Indian Journal of Science and Technology, Vol 8(24), DOI: 10.17485/ijst/2015/v8i24/80037, September 2015 ISSN (Print) : 0974-6846 ISSN (Online) : 0974-5645

Optimal Operation of ERV System Installed in the Apartment Houses in South Korea

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Abstract

High air-tightness and high heat-insulation of buildings cause lack of fresh air inside the buildings. Operating the ventilation system in an apartment house may improve the indoor air quality, but may generate the problems, such as high air-conditioning load and cold draft. In order to improve the indoor air quality while maintaining pleasant heat environment to a certain level, it is necessary to consume energy for cooling and heating. Energy Recovery Ventilation system (here in after "ERVs") is the typical way to minimize the consumption of energy. To solve the problem, the installation of ERVs has been made mandatory for new apartment buildings that are constructed in the Republic of Korea. The interest in ERVs has increased recently in that the System is viewed as helping to: 1. Reduce energy costs of heating and cooling apartment buildings, which costs claim a significant portion of apartment building management budgets, and 2. Secure appropriate levels of ventilation in such buildings. Despite the enthusiasm, the lack of efficient implementation of ERVs persists. Based on the rationale, this study realized the optimal operating algorithm for ERVs. The study took actual data on temperature and humidity; operation status on air conditioners and ERVs; electricity consumptions; and PMV. The study analyzed air-conditioning ventilation loads and energy-saving effects related thereto according to the optimal operating algorithm for ERVs. The results showed statistically significant figures that contribute to the reduction of loads and energy costs. Implications of the study include: 1. Introducing the optimal ERVs to apartment buildings will likely help the residents and building managers to better respond to changes occurring to the outside environment and to the inside loads being applied to indoor HVAC systems; and 2. Implementation of ERVs would likely help reduce the loads being imposed on the HVAC systems in apartment buildings.

Keywords: Apartment Houses, Energy Consumption, ERVs (Energy Recovery Ventilation System), Field Survey, Optional Operation, Resident

1. Introduction

Energy reduction policy is essential in the buildings sector, which takes around 22% to 24% of national energy consumption. Of the energy profile, approx. 11.6% is claimed by energy consumption in the residential sector, of which 70% is accounted for by heating and air conditioning. The data indicate, therefore, just how important it is to reduce air conditioning and heating loads in obtaining technical as well as economic assessments of and alternative solutions for energy consumption in apartment buildings[1].

Also, residential buildings are constructed to be highly air-tight and highly heat-insulated. In this case, in order to supply air and improve air quality inside buildings, residents might operate the ventilation system excessively, causing increase of load for cooling and heating. One such alternative solution that offers potentials is the energy recovery ventilation system (here in after "ERVs") where in heat that is released in the ventilation process is captured and re-used to minimize the heat losses occurring from inside of the buildings. To solve this problem, the related law provides that any new or remodeled apartment house or multipurpose building

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with 100 or more households ventilates at least 0.7 times per hour and is equipped with the mechanical ventilation system operating 24 hours a day if required.

Due to lack of understanding of residents on ERVs and absence of operating manuals, however, it is hard to expect efficient operation of the system. Also, the amount of energy actually saved is much lower than you can possibly achieve from operation of ERVs. In order to maximize saving of energy and to increase comfortableness, it is required to suggest residents a realistic operation method in terms of control[2].

In this study, the researcher implemented the ERVs control algorithm to create pleasant indoor environment while minimizing waste of energy, and operated ERVs using this algorithm. To verify the results of on-site experimentation and to evaluate the efficiency offered by ERVs operations, the present researcher measured the inside and outside temperature and humidity, electricity consumptions, and PMV. The data were then subjected to the analysis of loads imposed on the HVAC system and of the energy saving effects.

This study might provide a useful method to reduce cooling load for residents if this algorithm can increase utility of ERVs.

2. Methodology

This study was designed to suggest the method that enables residents of apartment houses to control indoor environment with low energy while reacting flexibly against the change of outdoor air and indoor load. To minimize the change of indoor thermal environment and to lower the cooling load in the summer, three variables (outdoor temperature, indoor temperature and indoor temperature setting) were set for control of temperature. Then, the researcher implemented the optimum ERVs operation algorithm. The algorithm was designed to minimize consumption of cooling energy through interworking of control between ERVs and coolers, and to consider the ventilation requirement for apartment houses, which is 0.7 times/hour. Figure 1 illustrates the optimal ERVs operating algorithm that was applied for the study.

