Sensors and Materials, Vol. 34, No. 11 (2022) 4157–4165
MYU Tokyo

S & M 3103

Analysis and Discussion of Energy Saving through Conversion Air Conditioner Heat Recovery

Wen-Ching Hsiao,[1] Raydha Zul Fitriani,[1] and Yean-Der Kuan[2*]

[1]Graduate Institute of Precision Manufacturing, National Chin-Yi University of Technology, No. 57, Sec. 2, Zhongshan Rd., Taiping Dist., Taichung City 41170, Taiwan
[2]Department of Refrigeration, Air Conditioning and Energy Engineering, National Chin-Yi University of Technology, No. 57, Sec. 2, Zhongshan Rd., Taiping Dist., Taichung City 41170, Taiwan

(Received June 4, 2022; accepted November 8, 2022)

Keywords: renewable energy, heat recovery, preheating tank, conversion air conditioner

In this study, we designed and developed an air conditioner with a heat recovery function and examined its energy-saving benefits. The heat recovery mode of the conversion air conditioner was first examined. The heat generated by the designed conversion air conditioner system was transferred into a preheating tank through a copper pipe to heat the water in the preheating tank. The operating power of the electric water heater and heat pump was reduced by recovering waste heat. The water temperature was monitored by placing several temperature sensors on the system. The optimal length for the copper pipe was calculated in an experiment. Copper pipes were configured into a one-to-one or one-to-many mode in accordance with the number of air conditioners on the consumer end. According to the experimental results, about 99% of the power consumption could be saved when the electric water heater was set at 45 °C. As calculated using the commercial electricity rate of Taiwan Power Company, the cost of the heat recovery equipment can be recovered in about two years. The designed air conditioner with the heat recovery function helps achieve energy saving, cost cutting, and environmental protection goals.

1. Introduction

Taiwan relies heavily on imported energy sources. Owing to efforts by the government and enterprises to promote renewable energy (such as solar energy, photoelectricity, and wind energy), the proportion of renewable energy consumption is gradually increasing but is still limited. In addition to continuous effort in energy development, energy-saving measures are also necessary. Currently, about 20 to 50% of the energy consumed in Taiwan is released into the environment as waste heat. Therefore, effort should be made to make use of industrial waste heat.

There is a wide range of waste heat sources. Mechanical operations in situations from conductor manufacturing and boiler combustion to air conditioners all generate heat. When equipment produces heat energy, it is released directly into the environment, causing thermal energy waste and increased carbon emissions. If the released heat can be reduced through waste

*Corresponding author: e-mail: ydkuan@ncut.edu.tw
https://doi.org/10.18494/SAM4157

ISSN 0914-4935 © MYU K.K.
https://myukk.org/

heat recovery, energy can be saved and reused.

The conversion air conditioner system developed in this study applies an innovative heat recovery mode. The optimal length of the copper pipe in view of the conversion air conditioner capacity was calculated. All air conditioners used in this study were modified and the preheating tanks for heat recovery were customized so that consumers can obtain hot water when their air conditioners work in both cooling and heating modes. This function helps achieve power saving, energy saving, cost cutting, and environmental protection goals.

