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MINING EXTRA PROFITS-DYNAMIC APPROACH TO ASSESS ENERGY SAVING

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Abstract

In response to the global trend of energy saving and the reduction in greenhouse gas emissions and operating costs, heat pumps are widely installed in university student dormitories to supply hot water without time limits. To ensure hot water is always available, the set point of water temperature is usually very conservative and accompanied by additional backwater heating equipment. However, the energy efficiency could be enhanced by using more accurate temperature set-point. To our best knowledge, there is no prior studies using big data analysis for improving energy efficiency. In this study, we use actual operational data to identify the advancedly potential energy-saving factors in the first place, and then outline the system modules of how to set temperature dynamically.

Using a real case of automatic control modules of heat pump hot water system in 2016 we identify two key factors: outside air temperature and the date of setting temperature point. We demonstrate a significant improvement on energy efficiency: a saving of 1/3 energy waste, 1/5 re-start times, and 30.37% energy costs. Our model of showing a significant improvement on energy efficiency indicates that innovative and sustainable energy business models could be expected.

Keywords: Backwater heating, Energy Service Companies (ESCO), Heat Pump, LOESS

Background

The business for energy service can be attributed to the energy crisis of the late 1970s which caused enterpriser to develop solutions to combat the rise in energy costs.(Wesley D Sine &Robert J David 2003) The booming of the energy service company (ESCO) business is responding to the trending of global energy saving. An ESCO is a company that provides comprehensive energy solutions to its customer, including redesign and implement changes to the ways the customer consumes energy. The primary goal is to improve energy efficiency of the existing energy system. Thus, the services from an ESCO will differentiate from a common energy company whose core business is solely providing energy to its customers.

Typically, compensation to the ESCO is performance based so that the benefits of improved energy efficiency as shared between the client and the ESCO. Figure 1 depicts the ESCO business model for this study. The ESCO starts by performing an analysis of the properties, designs an energy efficient solution, installs the required elements, and maintain the system to ensure energy savings during the contract period. The most difficult is to resolve the doubt from customers about the accurate calculation of energy savings to satisfy the sharing needs for both parties of ESCO and client. This study is to establish a dynamic model to resolve this difficult. It is also noted that the ESCO business model established in this study (see Figure 1) will become an energy-saving tool of profits sharing for the following potential customers, such as hospitals, security centers, hotels, leisure halls, dormitories, swimming pools and other for hot water demand.

Considering the classifications of the work (energy consumption) for heating equipment are electric, liquefied gas, diesel boiler, natural gas, small heat pump, and large heat pump. The coefficients of performance (COP) for this equipment are listed in Table 1. The COP is a ratio of useful heating value provided to work required. It shows only COP of heat pump is greater than 1 (2.6 or 3.6) which means it pumps additional heat from a heat source to where the heat required instead of just converting work to heat. Higher COPs equate to lower operating costs. The energy consumption diagram shown in Figure 1 shows the heat pump can save 25% ~ 50% of cost comparing with other heat equipment based on the same heating outputs required.

The Air-to-Water Heat Pump (AWHP) would be selected in this study. Figure 2 presents the schematic diagram of AWHP. The electricity power (We) is used to drive the heat pump compressor, which will lead the state change of the refrigerant through the compressor's thermal cycle principle (Rankine cycle) to extract the heat (QL) of atmosphere to produce the thermal energy (QH). Based on the conservation of energy, QH = QL + We, it is concluded during the process of moving heat (QL) through the heat pump, the final collected thermal energy (QH) will be much higher than the external input power (We). It is more like a "energy amplifier" such that the purpose of energy savings can be achieved.

In this study, a dormitory in the university located in northern Taiwan is adopted as an example. Total of 583 beds are arranged in a 9-story building and the shower type is equipped in the bathroom. Dormitory would supply hot water shower with temperature about 50 ~ 55 C. (Taiwan Green Productivity Foundation Energy conservation center 2005).

A Heat Pump Hot Water System (HPHWS) is used to provide the required hot water whenever the students need it. It means there is no time limit for student to use hot water. By analyzing the actual operating data of this case, expect to identify opportunities for further energy savings to generate additional profits.