Measurement was made during 08:00~20:00 (12 hours), the main living hours. According to the optimum ERVs algorithm, A/C temperature was set to the summertime temperature limit (26°), and on/off is controlled according to the conditions at the time step of 15 minutes. Electricity consumption of A/C and ERVs was monitored in real time. Data-loggers were provided at the inlet of each indoor duct and of each outdoor duct to take data on the inside and outside temperature and humidity. PMV readings, too, were obtained on real-time bases. Result of paper, to verify the results obtained from on-site experiments and to determine the efficiency associated with ERVs operations, the actual ERVs operating profile regarding the households living in the apartment buildings was subjected to calculation of HVAC loads for two cases:

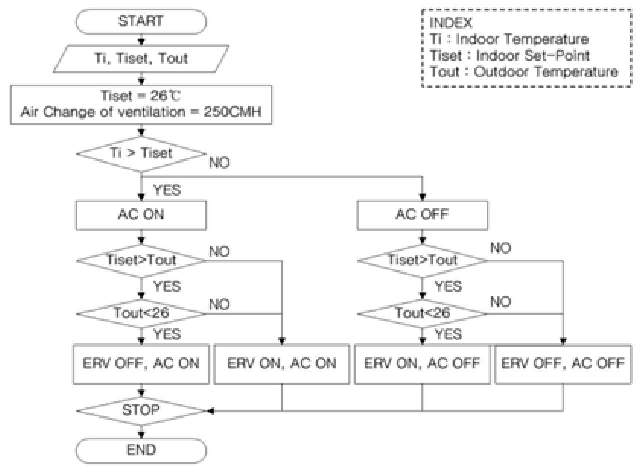

Figure 1. The optimal ERVs operating algorithm.

- Case 1 - field-surveyed current operating practices with ERVs.
- Case 2 - actual operation of ERVs as per the optimal ERVs operating algorithm.

The calculations under each case were compared for analytical purposes.

Next, the said two cases were divided further into four cases, namely:

- Case 1 - field-surveyed current operating practices with ERVs.
- Case 2 - ERVs is not operated.
- Case 3 - ERVs is operated for 24 consecutive hours.
- Case 4 - Operating ERVs per the optimal operating algorithm.

For each of the four cases, calculations were prepared about the monthly electricity consumption (kWh) during summer and about the energy cost savings (KRW) accomplished by each household. The four sets of calculations were compared with one another to determine if there was any energy saving effects relating to ERVs (Figure 2). Flow chart.

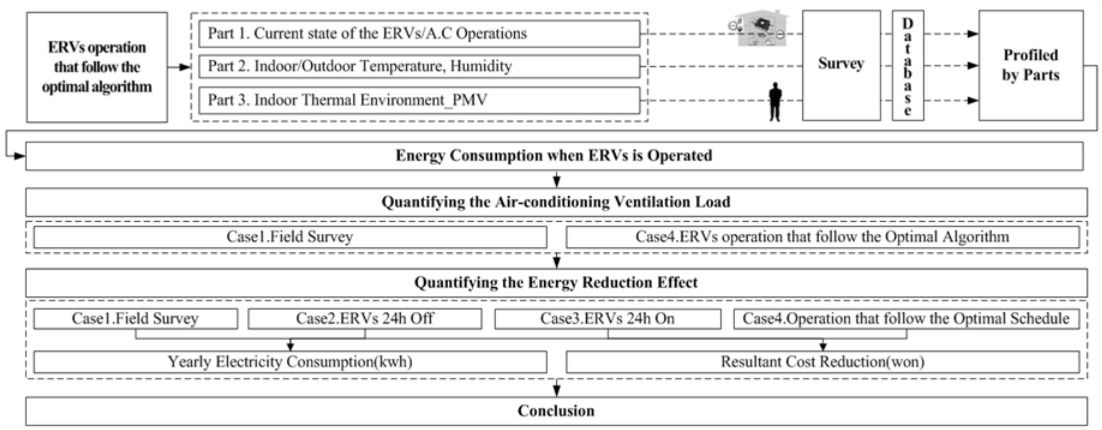

Figure 2. Flow chart.

