Analysis of Air-Conditioning Energy Consumption Depending on Optional Operation of ERV System Installed in the Apartment Houses in South Korea

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***Abstract*—Recently, air tightness and thermal insulation performance of residential buildings have enhanced. However, that causes lack of ventilation. To improve indoor air quality, ventilation is important. In fact, natural ventilation in apartment buildings enhances indoor air quality but can lead to an increase of heating and cooling loads and cold draft. Maintaining both high-quality indoor air and pleasant heat conditions involves heating and air-conditioning energy consumption. Under the circumstances, Energy Recovery Ventilation System ("ERVs") is widely used to reduce energy consumption while maintaining good indoor air quality. The interest in ERVs has been increasing, but it has been lack of the efficient operating procedures for the systems. In this regard, this research offered two operating options (temperature-controlled and PMV-controlled) of ERVs and A/C, established relevant ERVs operating algorithms, and performed optional operations. Additionally, indoor and outdoor temperatures and humidity, A/C and ERV's operating status for each time zone, power consumption, and PMV (Predicted Mean Vote) values were measured to analyze the energy reduction effect depending on each control condition. As a result of the optional operation, higher air quality and more comfort of residents were achieved and energy consumption was reduced more in both optional operations compared to natural ventilation. If ERVs operating methods are adopted in apartment buildings by considering PMV and temperature changes, it will be useful to control the indoor environment in response to outside conditions and indoor load changes.**

***Index Terms*—ERVs (Energy Recovery Ventilation System), apartment houses, optional operation, field survey, energy consumption**

I. Introduction

Since buildings in Korea consume 22-24% of the country's total energy consumption, it is necessary to establish energy reduction plans for buildings [1]. In particular, the energy consumption of residential buildings accounts for 11.6%, out of which 70% is consumed for heating and cooling [2].

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The residential buildings are built with the construction methods to improve air tightness and thermal insulation [3]. Therefore, residents tend to open windows so frequently to get some fresh air and improve indoor air quality. But that can also lead to increasing heating and cooling loads [4]. ERVs is a widely-used system, which collect the waste heat emitted from the ventilation process to minimize indoor heat loss [5], [6]. Recently, the Korean government demanded that apartment buildings and multipurpose buildings accommodating 100 households or more should meet the given number of ventilation per hour (0.7/hr.) and, where necessary, it was mandatory to install 24-hour running ventilation equipment [7]. However, it is still difficult to operate ERVs efficiently [8]. To reduce energy consumption and improve indoor air quality, it needs to offer practical ERVs operating methods to residents [9], [10].

To this end, in this research, ERVs and air-conditioner operating modes were set as temperature-controlled and PMV (Predicted Mean Vote)-controlled operations, relevant algorithms were created and actual optional operations were performed in order to establish proper ventilation measures that could offer a pleasant indoor thermal environment for residents. To verify field test results and determine the efficiency of ERVs operation, indoor and outdoor temperatures and humidity, A/C and ERV's operating status, power consumption, and PMV were measured to analyze residents' thermal comfort and energy reduction effect for each control condition. If residents use ERVs more efficiently based on the analysis results, the system can be a useful device to reduce A/C loads and to respond to outside air conditions and indoor load changes [11].

II. Methodology

This research aims to suggest ways for residents who live in apartment buildings to respond to outside air conditions and indoor load changes and to adjust an indoor environment to ensure more pleasant and energy-efficient indoor conditions.

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As a research subject, apartment building A in Daegu Metropolitan City was selected, its ERVs operating status were identified, and the optional operations (temperature-controlled and PMV-controlled) were carried out. As apartment building A was located in the proximity of the international airport, opening windows for ventilation resulted in noise, which was generated when aircraft was taking off or landing. Under the circumstances, using ERVs was more advantageous than the 'open window' method.