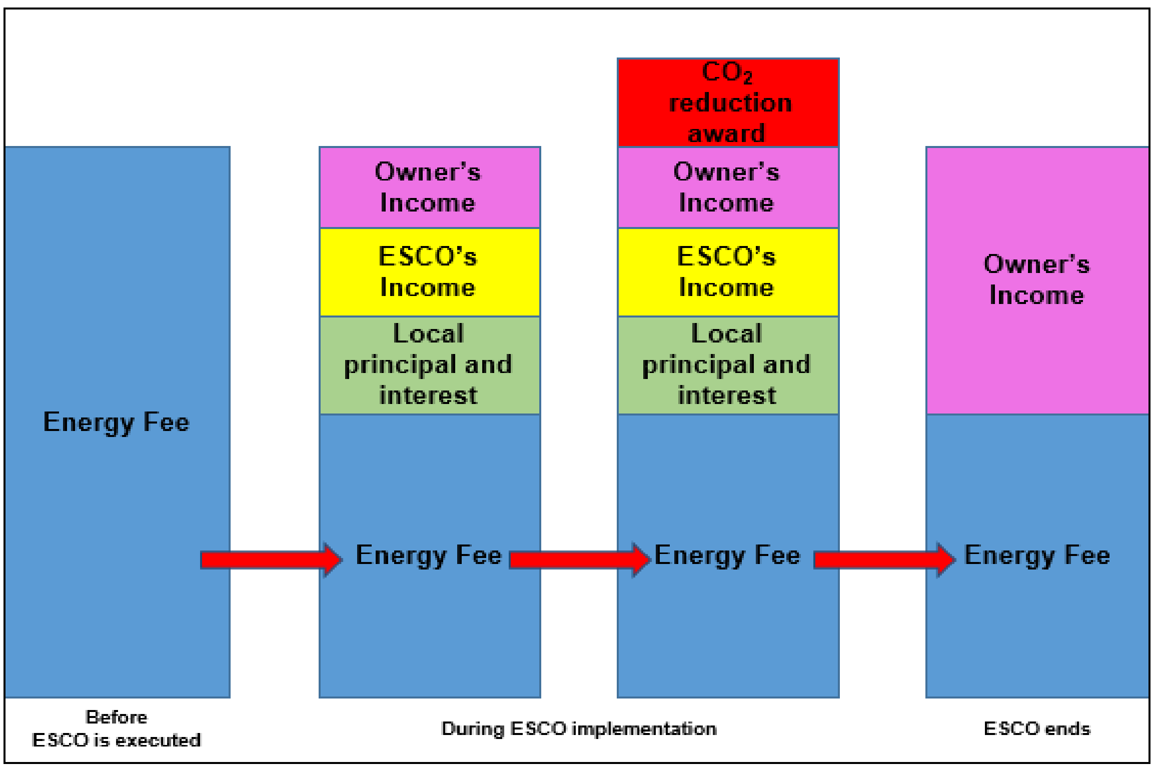

Figure 1 The ESCO business model

Table 1 The COP of different water heating equipment

Heating equipment	heating value	The Average of COP	Output of heating value
Electric	860(Kcal/℃)	90%	774(Kcal/℃)
Liquefied gas	12,000(Kcal/Kg)	75%	9,000(Kcal/Kg)
Diesel boiler	8,816(Kcal/Kg)	75%	6,612(Kcal/Kg)
Natural gas	8,942(Kcal/℃)	75%	6,707(Kcal/℃)
Small heat pump	860(Kcal/℃)	260%	2,236(Kcal/℃)
Large heat pump	860(Kcal/℃)	360%	3,096(Kcal/℃)

Source: Q & A Energy-saving Technical Manual for Heat Pump Hot Water System (Compiled and printed by Bureau of Energy Ministry of Economic Affairs, Taiwan in 2006)

