addressed. The major features, current status and existing difficulties related to the various types of solar thermal collectors were identified. Several factors affecting the thermal performance, characteristics of the solar thermal systems and building integration possibilities were also summarised. This study facilitates understanding the questions prevailing in solar thermal collector technology, diagnosing new research directions towards further improvement of the performance, addressing the important issues related to architectural barriers, system design and installation. Also, this review reveals the trend of the technology, particularly the advancement in recent years and the future work required.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.06.009
1364-0321/

1. Introduction

Future projections stating the growing gap between energy supply and demand have motivated the development of environmentally benign energy technologies. Among others, solar energy, as a major renewable and eco-friendly energy source with the most prominent characteristic of inexhaustibility, seems to be more promising to offer sustainable solutions towards environmental protection and conservation of conventional energy sources. Thus, solar energy based systems can meet energy demands to some extent to maintain the balance in the ecosystem. However, public acceptance of solar energy technologies depends heavily on factors such as efficiency, cost-effectiveness, reliability and availability [1,2].

Solar thermal collectors are particular type of heat extracting devices that convert solar radiation into thermal energy through a transport medium or flowing fluid. These collectors, as being a significant part of any solar energy system, absorb the incoming solar radiation, convert it to heat energy and convey it through a working fluid such as air, water or refrigerant, for various useful purposes. In general, they are utilised as air heating/air conditioning of buildings drying/heating of agricultural or products [3].

In addition to being technically and structurally efficient, solar thermal collectors must satisfy the following requirements for architectural integration. These requirements are a generalisation of the criterion set by IEA Task 41 Solar Energy and Architecture for aesthetic quality of buildings integrated solar thermal collectors as follows [4]:

- Integrating naturally.
- Architecturally pleasing design.
- Good composition of colours and materials.
- Size that suits the harmony and combination.
- Consistency to the context of the building.
- Well composed and innovative design.

Building integrated solar thermal collectors may be installed either on the building façade or on the roof causing in each case a different visual impact. Depending on the type and dimensions, the system may be integrated in such a way that it is invisible, aesthetically appealing or appearing as an architectural concept [5].

The contribution of this study is twofold: first, it presents the new concepts and recent developments in solar thermal collectors by revealing the trend of the technology, particularly the advancement in recent years. Secondly, the outcome of this paper offers insights for researchers by diagnosing new research directions towards further improvement of the performance, and addressing the important issues related to architectural barriers, system design and installation.

This study is organised as follows: Section 1 introduces the solar thermal collector concept; Section 2 describes the PV/T concept; Section 3 gives a clear insight into solar thermal collectors; Section 4 investigates the future potential of the building integrated solar thermal collectors; Section 5 discusses the building integration criterion set by IEA SHC Task 41 Solar Energy and Architecture; and Section 6 involves the conclusion of this communication.

2. Photovoltaic/thermal (PV/T) collectors

A photovoltaic/thermal (PV/T) collector is a combination of photovoltaic (PV) and solar thermal components that produce both electricity and heat simultaneously. This dual function of the PVT enables a more effective use of solar energy that results in a higher overall solar conversion. Much of the captured solar energy in a sole PV module elevates the temperature of its cells which causes degradation in module efficiency. This waste heat needs to be removed to ensure a high electrical output. The PV/T technology recovers part of this extracted heat to utilise for low-and-medium-temperature applications [6].

The merits of PV/T concept comparing to alternative technologies contain eco-friendly, proven long life (20–30 years), noise free and low maintenance. However, several factors restrict the efficiency of the photovoltaic module such as particularly temperature increase and utilising only a part of solar spectrum (photon energy threshold is less than 1.11 μm for c-Si) for power generation. The band gap of silicon (1.12 eV) limits the total energy collected in solar spectrum even less than 1.11 μm. So, photons of longer wavelength dissipate their energy as waste heat rather than generating electron–hole pairs. As PV modules are able to convert only 4–17% of the incoming solar radiation into energy depending on the solar cell type and working conditions, cooling PV modules simultaneously by a fluid stream like air or water boost energy yield significantly. Conceptually, re-use of heat energy extracted by the coolant is ideal. Thus, PV/T collectors offer a higher overall efficiency [7].

At present, various types of PV/T collectors are in practical use based on working fluid and conduit shape such as PV/T air, PV/T water etc. Next section will introduce these types of building integrated PV/T systems briefly.

2.1. PV/T air collectors

Substantial research has been conducted on PV/T air collectors regarding design, simulation, building integration, and experimental testing. The air type design, as shown in Fig. 1, can offer a basic and cost-effective solution to PV cooling and also the air can be heated to certain temperatures through forced or natural air flow. In terms of efficiency, the forced flow is superior to the natural flow due to better convective and conductive heat transfer although energy consumption of fans limits the net electrical power gain.

Hegazy [9] performed a comparative study using four common designs. These four designs include the configurations of air flow passage above the absorber (I), below the absorber (II), both side of the absorber (III) and double pass (IV) as shown in Fig. 2. Numerical simulations point out that in terms of electrical and thermal outputs, the configurations II–IV are similar and outperform the configuration I. Configuration III consumes the least fan power and second lowest is configuration IV.

Agrawal et al. [10] compared the various type PV/T air collectors including glazed, unglazed hybrid PV/T tiles, and conventional hybrid PV/T air collectors. The simulation results revealed that unglazed hybrid PV/T tiles air collector was superior by 27% and 29.3% to the glazed hybrid PV/T tiles air collector and by 61% and 59.8% to the conventional hybrid PV/T air collector with respect to overall annual thermal energy and exergy gain. Annual exergy gain was also upward by 9.6% and 5.38% on the account of unglazed and glazed hybrid PV/T tiles air collectors, respectively in comparison to the conventional PV/T air collector. Dubey et al. [11] both theoretically and experimentally investigated the performance characteristics of various configurations