Experimental Study of HFC-32 Split-Type Air Conditioning Systems in Different Indoor Temperatures

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Abstract. Energy management has become one of the main issues in world energy scenario, every energy consumed system should be investigated and developed to increase its performance; especially air-conditioning systems which consumes more than half of the total power required by one air-conditioned building. In agreement with “Montreal Protocol on Substances that Deplete the Ozone layer”, HCFC-22 was stopped its production and its refrigerating system must take another refrigerant; HFC-32 as the working fluid. This work presented information about two 12,000 Btu/h HFC-32 split-type air-conditioning systems with the hermetically sealed swing compressor (so called Inverter compressor) and the hermetically sealed rotary compressor. Both systems were placed in two identical rooms where 3,500 Watt heaters were also set in the middle of the rooms and operated under the constant heat flux condition in two different indoor temperatures; 20 and 22 Celsius. From experiment results in both indoor temperatures, the system with the hermetically sealed swing compressor escorted better energy consumptions, Coefficient of Performances (COPs) and Energy efficiency ratios (EERs) than those of another system with the hermetically sealed rotary compressor by 29.70% and 31.86% at 20- and 22-Celsius room temperature, respectively. The performances of both HFC-32 systems in different indoor temperatures were variant. The double pipe heat exchangers (DPHXs) were also investigated in this work, the COPs of the system with the swing compressor and DPHX were higher than those of another system with the rotary compressor and DPHX by 65.17% and 75.88% at 20- and 22-Celsius room temperature, respectively. The information in this work was used in making decision on the A/C system selection, as well as, the A/C energy management to reduce total A/C power consumption in macro views.

1. Introduction

In countries with hot and humid weather, air-conditioning systems are preferred to adjust living space conditions to be comfortable. Such as in Thailand, the southwest monsoon influence the weather in the rainy EER season which increases the humidity significantly. The air-conditioning systems are operated almost throughout the year in every living space both public and private sectors; i.e. residents, offices, factories, etc. Information presented by Air Conditioning Engineering Association of Thailand (ACAT) reveals that split-type air conditioning systems; in which the condensing unit is installed separately from the fan coil unit, were the most installed system in Thailand [1]. In the energy point of views, the air conditioning systems consume about 60% to 70% of the total energy consumption in any office buildings [2]. Many air conditioning systems are older than 10 years and they have been operated
regularly, however, the older the system the higher energy consumption required to produce the same refrigerating rate. One of the solutions to improve energy consumption rates of the air conditioning systems was replacing the old systems with the new systems but their investment costs were the main issue and only few system owners could afford the new systems; especially in the building with large numbers of old systems. In refrigeration theory for any refrigerators, when refrigerant enters an evaporator at lower temperatures and pressure, the system Coefficient of Performance \((\text{COP})\) is higher. To reduce the refrigerant temperatures and pressure, the refrigerant need to release its heat to another fluid or the refrigerant which enters a compressor.

Ahmadzadehtalatapeh and Yau [3] experimentally investigated the use of double heat pipe based heat exchangers (HPHXs) in a conventional fully fresh air-conditioning (A/C) system. They found that the A/C system equipped with the double HPHX with double eight rows of HPHXs was superior in terms of energy savings. Zhang and Zhang [4] simulated and investigated the heat pipe heat exchangers (HPHXs) in the air handler to decouple dehumidification from cooling to reduce energy consumption by simulations and experiments. They claimed that the dedicated ventilation system combined with heat recovery technology could be efficiently applied to buildings; especially for laboratories in subtropical areas. Monirimanesh et al. [5] presented the effect of using nanofluid in thermosyphon-type heat pipe heat exchangers on energy conservation of an air conditioning system. They claimed to innovate two heat exchangers in-series using TiO\(_2\)/methanol nanofluids with 0–4 wt% concentrations as working fluids. They found that impacts of temperature and relative humidity on the effectiveness of 2 and 4-row heat exchangers were more than 40 % energy saving. Qian et al. [6] reviewed fundamental principles and clarified common features and major differences of regeneration methods for various typical cooling technologies by classifying regeneration methods into three categories. The first group of regeneration methods were recuperative heat exchangers, the second group of regeneration methods were regenerative heat exchangers, and the third group of regeneration methods were internal heat recovery processes, wherein fluid was applied as a regenerator to store/release thermal energy cyclically to pre-cool and pre-heat the solid-state functional materials. Devotta et al. [7] simulated and experimentally evaluated a few selected low global warming potential refrigerants; HC-290, HC-1270, HFC-161, HFC-32, and HFC-1234yf, as alternatives to HCFC-22 for room air conditioners. They evaluated each alternative refrigerant by optimizing heat exchangers, compressors and capillary to get the maximum Energy Efficiency Ratio \((\text{EER})\). Their results showed that HFC-32 gave the \(\text{EER}\) of 3.7 but the discharge temperatures of HFC-32 were high, they suggested that this issue needed special attention in the compressor design. Mota-Babiloni et al. [8] informed that the HFC-32 value of Global warming potential is 677, which is below the HFC regulation limit in refrigeration equipment (750). They concluded that HFC-32 has significantly good heat transfer characteristics and a level of performance that make it acceptable at low condensing temperatures and its performance is very similar to that of R410A across the entire operating range, but they also noted about overly high compressor discharge temperatures. Antunes and Bandarra Filho [9] introduced their experimental investigation of the drop-in alternative halogenated refrigerants processes; HFC-438A, HFC-404A, HFC-410A, HFC-32, HC-290 and HC-1270, for HCFC-22 in a 5-ton refrigeration system. Their experimental setup composed of a semi-hermetic reciprocating compressor, tube in tube heat exchangers and an electronic expansion valve. The main parameters were varied to verify the range and performance of each refrigerant and then compared to the HCFC-22. Their results showed that the natural refrigerants presented the best coefficient of performance and that results for HFCs. We noted
that they found that the HFC-32 remained below in performance compared to HCFC-22. However, they experimentally investigated 5-ton refrigeration system with variable speed compressor.