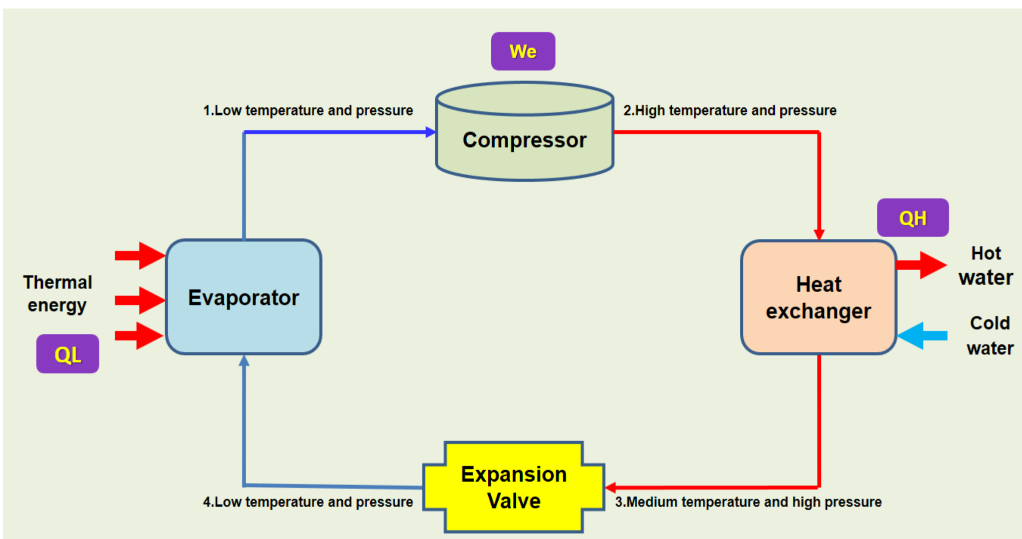

Figure 2 Air-to-Water Heat Pumps Schematic diagram

Method

Three phases were involved in this study, design, implementation, and comparison. During design phase, the energy audit was the primary task. (Albert Thumann et al. 2013) The hot shower water would be supplied by the dormitory and the heating rate to produce hot water from the heat pump system is constrained by the equipment capacity. Thus, an energy audit would be performed before the traditional hot water facilities are replaced by the heat pump system in order to understand the existing system functions and characteristics. Five major steps are required during energy audit:

1. Perform the diagnosis for the customer's original system,
2. Request customers to provide the original system of energy consumption of historical data,
3. Assess whether there are alternatives and its extent and scale of energy saving,
4. Discuss with customers to reach a cooperation agreement,
5. Plan and design the new system.

During implementation phase, two major tasks were performed. One is for hardware equipment installation, and the other one is for software development. The capacity of water storage tank would be considered such that whenever the hot water shall be provided to satisfy the needs. The temperature control setpoint through on-line software would be considered such that the energy efficiency would be optimized to produce the maximum energy saving.

After the HPHWS has been installed on the dormitory, the new system functional data would be collected in order to establish the dynamic model to adjust the temperature requirement to optimize and maximize the system energy efficiency. In this study, the actual operation data from 2016/1/1 to 2016/12/31 were collected and analyzed. The data flow to form the optimized dynamic model is presented in Figure 3.

On-line real-time software has been developed by R language to perform system temperature control function. The software will collect system operation data every 5 minutes and then convert every five minutes of data to hourly information. The Locally Weighted Scatterplot Smoothing (LOWESS) method is adopted to convert the discrete data to smooth curve. Using this method in the temperature control software, the optimized energy efficiency can be achieved. (Willian S. Cleveland and Susan J. De 1988).

During comparison phase, the comparison of energy efficiency between the HPHWS through dynamic on-line temperature control and original heating system would be implemented. And based on the analyzed data during 2016, the total natural loss of temperature difference, the total natural loss of calorie difference and the total number of start-up heating difference would be obtained. According to the electricity standard price announced by the government, the cost difference between the old and new system would be calculated to show the efficiency of energy saving and cost savings.