3. Experimental Results

This study carried out tests that incorporated the optimal ERVs operating algorithm to find out how the apartment residents can efficiently implement the ERVs which was provided for:

- Securing the Republic of Korea's Enforcement Decree of the Building Act-mandated ventilation rate for apartment buildings (i.e., 0.7 ventilations per hour) for a 24 consecutive hour schedule.
- Reducing energy loads that are imposed on the buildings' HVAC systems.
- The rationale for this study's first-hand experiments was:
- Energy maintenance in apartment buildings is most directly related to the residents' energy consuming behaviors which suit their purposes.
- Only such first-hand tests can draw the most realistic implications for solutions to ensuring both the least amounts of energy consumption and the maintenance of pleasant indoor heating environment.

3.1 Overview of Experiment

The experiment on the optimum algorithm for ERVs was conducted at the apartment A in Daegu, Korea. The apartment house is ventilated with ERVs. Because the apartment house is adjacent to an international airport, it is difficult to ventilate by opening windows due to noise.

The field experiments conducted for the study concern a household that sits on the third floor of a 23-storied apartment building (here in after the "Apartment"). The Apartment comprises four bedrooms, a living room, a kitchen, a dining room, two bathrooms, a balcony, a dressing room, and a multi-purpose room. Facing south, the Apartment is not blocked by any other buildings or structures that face it. Figure 3 shows the size of the Apartment and the data-logger locations for measuring temperature and humidity data.

Table 1 and Table 3 show the details of the apartment houses and overview of ERVs.

Table 1. ERVs specification[2]

Division			A type	B type
Air flow		CMH	250	350
Electric Current		A	0.52	0.68
Electricity Consumption		W	114	150
Static pressure		mmAq	13.8	14.6
Heating Temperature Effectiveness		%	84.3	82.1
Net Enthalpy Effectiveness	Heating	%	74.5	72.5
	Cooling	%	47.5	46.3
Noise		dB	40.0	40.0
Dimension (LxDxH)		Mm	700*640*360	750*640*360
Weight		Kg	36	42
Duct Size		ø	150	200
Electrical Data	Ø, V, Hz		1 ø, 220V, 60Hz	
Heat Exchange Element Material			Pulp	

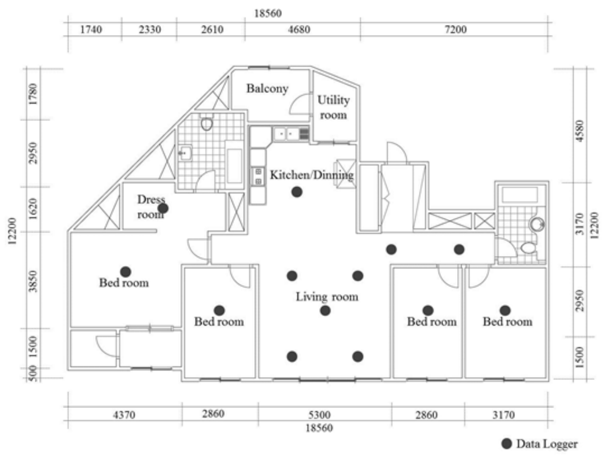

Figure 3. The size of the Apartment and the data-logger locations.

3.2 Results of Experiment Units

According to the optimal ERVs operating algorithm, Figure 4 exhibits ERVs and air conditioner schedules (on vs. off). Real time based monitoring was provided for the air conditioner and ERVs electricity consumption which is required by the said algorithm while maintaining room temperatures at 26℃.

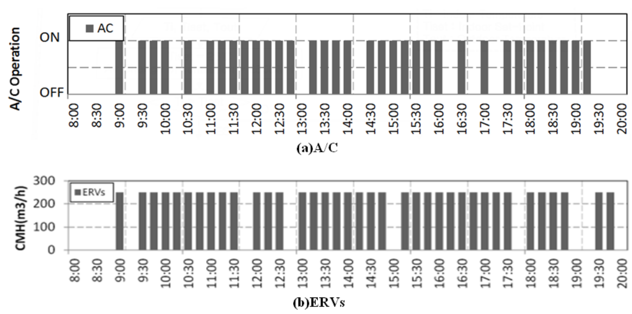

Figure 4. Operated ERVs by applying the optimum operation algorithm.

