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Load Shifting Assessment of Residential Heat Pump System in Japan

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Abstract

With the economic growth and increasing requirement of indoor thermal comfort, the load of building sector presents a greater variability.This paper aims at analyzing the energy consumption characteristics and influencing factors of the residential heat pump system. Firstly, we selected residential households as investigated objective in Kitakyushu, Japan, and compared the energy saving performances of heat supply systems between heat pump and natural gas boiler. The results were based on real measured residential load during winter period, and calculated the cost saving performance of residential heat pump system compared with traditional natural gas boiler. We also did a survey of residential occupation behavior for the 12 selected residential customers. The result indicated that there was low relationship between power consumption and occupation hours, and the number of family members had a significant impact on the power consumption. The results indicate that residential heat pump system presented promising energy saving and cost reduction potential.

Keywords

Heat pump system; Eco-cute；Economy analysis

1. Introduction

The heat pump is one of the most promising heating technologies for energy-efficient building. In recent years, heat pump was also proven to be an economical efficient option for the residential heating supply system via power to heating transform. Residential heat pump system has gradually become a hot topic in research in various researches.

Brian Drysdale pointed that residential daily load had a significant seasonal and daily variations. There was a significant energy saving or economic benefit potential to manage the flexible load through optimal demand side management, such as power to heat transforms application (Drysdale, Wu, & Jenkins, 2015). S. N. Petrović proposed optimized model to improve the performance of residential heat pump system, and his simulation results indicated that coefficient of performance(COP) presented a higher value during summer period. However, it shown a lower value in winters when heating demand was higher (Petrović & Karlsson, 2016). Jenny Love compared the heat pump and gas boiler operation, and discussed daily mean and peak power under different external temperatures. The aggregate profile shown two peak heating period at the same time as those found in homes heated by boilers, but with lower peaks and more night time operation (Love et al., 2017). Primož Poredoš did a thermo-economic analysis based on the field-test results for a residential air-to-water heat pump. The results revealed that the considered air-to-water heat pump represents the most thermo-economically efficient system in terms of the aver final costs for heat production (Poredoš, Kitanovski & Poredoš, 2017). Viorel Popa implemented an air to water heat pump in Galati city to calculated medium value of the coefficient of performance of the heat pump system. Comparing with other heating system, heat pump system has low operating and maintenance costs and shows promosing environmental performance (Popa, Ion & Popa, 2016).

Research on residential heat pump systems is analyzed based on the energy market in Japan. This research is composed as follow. Section 1 based on the measured data, we analyze the economic benefits of residential heat pump systems, according to the factors such as temperature, coefficient of performance and the distribution of residential electricity consumption. Section 2 introduces the objective and data resource. Section 3 presents the method. Section 4 does a detail analysis that consider the energy saving and economic performance, and the occupation impact. In the last section, the conclusion is provided.

2. Objective and data resource

According to the data book from Kyuden Electrical Company (Kyuden Electrical Company, n.d.), it can be seen that the Kyushu area is presenting a full electrification trend. All electrified housing number in Kyushu area has increased twice from 2008 to 2017. According to (Zhang, Qin, & Wang, 2015), numerous heat pump water heaters have been developed for the residential sector, alongside the promotion of all-electrification households over recent years. Energy for hot water accounts for about 30% of total residential energy consumption in Japan. As evidenced in many empirical studies, the energy consumption of each household was statistically investigated for different outdoor temperatures, family composition, house time and economic conditions. In addition, load flexibility is closely related to the load consumption patterns of different customers. As shown in Figure. 1, this research selected 12 households located in Higashida District, northern part of Kyushu Island, Japan. Analyzing their residential electricity usage during weekly period in winter in 2017. This section analyzed the time series power consumption by each appliance at 1-hour interval, compares the residential energy consumption after the application of heat pump system,

Figure. 2 presents the detail structure of residential heat pump system. Customers can use electricity from power grid, evaporator absorbs the heat form air, and transfer it to the thermal storage system. And the stored energy in the tank will be used later in the residential house. We also did a survey of family members' basic information for the 12 selected customers, the survey can be seen in Table 1.

