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Evaluation on energy performance in a low-energy building using new energy conservation index based on monitoring measurement system with sensor network

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ABSTRACT

Improving building energy efficiency and decreasing building energy consumption through monitoring of heating, ventilation and air conditioning (HVAC) and heat recovery systems are becoming increasingly significant due to global energy crisis and carbon emission. Therefore, evaluation on building energy efficiency and energy conservation is extremely necessary. In the present work, energy conservation performance of one low-energy school building will be intensively investigated based on more than three-year measurement results from the monitoring system with sensor network. Heat recovery efficiency and new energy conservation parameter were analytically modeled, taking the building mechanical ventilation network into account. Following that, building energy performance has been experimentally investigated concerning the effects of mechanical ventilation rates, outdoor temperature and the efficiency of the heat recovery facility. Subsequent energy performance analysis demonstrates that building energy demands for ventilation and winter heating could be decreased with the enhancement of heat recovery efficiency of the ventilation facility, and the energy conservation ratio of the air conditioning unit increases with the temperature of supply fresh air. Diverse situations of energy conservation ratio and heat recovery efficiency have been detailedly correlated according to measurement results.

1. Introduction

In today's world, the global energy crisis and carbon emission have placed heavy pressures on the building energy reductions, particularly on high-energy consumption buildings [1–3]. The building sector in Germany accounts for approximately 40% of total final energy consumption [4,5] and for about one third of CO_2 emissions into the atmosphere, which can result in global warming and climate changes due to depletion of the ozone layer [6,11,12]. Furthermore, in Germany, over 70% of the building energy consumption is expended on indoor space heating [6]. Similar statistics also appear in other most countries, where around 40% of total final annual energy consumption is because of buildings [4,7].

Recently, avalanche energy consumption of public school buildings have pushed government administrators in Germany to design and build up ultra-low school buildings or plus-energy school buildings or passive school buildings. For those school buildings, high level insulations, thermal bridge free construction, energy efficient windows, low air infiltration (extremely airtight building envelopes) and mechanical heat/cooling recovery ventilation systems as well as night ventilation in summer have been simultaneously applied [6]. In addition, the air pre-heating (air conditioning) provided by the geothermal district heating and air pre-cooling (air conditioning) from the groundwater cooling system were also put into use respectively in winter and summer periods [6,8]. Moreover, it is increasingly significant to optimize HVAC and heat recovery systems in buildings in order to improve building energy efficiency and reduce building energy losses. Therefore, it is an ongoing challenge to find novel approaches

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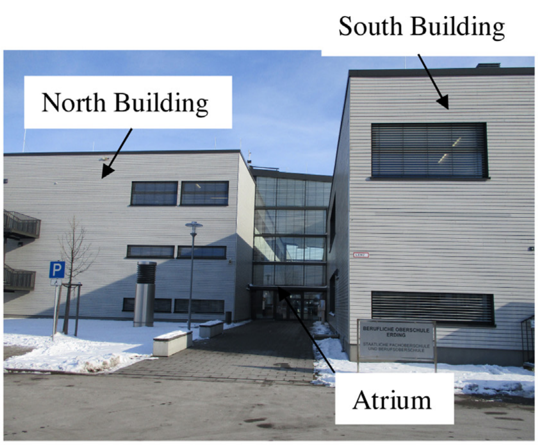
using new energy performance parameters, minimizing energy consumption in buildings without compromising thermal comfort and indoor air quality [7,9,10].

Over the last few decades, there have been many researches and experience on the building energy performance and its evaluation [6,10–30]. Bakar et al. [11] provided an overview on the Energy Efficiency Index (EEI), which is a universal index for energy efficiency practices in buildings, as an indicator used to track and measure the performance of energy consumption in a building. The EEI is important as a means to determine a specific building's energy performance in terms of energy efficiency. Their review indicated that further research work in the field of EEI is still required to develop standardized procedures towards the establishment of a universal index for buildings. Gonzalez et al. [12] presented a novel index, EEI_B, for measuring the energy efficiency of both new built and existing buildings. This index has the following significant advantages: (1) the index represents a real measurement of efficiency. (2) The index can be updated in time and use real data. (3) The index promotes energy efficiency improvements. The proposed energy index can be obtained in a simple method by integration standard measurements of energy consumption, simulation and public database. Guillermo et al. [13] proposed new indices based on building energy consumption during diverse periods; as well as other factors of the buildings including construction area, number of occupants, and air-conditioned volume. The ERF (Energy Rating Factor) index presented in this work illustrated that buildings with centralized air conditioning units had poorer energy behaviour than those buildings with split-systems. That is mainly because those centralized units require much higher energy input, do not adapt easily to variable outdoor temperatures, and occupants do not efficiently control those systems. Their research results have been presented as an application for different buildings on the campus of the Polytechnic University of Valencia. Juodis [14] investigated extracted ventilation air heat recovery efficiency as a function of a building's thermal properties. He presented that real heat recovery efficiency depends not only on single unit efficiency but also on the heat gain/loss ratio of a building. Maximal efficiency of heat recovery becomes unnecessary when the heat gain compensates the heat demand from a heat generator. The ratio of heat gain/loss becomes an important factor which affects ventilation equipment energy efficiency. Hence, expected heat recovery effectiveness of a building has to be calculated from the local climate and the heat gain/loss ratio points of view. Wang et al. [15] employed CFD numerical methodology in a creative way to investigate and evaluate building energy performance taking the building mechanical ventilation network into account, in particular cooling energy efficiency of a passive school building operated by the heat recovery air conditioning unit. Angrisani et al. [16] introduced several new contributions including the high number of operating conditions analyzed and of performance parameters used, the definition of a new COP (Coefficient of Performance) and a comparison of the DCS (Desiccant Cooling System) with other air-conditioning options. Effects on energy performance have been analyzed for varying five operating conditions: regeneration temperature, rotational velocity, ratio between flow rates of regeneration to process air, outdoor air temperature and humidity ratio. Different performance parameters according to electrical, thermal and primary energy have been investigated. Research results illustrated that thermal performance reduces when regeneration temperature or regeneration flow rate increases, on the contrary, electric and primary energy based parameters increase, thanks to the enhancement of the useful cooling effect supplied by the DCS. Moreover, optimal operation is found for a narrow range of rotational velocity (around 2–7.5 rev/h), however, outdoor air temperature and humidity ratio have a very weak impact.

In the present work, it was not just confined to the energy performance investigation for HVAC and heat recovery systems in buildings as the previous studies quoted above. A new energy conservation index has been put forward and evaluated. In the following sections, one low-energy school building operated by the heat recovery ventilation unit will be firstly introduced and analyzed. Subsequently, energy performance of this building will be experimentally investigated concerning the effects of mechanical ventilation rates, outdoor air temperature and the efficiency of the heat recovery facility. Finally, the energy conservation ratio of air conditioning unit through the heat recovery ventilation system will be correlated with functions of supply air and entraining fresh air temperatures based on measurement results, together with the comparison with numerical results.



(a) New low-energy school building in Bavaria, Germany

(b) South façade picture of school building

(c) North façade picture of school building

Fig. 1. Façade pictures of low energy building including north and south buildings and atrium (a), south (b) and north (c) sides in winter.