First, overall, there were many times where the inside temperature rose above 26℃, thus requiring a frequent running of air conditioning system to keep the indoor environment pleasant enough. The study's data analysis focused on time-specific operating rates of the system during summer, when ERVs operating rates are relatively higher. The analytical data showed that larger demands were made for ventilation in the morning time due to still rapid temperature rises in the morning which made it necessary to ventilate the air from hot indoor space. In the evening hours, high operating rates were observed in response to the need for changing indoor air that has turned stale. The duration of such operation was found to range between 15 and 150 consecutive minutes.

Of the 24-hour period, about 68% was accounted for by simultaneous operation of air conditioning system and ERVs. The data implies that the demands for air conditioning remained high even when ERVs was operating to maintain inside temperature.

Figure 5 summarizes the results of indoor and outdoor temperature and humidity measurements that were taken by the temperature and humidity data-logger provided at the inlet of each duct inside the Apartment.

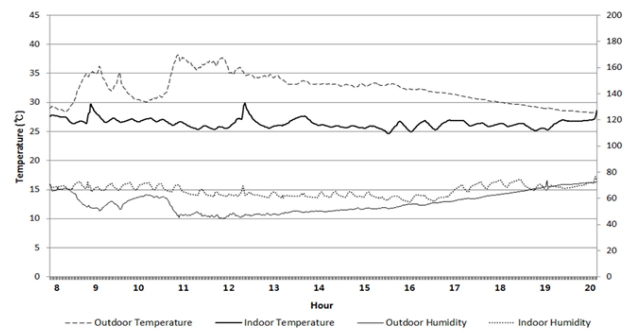

Figure 5. Variation of temperature and humidity.

The outside and inside temperature and humidity readings obtained during field survey showed ordinary distributions that are expected to be found in the Daegu area. In terms of temperature, outside temperatures ranged between 28.1 and 38.1℃, which had likely responded sensitively to solar radiation and altitude variations. Similarly, the indoor temperatures frequently rose above 26 ℃, which necessitated the use of air conditioning.

Humidity-wise, the relative outside humidity varied from 44.33% to 73.76%. Specific variations include a drop in humidity which coincided with the sunrise, followed by an increase until 10 am, after which a slight decrease took place. From the noon onward, the humidity gradually increased and persisted at or above 70% even after the sunset. The humidity measured from inside the Apartment was even higher. Based on the findings, it is considered that the maintenance of the required indoor humidity range would first require dehumidification when introducing outside air, followed by the introduction of outside air to the indoor space.

The indoor temperatures rose from 24.6° to 29.7°. When compared with the outdoor temperature readings, a constant level was found to have been maintained in the process of outside air coming inside the Apartment. Such consistency is considered to have resulted from the heat exchange process taking place in ERVs and from the operation of air conditioning system. Heat exchange occurring in ERVs amidst such fluctuations in outside temperature and humidity would likely contribute to energy savings for air conditioning. Contrary to summer (the season selected for the study) when small differences exist in inside and outside temperature, the winter season is expected to see higher energy saving effects from ERVs.

Table 2. The result of PMV value according to thermal environment conditions

	Max.	*Min*	*Ave.*
PMV	1.35	0.24	0.99

In order to analyze the indoor thermal environment when operating ERVs with the implemented algorithm, the researcher conducted the analysis using the PMV indexes (Table 2). The PMV result was 1.35, 0.24 and 0.99 for max., min. and mean value, respectively, which is out of the recommended pleasantness range of -0.5 ~ 0.5.

From the aspect of residents, in order to maximize saving of energy and indoor pleasantness through ERVs, it is required to set the indoor temperature conversion point of the algorithm in consideration of not only the variables based on temperature control, but also the indoor thermal environment indexes like PMV.

4. Results and Discussion

4.1 Air Conditioning Ventilation Load

Generally speaking, the hot and humid outside air in summer increases the loads on indoor air-conditioning systems when introduced inside the buildings for ventilation purposes. In order to improve the indoor air quality while maintaining pleasant heat environment to a certain level, it is necessary to consume energy for cooling and heating. ERVs (namely, Energy Recovery Ventilation System) are the typical way to minimize the consumption of energy.

