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Effect of tilt angle and connection mode of PVT modules on the energy efficiency of a hot water system for high-rise residential buildings

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ABSTRACT

The tilt angle and connection mode of PVT modules are critical factors influencing the energy efficiency of PVT systems. To evaluate their effect, we built a PVT hot water system which is naturally driven by gravity and the PVT modules are installed on vertical facades of high-rise residential buildings. We develop a dynamic model for the simulation of the PVT hot water system. The simulation results are in good agreement with indoor experimental data. Compared with parallel connection, electric power for series connection decreases by 2.0%, thermal energy increases by 11.4% and total energy increases by 5.4%. The connection mode has more obvious influences on thermal energy than electrical power. Considering only total energy, PVT modules with a tilt angle of 20° can produce maximum energy benefits. However, the projection lengths of PVT modules should also be considered when selecting the optimum tilt angle. The optimum tilt angle is chosen as 40° when both total energy and projection length are considered. These findings are good references for the installation of PVT modules on vertical facades of high-rise residential buildings.

1. Introduction

The growing concern on the energy conservation has heightened the need for the increasing use of solar energy in the building sector. Of particular interest and complexity is the photovoltaic thermal (PVT) system which has the potential to become a dominant source of solar energy for buildings. A great deal of research has proven that PVT systems are appropriate and efficient to provide electricity, warm air and/or hot water for various buildings' requirements [1–7]. The PVT hot water system is particularly suitable for hot or warm climatic zones, since the use of solar energy to produce hot water has a wider application than to generate warm air for space heating [5–7].

The installation of PVT modules has become a key issue, as they can significantly influence the energy efficiency of a PVT hot water system. The roof is the first choice of the installation of PVT modules because the optimum tilt angle can be easily achieved. Hence, PVT modules have been used as the rooftop of a building to generate higher electrical energy per unit area and to produce necessary thermal energy required for hot water generation [8–12]. Although the roof is the most desirable option, the limited roof area for the installation of PVT modules could be a great barrier to the application of PVT systems in high-rise buildings. If PVT modules can be used on vertical facades of such high-rise buildings, the problem of limited roof access can be solved. Thus, the vertical facades are the alternative choices for applying PVT modules in high-rise buildings [13–15]. As the integration of PVT modules with vertical facades, the tilt angles of PVT modules do not only depend on the total energy benefits, but they are also restricted to the feasibility and safety of their installation. For given PVT modules, larger tilt angles result in shorter projections. Hence, for easy and safe installation, some PVT modules are installed vertically on vertical facades, although the total energy efficiency is inevitably lower than that positioned at the optimum tilt angle [13,14]. Therefore, when selecting tilt angles for PVT modules, a compromise must be made between the projection length and energy efficiency of PVT modules.

For most of the PVT hot water systems reported, PVT modules are connected in parallel [11,13,14,16]. Few researchers have attempted to evaluate the effect of series connection on the total energy benefits of PVT modules [17,18]. Shan et al. [17] indicated that the less common series-connected PVT modules will result in lower inlet temperature of water and higher electrical efficiency.

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Shyam et al. [18] evaluated the performance of a series combination of PVT modules and indicated that for a given number of PVT modules connected in series, the outlet water temperature decreases with increasing mass flow rate and approaches a constant value after a mass flow rate of 0.04 kg/s. These articles just focus on one particular connection, either parallel connection or series connection. Further investigations need to be carried out to do the comparative analysis of parallel connection and series connection.

This paper aims to propose a PVT hot water system for a high-rise residential building, with PVT modules installed on its vertical facades. Given that this system supplies hot water for people in a typical apartment, natural circulation is chosen as the driving force for circulating water. The dynamic simulation model for the PVT hot water system is established and validated. The effect of connection mode and tilt angle of PVT modules is investigated concerning the total energy benefits of the PVT hot water system. The findings will be good references for the installation of PVT modules on vertical facades of high-rise buildings.

2. System descriptions

In this study, a PVT hot water system with natural circulation is proposed for a small, two-person flat in a high-rise residential building. As shown in Fig. 1, the proposed system mainly consists of two PVT modules and a thermal storage tank. Two types of PVT hot water systems exist according to different connection modes of PVT modules. Each system is designed for natural circulation. Given the small size of the system, natural circulation can provide sufficient impetus for circulating water. The PVT modules are installed on a south external wall of a typical residential building (Fig. 2). As shown in Fig. 3, each PVT module consists of a covering glass, PV module, silicon gel, thermal absorber, water tubes, insulation materials and metal frames. Ten water tubes are attached evenly along the length of the thermal absorber and placed in parallel. The thermal storage tank is placed in the bathroom. The barycentre of the thermal storage tank is higher than that of PVT modules. In addition, a auxiliary electric heater is provided in the water storage tank for heating water during cloudy and rainy days.

