ENERGY SAVING POTENTIAL OF A DEDICATED OUTDOOR AIR SYSTEM WITH DESICCANT WHEEL ASSISTED BY THERMOELECTRIC MODULES

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SUMMARY

The main objective of this study is to evaluate the energy saving potential of a dedicated outdoor air system (DOAS). A desiccant wheel was used to control the humidity of outdoor air and a thermoelectric module (TEM), which is a solid heat pump, served as the heat regeneration source for the desiccant wheel and sensible cooling source for process air, respectively. The annual thermal performance and operating energy consumption of the proposed system were compared with those of a reference DOAS (comprising a desiccant wheel, boiler, and chiller) to examine the energy saving potential of the proposed system. The results show that the cooling coefficient of performance (COP) of the TEM ranged from 0.4 to 0.7 and the heating COP of the TEM ranged from 1.4 to 2.5, respectively. Consequently, it was found that the proposed system consumed 9.8% less operating energy compared to that of the reference DOAS.

Keywords: thermoelectric module (TEM), dedicated outdoor air system (DOAS), energy simulation

1 INTRODUCTION

A dedicated outdoor air system (DOAS) is a ventilation system that supplies conditioned outdoor air, which is cooled and dehumidified, to meet the ventilation demand and support all the latent loads in an energy conservation manner (Jeong et al, 2003). In many existing DOAS configuration, a solid desiccant dehumidifier is used to support the latent load of the conditioned zone, and a conventional cooling coil has been commonly considered to control the air cooling process. Desiccant wheels have been conventionally employed as solid desiccant dehumidifier to prevent condensation in the ventilation system unit.

The use of DOAS with the desiccant wheel type to reduce regeneration heat energy in dehumidifying outdoor air has been studied because regeneration heat energy takes a large position for operating the DOAS. In a previous study, a solar thermal system was employed to supplement regeneration heat energy in DOAS with desiccant wheel (Khan et al, 2017). Analysis of the primary energy consumption indicates that compared with the DOAS chiller, the DOAS integrated with a solar thermal system exhibited energy saving potential owing to reduction in the regeneration heating load. A hybrid DOAS comprising an active desiccant wheel and sensible heat exchanger has also been proposed (Liu et al, 2007). In this study, the regeneration flow rate ratio of a hybrid DOAS is analyzed and compared with that of DOAS with a chiller for various regeneration heat sources in terms of the coefficient of performance (COP) and energy consumption.

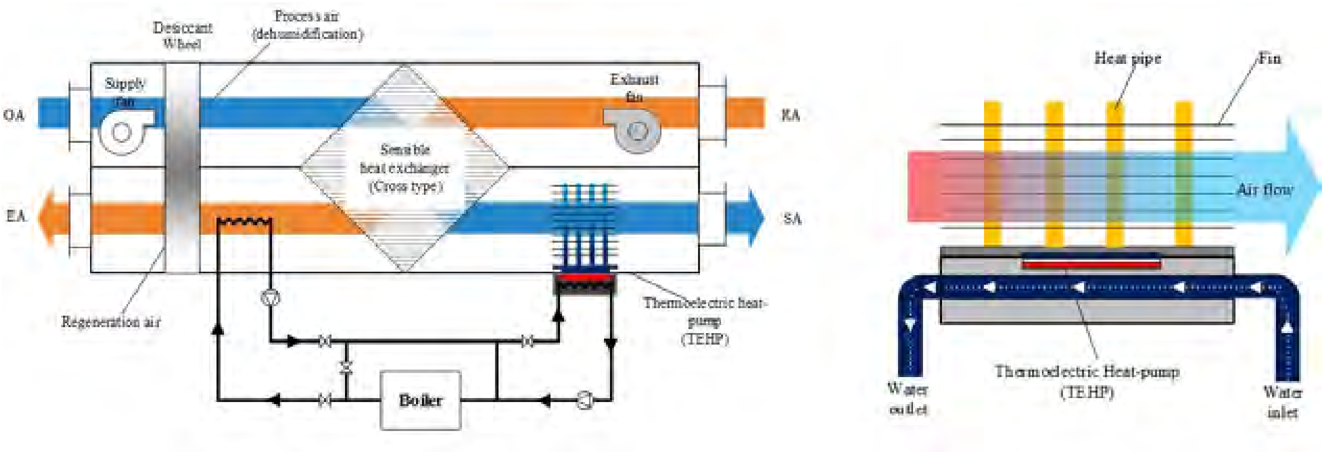
Active desiccant wheel combined with a heat pump can be employed as heat source for regeneration heat and cooling source for supply air. A high temperature heat pump was proposed with desiccant wheel, and the energy saving potential when a heat pump is used as the conventional vapor compressor, which is condensation cooling of the process air, was analyzed (Sheng et al, 2015). Since heat is recovered from the hot side of the condenser, the regeneration load decreased, and the total system energy saving decreased by approximately 51% compared to conventional vapor compression. A hybrid desiccant air source heat pump (ASHP) system was proposed, and analyzed energy saving potential of proposed system by comparing the conventional ASHP system, which was conventional vapor compression system as process air to be cooled below the dew point and reheating process (Ge et al, 2011). The study showed that the primary energy consumption can be reduced by more than 14.4% in dehumidification mode compared to the conventional ASHP.

