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Cooling energy performance analysis depending on the economizer cycle control methods in an office building

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ABSTRACT

The current building tends to pursue high air-tightness for the reduction of the outside air supply to prevent an increase in the energy consumption of air conditioning, resulting in high dependency on mechanical ventilation and adverse effects on indoor air quality, occupant health and productivity. In this circumstance, many developed countries improved the ventilation regulation, but mere increase in the outdoor air introduction without considering the outdoor condition elevated the cooling energy. Therefore, study of the economizer cycle system that can cause fresh outside air introduction and energy saving has been actively conducted. In this study, we analyzed different economizer control methods, addressing mixed air temperature, outdoor air fraction and cooling demand according to the outdoor air temperature. Also, we analyzed the energy consumption of the three control types of the economizer cycle through detailed EnergyPlus simulation modeling under a variety of climatic conditions. As a result, differential enthalpy control method showed the greatest energy saving by around 10% under Korean climatic conditions compared to other methods. Differential dry-bulb control method showed 12.7% lower energy consumption than no economizer method in an intermediate period, but it did show 7.1% more energy usage during the summer period under a humid region. When properly considering the latent load, it was found that the resultant energy saving potential due to economizer operation is significant.

1. Introduction

1.1. Background

With the global interest in energy-saving techniques after the energy crisis in the 1970s, high air-tightness has been required for new construction and remodeling in the building field. In particular, with the development of high-rise and large office buildings in modern society, securing air-tightness have been strictly applied in terms of energy reduction. Accordingly, to prevent the load from the introduction of outdoor air, supply of fresh outdoor air was reduced; and it made the contaminated air stay in the building [1]. This led to the deterioration of the indoor air quality, resulting in the decline of the occupants' health, work efficiency, and productivity. As a result, a large economic loss could be induced, and thus it is very important to secure fresh indoor air in office buildings [1–3]. Therefore, to satisfy indoor amenity, many developed countries have modified and strengthened the regulations for ventilation. In particular, the American Society of Heating, Refrigerating, Air-conditioning Engineers (ASHRAE) increased the minimum outdoor air flow rate per person for office buildings by four times [4].

To secure amenity in office buildings, fresh outdoor air needs to be continuously supplied through an HVAC system. However, in the case of conventional large-scale office buildings, the energy consumption of a heating, cooling, and ventilation system accounts for 40–50% of the total energy consumption of the building [5].The heating and cooling energy increases further due to the increased introduction of outdoor air for improved indoor air quality and due to inappropriate operation of an HVAC system where the condition of outdoor air is not properly considered. Thus, office buildings have gradually decreased the introduction of outdoor air in recent years, and some buildings are at a more serious level. The heating and cooling energy can be saved by decreasing the introduction of outdoor air and increasing the circulation of indoor air, but this leads to the deterioration of the indoor air quality [3].

Therefore, appropriate operation of an economizer system, which is a method that can be used to resolve the aforementioned problem, is required. An economizer system is a cooling system that can save energy by strategically introducing fresh outdoor air into the building based on the comparison of the temperature/enthalpy

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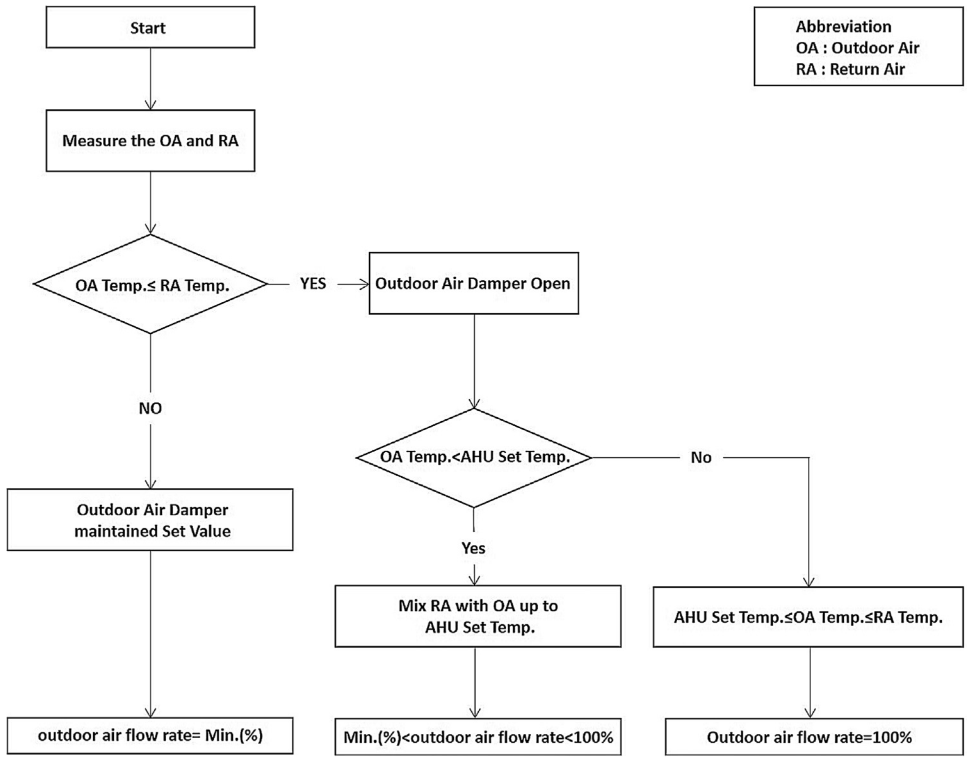