1.1 Literature review

Many works related to recovering waste heat in refrigeration systems, such as that of Gu *et al.*, have mentioned that the latent heat storage in an air conditioner heat recovery system can be used to produce domestic hot water while reducing the heat emitted to the surrounding environment.(1) Gong *et al.* pointed out that the coefficient of performance (COP) of an air conditioner heat recovery system can reach 6.0 and that water can be heated to a high temperature when an auxiliary electric heating device is used.(2) Ali and Theeb collected 35% of the heat from a cooling condenser to heat hot water for domestic purposes. Their cooling devices developed to reduce electrical consumption used two types of systems consisting of helical heat exchangers with two stages.(3) Roomi and Theeb used a helical coil tube-shell heat exchanger in a refrigeration system to utilize the waste heat generated to produce hot water and increase the COP.(4) Malik and Wankhade used waste heat from a vapor compression refrigeration system that employed ammonia as a refrigerant in a beverage bottling plant to heat PET bottles for carbonated drinks and for use in the cleaning in place (CIP). This improved the system performance.(5) Xie analyzed the exhaust heat energy from an ammonia chiller in the food production industry for latent and sensible heat. The sensible heat recovered from the chiller was used to obtain hot water of 40–70 °C for employee baths and sanitary cleaning.(6) Zheng and Cao proposed an air conditioning (AC) waste heat conversion system that combined AC with four different systems. From the performance evaluation, the organic Rankine cycle (ORC)-based system had the highest performance and enhanced the COP by between 15 and 30%.(7) Ramadan *et al.* designed a heat recovery system for heating, ventilating, and air conditioning (HVAC) to obtain hot water. Their system could heat water to 347 K.(8) Rongdi *et al.* presented a new heat pump air conditioner for hybrid vehicles that had a heat exchanger between the engine circuit and air conditioner circuit to enable waste heat recovery. The system was simulated using a software-in-loop platform based on KULI and MATLAB/Simulink, which increased the flexibility and efficiency and lowered the cost.(9) Energy saving is one of the key ways of protecting the global environment. Jadhav *et al.* attempted to utilize waste heat from a domestic refrigerator condenser for various domestic and industrial purposes, such as heating water and collecting the waste heat in a box.(10) Sarangi used an absorption heat pump to convert the waste heat from air conditioners into high-temperature heat that could be used for industrial purposes.(11) Suamir *et al.* integrated a heat pump and AC system to provide heating for hot water and cooling for hotel services in a five-star hotel, in accordance with the weather conditions. The integration of this system reduced the energy consumption of the hotel by 36.7%.(12) Yu *et al.* integrated the Evans–Perkins heat pump cycle with a heat recovery and storage system that could be used as an ancillary heat source for the operation of the heat pump.[13] Madhikermi *et al.* proposed a method to detect different kinds of failure of heat recovery units (HRUs) in a modern air handling unit. They placed several sensors in the main controllers to measure the HRU efficiency and collected the data for analysis.[14]

1.2 Research motives and purposes

Owing to the promotion of energy saving and carbon reduction as environmental measures, air conditioners that combine the features of heat pump water heaters and cold and warm air heating radiators should be popular. However, such products did not receive the expected interest from the public. The major reason for this was the price.

A hybrid air conditioner requires an additional outdoor heat pump unit and water storage tank. The air conditioner models suitable for this transformation are limited, resulting in extra expenditure for an average family. Therefore, such products are not attractive despite their energy-saving effect for the heat recovery system. It is also the major cause of obstacle for average families to widely adopt such products.

If such products can be made simpler, consumers will not need to purchase additional equipment. Instead, they only need to modify their existing air conditioners to obtain the benefits of hybrid air conditioners. It is expected that this approach will be more acceptable to the general public.

2. Experimental Planning and Setup

The architecture of our proposed system is reasonably simple: a preheating tank is set between an air conditioner and an electric water heater to utilize the heat discharged from the air conditioner to preheat the cold water in the preheating tank. When a user desires hot water, the electric water heater can directly provide the hot water in the preheating tank. In this way, the power consumption of the electric water heater in heating water is reduced and the user can obtain hot water more quickly.

2.1 Experimental method

We conducted an equipment test by simulating the hot water volume used by a hair salon that serves about 60 to 80 customers in one day. The simulated environment was established as follows: 60 customers were served per day, the air conditioner was preset at 7.1 kW, and a 400 L preheating tank was configured.

Normally, one customer requires about 4 L of water for shampooing. As tested under a fixed flow, 4 L of water was discharged for 1 min and water was discharged every 10 min. In addition, the hair salon was assumed to be open from 10:00 a.m. to 9:00 p.m., a total of 11 h. Therefore, 60 drainage tests were implemented.

This experiment tested the difference in power consumption with and without the use of the heat recovery equipment.

2.2 Establishment of environmental controls

Air conditioner heat recovery mainly targets the compressor discharge temperature. As shown in the Mollier diagram in Fig. 1, the compressor temperature in the overheated zone after the compression process is recovered. The compressor discharge temperature varies with the cooling capacity or refrigerant, and hence, the heat recovery temperature also varies.

As required in the experiment, a preheating tank was added between the air conditioner and the water heater. Figure 2 shows the temperature measurement points, the locations of the instruments and the refrigerant, and the cold air and hot water flow directions when the air conditioner operates in the cooling mode.

If an air conditioner can operate in both cooling and heating modes, the system configuration can be maintained and the pipeline design does not need to be changed. In this way, energy can be saved whether the air conditioner works in the cooling or the heating mode. Figure 3 shows the temperature measurement points, the locations of instruments, and the warm air and hot water flow directions when the air conditioner is in the heating mode.

