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Experimental Investigation of Using Liquid Suction Heat Exchanger with Condensed Cold-Water on the Performance of Air Conditioning System

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ABSTRACT

This paper reports experimental investigation of using liquid suction heat exchanger (LSHX) with condensed cold-water (LSHX-CW) on the performance of a split type room air conditioning. To this end, we used a large room of a residential house of 64 m^3 equipped with a 2-tons conventional commercial split-type air conditioner fitted with R22. The coaxial design of LSHX-CW allows to exchange heat between the vapor and liquid refrigerants in the center part and condensed water and the warm liquid refrigerant on the outer part. LSHX-CW was well insulated on the outside to reduce heat transfer with ambient. The air conditioning was tested several times for three scenarios namely, conventional system, system with LSHX alone and LSHX with condensed water LSHX-CW. Experimental results showed that the use of LSHX-CW improved the performance of air conditioning noticeably when compared to the use of LSHX alone. The maximum LSHX-CW effectiveness was 7.67%. The pressure discharge line and electricity consumed decreased by 8.23% and 9.40% respectively.

1. INTRODUCTION

Since 1980s and due to the high economic growth and affordable cost of mechanical cooling systems, especially split-type units, an important increase of units sold worldwide was registered. In Thailand, modern residences and buildings are now designed with air conditioning systems to achieve thermal comfort. Occupants turn to use them extensively that increased electricity consumption in the domestic considerably. In tropical countries, electrical energy consumption used for air conditioning system represents accounts for 60–70% of the total electricity consumption, Pasek and Suwono [1] in Indonesia, and Chirarattananon et al. [2] in Thailand.

The use of heat exchangers is widely used in different mechanical systems to recover cold energy and/or waste heat in order to improve systems efficiency and save energy, however, currently the energy-saving is not high. During the last three decades, extensive efforts were paid by researchers, engineers and professionals and various concepts to improve the performance of air conditioning systems were introduced worldwide. The effect of refrigerant combinations on performance of a vapor compression refrigeration system and dedicated mechanical sub-cooling were reported in the studies [3-9]. Inserting nanoparticles in refrigerant or in compressor lubricant to enhance the heat transfer process were also suggested in the studies [10-12]. The use of a cooling water loop to improve thermal performance of air conditioning system was investigated in the study reported in the studies [13]. Investigation of the effect of the condenser subcooling on the performance of vapor compression systems was published in the studies [14-16]. The use of liquid-suction heat exchanger (LSHX) received considerable attention and several numerical and experimental studies were published [17-23]. A recent publication [24] investigated room air conditioning performance using liquid-suction heat exchanger retrofitted with R290.

In general, all above mentioned references showed reasonable improvement, however, general applications are still limited to various reasons including practical and technical issues, efficiency and cost effectiveness. The main finding regarding the application of liquid-to-suction heat exchangers is that the performance depends closely on the refrigerant used. Klein et al. [18] reported that liquid suction heat exchangers are useful for refrigeration systems using R507A, R134a, R12, R404A, R290, R407C, R600a, and R410A. However, they are not useful for systems with R22, R32, or R717.

In Thailand, considerable amount of split type air conditioners that are sold are still use R22. Manufacturing technical advances and law enforcement and labeling has helped to improve their thermal performance. However, further improvement is till needed for the country to alleviate the burden of peak load. More especially, reducing electricity consumption of already installed split type air conditioners is an interesting challenge that would profit the economy and the country.

Due to Thailand location in the tropical zones and high ambient humidity year-round [25], significant amount of condensed cold water is generated when operating air conditioning. For instance, with a 1-ton split type air conditioner, this amount varies between 15 to 35 liters a day. Obviously the more humid is the day, the higher the amount of condensed water. Actually, this condensed water is drained out of the residence directly to the drainage domestic water system. In this paper, we propose to make use of this available condensed cold water for improving the performance of a conventional liquid-to-suction heat exchanger (LSHX). This concept is referred to as liquid-to-suction heat exchanger with condensed cold water (LSHX-CW). Its effectiveness and effect on the performance of a split-type air conditioning system using R22 refrigerant will be analyzed experimentally.