First, temperature-controlled ERVs algorithm was established (refer to Case 1: Temperature Control in Fig. 1). Variables were outside air temperatures, indoor temperatures, and the set indoor temperature. The set indoor temperature was in compliance with Design Standards for Apartment Building Heating and Air-conditioning System specified in "Design Standards for Energy Saving of Building Structures" established by the Ministry of Land, Transport and Maritime Affairs.

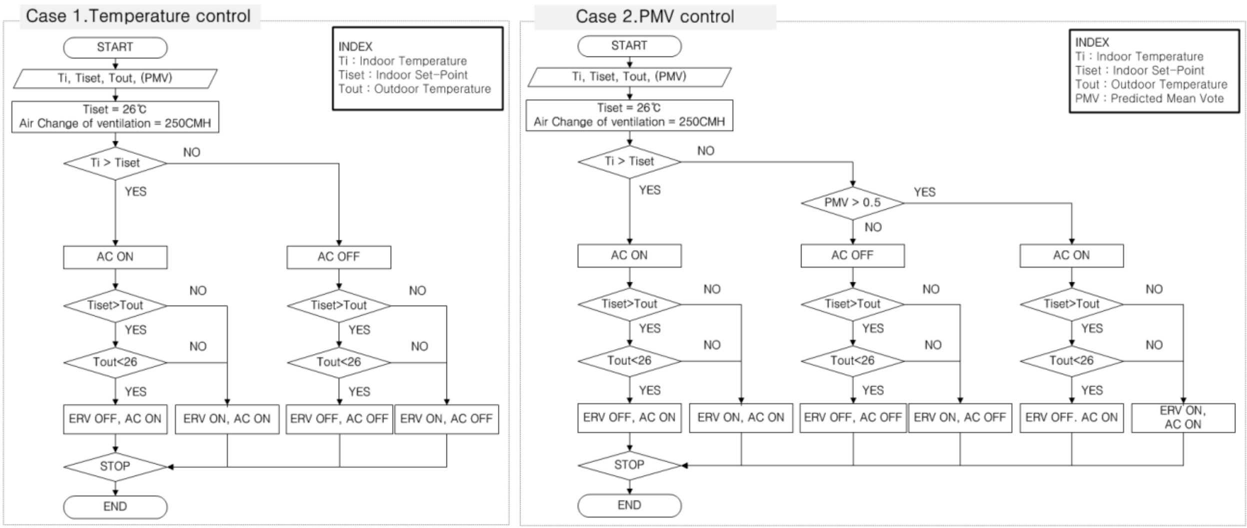

Figure 1. ERVs operating algorithm

Second, PMV-controlled ERVs algorithm was established to identify residents' comfort (refer to Case 2: PMV control in Fig. 1). Generally, PMV is an index to comprehensively assess thermal comfort considering clothing R-value, dry-bulb temperatures, mean radiant temperatures, air current, and relative humidity. Out of the entire range from -3(cold) to +3(hot), $-0.5<PMV<+0.5$ means that the inside and outside heat of human body is well balanced. Therefore, $-0.5<PMV<+0.5$ is recommended limit for thermal comfort.

The temperature-controlled and PMV-controlled algorithms used in this research are as follows.

Data measurement with the ERVs operating algorithms was performed from 8 am to 8 pm (for 12 hours), main hours of living. Energy consumption for cooling was minimized through interworking control with air-conditioner, and the number of ventilation for apartment buildings, 0.7 times/hour was met.

First, in accordance with the temperature-controlled ERVs operating algorithm (Case 1), the temperature of A/C was set to 26℃, which was the limit indoor temperature in summer, and On/Off control operation was performed at 15-minute intervals.

Next, in accordance with the PMV-controlled operating algorithm (Case 2), the temperature of A/C was set to 26 ℃ and On/Off control operation was performed at 15-minute intervals.

