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Research Paper

Experimental research on a novel sun shading & solar energy collecting coupling device for inpatient building in hot summer and cold winter climate zone in China

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HIGHLIGHTS

- A novel device coupling sun shading and collecting was suggested and evaluated.
- Sun shading and collecting elements with arc type I and involute type are favorable.
- The novel device can generated demotic water and reduce air conditioning load.
- The design idea will be benefit for further more advanced systems design.

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ABSTRACT

According to characteristics of solar radiation in hot summer and cold winter climate zone in China, and hot water high demand and cooling load of air conditioning of the inpatient departments in summer, a novel equipment integrating shading and domestic water generation is proposed and analyzed by theoretical and experimental methods, which consists of four parts: Arc sun shading reflecting plates, vacuum heat collecting tubes, domestic water tank and cold water supply unit. An inpatient department located in Changsha city is selected as the experimental site. Three kinds of shading and collecting elements were tested by experiments, key design parameters, such as the cross section size of the shading reflector, the solar radiation intensity, the circulating water flow were evaluated. The results showed that: this novel equipment can absorb 2.5–2.8 times heat when compared with traditional vacuum tube solar collector; in the case study, 100% hot water demand of hospital can be met in summer, 31.7% in transitional seasons and 10.8% in winter; the annual air conditioning energy consumption can be reduced by about 2.7% and the annual electricity savings are estimated.

1. Background

With the developing of social and economic level and the increasing requirement of human living condition, more and more energy are consumed by buildings. It is estimated that the total building energy consumption will increase to 35% of total energy consumption by 2020 in China [1].

And currently, the consumption used for the heating, ventilation and air-conditioning (HVAC) system accounts for more than 55% of the total building energy consumption in China. Generally speaking, there are several measures to reduce the energy consumption of air conditioning systems, such as remodeling the envelope structure to improve the building insulation performance, using efficient air conditioning system to reduce energy consumption, utilizing more advanced energy supply systems or renewable energy and so on. Reducing the heat or cold losses through windows is an important way to realize energy saving, because the heat or cold transferred through the windows always accounts for 40% of total energy consumption. Research on windows in order to realize energy saving is attracting more and more attention, especially on windows shading, which has been the most direct and economical way to reduce HVAC energy consumption [2].

Architectural shading has been investigated widely all over the world. The researches focused on the sizes of shading components, the shading performance and the influence on the building appearance, etc. several representative works are summarized as following:

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Nomenclature

I_{dc}	direct solar radiation intensity of vertical surface (W/m^2)
I_{ds}	direct solar radiation intensity of horizontal surface (W/m^2)
I_s	diffuse solar radiation intensity (W/m^2)
I_n	the sum of solar radiation intensity of vertical diffuse and floor reflection (W/m^2)
I_0	solar radiation constant (1367 W/m^2)
P	the atmospheric transparency, taking the average annual value of 0.623 in Changsha
m	Air mass (kg)
ρ_s	the reflectivity of surroundings to solar radiation, typically equal to 0.20
h_g	the solar altitude (°)
A_1	the solar azimuth (°)
A_2	the angle of the wall and south (°)
ω	hour angle (h)
Φ	declination angle (°)
θ	the geographical latitude (°)
t	the solar time (h)
n	the sequence number of date (date number)
L	width of horizontal boards (m)
D	length of the wing (m)
H	the distance between the windowsill and the horizontal board lower surface (m)
N	the geographical latitude(°)
I_z	total solar radiation (I_z) per unit area in the typical measurement date period (9:00–16:00)
t_1	initial water temperature(°C)
t_2	final water temperature(°C)
V	heated water volume (m^3)
C_ρ	the specific heat of water 4200 J/(kg·°C)
ρ_w	the density of water (1000 kg/m^3)
A	the width of heat collection surface (A = 1.60 m)
B	the length of heat collection surface (B = 3.20 m)

Ghosh and Neogi analyzed the influences of geometrical factors, such as window to wall ratio and window positioning, on the energy consumptions of a south facing building cell in warm and humid climate. Besides that the performances are also compared between a proposed external fixed shading designs and existing commonly used external solar shading device; in which the novel design shows some advantages then other shading devices [3].

