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Research Paper

Technical feasibility study of a compact desiccant-based outdoor air system using cogenerated hot water

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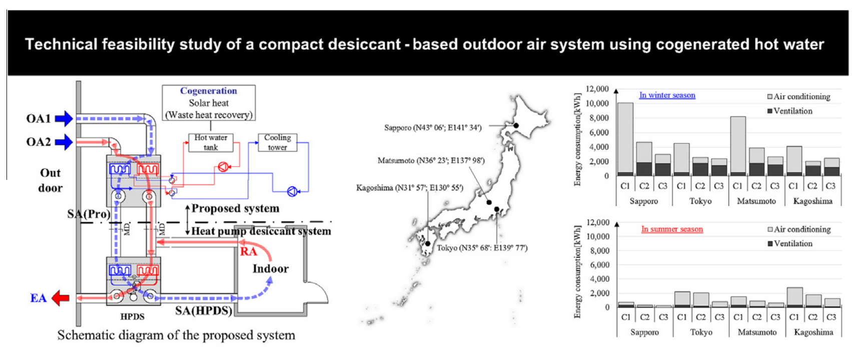
HIGHLIGHTS

- Desiccant-based outdoor air system using low-temperature energy was proposed.
- Technical feasibility study of a proposed system with HPDS and VRF was conducted.
- The energy consumption of the proposed system in an office building was evaluated.
- The proposed system with HPDS saves more energy than HPDS in cold and dry weather.

GRAPHICAL ABSTRACT



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ABSTRACT

To reduce energy consumption and control indoor humidity in buildings, a desiccant-based outdoor air (OA) system, thermally activated by comparatively low-temperature energy such as cogenerated or solar hot water, has become an interesting alternative to solve problems in electrical energy over-consumption in conventional air-conditioning systems. The purpose of this study is to develop a compact desiccant-based OA system using comparatively low-temperature energy. The proposed system can be used in single or combined systems to improve the cooling and heating humidification performance by pre-processing OA. First, this paper describes a technical feasibility study of the proposed system by computational energy simulation using regression physical models. The case studies were conducted in which various ventilation systems were compared, such as a general ventilation system, a heat pump desiccant system (HPDS), and the proposed system combined with HPDS. Each system is operated with a conventional variable refrigerant flow (VRF) air-conditioning system in office buildings in each of the four cities (Sapporo, Tokyo, Kagoshima, and Matsumoto) in Japan. We evaluate three systems with a VRF system for potential energy savings under different weather conditions (hot, cold, hot and humid, cold and dry or different). As a result, the proposed system combined with HPDS in Sapporo and Matsumoto consumed less energy compared with the HPDS under cold and dry climate, as well as in pre-processing OA.

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1. Introduction

Energy consumed using heat, ventilation, and air-conditioning (HVAC) systems accounts for approximately 43% of all energy

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consumption in the building sector according to a study by the Energy Conservation Center, Japan [1]. Innovative HVAC systems and system components have been proposed and applied to buildings to reduce energy consumption and to maintain a comfortable indoor environment. Moreover, moisture control becomes an important factor with the need to provide thermal comfort and acceptable indoor air quality and maintenance of building materials. Some moisture problems in buildings have been reported, such as surface mold, health-related problems, and damage from expansion of materials [2]. Accordingly, the building sector is obliged to reduce energy consumption while maintaining control over humidity in buildings.

In a conventional air-conditioning system, outdoor or practically recirculated air, used to balance the sensible and latent loads of an occupied space, is cooled below the dew-point temperature using a coil that interacts with an electric compression chiller to reduce the humidification ratio. Subsequently, it is heated up to the desired supply temperature using an electric heating coil or a boiler [3,4].

Desiccant-based systems represent an efficient humidity-control technology that utilize the capabilities of solid [2] and liquid desiccant materials [5] to control the moisture content in air compared with the refrigerant-based system, which is electrically operated.

The advantages of this system compared with the conventional air-conditioning systems are occupant comfort, quality improvement in building air, and moisture damage control [4,5]. Moreover, the energy savings and reduction in environmental effect are higher when the desiccant material is regenerated by renewable thermal energy sources such as industrial waste heat or cogenerated heat or solar energy [6–8]. However, this technology suffers from disadvantages such as increased initial cost, system size, and maintenance of additional equipment. The desiccant material has to be regenerated for effective reuse [6].