Recently, a thermoelectric module (TEM) has been studied to implement a non-vapor compression heat pump as a solid heat pump system (Lee et al, 2015). TEM, which is integrated with HVAC systems, has several advantages compared to a vapor compression heat pump such as no moving part, no noise, and no refrigerant (Daly, 2006). In this research, TEM integrated DOAS, which is a combined active desiccant wheel, is proposed and the energy benefit of integrating TEM into DOAS with desiccant wheel was investigated using energy simulation. The energy saving potential of the proposed system was analyzed by comparing it with that of a conventional DOAS, which is a conventional vapor compressor system.

2 METHODS

2.1 System configuration

Figure 1-a shows the configuration of a dedicated outdoor air system integrated with thermoelectric modules (TEM-DOAS). The proposed system is composed of desiccant wheel (DW), heat exchanger, TEM, and boiler. The DW is used for dehumidification of outdoor air, the heat exchanger is used to reduce the cooling and heating load of TEM, while TEM controls the supply air temperature condition. The main role of the boiler is to supply heat to the regeneration air part. Figure 1-b shows the detailed configuration of TEM, which is composed of heat fin for air heat transfer and water jacket for water heat transfer. In the cooling mode, the cold side of TEM is the heat fin side for air cooling, while the hot side of TEM is the water jacket side for heat recovery. In the heating mode, the reverse of the cooling mode occurs: the hot side of TEM is the heat fin side for air heating and the cold side of TEM is the water jacket side for controlling the heating part of TEM.



a. Dedicated outdoor air system with thermoelectric modules

b. Detailed configuration of thermoelectric module

Figure 1. Schematic diagram of proposed system (TEM-DOAS)

Figure 2 shows the schematic of the thermoelectric element and Peltier effect. The thermoelectric element is composed of n-type and p-type semiconductors. As shown in figure 2, cooling and heating occur simultaneously by applying direct current (DC) to the TEM. Electrons and poles flow by electromotive force, and heating and cooling occur on each side of TEM by the Peltier effect. When the direction of the DC is changed, heating and cooling is reversed at each surface.