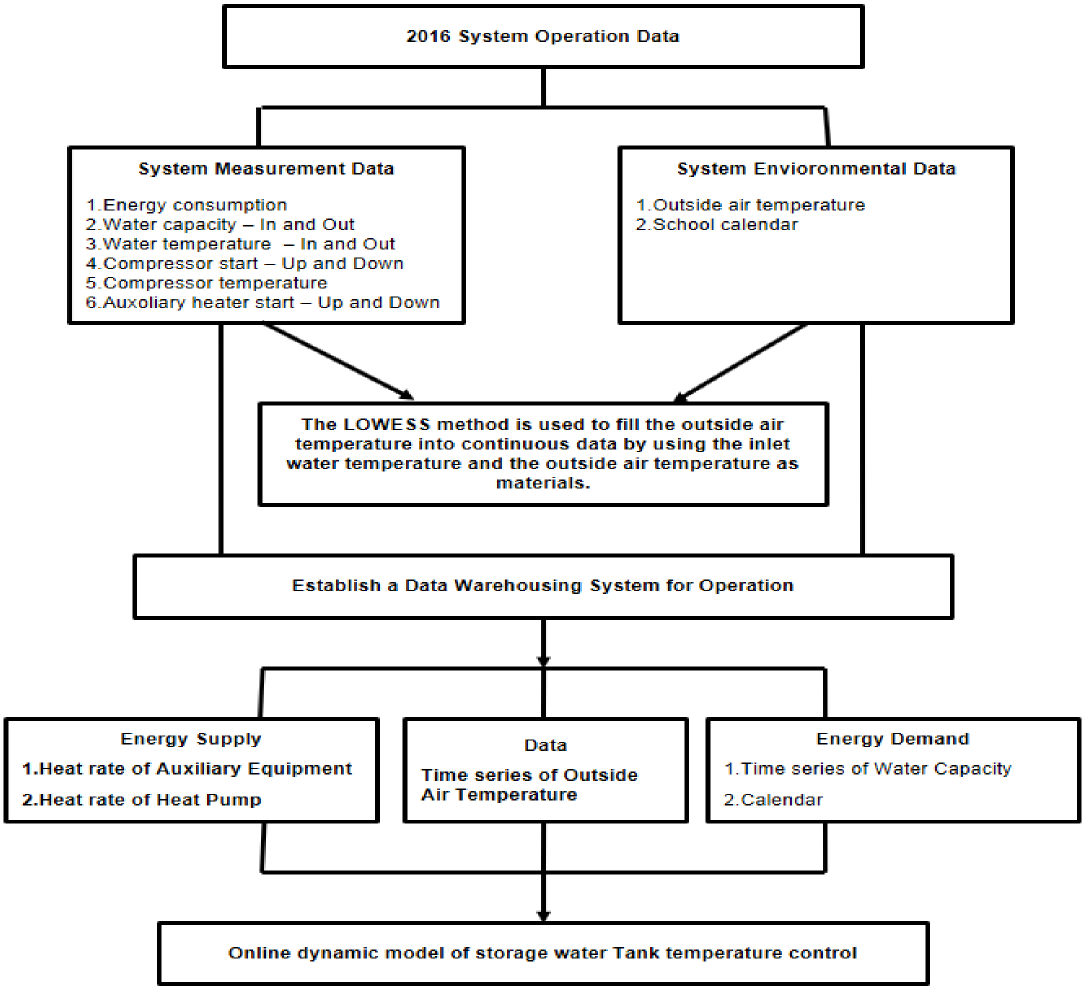

Figure 3 Data flow of the optimized dynamic model

Results

In this study, the energy saving sharing model (Sharing Save) is adopted and is agreed with the most of cases. The construction cost of the heat pump will be allocated yearly basis according to the difference between the actual cost of energy consumption from the HPHWS and the energy cost from the original system operation. The final system block diagram of HPHWS is presented in Figure 4. Tank #1 and #2 are classified as the system heating tank which is connected to the heat pump main machine and Tank #3 and #4 are water storage tank which is connected with the auxiliary heating equipment. Each tank has its own target temperature setpoint. Additional minimum temperature setpoint is applied on the Tank #1 for backwater heating through heat pump and additional alarm temperature setpoint is applied on the Tank #4 for auxiliary heating in order to speed up the rising of water temperature.

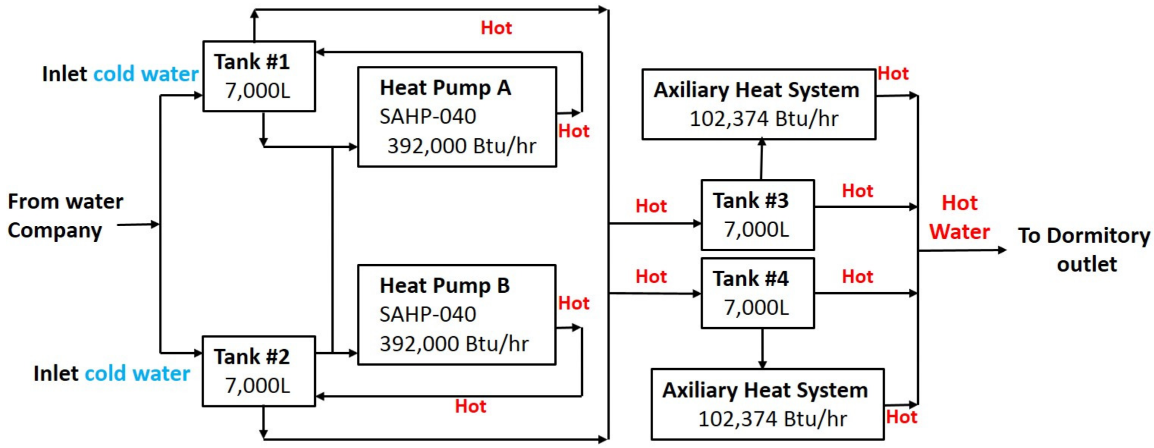

Figure 4 Block Diagram of Heat Pump Hot Water System

In order to validate the energy efficiency, it is required to set up various type of measuring equipment for the HPHWS to collect system functional data, transmit the required data back for validation, and monitor the normal operation of system facilities in order to avoid the occurrence of the critical system failures. Due to the character of real-time monitoring and all kinds of data transmission back with high frequency so that the collected data volume will grow up rapidly to form a huge database.

