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Case study of green energy system design for a multi-function building in campus

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ABSTRACT

The energy system design for a multi-function building in Shanghai Jiao Tong University (SJTU) is presented in this paper. In order to meet the different demands of office, laboratories and demonstration test apartments in this building, three kinds of energy systems, namely main system, parallel system and independent system, are designed. These systems which combine HVAC technology and renewable energy application are discussed and analyzed based on calculation load of room, schedule of occupants and purpose of experiment. The features, working principal and evaluation of typical systems are also provided. One integrated solution for one "net zero energy" apartment which is on the 3rd floor of this building is also introduced in brief. Finally the performance of whole energy system was evaluated by energy-saving ratio, ratio of renewable energy and CO_2 emission reduction.

1. Introduction

An important factor in green building design is the energy system that supplies heating, cooling, electricity, etc, to the indoor space. The conventional HVAC systems have a number of drawbacks, such as consumption of non-renewable fuel, the HVAC coupling processing of temperature and humidity, the environmentally unfriendly working fluid. These drawbacks have inspired the researchers to propose new solutions to green energy system. Some new features and trends of energy system have emerged in the last decade, for example, solar energy systems for building integration, renewable energy source heat pumps, high efficiency cogeneration system, etc. These growing technologies are encouraged by governments to save fossil fuel and to keep a sustainable development for human society.

Owing to rapid population growth and limited land area, a trend towards multi-function building has appeared in modern society. Some examples of this trend are a mall that includes stores, restaurants and theatres, or a gymnasium that has a swim pool, fitness centre, and rest rooms. In such settings, an individual energy system may not have sufficient adaptability to meet the various demands of different function zones. Thus, greater requirements are necessitated in terms of feasibility, energy savings and environmental protection in the design of an energy system for a multi-function building. In this paper, the design of a whole energy system for a campus building that has offices, laboratories, demonstration apartments, etc. is introduced. The features and feasibility of the typical parts in such an energy system are discussed, and then energy-saving ratios and CO_2 emission reduction are used to evaluate the total efficiency of energy system.

2. Literature review

The typical features of energy system development in recent years are briefly reviewed:

2.1. Solar thermal-powered cooling system

The hot-water-driven lithium bromide absorption chiller was commonly used in the most of solar thermal-powered cooling system experiments (Helm, Keil, Hiebler, Mehling, & Schweigler, 2009; Li & Sumathy, 2001; Syed et al., 2005) and practical projects (Li, Bai, Ma, Wang, Li, &Jiang, 2006; Rosiek & Batlles, 2009). Another potential solar-assisted cooling system is the solar adsorption cooling system, which allow for lower driving temperatures compared to an absorption system. The use of adsorption cooling technology is preferable for a mini-type solar-powered cooling system (Balaras et al., 2007; Wang, 2001). A solar thermal-powered cooling system is appropriate for combining other solar energy utilization devices to form an integrated solar energy system that can meet the energy load of building.

2.2. Temperature and humidity independent control air-conditioning system

In some regions, the combination of high temperature and high humidity defies a remedy by conventional air-conditioning which is biased towards temperature rather than humidity. Therefore, if the latent heat and sensible heat for cooling can be treated independently by a hybrid energy system, energy-saving and comfortable

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Nomenclature

$E_{consumption}$	electricity consumption of energy system per year, kWh/a
Q_{demand}	energy demand of zone per year, kWh/a
COP	coefficient of performance
ABS	absorption chiller
HP	heat pump
DHW	domestic hot water
HVAC	heating, ventilation and air-conditioning
CCHP	combined cooling heating and power
WSHP	water source heat pump
S AC	split air-conditioning unit
OTRDC	one-rotor two-stage rotary desiccant cooling system
RHPEC	residential heat pump energy centre

indoor environment can be achieved simultaneously. An independent liquid dehumidification air-conditioning system (Chen, Li, Jiang, & Qu, 2005) and solar-powered rotary wheel desiccant dehumidification system (Dai, Wang, & Xu, 2002) have been installed together in a demonstration building. A number of hybrid energy systems for buildings that employ desiccant dehumidification technology as an important component have also been reported (Liu,Geng, Lin, & Jiang, 2004; Ma, Wang, Dai, & Zhai, 2006). It should be noted that solar energy is considered as a proper and "free" heat source for regeneration process and the performance can be improved if the periodic availability of solar energy can be overcome by some approaches, like the high energy storage capacity of desiccant or a matched energy-storage system.

