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Utilizing the building envelope for power generation and conservation

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ABSTRACT

Heat loading of the building envelope is caused by strong solar radiation and incorrect material selection. As a result of the heat loading of the building envelope, the indoor air temperature is increased, resulting in high energy consumption by air conditioners to maintain a comfortable indoor thermal environment. This study explores the use of a hybrid wall integrated with heat collectors (water piping system) and solar thermal power generators, which absorbs solar radiation through water to reduce heat transmission thereby saving energy and generating power. Power generation is achieved by an OD (oscillator device) that installed between a water tank (hot side) and building interior (cold side). The device acts by temperature differences between hot air (expansion) and cold air (contraction). CFD (computational dynamic simulation) was used to assess the effects of the hybrid wall on the interior environment. The results show that exterior heat is absorbed by cool water thereby reducing the heat transmission into the building, resulting in less energy consumption by air conditioners and power generation by use of temperature differences.

1. Introduction

Heat loading of the building envelope is caused by strong solar radiation and incorrect material selection. Based on the second law of thermodynamics, heat flows from higher temperature to lower temperature. Building envelopes act as conductors and transfer the higher outdoor temperatures to the indoor, through a process called heat transmission [1]. In subtropical Taiwan, the mean annual temperature is relatively high, and the most common building envelope material is concrete, which has a low heat transfer rate and high heat capacity. In Taiwan, the annual average building envelope insulation is about 11,902 kJ/m^2·day [2] and horizontal irradiation is around 3360 $\pm$ 30 kWh/m^2 [3]. Indoor building environments are usually uncomfortable due to heat transmission through the building envelope, especially in the south and west direction, as shown on Table 1 [4]. Liao had taken infrared thermal images of Shin Kong Mitsukoshi A9 in Taipei Xinyi District, and found the building envelope temperature is greater than 40 °C after absorbing solar radiation, as shown in Fig. 1a. The temperature of the building envelope at midnight is about 35 °C, as shown in Fig. 1b [5]. This means that the building envelope absorbs solar radiation and retains the heat until midnight, requiring high energy consumption by air conditioners to cool the interior.

By using a water piping system, the exterior to interior heat transmission can be reduced, which results in interior thermal comfort and reduced energy consumption by air conditioners. The heated water in the piping system is stored in an insulated water tank and is used for domestic hot water to save energy. Gertzos developed some ideas for building envelope ICSSWH (integrated collector storage solar water heater) to heat water [6], and simulated the performance via numerical predictions [7] and 3D CFD (computational fluid dynamics) model [8], he also figured out that efficiency can be improved via increased water velocity [9]. The hybrid wall developed concept is similar with ICSSWH, but the design concept is totally different with the fins and temperature difference power generators in the hybrid wall. The fins are like shutters to lead the light into the rooms by natural lighting. The temperature difference power generator is installed between the hot water tank (hot side) and indoor space (cold side), the generator operates via two different temperatures at each side to generate electric power. The piping system and power generators are integrated with the building envelope and is called a “hybrid wall”. The purpose of the hybrid wall is to save energy and to generate power.

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Nomenclature

E	energy
R	total thermal resistance
U	heat transmission coefficient
k	thermal conductivity of the material in each layer of hybrid wall
d	wall thickness
h	thermal transfer
ra	air layer resistance

Superscript

—	before hybrid wall installation
′	after hybrid wall installation

Subscript

AC	energy consumption of air-conditioner
E	efficiency
F	energy consumption of fan
H	energy saving of heating water
P	energy generating of power generator
i	indoor
o	outdoor

electricity demand." stated by Solar system Ltd [10]. However, high costs of establishing the electric grids, maintenance, and energy decay are the big problems with this concept. Integrating a solar thermal plant with the building envelope reduces the high cost of electric grids, but also generates the electric power by buildings demand.

Generating power in buildings by solar heat can save and create energy. Solar thermal collectors absorb heat to generate power and is also used to heat water, however the reflectors and receivers require large areas for installation [11]. The highest efficiency of existing concentrated solar power system generates power by traced solar with Stirling engine to generate power via temperature difference (as Fig. 2 [12]). Therefore, solar power generator integrated with building via temperature difference is the best way to generate the power and directly consuming in the building. Some thermoelectric cells have been developed, but thermoelectric efficiency is only 5–8% [13,14]; therefore the efficiency needs to improve before being integrated with the building.

The purpose of this study is to transfer heat from the building envelope and discuss the possibility of power generation methods which are integrated with building, as shown in Fig. 3, and also discuss some techniques to reduce the required installation area to make building integration possible. The design concept of temperature difference power generation utilizes an oscillator with a magnet in an airtight capsule to divide the space into the hot side and the cold side. The oscillator

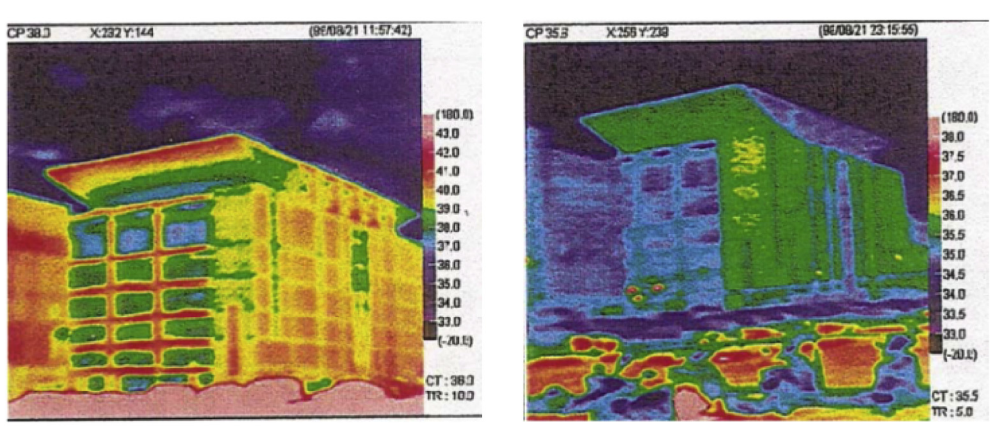
Table 1
Annual solar gained in 4 vertical facades in four cities from north to south in Taiwan.

Location direction	Annual solar gained in vertical facades in Taipei (kW/m^2·yr)	Annual solar gained in vertical facades in Taichung (kW/m^2·yr)	Annual solar gained in vertical facades in Tainan (kW/m^2·yr)	Annual solar gained in vertical facades in Hengchun (kW/m^2·yr)
North	76	92	102	112
East	546	700	732	773
South	481	676	654	668
West	546	700	732	773
Total	1649	2168	2220	2326
Total Difference	+0	+519	+581	+687

2. Design concept of hybrid wall

2.1. Thermal power generator

"A solar thermal power plant built on about 1% of the surface of the Sahara Desert would be sufficient to satisfy the entire world's will oscillate between the hot side and the cold side via air expansion and contraction due to temperature differences, as shown in Fig. 4. The operating concept is similar with Stirling engine by temperature difference, but the power generating method is totally different. Unlike the wheel running inside a Stirling engine, an OD (oscillating device), similar to a displacer



a b

Fig. 1. (**a**) Infrared thermal image of Shin Kong Mitsukoshi A9 at noon. (**b**) Infrared thermal image of Shin Kong Mitsukoshi A9 at midnight.