Exergoeconomic-optimized design of a solar absorption-subcooled compression hybrid cooling system for use in low-rise buildings

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**ABSTRACT**
An optimized design for a solar absorption-subcooled compression hybrid cooling system used in low-rise buildings is complicated because of the overall considerations involving increases in investment costs and energy savings, which are associated with an increase in the size of the absorption subsystem. To this end, this paper's main contribution lies in its exergoeconomic-optimized design of a solar absorption-subcooled compression hybrid cooling system employed in low-rise buildings for different design cases. In this paper, not only the minimum product-cost flow rate but also the lowest relative cost difference is taken as the objective function owing to the notable changes in fuel cost flow rates. The results of the exergoeconomic optimization shows that the actual cooling capacity of the absorption subsystem should not be designed based only on the maximum collector area. Instead, the actual installed collector area should be determined by the optimal cooling capacity of the absorption subsystem. It was also found that the optimal cooling capacity of the absorption subsystem strongly depends on solar irradiance and cooling demands. In addition, optimal sizes for the absorption subsystem should be designed according to the different minimum product cost flow rates or the lowest relative cost difference, and this difference is sensitive to the local mean solar irradiance but weakly relies on the cooling demand. The paper is helpful in its cost-effective design for a solar absorption-subcooled compression hybrid cooling system used in low-rise buildings.

1. Introduction
There is no doubt that the economic development is inseparable from the advance in energy utilization [1]. Nowadays, the use of renewable energy to solve space heating and cooling has received considerable attention [2]. That can be attributed to the high price of fossil fuels and the visible risk of environmental degradation [3]. Solar absorption refrigeration is considered an appropriate solution to reduce air conditioning consumption and greenhouse gas emissions. The most common working pairs in absorption chillers are lithium bromide/water (LiBr/H\textsubscript{2}O) and water/ammonium (H\textsubscript{2}O/NH\textsubscript{3}), where the former is usually employed to meet the cooling demands of buildings and the latter is used to produce cooling under 0 °C [4].

Since solar collectors are usually installed on the roof of a building, the maximum cooling output of a solar absorption chiller is restricted by the area of the roof [5]. This means that the building’s cooling demand cannot be met entirely, especially in the case of high-rise buildings. A solar/natural gas driven absorption chiller (SNGDAC) including a solar system and auxiliary heat system is a common method to increase cooling output [6]. However, the natural gas consumption is high when the system operates in a building with high cooling demands, which results in an operational cost for the SNGDAC which is even more expensive than a vapor compression chiller [7]. Recently, a new methodology, i.e., a solar vapor compression-absorption integrated refrigeration system with parallel configuration (SVCAIRSPC) was put forward [8]. In this configuration, the total cooling load is shared by both subsystems. The chilled water flows through the evaporators of the absorption subsystem and the compression subsystem successively to output the cooling power. This method has been proved to be economical by reducing the consumption in the compressor [9], but its payback period is too high because of the poor energy savings. Subsequently, a similar configuration called solar absorption-subcooled compression hybrid cooling system (SASCHCS) was developed. The cooling output of its absorption subsystem does not directly cool the chilled water, but it subcools the refrigerant in the compression subsystem. Since the maximum cooling capacity of the absorption...
subsystem (i.e., subcooling power) in the SASCHCS is restricted by the area of the collectors, the ratio of maximum subcooling power to total cooling demand (defined as RMSPTCD) is small for configurations applied to high-rise buildings (RMSPTCD is 0.083 in Ref. [10]). In this case, with the increase in subcooling power, the growth in the generator heat load as well as the collector area caused by the drop in evaporator temperature in the absorption subsystem (Teva-a) is not significant, although the electricity savings in the compressor consumption increases. Consequently, the higher subcooling power leads to a decrease in fuel and product cost flow rate [10]. In addition, when SASCHCS is applied to low-rise buildings, the value of RMSPTCD is high because of the cooling demand in the low building. Under this condition, the growth in compressor consumption savings simultaneously. The change in the former leads to a rise in the fuel and product cost flow rate caused by the significant increase in the generator heat load as well as the collector area. However, the change in the latter benefits the decline in the fuel and product cost flow rate instead. In other words, there should be an optimal subcooling power level that leads to the minimum product cost flow rate for the SASCHCS employed in low-rise buildings. As a result, the design principle for the absorption chiller size for the SASCHCS applied to low-rise buildings is different from that applied to high-rise buildings. The latter were studied in the previous research [10], so this paper mainly aims to study the design principles for configurations applied to low-rise buildings.

Conventional thermodynamic design focus on the energy balance and the main sources of irreversibility of thermal systems [11]. Exergoeconomics combines thermodynamics and economics and is used to provide design principles that cannot be obtained from conventional energy analysis or economic evaluations: this allows the designer to make the system cost-effective [12]. The objectives of an exergoeconomic analysis are usually (a) to allocate separately the costs of each product in multiproduct systems, (b) to describe the cost formulation process of a component in the system, (c) to optimize the thermoeconomic indicators in a single component or the overall system, and (d) to evaluate the effects of malfunctions [13]. Accordingly, exergoeconomics is considered an appropriate method for designing the cooling capacity of absorption subsystems and principles of performance for SASCHCS applied to low-rise buildings.

Much exergoeconomic research on absorption refrigeration systems has been reported in previous literature. Initially, this method was applied to optimizing single-effect LiBr/H₂O absorption systems to minimize their overall operation and amortization costs [14]. Subsequently, a storage system using a phase change material technique (PCM) for a single-effect absorption chiller was designed by exergoeconomic analysis [15]. Nevertheless, the result showed that its payback period increased because of the auxiliary storage system. Exergoeconomics was also used to analyze various double-effect
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