Most solid-desiccant systems in early research focused mainly on the wheel type. The desiccant wheel is configured as a rotating wheel with an axial counter flow of both air streams. During the regeneration process of the solid desiccant material, hot air is generally made to pass through the desiccant wheel, and the heated air is carried out using an electric heater, regenerated waste heat, or solar collector. However, the hot air is indirectly heated by an electric heater, resulting in consumption of a large amount of energy for regeneration. Moreover, the highly heated desiccant wheel for regeneration at around 70 °C decreases the dehumidification efficiency of the desiccant wheel during the air-stream process [9]. Because, the desiccant material is still too hot for effective adsorption (dehumidification) in the wheel after the regeneration, the alternative wheel designs in early research have included the purge stage to the wheel, in addition to the process and regeneration stages.

Nobrega and Brum [10] suggested that a purge section is most appropriate when low regeneration energy consumption is desired and an increase in electrical power consumption is deemed tolerable. Golubovic et al. [11] evaluated the performance of a rotary desiccant wheel based on three factors: purge, process, and regeneration. The results show that the rotary desiccant wheel with purge had an overall positive effect on the dehumidification performance.

Yadav and Yadav [12] investigated the purge sector angle for clockwise and counterclockwise rotation of a desiccant wheel. They found that moisture removal (desorption, humidification) in the counterclockwise direction is better than that in the clockwise direction, and a purge sector angle of 15° yielded better performance results. To overcome the influence of the adsorption heat, the application of direct heating and cooling method for the regeneration and removal of the adsorbed heat in the desiccant material is considered as a strategy to solve the above-mentioned problems. Therefore, a desiccant-coated heat exchanger in which a sorbent material is coated on the surface of a conventional air–water heat exchanger was proposed and investigated. Ge et al. [13] developed a mathematical model of a silica gel-coated fin-tube heat exchange cooling system. Experimental results also showed that the performance of a silica gel-coated air–water heat exchanger is better than a polymer-coated air–water heat exchanger, which showed that the desiccant-coated heat exchanger eliminated the disadvantages of the desiccant wheel-based systems. Award et al. [14] investigated a radial flow silica-gel packed bed using numerical simulation and measurement. The results showed that the dehumidification performance of the silica-gel bed improved with the decrease in the bed diameter ratio, and the adsorption capacity increased for short operation periods. The potential of the desiccant-coated air–water heat exchanger to improve the wheel-type desiccant system is promising. Fang et al. [15] developed a desiccant coating with lithium and magnesium modified ion exchange resin on a finned-tube heat exchanger. The results showed that the desiccant heat exchanger can be a good candidate for adsorption dehumidification.

Zhao et al. [16] investigated a desiccant dehumidification unit using a novel concept of solid-desiccant-coated heat exchanger by solar energy. The result shows that the system could provide stable and continuous dehumidification capacity.

Recently, Ikegami and Matsui [17] have proposed a heat pump desiccant system (HPDS) in which a desiccant material is coated on the surface of a conventional heat exchanger. HPDS has a good dehumidification performance and is more compact. Aynur et al. [18,19] evaluated the performance of the heating, humidification, and dehumidification modes in the field. HPDS could supply a higher dehumidification capacity and consumed less energy than the heat-recovery ventilation units. In addition, it showed significant energy-saving potential compared with the conventional package air conditioning. However, it had the limitations that must be overcome to enhance the cooling dehumidification and heating humidification performance potential during high temperature and high humidity and in cold and dry winter season. Moreover, several innovative approaches to use heat pump systems have been initiated, but such systems suffer from operating problems in cold climates during the heating cycle when heat pumps are not running due to clogged air filter and from any negative effects caused by loss of refrigerant.

To overcome the limitations observed in the HPDS operation, this study develops a compact desiccant-based outdoor air (OA) system using comparatively low-temperature energy such as cogenerated hot water [21]. The proposed system can be used in single or combined systems to improve the cooling dehumidification and heating humidification performance by pre-processing OA.

First, this paper describes a technical feasibility study of the proposed system by computational energy simulation using regression physical models. These models are based on physical characteristic values obtained through a regression analysis of the HPDS manufacturer data. The second one is to improve the HPDS performance using the proposed combined system. Case studies were conducted, which were then compared with various ventilation systems such as the general ventilation system (Case 1), HPDS (Case 2), and the proposed system combined with HPDS (Case 3). Each system operates using a conventional variable refrigerant flow (VRF) air-conditioning system in office buildings in each of the four cities (Sapporo, Tokyo, Kagoshima, and Matsumoto) in Japan. We evaluated three systems with a VRF system for potential energy savings under different weather conditions.

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