2. METHODOLOGY

2.1 Liquid-suction heat exchanger with condensed cold water (LSHX-CW)

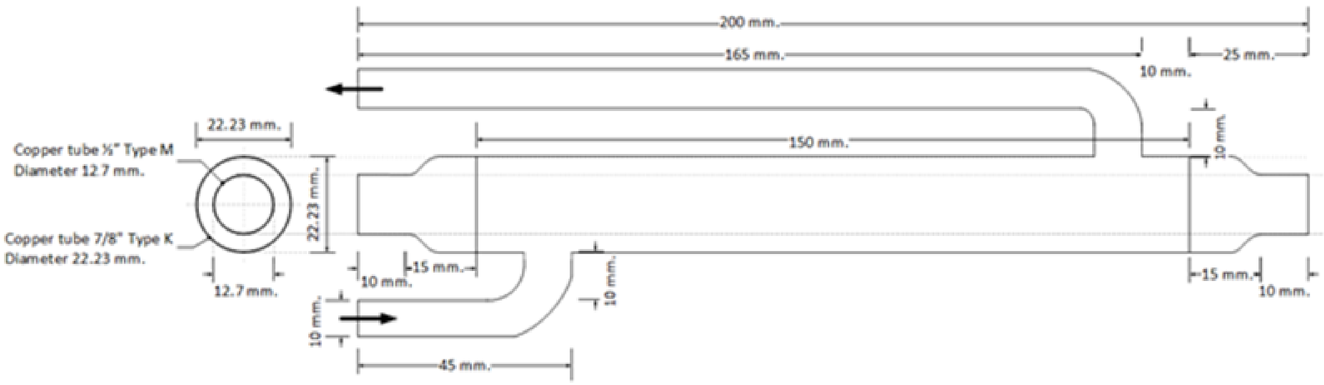
Figure 1 shows a schematic diagram and dimensions of the proposed liquid-suction heat exchanger with condensed cold water (LSHX-CW). A coaxial design concept is adopted to exchange heat between the vapor and liquid refrigerants in the center part and condensed water and the warm liquid refrigerant on the outer par. The cool refrigerant leaving the evaporator is admitted at the top of inner pipe (point 3, Figure 2) and leaves at the bottom (point 4, Figure 2) towards the compressor. Whereas the warm liquid refrigerant leaving the condenser (point 6, Figure 2) enters at the top of LSHX (point 1, Figure 2) flow down to exchange heat then exit at the bottom and flow upward leaving the LSHX-CW at the top (point 2, Figure 2) towards the evaporator. The condensed cold water at the evaporator circulating by gravity enters the LSHX-CW at the lower inlet of water tank and leaves at the higher outlet as schematically shown in Figure 1(c). The other opening at the lower part of the water tank is to draw water when required. The LSHX-CW was well insulated on the outside to reduce heat transfer with ambient. For simplicity of manufacturing and assembly, the liquid-suction heat exchanger was made using copper pipes whereas the small water reservoir tank used stainless, for dimensions refer to the Figure 1. The LSHX-CW was fitted to the air conditioning pipe lines by brazing and well insulated. The volume of water that can be retained in the water tank is about 0.42 litre. Figure 1(c) shows a photograph of the assembled LSHX-CW [26].