When an air conditioner is in the cooling mode, the indoor energy efficiency can be higher and the compressor output power lower if outdoor thermal dissipation is more efficient. The water temperature in the preheating tank can effectively lower the high temperature of the compressor discharge, which will make thermal dissipation more efficient and consequently save more power.

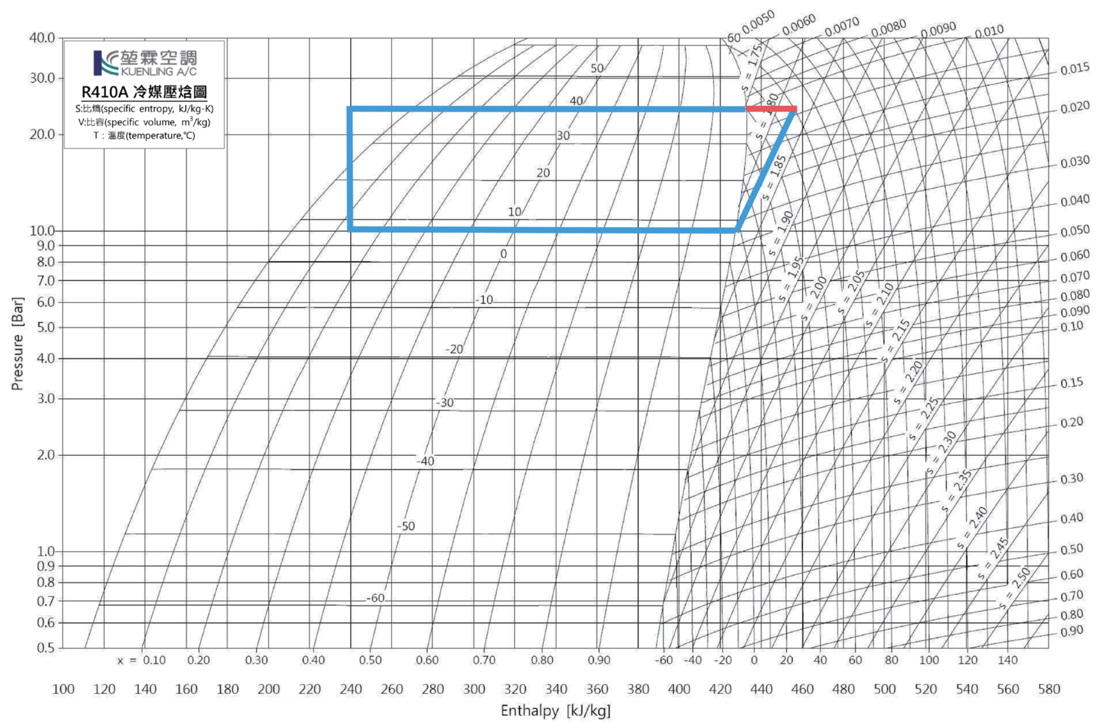

Fig. 1. (Color online) Mollier diagram of conversion air conditioner heat recovery.