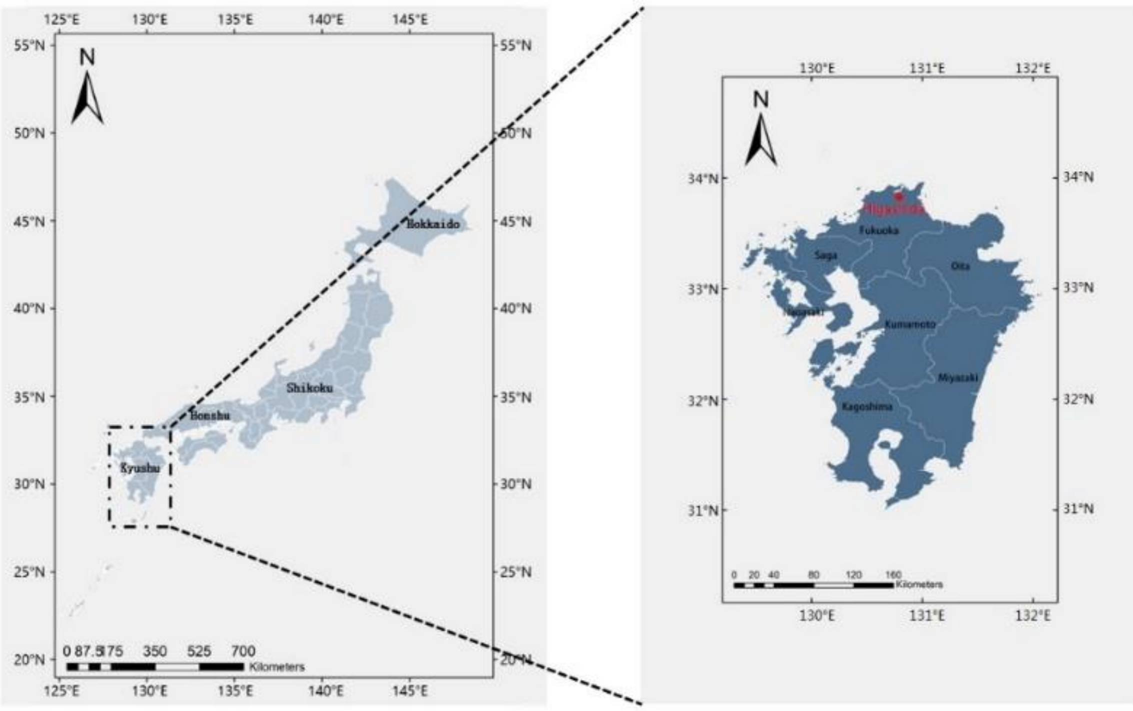

Figure 1. Location of Higashida region in Japan.

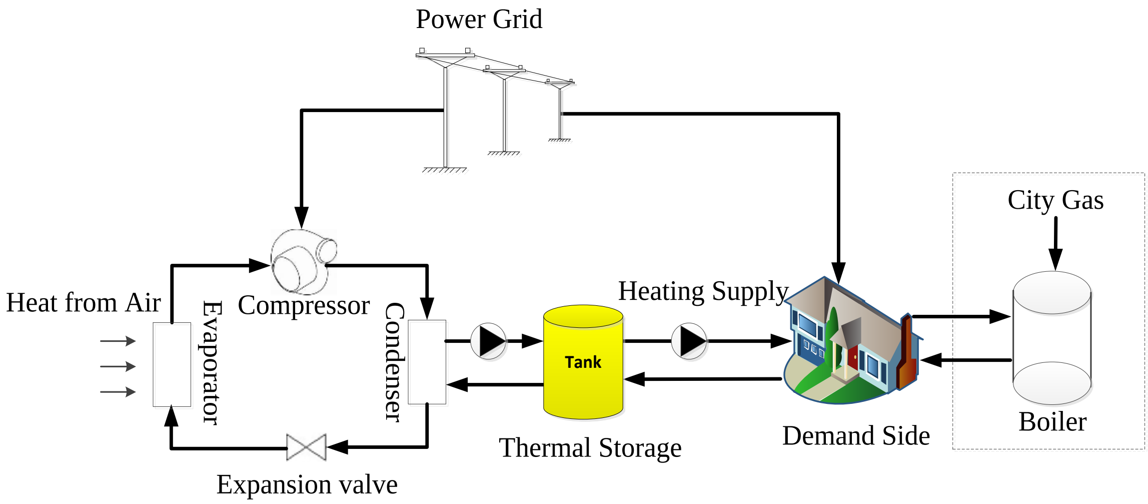

Figure 2. Structure of residential household with heat pump water heater system.