For the purpose of this study, analysis was made as to whether or not ERVs can reduce the ventilation-induced large loads that are imposed on air conditioning system by implementing heat exchange processes at the time of introducing the outside air into the Apartment. To verify the results obtained from on-site experiments and to determine the efficiency associated with ERVs operations, the actual ERVs operating profile regarding the households living in the apartment buildings was subjected to calculation of HVAC loads for two cases:

- Case 1 - Field-surveyed current operating practices with ERVs.
- Case 2 - Actual operation of ERVs as per the optimal ERVs operating algorithm. The calculations under each case were compared for analytical purposes[3].

$$Q_{vi} = 1.2 * 1.01 * V * (T_s - T_i) \quad (1)$$

Q_{vi} : Air conditioning-ventilation load (kw)
V : Introducing outside air (m^3/h)
T_s : Supply air temperature (℃)
T_i : Indoor set point (℃)

Using the following formula (Formula 1), calculation was carried out for:

- Loads on air conditioning as imposed by the outside air that was introduced directly into the Apartment for ventilation purposes.
- Loads on air conditioning as demanded by the outside air that was let in via ERVs. Figure 6 summarizes the air conditioning-ventilation loads that were calculated for each Apartment using Formula 1 for Case 1 (field-surveyed current operating practices with ERVs) and for Case 4 (operating ERVs per the optimal operating algorithm). The figure also presents energy saving effects (%) based on the comparison of

Table 3. Monthly energy cost summary

		Monthly Energy Cost summary (A apartment, per 1 household)		
		Jun	*Jul*	*Aug*
Monthly Energy Cost (KRW)	Case1.Field Survey	58699.36	61455.98	88483.24
	Case2.ERVs 24h Off	59491.80	62285.64	89677.76
	Case3.ERVs 24h On	50686.89	53067.24	76405.27
	Case4. ERVs Operation that follow the optimal Algorithm	42019.43	43992.74	63339.97

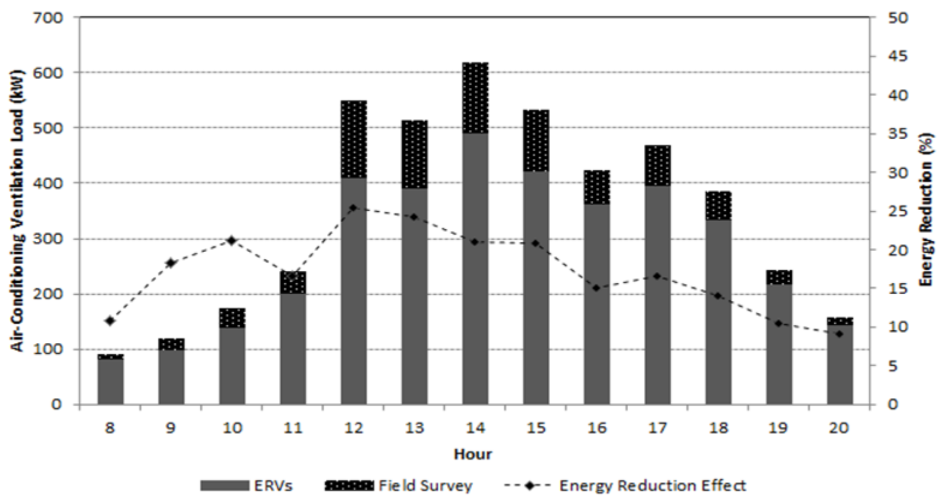

Figure 6. Air conditioning-ventilation loads and Energy saving effect.

the two cases.

First, overall patterns found in the ventilation-induced loads for air conditioning showed those similar to the indoor and outdoor temperature fluctuations. In Case 1 (field-surveyed current operating practices with ERVs), large loads were found to have occurred for air conditioning and ventilation loads. The increases in such loads are thought to have resulted from hot humid outside air introduced directly into the Apartment while no heat exchange was taking place between the high-temperature high-humidity air from outside and the air being released from inside.

Contrary to Case 1, Case 4 (operating ERVs per the optimal operating algorithm) showed large decreases in loads for air conditioning and ventilation loads. Based on the comparison between Cases 1 and 4, more energy demand for air conditioning is expected with Case 1, which demand will correspond to the increase in the air conditioning and ventilation loads. Comparison between Case 1 and Case 4.