A/C and ERVs power consumption required for the optional operations was monitored in real time. Indoor and outdoor temperatures and humidity were measured through the temperature and humidity data logger at the indoor and outdoor ducts. PMV values were measured in real time regardless of on/off status of A/C and ERVs to analyze the level of indoor thermal comfort depending on the control conditions.

To verify the research and field experiment results and to determine the effectiveness of ERVs operation, energy consumption (MJ/hour) per household was calculated, compared and analyzed for the three operation modes: current ERVs operation (field survey), operation following the temperature-controlled ERVs operation algorithm (Case 1), and operation following the PMV-controlled ERVs operation algorithm (Case 2).

The flow of this research is shown in Fig. 2.

III. RESULTS

In summer, ERVs and A/C are frequently operated, but it is hard to determine proper operating hours and frequency for residents because their thermal comfort relies on indoor temperatures, air current, and many other factors. Therefore, this research set the operating modes of ERVs and A/C as temperatures-controlled and PMV-controlled operations, created relevant algorithms, and implemented actual optional operations in accordance with both algorithms. Fig. 3 shows indoor PMV values in both operation modes.

In the case of the temperature-controlled operation(Case 1), the indoor temperatures were set not to exceed 26 ℃, but actual indoor temperatures were frequently above 26℃. And PMV values ranged from 0.24 to 1.35 and they were concentrated between 1 and 1.35, which were out of the recommended comfort limit (-0.5 to +0.5). That indicates the residents feel slightly hot.

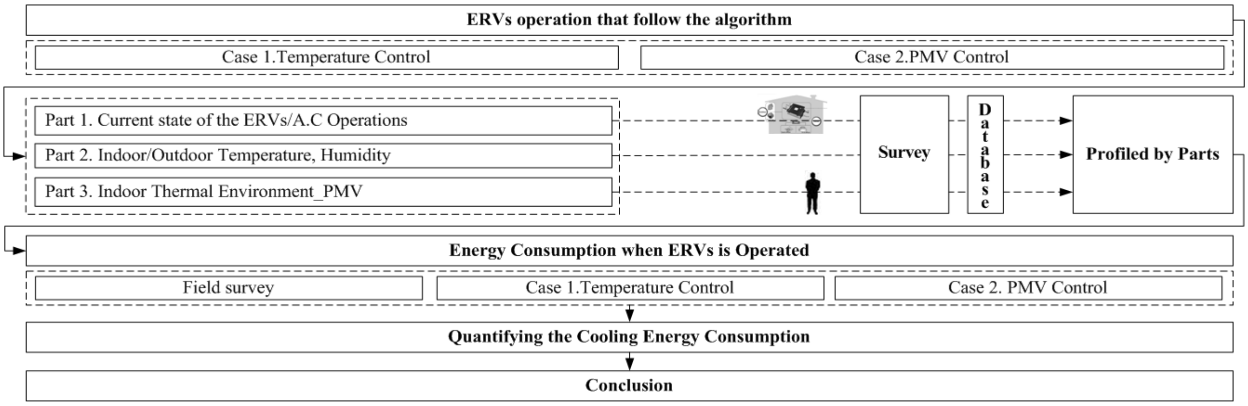

Figure 2. Flow chart

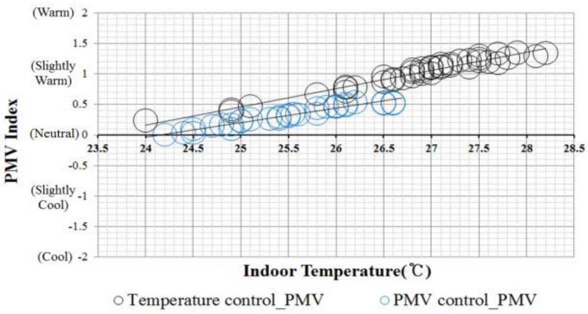

Figure 3. PMV Values according to the Thermal Environment.