Pramuanjaroenkij et al. [10] experimentally studied effects of a double-pipe heat exchanger which installed inside a 24,000-BTU/h split-type air-conditioning (A/C) system. Refrigerant inside the suction line (the refrigerant tube between the evaporator and the compressor) received heat from high temperature refrigerant inside the liquid line (the refrigerant tube between the receiver tank and the refrigerant flow control valve). They investigated the A/C power consumptions before and after the heat exchanger installation and they also investigated the A/C power consumption when the system with the heat exchanger coupled with fabric drying application which induced the evaporative heat transfer effect at the condensing unit in 4 different weather conditions; the normal and rainy daytime and night time.

Hoonpong and Skullong [11] experimentally studied on heat transfer and flow friction characteristics in a solar air heater duct roughened artificially with V-shaped baffles. The absorber plate is mounted with V-baffle vortex generators to improve the performance of the solar thermal system for energy saving. The experiment in the test duct having the aspect ratio (AR) of 10 is conducted for Reynolds number (Re) based on the hydraulic duct diameter ranging from 5300 to 22,600. In the current work, V-baffles are placed on the absorber with three relative baffle heights (RB=b/H = 0.1, 0.2 and 0.3) and pitches (RP=P/H = 0.5, 1.0 and 1.5) at a single attack angle (b) of 60°. The experimental results reveal that the use of V-baffle vortex generators yields the considerable increase in heat transfer over the smooth duct around 2.32–4.3 times while the friction loss increases around 4.08–36.9 times. The heat transfer and the friction loss tend to rise for increasing RB but show the reversing trend for increasing RP. The maximum thermal performance for the V-baffle vortex generators around 1.57 is seen at RB = 0.2 and RP = 1.0.

Chingtuaythong and Chokphoemphun [12] experimental and numerical investigation on thermal performance in a uniform wall heat-fluxed tube inserted with 45º inclined oval–pentagon rings (OPR) for turbulent flow region using air as the working fluid. The ring parameters included three blockage ratios (RB=e/D=0.05, 0.10 and 0.15) and four pitch ratios (RP=P/D=1.0, 1.25, 1.5 and 2.0) are introduced. The results from the inserted tube are compared with those from smooth tube alone and show that the OPR can augment the heat transfer rate and friction loss around 2.25–4.86 and 14–100 times over the smooth tube, respectively, depending upon operating conditions. The maximum thermal enhancement factor for using OPR tabulators at about 1.36 is for Re=3900, RB=0.05 and RP=1.0. It is worth noting that the results of numerical study are in good agreement with the experimental ones. The average deviation of both results is within ±7% for Nusselt number and ±10% for friction factor.