During operation under Case 4 (optimal algorithm applied), the reduction in air conditioning and ventilation loads was on average 17.22% and was found to be maximum 25.45% in ventilation-induced air conditioning loads. According to the comparison made of the two cases in reduction of air conditioning and ventilation loads, the reduction gradually increased from around 8 am (the ERVs operation start time), subsequently reaching the highest rate around between the noon and 3 pm, during which time the greatest difference is observed between inside and outside temperature. Such results are thought to have resulted, in large part, from the fact that ERVs operating efficiency increases when the in- and outdoor temperature difference is more than 7℃. In other words, the bigger the temperature difference, the larger the ERVs operating efficiency.

Based on the above results, it is likely that significant levels of decrease in air conditioning loads can be achieved through introducing outside air during summer via ERVs as opposed to simply letting in the air via natural ventilation.

Furthermore, aggressive implementation of ERVs during winter, when indoor and outdoor humidity differences are smaller and differences in temperature are larger than summer, will likely contribute to even more effective ventilation, hence larger reduction in air conditioning and ventilation loads.

4.2 Energy Reduction Effect

To evaluate the air conditioning saving effects for the Apartment in relation to whether or not ERVs is operated and to which operating mode is implemented, calculation was performed to obtain:

- Monthly electricity consumption (in kWh) under each Case during summer.
- Energy savings (in KRW) accomplished by each Apartment.

First, the above said two cases were divided further into four cases, namely:

- Case 1 - Field-surveyed current operating practices with ERVs.

- Case 2 - ERVs is not operated.
- Case 3 - ERVs is operated for 24 consecutive hours.
- Case 4 - Operating ERVs per the optimal operating algorithm.

For each of the four cases, calculations were prepared about the monthly electricity consumption (kWh) during summer and about the energy cost savings (KRW) accomplished by each household. The four sets of calculations were compared with one another to determine if there was any energy saving effects relating to ERVs. Figure 7 summarizes the electricity consumption in each of the summer months for each experiment case.

The analytical data showed that for Case 2 (no ERVs operation), the highest level of electricity consumption was exhibited in all three of the summer months (i.e., June, July and August), whereas Case 3 (ERVs operated for 24 consecutive hours) and Case 4 (Operating ERVs per the optimal operating algorithm), in this order, were found to have contributed to the lowest levels of energy consumption during the same period. Across all cases, however, the highest level of energy consumption was observed when the summer progressed from June towards August owing to the relatively higher outside temperatures which made maintaining the required indoor temperature more energy-consuming.

That being said, around August, despite the largest level of absolute energy consumption, the increasing difference between in- and outside temperatures had contributed to the increased heat exchange efficiency, thus leading to the significant difference in energy consumption between Case 2 (no ERVs operation) and Case 4 (Operating ERVs per optimal algorithm). The larger the difference in energy consumption between the cases, the higher the ERVs operating efficiency as compared with non-ERVs based cases.

In other words, according to the data presented above, compared with Case 2 (direct introduction of outside air, without ERVs operation), the continuous operation of ERVs (Case 3) is a more desirable way from thermal environment and energy conservation points of view. Better still, compared with imprudent operation, the optimal operation of ERVs (Case 4) would more likely ensure appropriate levels of ventilation cycle and dilution of contaminants in indoor air as well as conservation of energy to avoid waste.

Energy costs and expenses are factors that directly affect the Apartment residents' saving of maintenance costs and as such they are one of the indexes for evaluating energy saving effects. Incorporating this rationale, the study calculated the electricity consumption (in KRW) for each operating case as obtained by each Apartment based on the data about the apartment buildings' monthly energy unit price (in KRW). From the angle of energy cost/expense saving, examination was made of each Apartment's energy cost saving with ERVs operation. Compared with Case 2 (no ERVs), Case 3 (around-the-clock ERVs operation) saved, on monthly average, 10,432 KRW for each Apartment. As opposed to Case 2 (no ERVs), Case 4 (optimal ERVs operation schedule) showed a saving amounting to 20,701 KRW. Appropriate ERVs operation according to the in- and out-door temperature and humidity enables that energy costs can be saved up to