This study analyzes the actual data and customer requirements to achieve the optimization and maximization of the energy efficiency such that unnecessary energy consumption would be reduced. In fact, the HPHWS uses a small amount of electric power to drive the heat pump compressor to extract heat from the air, and then heat the water temperature through heat exchange and find that the heat generated is very high to the outside temperature. If the outside air temperature is too low, it is not conducive to the performance of the heat pump, and the heating rate is also slow comparing with the traditional type of direct heating equipment. Therefore, in addition to the original heating system, the auxiliary heating equipment with relative energy consumption is required. Therefore, in addition to the system heating tank, the storage tank is used as a water buffer for the resolution of slow heating rate, it would supply enough water within a short time of period. The temperature set point control technology is used for the system heating tank and water storage tank in order to ensure the enough hot water would be provided. A target temperature is set for the system heating tank. The heating pump would function continuously until the target temperature is reached. A alert safety temperature set point is set for the water storage tank. When the storage water temperature is lower than the safety water temperature, the storage tank water would be pumped back to the heating tank for reheating (called backwater heating).

In response to the hot shower habit in Asia, it has to guarantee to supply enough hot water to those users who are in shower in order to avoid complaints from users due to less hot water provided.
According to the results of the Energy Bureau of the Taiwan Ministry of Economic Affairs, water consumption is around 60 liters per person per day for male, 70 liters for female, the outlet water temperature of bathroom is between 40 and 42°C, which is the mixed temperature of hot water and cold water. So far, for avoiding complaints, the set point for heating tank and storage tank of the HPHWS installed on the university dormitory is set to be minimum which is very conservative. The inefficient energy consumption would exist due to this conservative set point. The outside air temperature is selected as a reference temperature due to its stability and reliability provided by government Weather Bureau at exact hour. The LOWESS is used to correlate the outside air temperature and system inlet water temperature. The results are shown in Figure 5. The X-axis is outside air temperature and the y-axis is system inlet temperature.

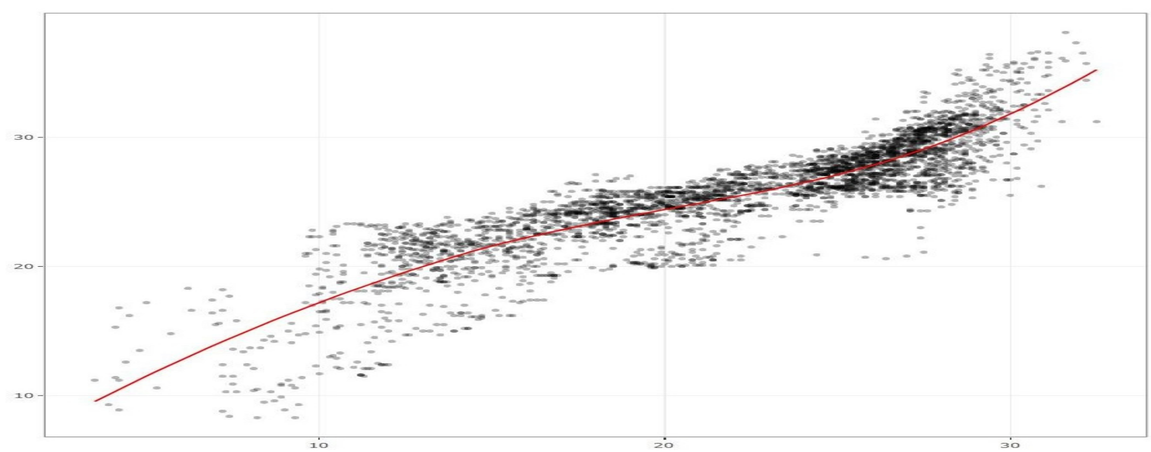

Figure 5 Actual data points with LOWESS curve

This analysis of LOWESS provides the basis of the dynamic model. The required the minimum and alarm temperature setpoint can be set dynamically in advance according to the given date-time series of outside air temperature.