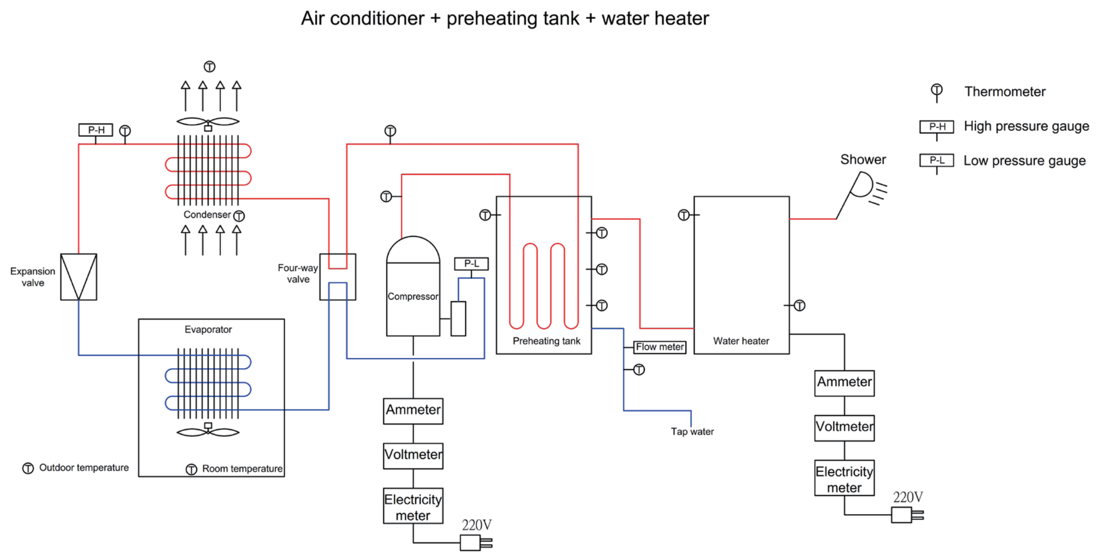

Fig. 2. (Color online) Temperature monitoring and control locations in the cooling mode.

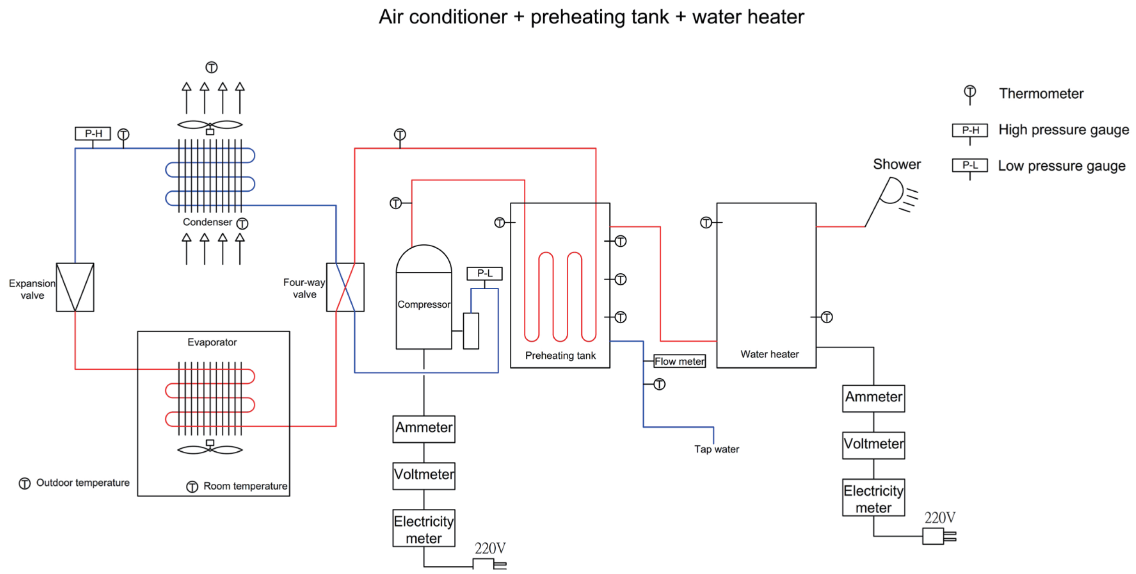

Fig. 3. (Color online) Temperature monitoring and control locations in the heating mode.

3. Description of Experiment

This experiment was implemented in two phases. In phase 1, the optimal length of the copper pipe was calculated. In phase 2, the power consumption was measured to test whether the actual power consumption is reduced with the optimal copper pipe length. In the experiment, we tested the difference in the power consumption of a 7.1 kW air conditioner with and without the use of the heat recovery equipment.

3.1 Heating test of copper pipe

The heat energy released from the air conditioner was used to heat the cold water in the preheating tank through the copper pipe for heat recovery. The copper pipe length affects the heating duration and power consumption. For energy saving, the optimal copper pipe length must be identified to achieve optimal energy efficiency.

Four copper pipes (lengths: 8, 9, 10, and 11 m) were used to heat the cold water in the preheating tank. Table 1 lists the heating duration and power consumption in heating the preheating tank to more than 45 °C. Table 2 lists the highest temperature to which the water in the preheating tank could be heated using the four different copper pipes and the corresponding duration and power consumption.

A large amount of test data was obtained from the four copper pipes and cannot be exhaustively listed herein. Tables 1 and 2 illustrate the temperature and duration for the four copper pipes during heating. The results show that the desired experimental result can be theoretically obtained.

3.2 Experimental data analysis

In the copper pipe heating test, it was difficult to identify the optimal length from only the temperature and duration data. More data was therefore needed for analysis.