Table 1. Basic information of customers

Room number	Family member	Occupation hours(weekday)(h)	Occupation hours(Saturday)(h)	Occupation hours(Sunday)(h)
I101	3	42	60	72
I111	4	65	82	88
I205	5	70	93	70
I210	4	68	79	67
I409	4	56	60	68
I410	3	48	48	42
I411	5	81	94	97
I1001	4	60	79	79
I1101	4	62	75	89
II308	2	36	43	44
II411	3	33	38	48
II804	4	63	92	80

3. Methodology

The performance of COP is strongly dependent on changes of outdoor temperature. The daily heat consumption of the house also changes. There is an uncertainty in the cost savings, and the application of heat pump system provides a cost saving chance. We compare the performance between heat pump systems and traditional methods of extracting heat from natural gas.

The power consumption of heat pump E_{hp} (kWh) can be calculated as follow:

$$E_{hp} = \frac{Q_{re}}{COP_{hp}} \tag{1}$$

The equivalent consumption of natural gas V_{Gas} (m^3) can be calculated as follow:

$$V_{Gas} = \frac{Q_{re}}{LHV} \tag{2}$$

The fuel cost of natural gas C_{Gas} (Yen) can be calculated as follow:

$$C_{Gas} = V_{Gas} * Price_{Gas} \tag{3}$$

The power cost of heat pump C_{re} (Yen) can be calculated as follow:

$$C_{re} = Q_{re} * Price_{Electric} \tag{4}$$

The cost saving P_{user} (Yen) can be calculated as follow:

$$P_{user} = C_{Gas} - C_{re} \tag{5}$$

Where, Q_{re} refers to the heating consumption of residential house (kJ), COP_{hp} refers the COP of heat pump, LHV is the heating value of city gas (kJ/m^3), $Price_{Gas}$ is the price of natural gas, and $Price_{Electric}$ refers to the electricity price.

4. Result and discussion

4.1. Energy saving performance

Selecting one household to analyze the power consumption of Eco-cute. As we all know the power consumption of Eco-cute has a close relationship with outdoor temperature.As we can see in Figure. 3, when the outdoor temperature increase the power consumption of Eco-cute is shown a decreasing trend. Taking one household as an example, when the outdoor temperature dropped from 6 degrees Celsius to minus 2 degrees Celsius, the hourly power consumption increased by 14%. In the following, we will calculate thermal load in different value of COP.

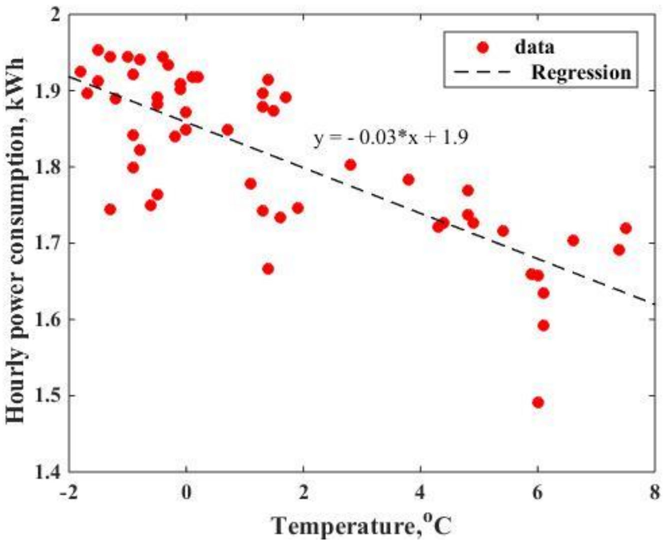

Figure 3. Power consumption of Eco-cute under different out temperature.