In order to study the potential possibility of energy saving, the natural heat loss due to heat radiation always exists during HPHWS operation. While the tank temperature is lower than the setpoint, it would lead the startup of heating devices. Therefore, the natural lost temperature would affect energy saving. Figure 6 shows the natural lost temperature comparison between the fixed temperature setpoint (50 degree C) and dynamic setpoint model. The line blue represents the system natural lost temperature with the fixed setpoint for whole year 2016 and the line red is for the dynamic setpoint. It shows the year 2016 accumulated natural lost temperature for dynamic model (5575 Degree C) is less than for the fixed temperature setpoint (7081 Degree C).

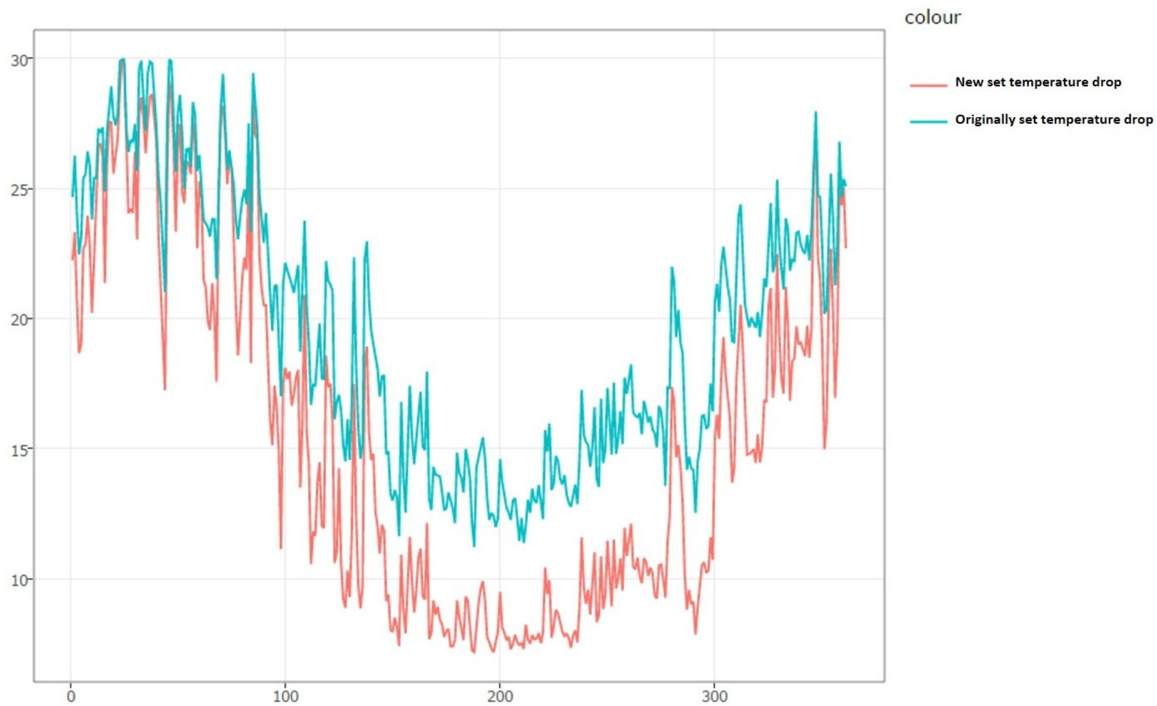

Figure 6 Comparison between the original fixed and new dynamical setpoint due to natural loss of year 2016

Usually, the number of startup of heat pump compressor is less, the more saving of energy. The counts to startup compressor between the fixed and dynamic setpoint are shown in Figure 7. The line blue is for the fixed setpoint and line red for dynamic model. It indicates total of 3675 startup for the fixed setpoint (Originally set) and 2681 for dynamic setpoint.

No matter what is the set point value of the fixed temperature or the newly dynamic temperature, the required heating amounts for water consumption used by showers are the same. The difference is how much amount of heat lost in the heating process. So the natural heat loss from the fixed temperature setpoint and the dynamic setpoint will be converted into electricity consumption, and then converted into electricity price for comparison. The prices of different time periods are shown in Table 2.