According to the experimental data, the 9-m-long copper pipe showed the highest heating rate and the longest duration at the highest temperature and therefore provided the optimal heating efficiency. Table 3 lists the heating data for the 9-m-long copper pipe.

According to Table 3, the highest heating capacity was 2135 W when the heating duration was 60 min. For this duration, the highest coefficient of performance of 1.416 was obtained. On the basis of these values, the 9-m-long copper pipe was used for the heating and power consumption test in phase 2.

Table 1
Heating duration and power consumption in heating the cold water to more than 45 °C.

Length of copper pipe (m)	Duration (min)	Water temperature (°C)	Power consumption (kWh)
8	480	45.3	7.8
9	240	45.7	5.1
10	300	45.6	5.9
11	240	45.8	5

Table 2
Highest temperature and corresponding duration and power consumption.

Length of copper pipe (m)	Duration (min)	Water temperature (°C)	Power consumption (kWh)
8	600	46.1	9.6
9	540	50.2	11
10	540	50.5	11.2
11	480	49.1	9.6

3.3 Power consumption test of electric water heater

In accordance with the previous experimental data, a 7.1 kW air conditioner and a 9-m-long copper pipe were used for the heat recovery and power consumption tests in the cooling and heating modes, respectively.

After the air conditioner was set to operate in the cooling mode, the electric water heater was set to 45 or 65 °C and the water was discharged 60 times for testing. Table 4 lists the results before and after the heat recovery equipment was installed.

After the air conditioner was set to operate in the heating mode, the electric water heater was set to 45 or 65 °C and the water was discharged 60 times for testing. Table 5 lists the results before and after the heat recovery equipment was installed.

According to the experimental data, when the air conditioner was in the cooling mode, the power consumption was reduced by 99 and 87% when the electric water heater was set to 45 and 65 °C, respectively. When the air conditioner was in the heating mode, the power consumption was reduced by 99 and 74% when the electric water heater was set to 45 and 65 °C, respectively.

As calculated using the Taiwan Power Company commercial electricity rate (NT$ 6.43/kWh for summer and NT$ 5.05/kWh for winter for power consumption of less than 1501 kWh), the installation cost can be recovered in about two years.

Table 3
Heating data for the 9-m-long copper pipe.

Duration (min)	Water temperature (°C)	Current (A)	Power consumption (kWh)	Heating capacity (W)	Coefficient of performance
0	31.7	34.3	0	0	0
30	34.6	1830	0.7	2030	1.109
60	40.1	1418	2.3	2135	1.416
120	43.3	1419	3.7	1785	1.273
180	45.7	1419	5.1	1505	1.056
240	47.8	1434	6.5	1313	0.931
300	49.5	1462	8	1183	0.829
360	50.1	1057	9	1068	1.110
420	50.2	943	10	925	0.973
480	50.2	844	11	818	0.952
540	50	867	12	716	0.831
600	49.8	862	12.9	637	0.750
660	49.7	853	13.3	573	0.672

Table 4
Test in the cooling mode.

Set temperature (°C)	Original power consumption (kWh)	Power consumption with heat recovery equipment (kWh)	Reduction of power consumption (%)
45	4.2	0.1	99
65	10	1.3	87

Table 5
Test in the heating mode.

Set temperature (°C)	Original power consumption (kWh)	Power consumption with heat recovery equipment (kWh)	Reduction of power consumption (%)
45	8.3	0.1	99
65	20.6	5.3	74

4. Conclusions

The air conditioning system we developed had a newly added preheating tank between the air conditioner and the electric water heater. The preheating tank was added to increase the thermal dissipation of the air conditioner and reduce its operating power, thus saving energy. Moreover, the water heated using the heat discharged from the air conditioner was transferred to a water heater to reduce the operating power of the water heater, also saving energy.

An experiment was carried out to observe its power consumption. In the experimental system, several temperature sensors were placed to monitor the water temperature to analyze the heat recovery in the performance test. In this experiment, we assumed that a 7.1 kW (CSPF 5.11 kWh/kWh) (performance factor) air conditioner is used in the family home. According to the experimental result, the heating capacity of the preheating tank was 2135 W and the heating coefficient of the performance was 1.416. When the electric water heater was set to 45 and 65 °C, the power consumption was reduced by about 99% and 74%, respectively. When the power consumption saved by utilizing the heat discharged from the air conditioner was included, the overall power efficiency was extremely high.