Base on he measured data, we analyze the power consumption of Eco-cute between the different customers. As we can see in figure. 4, the power consumption of Eco-cute of each building shows a peak of usage is presented before 0 to 8 o'clock, and the peak is reached during 3 and 4 o'clock.

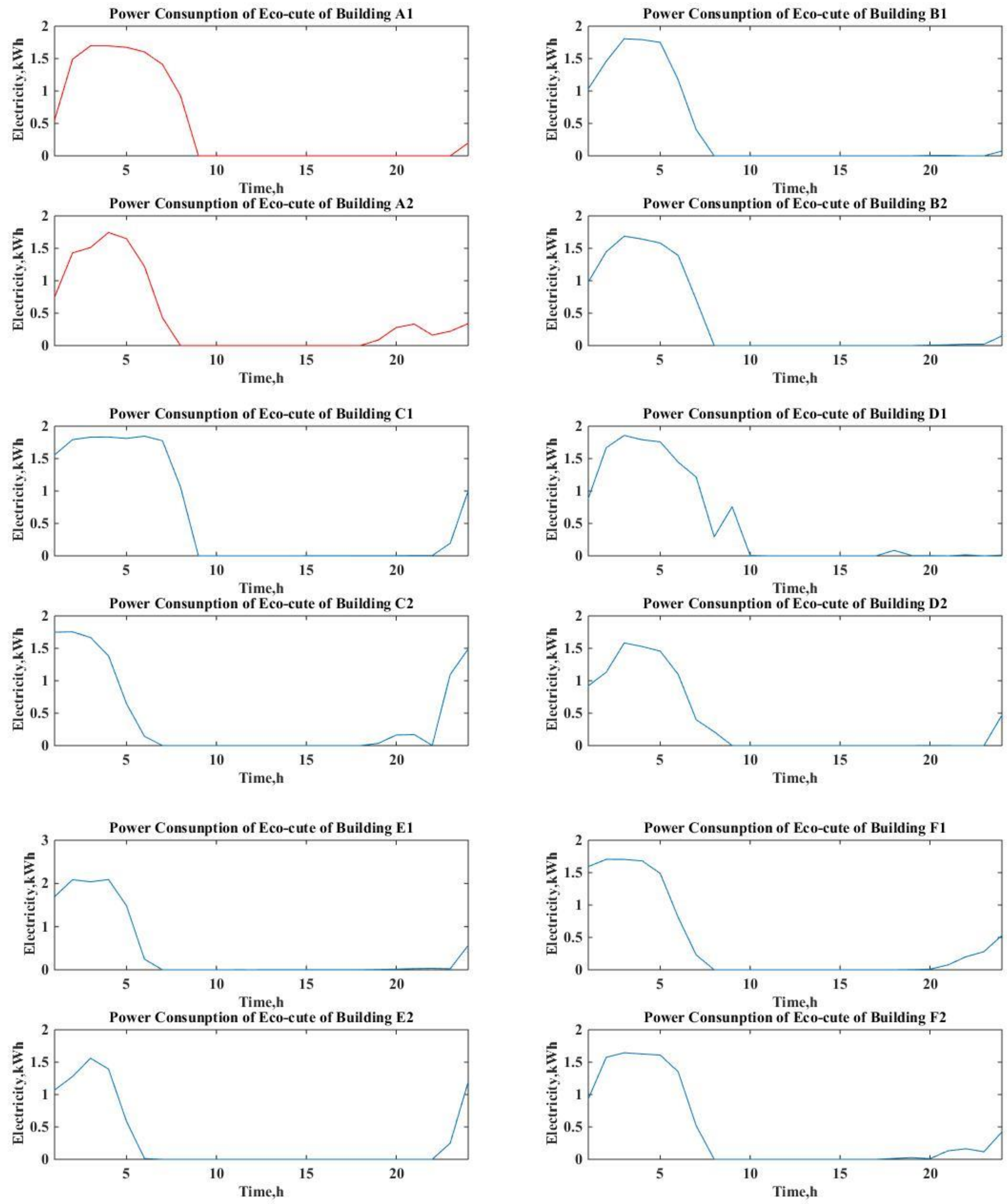

Figure 4. Comparison of power consumption of Eco-cute between the different customers.