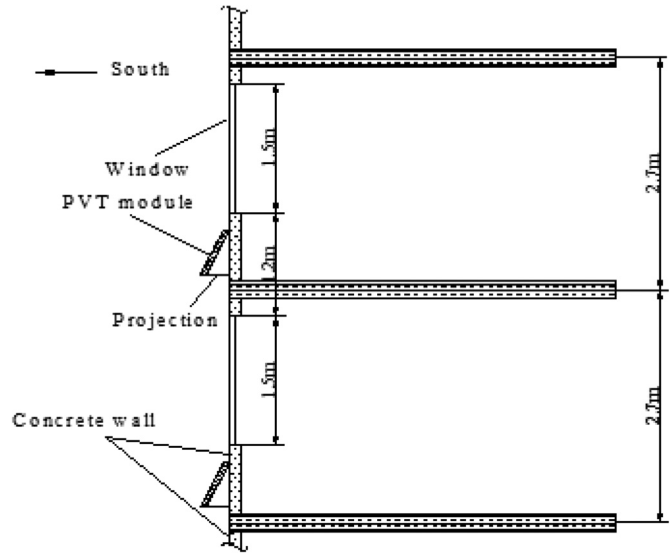

Fig. 2. Arrangement of PVT modules on a vertical facade.

3. Mathematical models

In this paper, a dynamic mathematical model for the PVT hot water system with natural circulation is developed. This model is composed of four parts, namely, PVT model, connecting pipe model, water tank model and flow rate model. The heat transfer

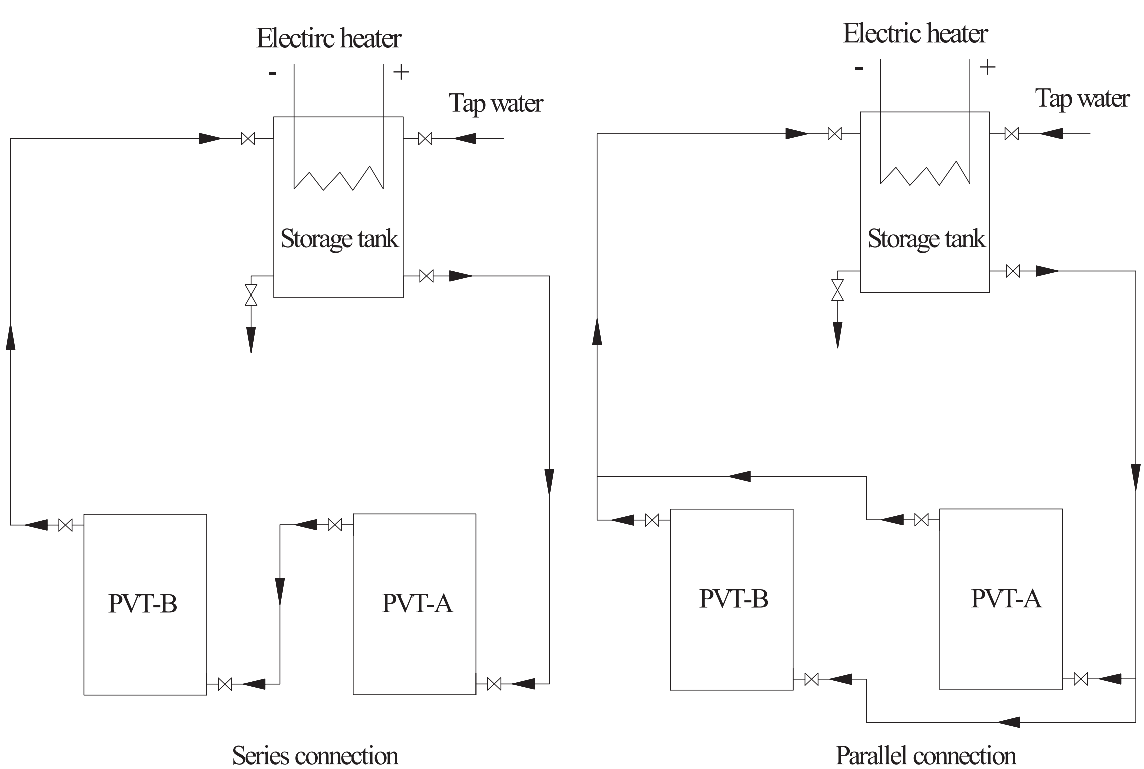

Fig. 1. Schematic diagram of two PVT hot water systems.