The heat recovery efficiency and energy efficiency may differ for different air conditioners, and the calculation methods may also vary accordingly. As indicated by the test result in our experiment, the preheating tank can indeed help save energy and reduce costs by simply modifying users' existing air conditioners.

References

1 Z. Gu, H. Liu, and Y. Li: Appl. Therm. Eng. **24** (2004) 2511. https://doi.org/10.1016/j.applthermalenf.2004.03.017
2 G. Gong, W. Zeng, L. Wang, and C. Wu: Appl. Therm. Eng. **28** (2008) 2360. https://doi.org/10.1016/j.applthermalenf.2008.01.019
3 S. M. Ali and M. A. Theeb: JEASD **26** (2022) 18. https://doi.org/10.31272/jeasd.26.3.3
4 B. K. Roomi and M. A. Theeb: Heat Transfer **49** (2020) 3560. https://doi.org/10.1002/htj.21788
5 G. Malik and P. P. Wankhade: IJSRD **8** (2020) 353. https://ijsrd.com/Article.php?manuscript=IJSRDV8I30279
6 T. Xie: AJPA **6** (2018) 162. https://doi.org/10.11648/j.ajpa.20180606.14
7 Z. Zheng and J. Cao: Energy Rep. **6** (2020) 3472. https://doi.org/10.1016/j.egyr.2020.12.005
8 M. Ramadan, M. Khaled, F. Hachem, A. A. Shaer, K. Chahine, and A. Assi: 2013 25th Int. Conf. Microelectronics (ICM) (2013) 1. https://doi.org/10.1109/ICM.2013.6734976
9 Y. Rongdi, Z. Qin, Y. Dian, and H. Guoping: IOP Conf. Ser.: Mater. Sci. Eng. **439** (2018) 052008. https://doi.org/10.1088/1757-899X/439/5/052008
10 P. J. Jadhav, N. D. Sapkal, M. R. Kale, and V. V. Bhandigare: IJERT **3** (2014) 349.

11 S. Sarangi: Int. J. Sci. Eng. **6** (2015) 1406.
12 I. N. Suamir, I. N. Ardita, and N. I. K. Dewi: Proc. 24th IIR Int. Congr. Refrigeration (Yokohama, Japan, 2015). http://dx.doi.org/10.18462/iir.icr.2015.0096
13 Z. Yu, A. McKeown, Z. H. Ouderji, and M. Essadik: Commun. Eng. **1** (2022) 17. https://doi.org/10.1038/s44172-022-00018-3
14 M. Madhikermi, N. Yousefnezhad, and K. Främling: Advances in Production Management Systems. Smart Manufacturing for Industry 4.0. APMS 2018. IFIP Advances in Information and Communication Technology **536** (2018) 343. https://doi.org/10.1007/978-3-319-99707-0_43

About the Authors

Wen-Ching Hsiao received his B.S. and M.S. degrees from National Chin-Yi University of Technology (NCUT), Taiwan, in 2019 and 2021, respectively. Currently, he is pursuing his Ph.D. degree at the Graduate Institute of Precision Manufacturing, NCUT. He also works at Hongxin Refrigeration and Air Conditioning Co., Ltd. His research interests are in refrigeration, air conditioning, and energy. (hongxin889@yahoo.com.tw)

Raydha Zul Fitriani received her B.S. degree from Politeknik Negeri Bandung, Indonesia, in 2019 and her M.S. degree from National Chin-Yi University of Technology (NCUT), Taiwan, in 2021. Currently, she is pursuing her Ph.D. degree at the Graduate Institute of Precision Manufacturing, NCUT. Her current research interests are in fuel cells and IoT.
(lb011007@gm.student.ncut.edu.tw)

Yean-Der Kuan is a distinguished professor and former chairman (2013/02–2019/01) of the Department of Refrigeration, Air Conditioning and Energy Engineering, National Chin-Yi University of Technology, Taichung City, Taiwan. He received his Ph.D. degree from the Department of Mechanical and Aerospace Engineering at the University of Missouri, USA, in 2000. Currently, he is the director of the Taiwan Society of Heating, Refrigeration and Air Conditioning, the director of the Taiwan Energy Association, the director of the Taiwan Association for Hydrogen Energy and Fuel Cells, and a member of the American Society of Heating, Refrigerating, and Air-Conditioning. His research interests include energy saving and renewable energies and air-conditioning components and systems.
(ydkuan@ncut.edu.tw)