4.2. Economic performance

We do an economic performance by comparing performance between Eco-cute and natural gas boiler. The cost of the Eco-cute and natural gas boiler for the same amount thermal load is calculated. As shown in the figure. 5, ranging the value of COP from 2.5 to 3.5, it shows that the cost saving is obvious at higher COP value.

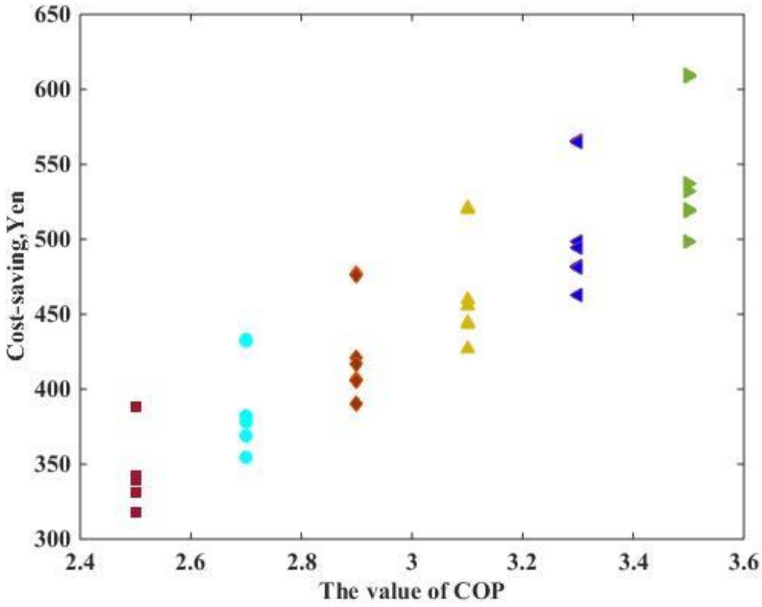

Figure 5. Cost saving by using Eco-cute under the different value of COP.

We also calculate the cost savings performance among customers. As shown in the figure. 6, we fix the performance of COP at 3.5, the cost savings can reach up to 5000Yenand the lowest is around 2500Yen. It indicates that Eco-cute is shown an economic advantage.

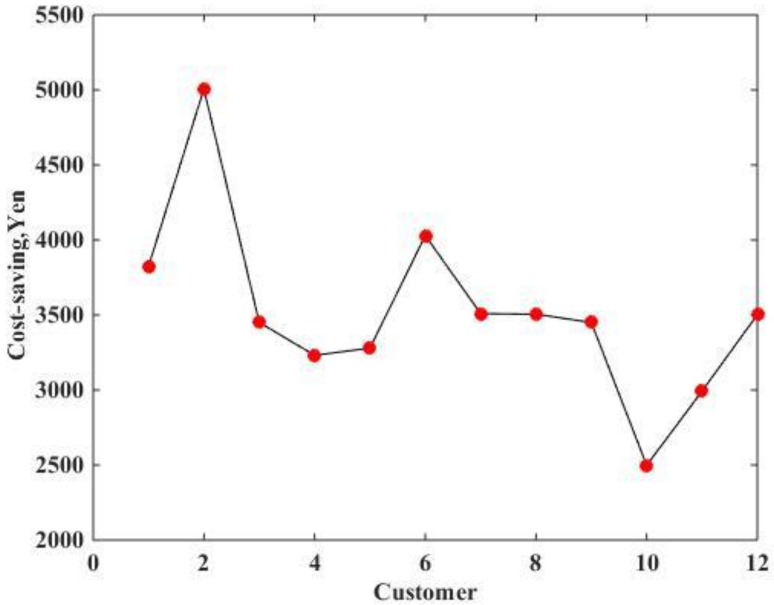

Figure 6. Cost savings performance among customers.

4.3. Occupation impact

As we all know, occupation has an impact on the load consumption. The survey result shows that the number of family members of the selected households ranges from 2, 3, 4, and 5 people, we calculated the power consumption of Eco-cute for these customers, respectively. The relationship between the number of family members and power consumption of Eco-cute is shown in figure. 7. The result present that the power consumption is in linear relationship with the number of family members. The impact of occupation hours on the total power and Eco-cute consumption are shown in figure. 8.