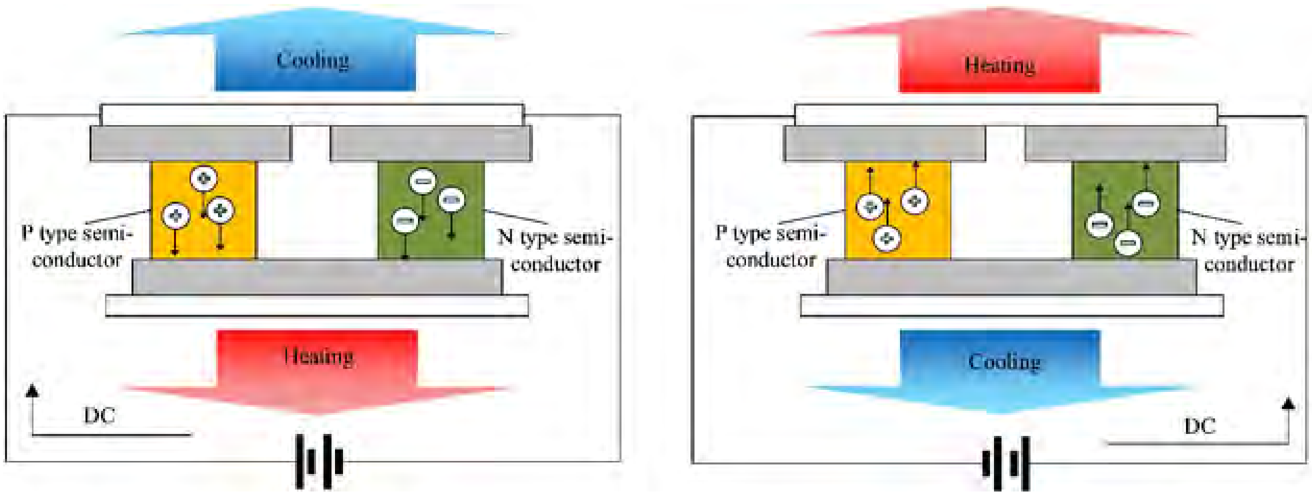


Figure 2. Schematic of thermoelectric element and Peltier effect

Figure 3 shows the configuration of the dedicated outdoor air system with DW and chiller as conventional DOAS with active desiccant wheel. Similar to the TEM-DOAS, the procedures for the operation of the DW and the heat exchanger are same. The main difference between TEM-DOAS and conventional DOAS is that the supply air is controlled using different methods: in TEM-DOAS, it is controlled using TEM (non-vapor compression system), while in conventional DOAS, it is controlled using the chiller (vapor compression system). To investigate the energy saving potential of the proposed system, its thermal performance and operating annual energy consumption were compared with those of the reference DOAS.

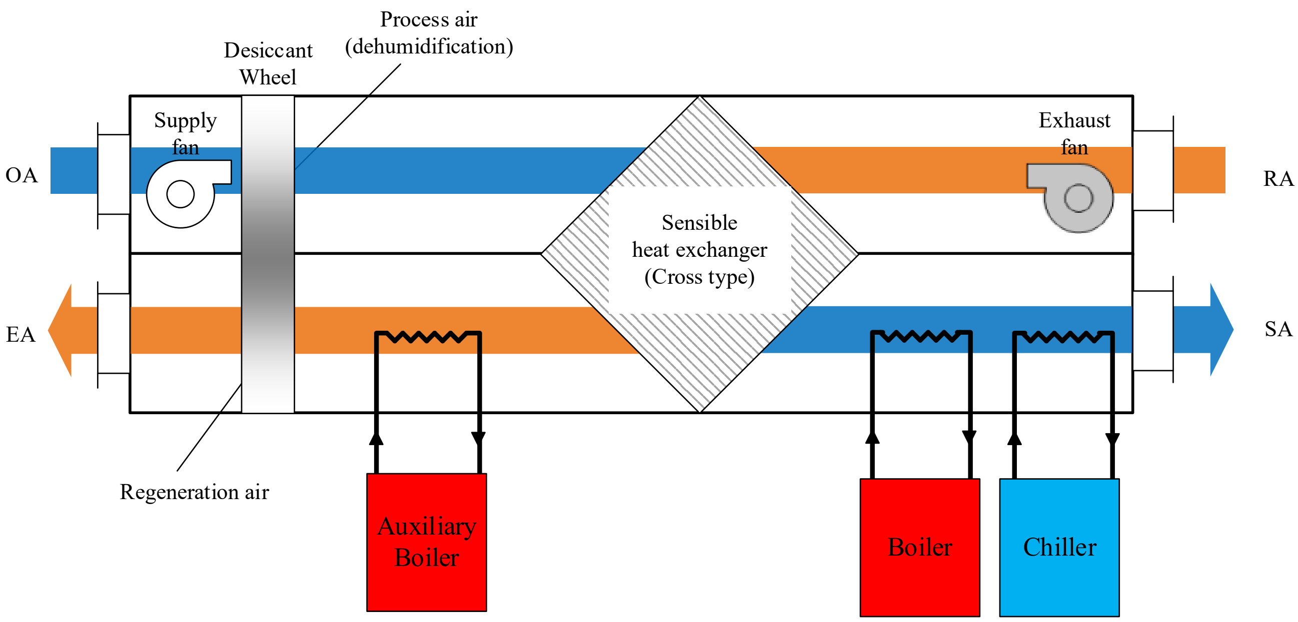


Figure 3. Dedicated outdoor air system with desiccant wheel and chiller (conventional DOAS)

2.2 Simulation models

DOAS is a ventilation system suppling minimum ventilation flow to a conditioned zone. The minimum ventilation flow is calculated using the ASHREA Standard 62.1 (Equation (1)). The conditioned zone area is 1000 m^2 and there are 20 people in the office building. The zone area factor and people factor for calculating the minimum ventilation are also obtained using the ASHREA Standard 62.1.