2.2 Thermodynamic analysis

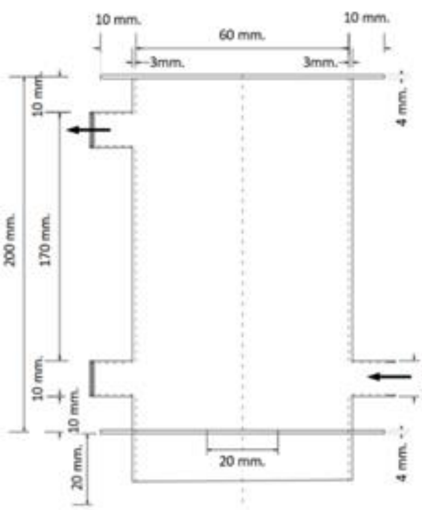
Figure 2 gives a schematic diagram of the split type air conditioner equipped with LSHX-CW. In order to assess the performance of our LSHX-CW, we consider three cycles for operating the air conditioner. The operation of these cycles is described below:

- System I (Basic cycle): Open valve V1 and close valves V2 and V3
- System II (Cycle with LSHX): Close valve V1 and open valves V2 and V3

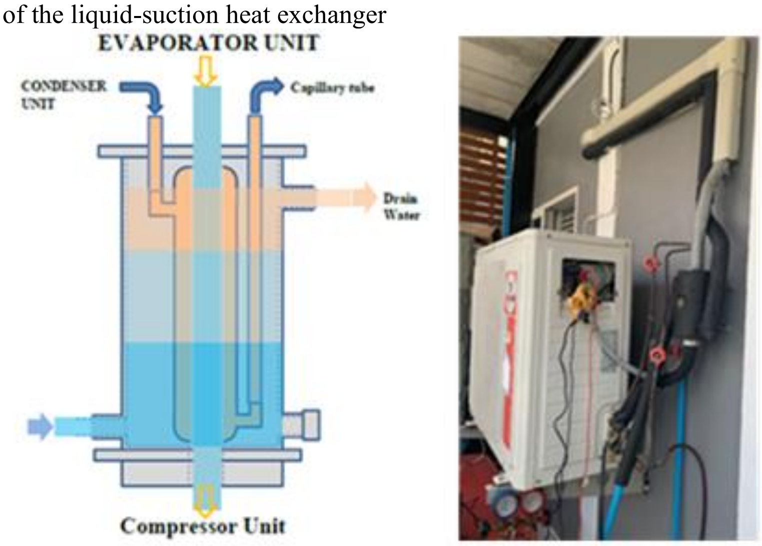
System III (Cycle with LSHX-CW): Close valve V1 and open valves V2 and V3 and circulate condensed cold water through the LSHX-CW.



(a) Dimensions of the liquid-suction heat exchanger



(b) Dimensions of condensed water tank



(c) The assembled LSHX-CW

Figure 1. Schematic and dimensions of the liquid-suction heat exchanger (a) with condensed cold-water tank LSHX-CW (b,c)