Based on figure. 8, it indicates that the number of family members has significant impact on the power consumption of Eco-cute.

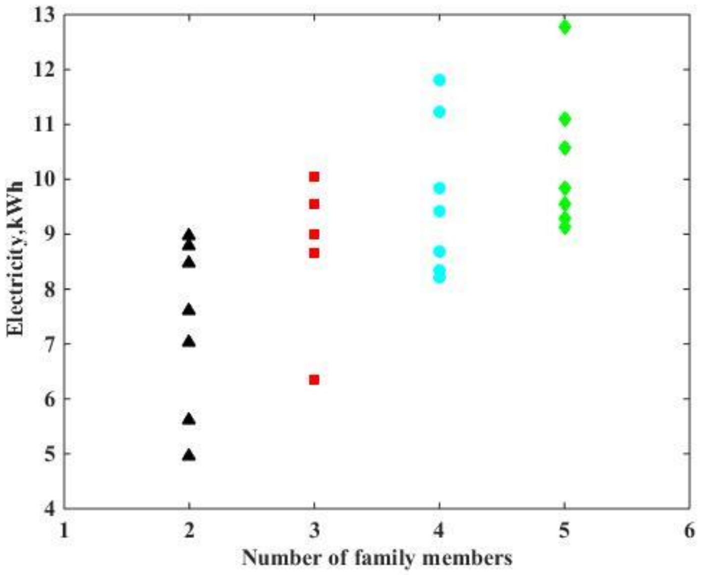

Figure 7. Relationship between power consumption of Eco-cute and number of family members.

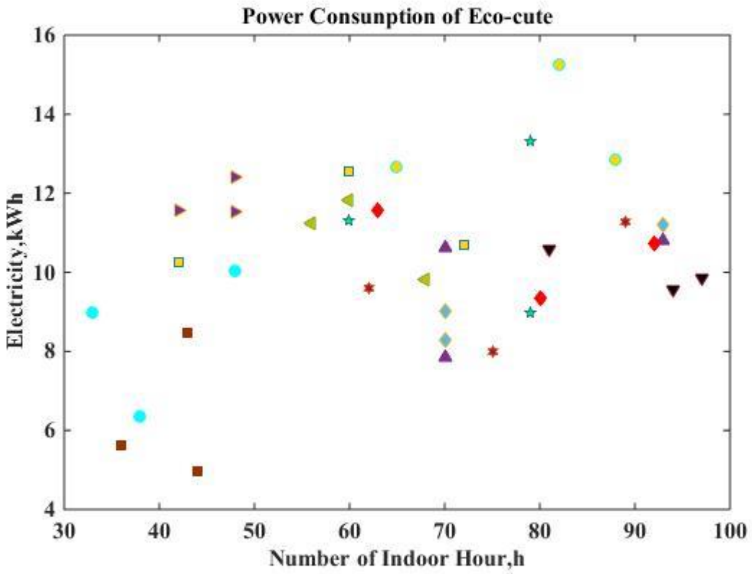

Figure 8. The impact of indoor hour on the Eco-cute consumption.

5. Conclusion

This study utilized the monitored history data to analyze the energy consumption characteristics and influencing factors of the residential customers, which equiped with heat pump heat supply system in Kitakyushu, Japan. Considering that load flexibility is closely related to the load consumption patterns of different customers. We selected 12 households located in Higashida district to analyzed their residential electricity usage, the daily demand curves and load consumption pattern of heat pump system were investigated in detail.

The characteristics of energy saving performance indicate that power consumption of Eco-cute shown a decreasing trend with increasing outdoor temperature. According to the economic performance comparison between Eco-cute and natural gas boiler, the result shown that Eco-cute exhibited an economic advantage, and the cost saving by using Eco-cute was obvious at higher COP value. As for the impact of occupation on the load consumption, we did a survey of family members' indoor hour for the 12 selected customers, the result show that there was a low correlation between power consumption and indoor hour, and the number of family members had a significant impact on the power consumption.

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