As for the PMV-controlled operation (Case 2), indoor temperatures were maintained close to the limit temperature by showing 26.6℃ at the highest. PMVs were evenly distributed between 0.01 and 0.54. The quantitative results indicate residents' thermal comfort is satisfactory.

When operating ERVs and A/C to maintain a pleasant indoor environment in summer, it is important to comply with the limit indoor temperature, but more importantly, PMV values should be considered for ERVs operation to ensure thermal comfort of residents.

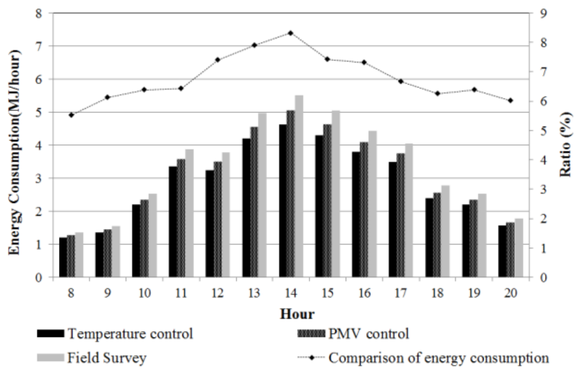

Figure 4. Energy consumption by ERVs operation case.

As shown in Fig. 4, energy consumption (MJ/hour) per household was calculated, compared and analyzed for the three operation modes: current ERVs operation (field survey), operation following the temperature-controlled ERVs operation algorithm (Case 1), and operation following the PMV-controlled ERVs operation algorithm (Case 2).

First, in the comparison of energy consumption between the current ERVs operation (field survey) and controlled ERVs operations, the latter considerably reduced energy consumption. It is considered that frequent natural ventilation and inefficient ERVs and A/C operation generate cooling loads, thereby making much energy loss.

Next, in the comparison of energy consumption between the temperature-controlled ERVs operation (Case 1) and PMV-controlled ERVs operation (Case 2), the former was analyzed to save HAVC energy by 6.2-7.9% than the latter. Thus, if a boiler, A/C, and ERVs, which are used for heating, air-conditioning, and ventilation, respectively, are controlled by PMV, approximately 7% more energy will be consumed than the temperature-controlled operation. However, it was revealed that residents felt more thermal comfort in the PMV-controlled operation.

To maximize energy saving and ensure residents' comfort by using ERVs, it is considered that determining a turning point is critical. For moderate thermal comfort and maximized energy reduction, temperature-controlled ERVs operation (Case 1) is preferred. However, to decrease excessive loss of energy due to the frequent 'open window' ventilation method and maximize residents' comfort, PMV-controlled operation (Case 2) is better than the other (Case 1).

IV. Conclusion

In this research, ERVs operation algorithms were created to minimize energy waste and build a pleasant indoor environment for an apartment building as a research subject, located in Daegu Metropolitan City, Korea. And the residents' thermal comfort and energy saving effect were analyzed by operating ERVs in different conditions.

First, in the temperature-controlled operation (Case 1), PMV values frequently exceeded the recommended limit (-0.5 to +0.5) while in the PMV-controlled operation (Case 2), they were distributed evenly within 0.01-0.54, which indicated that a comfortable indoor environment was maintained.

In terms of energy consumption, the temperature-controlled ERVs operation was analyzed to save HAVC energy by 6.2-7.9% than the PVC-controlled operation. However, to decrease excessive loss of energy due to natural ventilation and to maximize residents' comfort, PMV-controlled operation (Case 2) was revealed to be a better option than the other (Case 1).

To maintain a pleasant indoor environment of buildings in Korea, ERVs operation methods should be improved by setting appropriate control conditions based on the indoor comfort state, so that indoor air quality can be bettered and unnecessary energy consumption can be reduced.

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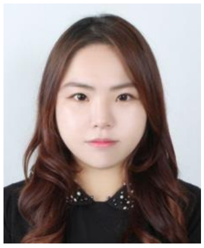

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