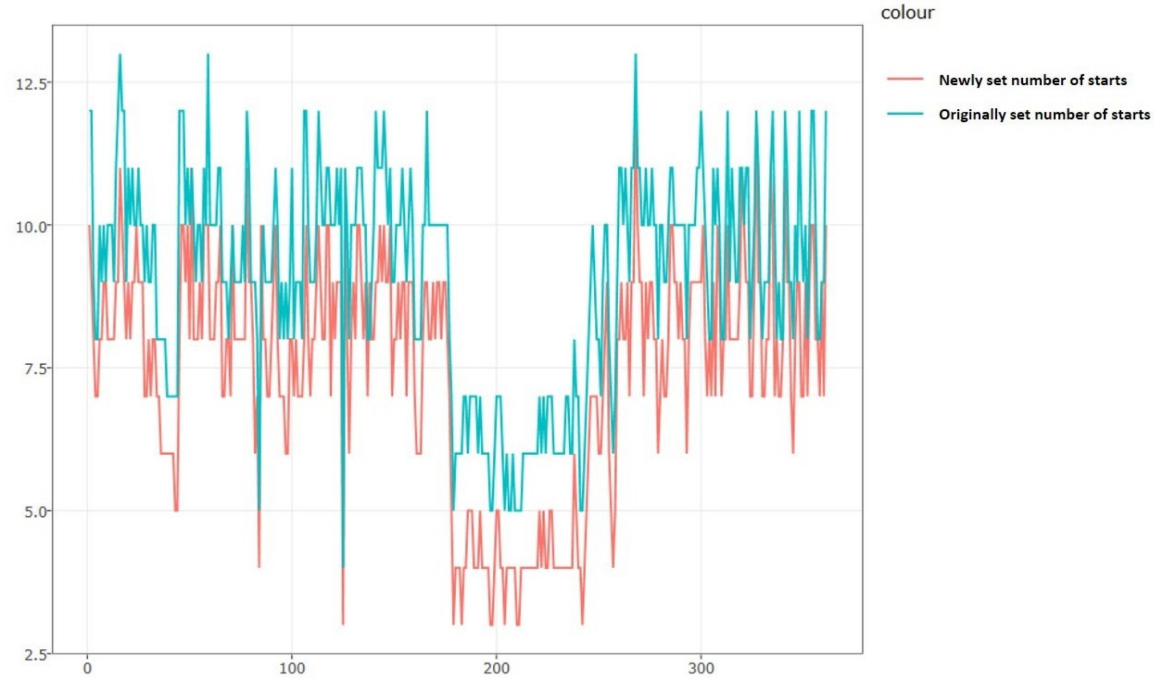

Figure 7 The number to restart heat pump compressor comparison between the fixed and dynamical setpoint of temperature

Table 2 The electricity prices of different time periods used in this study

Taxonomy			Time period	summer 6/1-9/30	Non summer
Segmented electricity bill (per kilowatt)	Monday to Friday	Peak time	07:00~22:30	NT$3.53	NT$3.42
		From peak time	22:30~24:00 00:00~07:30	NT$1.73	NT$1.63
	Saturday	Semi-peak time	07:00~22:30	NT$2.48	NT$2.39
		Non-peak time	22:30~24:00 00:00~07:30	NT$1.73	NT$1.63
	Sunday and from the peak day	Non-peak time	All day	NT$1.73	NT$1.63

Source: This study

Based on the recorded data in 2016, the electricity price and cost saving status for the difference between the fixed setpoint and the dynamic setpoint of temperature during summer time are shown in Table 3. Table 4 represents for non-summer time. Table 5 represents the whole year.

Table 3 Comparison between the original fixed and new dynamical setpoint during summer of year 2016

Taxonomy	2016(Summer)			
	Original settings (fixed)	New setting (dynamic)	Saving electricity bills	Savings Percentage
Peak hours of electricity costs	NT$8,403.07	NT$5,110.89	NT$3,292.18	39.18%
Semi-peak hours of electricity costs	NT$1,017.46	NT$641.70	NT$375.76	36.93%
Non-peak hours of electricity costs	NT$4,438.25	NT$2,379.28	NT$2,058.97	46.39%
Total	NT$13,858.78	NT$8,131.87	NT$5,726.91	41.32%

Source: This study

Table 4 Comparison between the original fixed and new dynamical setpoint during non-summer of year 2016

Taxonomy	2016(Non-Summer)			
	Original settings (fixed)	New setting (dynamic)	Saving electricity bills	Savings Percentage
Peak hours of electricity costs	NT$39,245.06	NT$28,517.27	NT$10,727.80	27.34%
Semi-peak hours of electricity costs	NT$4,636.46	NT$3,151.14	NT$1,485.32	32.04%
Non-peak hours of electricity costs	NT$17,426.39	NT$12,535.69	NT$4,890.70	28.06%
Total	NT$61,307.91	NT$44,204.10	NT$17,103.82	27.90%

Source: This study

Table 5 Comparison between the original fixed and new dynamical setpoint during year 2016