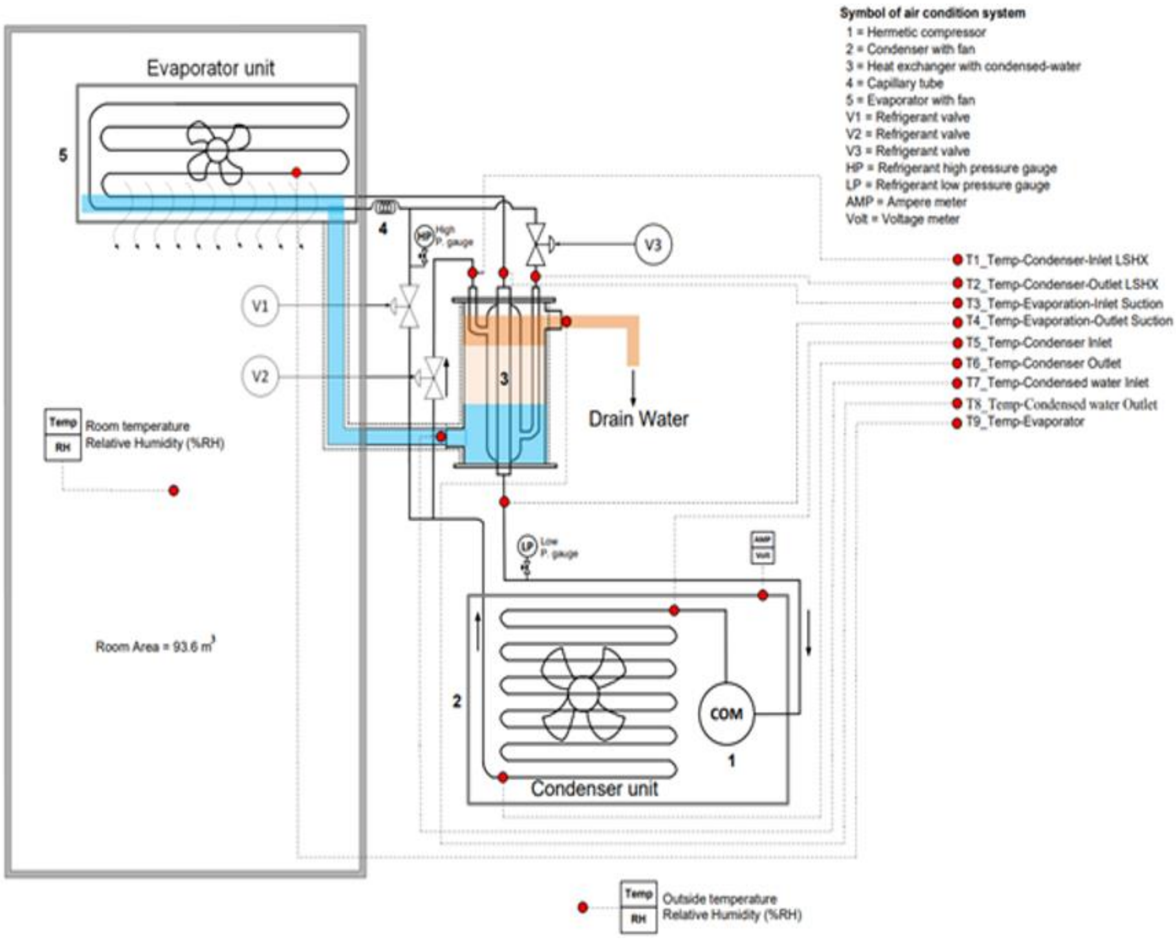
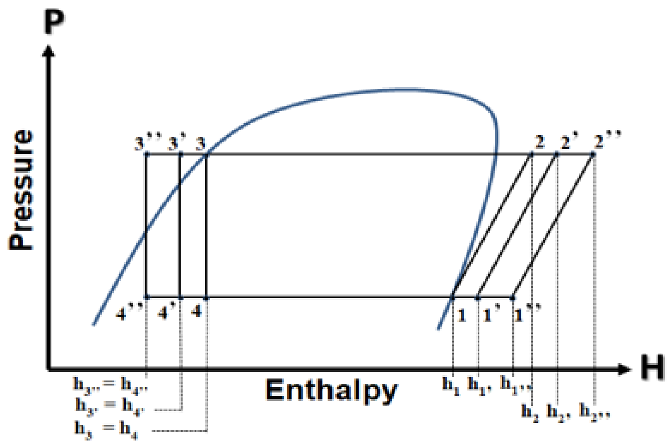
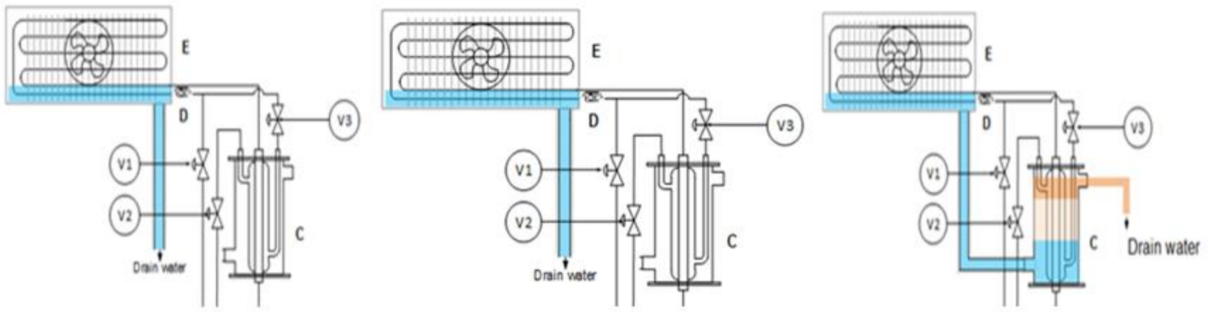