They presented that the drying application worked as the small evaporative air cooler behind the condenser and enhanced the A/C EER since the fabric moisture could absorb heat to vaporize itself, this circumstance assisted for the better heat exchanging between the heated air and ambient air because applying the drying setup without installing the heat exchanger could enhance the A/C EERs by 30.23% and 9.09%, in the normal daytime and night time, respectively. However, the heat exchanger could enhance the A/C EERs in all four weather conditions as 23.26%, 13.04%, 69.70% and 63.89% increased EERs in normal daytime, rainy daytime, normal night time and rainy night time, respectively. When they applied the drying setup couple with the heat exchanger, the A/C EERs could be enhanced by 48.48% and 17.5%, only in normal and rainy daytime, respectively. From this investigation, the A/C system with the heat exchanger consumed power less than that of the system without the heat exchanger in
all weather conditions. We noticed that the A/C system with the heat exchanger consumed power significantly less than that of the system without the heat exchanger in the nighttime.

If the air-conditioning system consumes less energy by installing an extra equipment; a heat exchanger, in the system while the system can operate with the same refrigerating rate, this installation should be considered as one of the energy consumption improvement techniques. In this current work, we experimentally investigated effects of the double pipe heat exchanger installation in air-conditioning systems on their energy consumption, Coefficient of Performance (COP) and Energy efficiency ratio EER. There was a limited number of literatures on HFC-32 in Thailand, therefore, this work focused on HFC-32 because HFC-32 was rising its role as the main refrigerant in the split-type air conditioning systems. The air-conditioning systems using HFC-32 as their working fluid with two compressor types were tested; one was the hermetically sealed rotary type and another was the hermetically sealed swing type (so called “Inverter type”), and installed in two identical refrigerating spaces where were controlled at 20 and 22 Celsius, respectively. This work also focused on installing double pipe heat exchangers (DPHXs) into both systems in two different room temperatures, the COPs and EERs of both systems were compared between values before and after the double pipe heat exchanger installations. These effects were important information for many sectors such as air conditioning owners, energy auditors, energy management responsible people, etc. to manage and invest on double pipe heat exchangers for lower energy consumption purpose.

2. Theoretical Study
Split-type air conditioning systems play an important role in residential applications in Thailand. Since the power consumption can be measured from the applications, one important indicator to show performance of any refrigerating systems; which can be calculated from the power consumption or power input, EER and EER can be determined as [10]

$$ EER = \frac{\text{Useful refrigerating capacity}}{\text{Power input}} $$

Where the useful refrigerating capacity is in Btu/hr and the power input is in Watts. Another indicator to show performance of any refrigerating systems is COP and can be determined as [10]

$$ COP = \frac{EER}{3.14188} $$

3. Experimental Study
Two refrigerated rooms were built identically in the same controllable environment and controlled at 20 and 22 Celsius, respectively. Two 12,000 Btu/h split-type A/C systems with different compressor types were installed; the hermetically sealed rotary type and the hermetically sealed swing type. In each experimental setup, there were 4 thermocouples, 2 hygrometers, and 2 power meters connected to one controller as shown in a diagram (figure 1). Four positions of the thermocouples in each setup were in the middle of the room, in front of the return air position of the A/C fancoil unit, in front of the supply air position of the A/C fancoil unit and intake air position of the condensing unit. Two positions of the hygrometers in each setup were in front of the return air position of the A/C fancoil unit and in front of the
supply air position of the A/C fancoil unit while there was one separated hygrometer placed between both condensing units. Then, both systems were operated without any heat loads to test the A/C and measurement systems and their power consumptions, air temperatures and humidity inside the rooms and at the condensing unit were recorded every 10 minutes for total of 24 hours in each of 3 test periods.

After that, two 3,500-Watt heaters were installed in the middle of both rooms (figure 2) and they were set to have the maximum temperature at 37 Celsius to protect them from any overload conditions. Then, both systems were operated with 49,450 Watts of power supplied to both heaters in both rooms while their power consumptions, air temperatures and humidity inside the rooms and at the condensing unit were recorded every 10 minutes for total of 24 hours in each of 3 test periods. Finally, two copper double pipe heat exchangers (DPHXs), type HE 1.0 with the trademark; Danfoss, Denmark, were connected to both systems. Each DPHX was connected to allow hot fluid or high temperature refrigerant inside the liquid line (the refrigerant tube between the receiver tank and the refrigerant flow control valve) to release its heat to cold fluid or refrigerant inside the suction line (the refrigerant tube between the evaporator and the compressor). All mentioned parameters were recorded every 10 minutes for total of 24 hours in each of 3 test periods. All power consumption values were used to evaluate COPs and EERs of both systems in three operating conditions; refrigeration without any heat loads, refrigeration with constant heat load without DPHXs and refrigeration assisted by DPHXs with constant heat load.