Taxonomy	2016 Annual			
	Original settings (fixed)	New setting (dynamic)	Saving electricity bills	Savings Percentage
Peak hours of electricity costs	NT$47,648.14	NT$33,628.15	NT$14,019.99	29.42%
Semi-peak hours of electricity costs	NT$5,653.92	NT$3,792.84	NT$1,861.08	32.92%
Non-peak hours of electricity costs	NT$21,864.64	NT$14,914.97	NT$6,949.67	31.78%

Total	NT$75,166.70	NT$52,335.96	NT$22,830.74	30.37%

Source: This study

Discussion

As shown in Table 1, Comparing with the efficiency of heating from traditional electricity, liquefied gas, natural gas or diesel boilers, the heating efficiency of the HPHWS is up to 1.3 to 4.8 times. Due to the energy cost has already saved about 30% - 75% by using heat pump facilities, it seems it is impossible to perform further enhancement of energy saving by switching the original heating facilities to HPHWS. (Ke Shangbin, Zhu Yaoming. 2009).

However, the software algorithms for dynamical settings have been applied on the HPHWS and after the system operation of the HPHWS for year 2016, it can dig out the more space of energy saving through the following tasks:

1. Understanding of the user's habits,
2. Simplification of data categories,
3. Supported by the actual operation data analysis results,
4. Adjustment of the set point of temperature through modular software algorithms in order to reduce the energy consumption from back water heating and energy waste caused by natural cooling loss.

This process is just like the lemon which is processed by the juice processor. Squeeze the residual peel to the maximum limit. The centrifugal dehydration power in this study is the big data analysis that leads to get more energy saving cost.

The benefit of energy efficiency from the results of using heat pump as hot water heating equipment is significant. Usually, the set point of temperature is set to be conservative and the value is fixed for the traditional heating equipment, the hidden energy saving space will be dogged out through the analysis of the collected system operational data after the proposal of energy saving plan from the results of the professional review of the original heating equipment. In this case, for example, the demand for hot water is closely related to the type of schedule (date type), and the inlet water temperature is closely related to the outside air temperature. Therefore, this study found that when adjusting the set point of temperature, it is simplified to consider the type of schedule (date type) and the outside air temperature only, the optimum set point of temperature can be obtained and the adequate time to adjust set point of temperature in order to reach the goal of reducing effective energy consumption. These relationships can be written into software programs and reach the goal of the system automation.

Conclusion

Since the most customers who adopt HPHWS have different operating habits, and data category of the outside air temperature is limited in the annual data, this study still can provide the following contributions:

1. Describe the procedures to obtain the required data categories through clarification and induction for hot water demand, so that the typical data categories can be applied on the different cases and then the goal of system simplification can be achieved.
2. Using LOESS method with limited outside air temperature data category (discrete data) to perform analysis in order to establish the continuous data according to the possible outside air temperature range in response to all possible temperature conditions, so the integrity of the automation program would be achieved.
3. The dynamical settings applied in this study can reduce:
   (1). The 1/3 of the energy waste due to natural cooling loss, and
   (2). The start number of the heat pump 507 times that are about the 1/5 of the original fixed setpoint.
4. Based on the analysis from this study, comparing with the original fixed settings, it shows:
   (1). The maximum additional electricity costs would be saved by 46.39% of energy costs within a certain time period due to use the new settings. Additional 27.34% is the minimum saving costs.
   (2). The annual average saving would be 30.37% of the energy costs.
5. This dynamic approach method provides the accountable calculations to share the benefit from energy saving to reach win-win situation.

Only one year 2016 of data is used in this study, it cannot perform the comparison of the same season under different years although the amount of data is up to 105,120. However, considering the dual variables of temperature and energy user behavior at the same time, compare the energy saving results on an annual basis. It will be a more objective choice.

It would be better if there are more years of information, especially more extreme types of outside air temperature data. At present, the collected data in the most of the cases is only a validation measurement of energy-saving effect, which establish the basis for sharing energy-saving benefits. The method of memory circular buffer is adopted and the size is only for one year of data in order to save the memory of the data storage space. However, if the multiple years of data is stored, it would be more accurately approach the maximum of energy saving by using LOESS (locally weighted scatterplot smoothing) (Willian S. Cleveland and Susan J. De 1988).

Whether maintaining the good performance of heating function, it will depend on the health status of the heat pump compressor. Some of the recorded data in 2016 are associated with the key information on the work of the heat pump equipment, therefore, it is recommended to perform a topic study of predictive maintenance by using the same up to 105,120 data of year.

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