Chu et al. carried out a research on the energy saving effect of a residential building in Shanghai with different kinds of shading facilities for the external south-facing window, by which establishing the building model using the building energy consumption analysis software and calculating annual building energy consumption of this building [4].

Cheng-Li Cheng et al. provided a methodical procedure to establish summarized correlation for evaluating shading performance of horizontal shading devices based on the shading ratio and shading coefficient via the simulation of shading variables of 22–25° latitude north in Taiwan. Meanwhile, horizontal-shading device with optimal design and regulations could be chosen to carry out more suitable utilization and peak effectiveness of shading device systems, which is one of the common and available shading types for southern facings of buildings in tropical and subtropical regions [5].

Rocha et al. proposed a methodology for uncertainty assessment, which is used to predict the sunlit area on building exterior surfaces with shading devices. Energy Plus are considered as the simulation software, which adopts a Polygon clipping method to calculate the sunlit area. The results showed that latitude, orientation and width of the overhang fins have higher influences on uncertainties on solar fraction results [6].

Evola et al. investigated the effectiveness of a series of shading devices applied to an existing office building in Southern Italy. The results illustrated that suitable shading devices can obviously decrease the energy demands especially in highly-glazed office buildings. Moreover, the dynamic simulation considering the visual and thermal comfort contributes to optimize the performances of highly-glazed office buildings [7].

Choi et al. adopted a shading device control algorithm, in which a shade fraction is used in conjunction with external movable shading device so as to meet the requirements of energy saving and visual comfort. Tests are conducted to analyze the energy and environmental performances of different control model. The results help the users to choose the preferred options for controlling movable shading devices of buildings [8].

Laura Bellia et al. analyzed the influence of external solar shading devices on the energy requirements of a typical air-conditioned office building for three Italian climates. By means of a suitable building energy simulation code, Energy Plus, the solar shading devices had the highest energy efficiency for warm summer climates: for example, the global annual energy saving related to the use of suitable shading devices has been evaluated between 8% for Milan (the coldest climate) and 20% (for Palermo, the warmest one) [9].

Seung-Ho Yoo et al. studied the efficiency of the BIPV (building-integrated photovoltaic system) and the variation of electrical power generation from the PV system during 1 year, taking into account the weather conditions aesthetic, safety, and cost. The yearly average efficiency of the sunshade solar panel is 9.2% (average over 28.6 °C surface temperature), with a minimum of 3.6% (average over 27.9 °C surface temperature) in June and a maximum of 20.2% (average over 19.5 °C surface temperature) in December [10].

Ding-Chin Chou et al. developed a prototype system integrating horizontal louver shading devices with solar collectors and further analyzed the benefit of energy saving and environmental conservation. The results showed that the daily collector efficiency, instantaneous efficiency, and collector efficiency coefficient satisfied Taiwan government standards. However, the solar collector system integrated with exterior horizontal shading was suitable only for south-facing windows [11].

Dutta et al. investigated the effects of orientation and external window shading on building energy consumption and thermal performance in tropical climate, and the economic analysis are also studied. A TRNSYS building model is introduced to validate the energy savings. The maximum energy savings can be obtained in June by movable exterior window shading, and the introduction of exterior shading device is economically viable [12].

Gon Kim et al. proposed that an experimental configuration of an external shading device can be applied to apartment houses in South Korea, which showed the most efficient performance with various adjustments of slat angle and provided better views for occupants by a series of simulations, e.g. the energy analysis program, IES_VE (Virtual Environment) [13].

Lau et al. studied the potential of three different formats of shading devices on cooling load savings when they are applied at distinct façade orientations, different structures and thermal performances of façade glazing combined with shading devices also analyzed. A high-rise office building in Kuala Lumpur is considered as the object through the IES (VE) building thermal software. The analysis concluded that the utilization of shading devices can effectively decrease the cooling energy consumptions unlike the use of high performance glazing in Malaysia [14].

Jinkyun Cho et al. presented an integrated approach for exterior