$$\dot{V}_{bz} = R_p \times P_z + R_A \times A_z \tag{1}$$

One objective of DOAS is to control the latent load of the conditioned zone. To meet the comfortable air condition, DW is used to dehumidify outdoor air. DW has two main streams, namely the process air stream, which is the dehumidification of humid air, and the secondary air stream, which is the regeneration process for dehumidification. The outlet air conditions (temperature and humidity) are affected by seven parameters: rotation wheel speed, process air temperature, wheel thickness, regeneration air temperature, process air humidity ratio, and air velocity. The rotation wheel speed, air channel diameter, and solid thickness of the desiccant wheel are assumed to be 20 rpm, 2.33 mm, and 0.2 mm, respectively. The outlet air conditions are predicted using numerical analysis models as given by Equations (2)–(4) (Nia et al, 2006).

$$\mathrm{T}_{pro,out} = g_1(N)g_2(\mathrm{T}_i)g_3(\mathrm{d}_t)g_4(\mathrm{T}_R)g_5(\omega_\mathrm{i})g_6(\mathrm{D}_h)g_7(U), \tag{2}$$

$$\omega_{pro,out} = \omega_{pro,in} - \varepsilon\omega_{pro,in}, \tag{3}$$

$$\varepsilon = f_1(N)f_2(\mathrm{T}_i)f_3(\mathrm{d}_t)f_4(\mathrm{T}_R)f_5(\omega_i)f_6(\mathrm{D}_h)f_7(U). \tag{4}$$

To predict the thermal property and energy consumption of TEM, a semi black-box model of TEM was used to estimate the compact thermal and electric properties of the semiconductor (Seebeck coefficient (α), electric resistance (ρ), thermal conductivity (κ)) (Lee et al, 2015). The thermal and electric properties are different depending on the material used in TEM. The lumped TEM properties are estimated using the thermal and electric properties of compact TEM as given in Equations (5)–(7) (Lim and Jeong, 2018). To calculate the thermal cooling capacity of TEM, heating, and electric power, Equations (8)–(10) are used.

$$\mathrm{S} = 2\mathrm{N}\alpha, \tag{5}$$

$$\mathrm{R} = \frac{2N^2L}{A_{TEM}f_p\rho}, \tag{6}$$

$$\mathrm{K} = \kappa\frac{A_{TEM}f_p}{l}, \tag{7}$$

$$\dot{Q}_c = \frac{Af_p}{l}\left(\frac{\alpha^2T_c^2}{\rho}\left(i - \frac{i^2}{2}\right) - \kappa\Delta\mathrm{T}\right), \text{ where } \mathrm{i} = \frac{I}{I_{max}}, \tag{8}$$

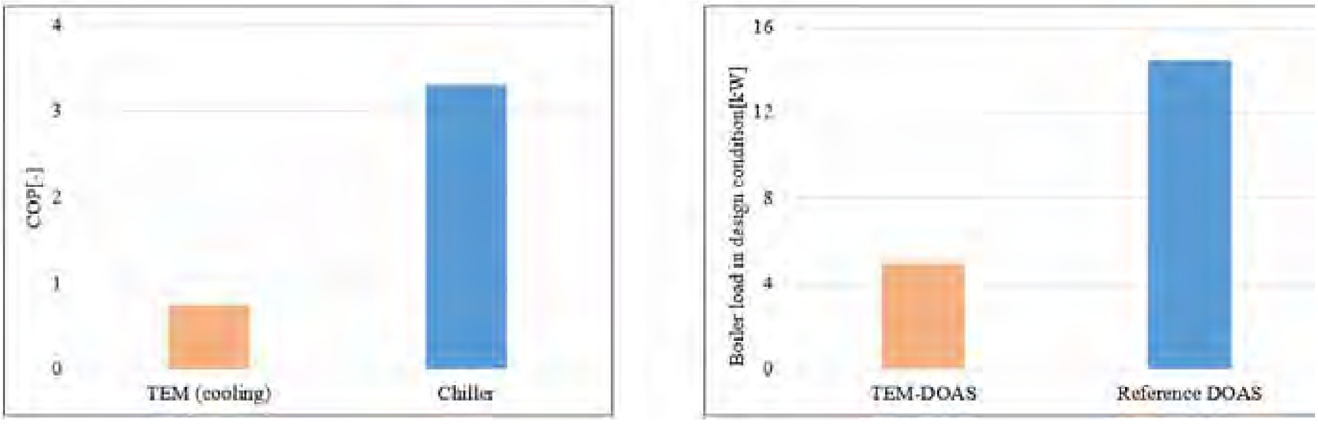
$$\mathrm{V} = \mathrm{IR} + \mathrm{S}\Delta\mathrm{T}, \tag{9}$$

$$\mathrm{P} = \mathrm{V} \times \mathrm{I} = \dot{Q}_h - \dot{Q}_c. \tag{10}$$

3 RESULTS AND DISUSSION

3.1 COP and energy consumption

Figure 4 shows the average cooling COP of TEM and the chiller, as well as the boiler load under design conditions. The COP for the cooling mode of TEM is 0.74, which is 4.46 times lower than that of the chiller. It means that the more energy consumption is occurred for handing cooling load of air to supply neutral temperature. However, heat from the hot side of TEM, which is attached using water-jacket, is recovered through circulating water. By recovering heat from the hot side of TEM, the boiler load for regeneration is reduced from 14.28 kW to 4.99 kW when operating with desiccant wheel.



