A novel merging Tubular Daylight Device with Solar Water Heater – Experimental study

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Abstract

Tubular Daylight device (TDD) and solar water heater (SWH) are two power saving solutions that are commonly employed individually in residential and industrial premises. This paper proposed a novel merged power saving system consisting of TDD and SWH in one model, which is the first attempt to integrate these two systems. The idea of merging the TDD with SWH is based on utilizing the existing area around the TDD to implement the SWH around the TDD tube through a serpentine collector. The main purpose for such integration is to enhance solar energy saving, space area saving, and to decrease the fabrication cost. The illumination and thermal performance of the new proposed model were tested and analysed experimentally in different seasons in Cairo - Egypt to assess its performance in practical use. The obtained results indicated that the merged system succeeded in transferring an acceptable illumination rate and increasing the water temperature. The transferred internal illuminance has reached approximately to 6.5 W/m² that fulfills the required needs of lighting. Additionally, the system increased the water temperature up to 62 °C, with a performance instantaneous efficiency that reached 21.17% which is very satisfactory. Furthermore, the performance of thermosyphon SWH with different serpentine collector coil number of turns has been evaluated. The results proved that, the collector number of turns has significantly affected the SWH performance in a directly proportional relation.

1. Introduction

The current situation involves an enormous increase in the demand for energy due to the expansion of industrial investment; the greater reliance on technology; and the rapid increase of population and economic performance. This high demand has led to a progressive decrease in conventional fossil fuel sources such as oil, coal, and gas. In addition, the reserves are not expected to meet future consumption usage. Also such increase in energy consumption would inevitably lead to increasing the CO₂ emissions, which are estimated to reach 35.6 billion metric tons in 2020 [1]. Consequently renewable energy (RE) and power saving have recently drawn more attention. As heat energy represents about 50% of the total consumed energy, the future of renewable energy used for water heating is promising and is increasingly growing.

As shown in Fig. 1, water heating consumes 4.3% of the global total energy consumed. The lighting energy also contributes with 2.1% of the global total energy consumed [2]. RE has recently become a low-cost competitive source in developing countries like Egypt following the recently applied energy subsidy cuts. Consequently, the aforementioned reasons and the environmental issues are directing efforts to search for alternatives in RE.

Many studies have focused on applications offering power saving solutions; such as daylighting devices and SWH. Daylighting devices are used as an alternative to conventional electric lamps. Such devices capture external sunlight and transfer it through a...
Solar water heater installed capacity worldwide has increased in the past few years from 124 GWth in 2006 to exceed 456 GWth in 2016, as shown in Fig. 2[4]. Currently, the SWH has a small payback period that will lead to increasing the installed capacities in the developing countries in the next years [5].

It was recently observed that people prefer using the TDD [6] and SWH systems to save more power. However, such individual systems occupy two separate spaces and require two separate fabrication costs. This encourages us for proposing a novel merged power saving system integrating TDD and SWH in one model. The idea of merging the TDD with SWH is based on utilizing the existing area around the TDD to implement the SWH around the TDD through a serpentine collector. The introduced SWH tubular design resembles the FPC in components but with different arrangement. The illumination and thermal performance of the new proposed model were tested and analysed experimentally in different seasons in Cairo - Egypt to assess its performance in practical use. Furthermore, the performance of thermosyphon SWH with different serpentine collector coil number of turns has been evaluated.

### 2. Daylighting devices technologies

Tubular Daylight Devices (TDDs) and Anidolic Daylighting Systems (ADSs) are two types of daylighting devices that are used to transfer sunlight (diffuse and direct light) into indoors and poor daylighting areas that always suffer from limited direct contact with outdoor environment and natural light through normal windows, such as underground spaces, deep-plan offices, and double loaded corridors. TDDs and ADSs capture sunlight from the top or the side of a building, and transfer through optical reflecting tubes to the diffuser unit or output aperture in a building’s interior spaces.

The installation and usage of daylighting devices in industrial, commercial and residential buildings are especially increasing due to their contribution to electric power saving consumed in lighting and also in air conditioning by means of decreasing heating loads. Increasing the number and size of windows in order to increase daylight in the building interiors will lead to increasing the heat loads inside the building [3]. By contrast, TDD’s dome filters the infra-red radiation from the incident sunlight and consequently prevents heating resulting from sunlight [7]. This power saving decreases environmental pollution that results from electric power consumption. It also reduces companies operation and accommodation costs as a result of decreasing the electric bill.

The energy saving of daylighting devices has been the focus of a big number of studies. Li [8] analysed the power saving resulted from using daylight inside office buildings and found that the cooling loads were also decreased due to the absence of heat dissipated from electric lighting. Along the same line, Li et al. [9] studied the performance of solar thermal shading system inside a building. The system provided alternative daylight for lighting in- teriors and also in air conditioning by means of decreasing heating loads inside the building and also in air conditioning by means of decreasing heating loads.

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As illustrated in Fig. 3, TDD is constructed of three components: dome to capture sunlight; reflecting tube to transfer sunlight; and diffuser to deliver sunlight to indoor places. ADSs capture sunlight from the side of a building, and transfer it through optical reflecting...
tubes to the output aperture in a building’s interior spaces as illustrated in Fig. 4 (see Table 1).

This part of the paper will focus on those studies exploring TDDs which in the present study will be merged with the SWH in one model. Several studies have focused on improving the TDD performance by increasing the captured light through the upper dome and decreasing the transfer losses. As a result of continuous improvements and efficiency developments, the transfer losses were reduced by using various materials. The most commonly used material in the transfer tube is aluminum sheets which transmit light with reflectance 96%. Recently, the aluminum sheets were replaced by higher reflectance sheets with a reflectance 98–99% [11]. Venturi [12] increased the performance of the TDD by adding a deflection sheet at the light inlet. The inclination angle of the sheet changes monthly according to sun position to optimize reflection of incident light. Edmonds and Moore [13] increased the performance of TDD for incident sunlight with elevation under 60° by using a light deflecting panel. Edmonds [14] introduced a movable light redirecting panel to transfer daylight to building interiors. The transferred light could be increased up to 6 times according to the panel tilting angle. Kocifaj [15] improved the performance by decreasing the transfer losses of diffuser. The resulted internal lighting improved significantly. Incident light on a surface is either reflected or absorbed by the surface. Total reflectance defines the quantity of reflected light by a reflector regardless of its direction after reflection. Reflected light is composed from specular and diffuse components. Specular reflection is the result of light incident on a smooth surface. In specular reflection, the incident light remains in a concentrated bundle after reflection [16]. Diffuse reflection happens when light rays strike a rough surface so it will reflect and scatter in many directions according to the law of reflection [16]. The required most effective tubular light design is to be of high specular reflectance.

In addition to improving the TDD performance, there are many researchers focusing on exploring more accurate ways for predicting the amount of light transferred through the TDD. Dutton and Shao [17] developed a model of ray tracing software to predict the TDD performance. It offers good prediction results over analytical and empirical methods. Zhang and Muneer [18] studied the performance of a TDD by a mathematical model. This model introduced a penetration factor that compares the internal luminance with the external incident light. Zhang et al. [19] also