**Figure 1.** The diagram of positions; A/C systems, temperature and humidity measurements [11].

**Figure 2.** Heaters which installed inside both rooms.
4. Experimental Results and Discussion
Firstly, the experimental setups; one room with the A/C system utilizing the hermetically sealed rotary compressor and another room with the A/C system utilizing the hermetically sealed swing compressor, both room temperatures were set at 20 and 22 Celsius, respectively. Their measuring sensors were operated, the results of both air conditioning systems without any heat loads were shown in Table 1. In the same condensing unit ambient without any supplementary loads, we noticed that the A/C system utilizing the hermetically sealed swing compressor at 20- and 22-Celsius room temperatures took power less than that of another system by 0.5 and 0.1 average unit different per 24 hours, respectively, the average power consumption taken from three repeating examinations. Since HCFC-22 was depleted and stopped its production, the information of the A/C systems applying HFC-32 as the refrigerant was conducted for both A/C systems; the rotary compressor and the swing compressor, this result reconfirmed that the hermetically sealed rotary compressor consumes more energy than that of the hermetically sealed swing compressor; especially during the motor starting period from the rest mode. Secondly, when the heat load was applied by the 3,500-Watt heater in each room under the constant heat flux condition for 24 hours per period in three repeating tests, the results revealed that the A/C system utilizing the swing compressor used up 7.7 and 7.2 average units per 24 hours at 20 and 22 Celsius, respectively, while the A/C system utilizing the rotary compressor used up 10 and 9.5 average units 24 hours, respectively, the latter consumed more energy than that of the former. We noted from Table 1 that the heat load in the rooms made both A/C systems displaying their performances which were quite different in comparison to the rooms without any loads in the same condensing unit ambient.

Table 1. The power consumption, temperature and humidity values obtained from the A/C systems with the hermetically sealed rotary and the hermetically sealed swing compressors.

| A/C systems          | Conditions                  | Room temperature at 20°C | Room temperature at 22°C |
|----------------------|-----------------------------|--------------------------|--------------------------|
|                      | Energy (kWh) | EER (BTU/hr W) | COP | Energy (kWh) | EER (BTU/hr W) | COP |
| The rotary compressor| 2.50          | -              | -   | 0.70         | -              | -   |
|                      | 10.00         | 15.55          | 4.95 | 9.50         | 16.37          | 5.21 |
|                      | 10.56         | 14.70          | 4.68 | 10.20        | 15.24          | 4.85 |
| The swing compressor | 2.00          | -              | -   | 0.80         | -              | -   |
|                      | 7.70          | 20.17          | 6.42 | 7.20         | 21.58          | 6.87 |
|                      | 6.40          | 24.29          | 7.73 | 5.80         | 26.80          | 8.53 |

Afterwards, the copper double pipe heat exchangers (DPHXs) were installed inside both A/C systems between their liquid and suction lines, then the systems were investigated while the 3,500-Watt heaters were turned on under the same condition as before for 24 hours per period in three repeating tests. In Table 1, the average power consumptions obtained from both systems at 20- and 22-Celsius room temperatures were as; 10.56 and 10.20 units per 24 hours,
respectively, for the system with the rotary compressor and 6.40 and 5.80 units per 24 hours, respectively, for the system with the swing compressor. We noticed that the system with the swing compressor performed better in the same condensing unit ambient and took noticeable power consumption than that of another compressor. We found that the DPHXs played their roles in only the A/C system with the swing compressor under the constant heat load condition as the differences of 4.16 and 4.4 units per 24 hours higher than those of the system with the rotary compressor at 20- and 22-Celsius room temperatures respectively. The A/C systems with the swing compressors installed with and without the DPHX consumed different power consumptions of 1.3 and 1.4 units per 24 hours at 20- and 22-Celsius room temperatures respectively. On the other hand, the A/C system with the rotary compressor installed with the DPHX consumed more power than that of the system without the DPHX. The results taken at 22-Celsius room temperature indicated lower power consumption than the results taken at 20-Celsius room temperature as the refrigeration theory, the higher vaporizing temperature the lower power consumption taken from the same A/C system.