Fig. 1. Economizer control algorithm.

of the outdoor air and return air from occupied spaces. It is an outdoor air introduction control method having a large energy-saving effect where the use of a chiller is minimized and outdoor air is used for cooling in order to reduce the cooling load of the interior (i.e., cooling of a space with high indoor heat gain) [6]. In this regard, Kim et al. [7] reported that when cooling was performed by applying an economizer cycle system to a library for education and research, 27% of the cooling load was reduced during one year in the case of temperature control. Sherif and Simon performed a systematic evaluation of the performance of various mixed-mode cooling strategies such as economizer operation using EnergyPlus simulation for office buildings with different levels of internal heat gain operated in four cities representative of arid climates. The results show that free-cooling approaches including economizer to maintain indoor environmental conditions have the potential to save approximately half of the plant energy consumption compared to common active air-conditioning systems. It was concluded that free-cooling strategies should be able to provide satisfactory indoor environments and can result in highly efficient office building designs and so should be considered for application in arid climates [8]. Ham et al. developed an energy optimization process for the air-side economizer in a modular data center with respect to various parameters such as supply air conditions, server thermal characteristics, cooling system configurations, and heat exchange effectiveness. The cooling energy simulation is conducted for three types of air-side economizers by changing the supply air temperature (SAT) and heat exchanger effectiveness in order to determine optimum supply air ranges. The simulation result showed that the lowest cooling energy consumption appeared when the computer room air handler (CRAH) SAT is within 18–23 °C. In addition, at higher SAT conditions, it was found that the cooling energy consumption increased, since chiller energy reduction was offset by the increase in CRAH fan energy [9]. Lee and Chen performed a dynamic building energy simulation program to examine the potential energy savings of the air-side free cooling technology with differential enthalpy control used in data centers in 17 climate zones, based on the required operating environment conditions for data centers suggested by the ASHRAE Technical Committee TC 9.9. The results showed that significant free cooling potential was achieved in data centers located in mixed-humid, warm-marine, and mixed-marine climate zones. Although the cooling degree day (CDD) and heating degree day (HDD) are key factors of climate classification and air conditioning energy consumption, they are not entirely correlated to the specific operating environment conditions of data centers. The results of this study showed that for every 2 °C decline in the indoor temperature of a data center, the energy saving of free cooling technology may decrease by 2.8–8.5%. It was also found that the rate of decline varied in different climate zones [10]. Wang and Song investigated the energy performance of air economizers with low-limit space humidity. Since the outside air may be dry during the economizer operations, humidification is needed for special applications where stringent space humidity controls are required. Therefore, the economizer can save cooling energy but may lose space humidity control or require additional energy for humidification. This study developed optimal economizer operation zones to minimize the total cost of mechanical cooling and humidification through both simulation and experiments. The results revealed that the significant energy benefits (up to 9.3 kW/(m^3/s) or15 Btu/h-CFM) existed by using air economizers while the space low-limit space humidity was maintained. However, the energy benefits heavily depended on humidification cost and required low-limit space humidity. For the low-limit space relative humidity of 30% in a moderate weather, the energy performance of regular economizer excelled non-economizer when the cooling price was twice of the humidification price or lower [11]. Yao and Wang assessed energy saving potential of air-side economizers on conventional VAV systems using energy simulation program. The potential energy savings of two types of air-side economizers, i.e. the temperature-based economizer cycle (TEC) and the enthalpy-based one (HEC), were investigated in a represen-