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Solar energy systems installed on Chinese-style buildings

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Abstract

A building-integrated solar energy system is proposed, with the panels installed such that the overall morphology resembles that of a traditional Chinese building, i.e., roofing (eaves) at each storey, in addition to that on top of the building. The panels include photovoltaic cells and solar thermal collectors, thus producing electric power as well as heating. The particular morphology provides a number of advantages, in terms of solar energy collection and shading, and their matching to temporal and locational variations in energy demand. These are in addition to the advantages of solar energy generally. Solar heating and photovoltaic power generation were calculated for a number of locations. These were compared with the space heating and air conditioning demands, respectively. The requirement for supplementary energy was calculated. Equivalent calculations for similar buildings without solar panels allowed the saving in non-solar energy to be estimated. Calculations were made for Beijing in winter, as an example of high space heating demand, for Hong Kong in summer, as an example of high air conditioning demand, and for Shanghai, as an intermediate example. These showed potential savings of up to 15% in space heating, and up to 55% in air conditioning energy demand.

Keywords: Solar; Energy; Photovoltaic; Thermal; Building; Chinese; Traditional

1. Introduction

China is the world's second largest energy user, and growth in its energy consumption is comparable to its economic growth (9.5% per annum over recent years) [1]. Approximately 65% of primary energy is derived from coal, which results in a significant contribution to global warming [1]. Rapid growth in oil consumption, together with diminishing production from some of the more mature oilfields, have resulted in an increasing dependence on imported oil [2]. In order to meet the conflicting demands of providing energy and limiting resource depletion and environmental effects, many researchers in China are developing renewable energy sources, including solar energy, generally in conjunction with energy efficiency measures [3,4]. Developments in the energy sector generally are being applied in the building sector, which consumes 28% of total energy (operation) and 15–20% (construction) [5,6]. This includes the various forms of solar energy. China is the largest producer and user of solar water heaters [7]. Installation of photovoltaic systems remains small, but is rapidly growing [8,9].

The specific solar technology being investigated here is a building-integrated system, in which the panels are mounted on the walls and roof, such that they resemble the traditional Chinese building style—roofing (eaves) at each storey, in addition to that on top of the building [10]. This is illustrated in Fig. 1.

The five-storey block of flats shown in this example is typical of residential buildings in many Chinese cities. Solar panels could be retro-fitted to such buildings. As well as these panels, newly built buildings could incorporate additional passive solar heating features, to further improve performance.

In addition to the general advantages of building-integrated solar energy (it does not deplete limited energy resources, or emit greenhouse gases, and is available at the point of use), this building style offers further advantages:

1. The eaves provide additional surfaces for collection of solar energy. Both the top roof and the eaves can be (or can include) solar panels. These can provide heating, electricity, or a combination of both [11].
2. The energy collection is distributed throughout the height of the building, which reduces the requirement for internal transfer. This can incur considerable energy losses, particularly for circulating air in space heating systems.

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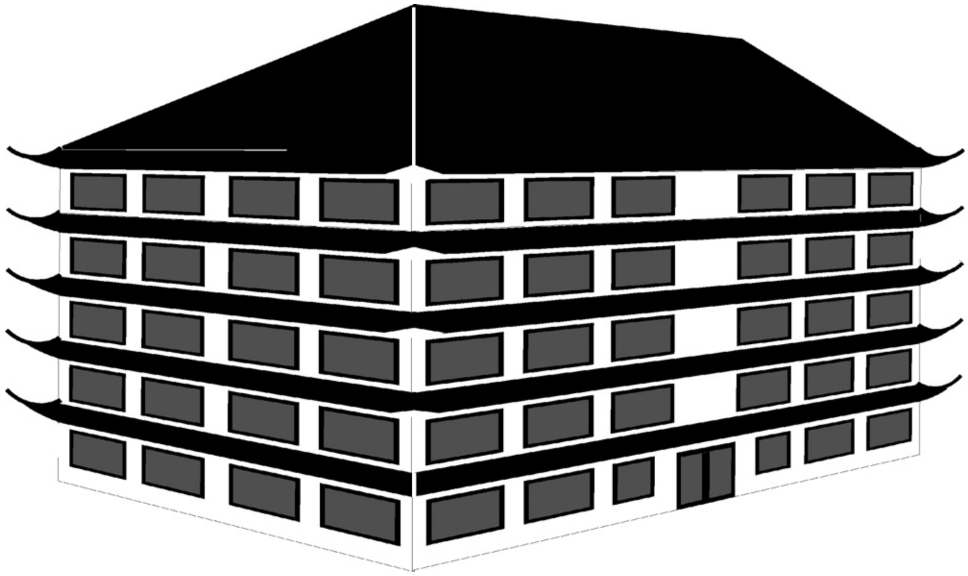

Fig. 1. Solar panels installed as roof and eaves on a five-storey block of flats. This building is typical of the residential properties in many Chinese cities.

3. The eaves will shade windows and roofing at lower levels, to a degree which varies with solar elevation, i.e., throughout the day and with season. Thus, shading is at a maximum in the middle of the day, when the temperatures tend to be higher. By suitable design, it may be possible to match solar collection to energy demand, and reduce solar gain and hence cooling requirements at the highest ambient temperatures.

As with all solar energy systems, non-solar supplementary sources of energy are required to meet demand, when solar energy alone is insufficient. The effectiveness of a particular solar energy system can be gauged in terms of the resultant reduction in the use of non-solar energy. In this work, buildings incorporating solar panels, in the configuration stated above, are compared with similar buildings without such panels. Computer-based modelling is used to estimate the energy demands for space heating and air conditioning, and the solar and non-solar contributions to energy demand are calculated for each case.

2. Modelling of energy supply and demand

Space heating is the largest component of energy demand in residential and commercial buildings. Air conditioning is also a major component of demand. In both cases, the system provides sufficient heat transfer across the building envelope to maintain a given indoor air temperature. This induced heat transfer balances the natural heat transfer, due to temperature difference, solar gain, etc. The natural heat transfer mechanisms are:

- Heat flow due to temperature difference between the indoor and outdoor air.
- Solar energy absorbed by the walls, roof, etc., and conducted to the interior. This is modelled by the solair temperature.
- Solar gain through windows.

The active systems, which must balance the above heat transfers, are:

- Solar heating panels, which provide hot air for direct space heating, or hot water for heating via radiators.
- Supplementary heating systems, based on electricity and/or fossil fuels.
- Air conditioners, possibly capable of functioning in reverse as heat pumps.
- Solar photovoltaic panels, providing electricity for the above functions, in addition to other loads.
- Supplementary electricity for air conditioners.

A number of case studies were performed for different locations in China. For all cases, the baseline model (i.e., without solar panels) was similar, so that variations due to location could be identified. This baseline was then compared with the same model, with solar panels included, in order to assess the contribution of solar energy to total demand. The model consisted of one storey of a tower block, with its longest axis running north–south, which was divided into four flats, forming the NE, SE, SW and NW quarters of the storey. Analysis of each flat separately allows the differences between south facing and north facing zones – an inevitable feature of solar energy systems in buildings – to be assessed. Combining the results for each flat allowed the potential benefits of heat transfer across the storey to be evaluated. For simplicity, it was assumed that the flats on the underlying and overlying floors were at the same temperature as those being analysed, and that vertical heat transfer could be neglected. Each flat was considered as a single thermal zone, with the interior thermal mass consisting of the cavities (air) and all the internal walls. The thermal properties of the building components are the standards for Chinese buildings, and are given in Table 1 [12].

The dimensions of these components, as used in the models, are given below, and are within the limits recommended by the Chinese building codes [13].