We have analyzed the power consumption in terms of refrigerating performance indicators; \(\text{COP}\) and \(\text{EER}\). From table 1 under the no load condition at 20- and 22-Celsius room temperatures, the \(\text{COP}\)s and \(\text{EER}\)s of the A/C systems with the hermetically sealed swing and hermetically sealed rotary compressors could not be calculated as shown on the table because there was no heat released from the heaters, “Useful refrigerating capacity” in equation (1) could not be substituted. When the 49,450-Watt load was applied to the A/C system with the hermetically sealed swing compressor at 20-Celsius room temperature, the \(\text{COP}\) and \(\text{EER}\) of the A/C system were higher than those of the A/C system with the hermetically sealed rotary compressor by 1.47 and 4.62, respectively, the higher percentage was 29.70% obtained from 1.47x100/4.95 and, at 22-Celsius room temperature, by 1.66 and 5.21, respectively, the higher percentage was 31.86% obtained from 1.66x100/5.21. After the DPHXs were installed in the A/C system with the hermetically sealed swing compressor at 20-Celsius room temperature under the same load condition, the \(\text{COP}\) and \(\text{EER}\) of the A/C system were higher than those of the A/C system with the hermetically sealed rotary compressor by 3.05 and 9.59, respectively, and by 3.68 and 11.56, respectively, at 22-Celsius room temperature. The A/C system with the swing compressor and DPHXs at 20- and 22-Celsius room temperatures achieved about 65.17% and 75.88% higher \(\text{COP}\) and \(\text{EER}\) than those of the system with the rotary compressor. To fulfill our purpose in introducing DPHXs for the A/C energy management, the \(\text{COP}\)s of the A/C systems with the swing compressor under the constant heat load condition with and without the DPHX performing were averaged as 20.40% and 24.16% at 20- and 22-Celsius room temperatures, respectively, the higher performances were found when the A/C System with the swing compressor was equipped with the DPHX. Therefore, this work found that the DPHX enhanced the performances of the A/C system with the swing compressor.

Additionally, to provide another viewpoint of energy management, the investment cost should be reviewed. When the building owner decides to replace new A/C systems with the swing compressors over the rotary compressors in this building, the saving per year in replacing the A/C systems with the swing compressors at 20- and 22-Celsius room temperatures can be calculated as 2.3 units per day x 365 days x 7 Baht per unit (assumed average energy cost) which equals to 5,876.50 Baht per year. If the owner considers total cost of the new A/C systems with the swing compressors, the owner must prepare about 20,000 Baht per system, the simple payback time without considering the future worth of the investment is 3.4 years, the amount of years may make the owner hesitates to do so. If one focuses on installing the DPHXs for the HFC-32 A/C systems with the swing compressors, the saving per year in connecting DPHXs at
20-Celsius room temperature can be calculated as 1.3 units per day x 365 days x 7 Baht per unit (assumed average energy cost) which equals to 3,321.50 Baht per year. The cost of DPHXs and their installation is about 7,000 Baht per unit, the simple payback time is 2.11 years, the amount of years can encourage the owner to consider the DPHX installation.

5. Conclusions
In the energy management, enhancing performance of refrigerating systems is one of the important issues to be considered. We would like to introduce interesting roles of compressor and heat exchangers into split-type air-conditioning systems. Two 12,000 Btu/h split-type A/C systems in this current work were connected with two different types of compressors; the hermetically sealed rotary type and the hermetically sealed swing type. The copper double pipe heat exchangers (DPHXs) were chosen to experimentally investigate in this work. There were two identical refrigerating spaces where two 3,500-Watt heaters and two A/C systems were placed, the heaters were operated under the constant heat load in both rooms. As the heat load applied, the system with the rotary compressor consumed more power than that of the system with the swing compressor by 2.3 more units per 24 hours at 20- and 22-Celsius room temperatures. The swing compressor performance expressed their potential to replace the rotary compressor. As the heat load also applied, the DPHXs only enhanced the performance of the system with the swing compressor, the DPHXs enhanced the COPs and EERs of the system with the hermetically sealed swing compressor as 20.40% and 24.16% at 20- and 22-Celsius room temperatures higher COP than those of the system with the rotary compressor. Noticeably, the double pipe heat exchanger has drawn our attention to apply it in the current split-type A/C system since the DPHX investment cost is acceptable, as well as, the DPHX enchantment on the system was outstanding. One more important point of views in this work was the information of the HFC-32 split-type systems with the hermetically sealed rotary compressor and the hermetically sealed swing compressor which were two choices in replacing current HCFC-22 split-type systems. According to “Montreal Protocol on Substances that Deplete the Ozone layer”, production lines of HCFC-22 itself and its split-type systems were stopped, the HFC-32 split-type systems were the proper choices to replace the HCFC-22 systems. The HFC-32 split-type system with the hermetically sealed swing compressor showed its potential. This important information of the DPHX enhancement on the HFC-32 system performance was presented and emphasized the use of DPHX in the energy management in the updated systems.

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