a. Cooling COP of TEM and chiller *b. Boiler load in design condition*

Figure 4. Cooling COP and boiler load in design condition

Figure 5 shows the energy consumption of TEM-DOAS and reference DOAS. The electric and boiler energy consumption to convert the primary energy is 2.75 and 1.1, respectively. The results show that the TEM-DOAS consumed 9.8% less operating energy compared to the reference DOAS. Although the cooling COP of TEM is less than that of a conventional chiller system, the TEM-DOAS saved 48% of the boiler energy by heat recovery from TEM heating in the desiccant wheel operated mode because the highest energy consumption process is regeneration heating energy to dehumidify process air. The annual energy consumption of the TEM-DOAS is 56.38 MWh, which is 9.7% lower than that of the conventional DOAS.

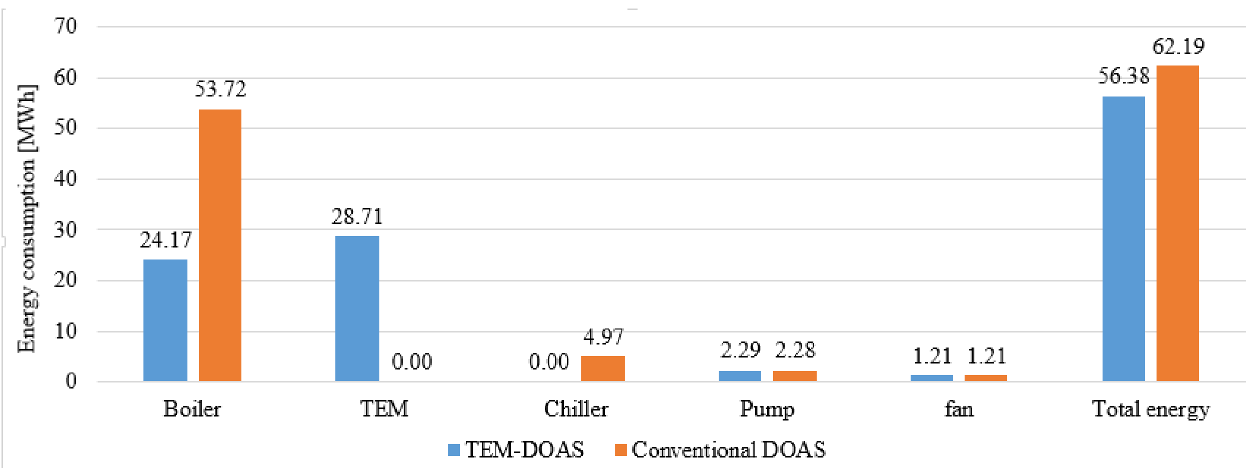


Figure 5. Annual energy consumption of TEM-DOAS and conventional DOAS

4 CONCLUSIONS

In this study, we analyzed energy consumptions and compared the latent load of a zone for a conventional DOAS and DOAS with TEM to evaluate the feasibility of using TEM in DOAS.

The energy saving effect of the proposed system was mainly achieved in the regeneration part of the desiccant wheel by reclaiming waste heat using TEM. When heat was recovered using TEM, the load of the boiler used for regeneration was reduced by approximately 34%. When TEM was used for the cooling mode in the proposed system, the cooling COP of TEM is 4.7 times lower than the COP of the chiller; however, the total system primary energy was reduced by recovering heat using TEM. When TEM was used for the heating mode without operating the boiler, the heating COP of TEM was approximately 2.53, which is 3.1 times higher than the COP of the boiler. The COP of TEM was higher than that of the boiler, which resulted in the energy saving effect of the proposed system. Therefore, the proposed system achieved primary energy savings of approximately 9.7% compared with the conventional DOAS. These results show that although TEM has a lower COP than a chiller, energy savings was achieved compared to conventional vapor-compression systems through system configuration using recovered heat from TEM.

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