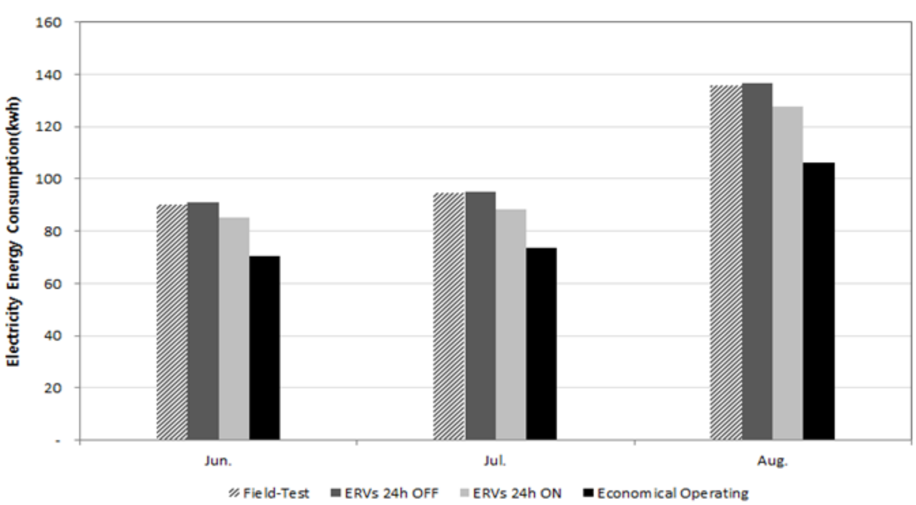

Figure 7. Electricity Consumption by ERVs Operation Case.

about two-fold for each Apartment which indicates that the role the residents play in increasing the efficiency of ERVs operation is all the more important.

Based on the findings, it is considered that the actual implementation of the ERVs scheme based on the optimal operating algorithm for real-world apartment buildings and complexes will further increase the savings in energy consumption due to the benefits that can be offered by heat exchange processes.

5. Conclusion

This study established the optimal ERVs operating algorithm which helps minimize waste in energy consumption and at the same time create pleasant indoor environment for apartment buildings in the Republic of Korea, particularly those located in the City of Daegu. The established ERVs schemes were put into operation for experiments. To verify the results of on-site experimentation and to evaluate the efficiency offered by ERVs operations, the present researcher measured the inside and outside temperature and humidity, electricity consumptions, and PMV. The data were then subjected to the analysis of loads imposed on the HVAC system and of the energy saving effects. Analysis of the data showed significant contributions were made by ERVs implemented at the optimal operating schedule in ensuring not only pleasant indoor living for the apartment residents but reduction in air conditioning and ventilation loads and subsequent increases in energy cost saving.

First, note even when ERVs was being operated per the optimal algorithm, great demands persisted for air conditioning to operate in order to maintain the required indoor temperature. For the PMV results, despite the observance with the established indoor temperature 26℃ throughout the data-taking period, the recommended pleasantness/comfort ranges -0.5 ~ +0.5 were generally exceeded by the maximum value +1.35, the minimum value +0.24, and the mean value +0.99.

Second, the implementation of the optimal operating scheduled ERVs resulted in reduction in air conditioning and ventilation loads which is equivalent to, on average, 17.22%. Such reduction was found to be possible up to 25.45% (max).

Furthermore, energy consumption was found to decrease from Case 2, Case 1, Case 3, and Case 4, with Case 1 representing the largest consumption and Case 4 the exact opposite. With the optimal ERVs scheme put into operation, about 20,000 KRW was accomplished in monthly energy saving.

The results of this study imply that the findings of the optimal ERVs operation case, when put into implementation for real-life apartment buildings and complexes, will likely lead to the avoidance of imprudent ERVs operation and to appropriate levels of ERVs which, in turn, will likely result in the maintenance of optimum ventilation cycle, improvement of indoor air quality, and avoidance of unnecessary use of energy.

In consideration of the Korean weather with four distinct seasons, even more significant energy-saving effects are expected with apartment residents and apartment buildings as well as in the building management sector, provided improvements are made to the overall ERVs operating rate and to the ERVs operating efficacy specific to each season.

6. Acknowledgement

This work was supported by the National Research Foundation (NRF) of Korea grant funded by the Korea government (MSIP) (NRF-2013R1A2A1A01014020).

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