2.3. Renewable energy source heat pump

Heat pumps driven by various renewable energy and waste heat sources have already been widely used in building energy systems. However, a number of factors still limit the development of solar, geothermal, water source heat pumps, such as instability, mismatch between summer load and winter load of building, and water body protection. Therefore, a number of demonstration projects have not used renewable energy source heat pumps as an independent HVAC system, but rather have employed them as one component in a whole energy system. For instance, a solar-assisted geothermal heat pump system has already been demonstrated in a greenhouse (Ozgener & Hepbasli, 2006) and a residence (Valentin, Bernard, & Gilbert, 2007). A hybrid energy system that consists of a solar collector, absorption chiller, and heat pump was built in Tianpu industry area in Beijing (Li et al., 2006). Its operation results showed that the COP of the chiller was approximately 0.8 and that the cooling efficiency of the entire system was 0.2–0.3.

2.4. Cogeneration system

A cogeneration system, which involves the simultaneous generation of electrical power and thermal energy from a single fuel source, has proven to be an interesting solution that can increase the total efficiency of a building energy production system and reduce carbon dioxide emission. Equipment based on various HVAC technologies, such as heat pumps, absorption chillers, adsorption chillers and desiccant cooling systems can be considered in conjunction with a cogeneration system to make up an integrated energy system for buildings, as mentioned in references (Fu, Zhao, Zhang, Jiang, Li, & Yang, 2009; Gao, Wu, Jin, & Yang, 2008; Kong et al., 2005; Míguez, Murillo, Porteiro, & López, 2004). However, due to technical complexity and higher cost of purchase or maintenance involved in such a system, it is not very competitive in sectors characterized by low consumption such as residential buildings, even though it may indicate an attractive direction for green building researchers.

Although a number of research projects on individual building energy systems have been reported, a number of problems have not yet been thoroughly addressed particularly with regard to the integration of energy systems. Actually green building energy system still needs more and more practical projects in order to check the actual operation performance of various technologies collocation. The case study in this paper demonstrates that it is possible to build an integrated energy system that combines various renewable energy utilization and high-efficiency HVAC technologies to meet the distinct demands of different zones in a single multi-function building.

3. Description of building

The Green Energy Laboratory (GEL), which was financially supported by Shanghai Jiao Tong University (SJTU) and the Italian Ministry for Environment, Land and Sea, will be completed in 2011. The GEL is expected to be a demonstration building for the climate of the middle and lower reaches of the Yangzi River, and the building will be especially useful for analysis and experiments on building energy systems, energy saving devices, indoor terminals, thermal comfortable environment, etc.

The building is located on the campus of SJTU and is closed to Gate No. 5 of university, as shown in Fig. 1(a). It enjoys a convenient traffic access and a superior natural environment. The main body of the building comprises three floors, with a total surface of 1500 m^2, as shown in Fig. 1(b). The first two floors will host laboratories, a meeting room, a staff room, a student room, an exhibition atrium, etc. The third floor, which is designed as a residential space, is divided into two independent apartments, in accordance with the design of typical residential structures in China. This area will be a platform for the simulation of residential living conditions and a place where tests can be performed on energy efficient facilities and building envelopes. A net zero energy apartment will also be demonstrated there. The atrium is covered by a glazed skylight that can be opened during transition seasons for free natural ventilation. The main function of the entire building is shown in Fig. 1 (c).

4. Design conditions of energy system

The simulation software DeST and EnergyPlus were employed to calculate the load of building. The 3D simulation model of the building is illustrated in Fig. 1(d). The bars in Fig. 2 show that the simulation results from the software are in good agreement. Compared to the baseline building, which has a conventional passive design in local areas, the energy demand of the actual design building is lower by appropriately 30% because of better thermal insulation. The cooling and heating peak loads of the building are 146.56 kW and 91.78 kW, respectively. Besides loads, another important factor in determining the capacity of an energy system is life custom of its occupants. As can be seen in Table 1, because the functions of the different zones in the building are not same, their energy and indoor environment requirements are different as well. Three main problems for design can be summarised and they can also be considered as design conditions.

(1) A single main HVAC system is needed to meet the peak load of the entire building. On extraordinary days, for example, during science fairs, workshops or celebrations, a comfortable indoor space is needed for the entire building, even though the full-load time is not long. On ordinary days, however, only two