Figure 2. Schematic diagram of the split type air conditioner with LSHX-CW



(a) Pressure-enthalpy diagram of the three systems considered



System I: Basic cycle System II: Cycle with LSHX System III: Cycle with LSHX-CW

(b) Schematic of the three systems considered

Figure 3. Pressure-enthalpy diagram and schematic of the three systems considered

Figure 3 shows the pressure-enthalpy diagram of the vapor compression refrigeration cycle for the three systems considered [24]. In the basic cycle, point 1 and 3 are actually saturated vapor and liquid respectively. When LSHX is used, the hot liquid leaving the condenser is cooled by the vapor coming from the evaporator.

Then point 3 is cooled to point 3' and point 1 being heated to point 1'. When condensed water is allowed to circulate, LSHX-CW cycle, additional cooling and heating is expected and point 3' moves to 3" and point 1' to point 1''respectively.

The effectiveness of the liquid-suction heat exchanger LSHX depends closely on the available surface area for heat exchange and flowing rates of fluids. Klein et al. [18] introduced as simple definition of LSHX effectiveness as the ratio of the actual to the maximum possible heat transfer rates. In this paper, the effectiveness is calculated by the Eq. (1) as proposed by Klein et al. [18]:

$$\varepsilon = \frac{(T_4 - T_3)}{(T_1 - T_3)} \tag{1}$$

where, the numeric subscripts of measured temperatures T values correspond to the locations indicated in Figure 2.

2.3 Experimental procedure

In order to investigate the performance of our proposed concept, we used a large room of a residential house 3m width, 8m length and 2.6m high. The room is equipped with a conventional commercial split-type air conditioner (Brand name: Central air, model number CFW-IF25). The technical specifications are given in Table 1. It has been installed since several years. The indoor and outdoor units are connected with refrigerant pipe lines of 5 m approximately.

Table 1. Specifications of the split-type air conditioner

Item	Unit	Information
Power Source		220V / 1P / 50Hz
Cooling Capacity	Btu/h	25,927.45
Running Current	Amps	10.16
Power Consumption	Watts	2228.60
EER	Btu/watts	11.63
Indoor unit dimensions	mm	901 x 381 x 25.4
Outdoor unit dimensions	mm	980 x 790 x 440
Refrigerant	-	R22

Various parameters were measured using different equipment at different locations as depicted in Figure 2. Thermocouples type K accuracy ±0.75% connected to a Wecon V=Box S-4G data logger were used to measure temperatures at different positions as follows:

- Point 1: Temperature of the refrigerant coming from the condenser at the inlet of LSHX
- Point 2: Temperature of the refrigerant at the outlet of LSHX going to the evaporator
- Point 3: Temperature of the refrigerant coming from the evaporator suction line at the inlet of LSHX Inlet
- Point 4: Temperature of the refrigerant at the outlet of LSHX going to the compressor
- Point 5: Temperature of the refrigerant leaving the compressor (condenser inlet)
- Point 6: Temperature of the refrigerant leaving the condenser (condenser outlet)
- Point 7: Temperature of the evaporator

Indoor and outdoor temperature and relative humidity were measured using portable temperature and relative humidity data logger TENMARS model TM-305U: RH accuracy ±3.0%(20-80%), ±5.0%(<20%,>80%), temperature accuracy ±0.6°C(-20-50°C). Measured data were recorded every minute. The R22 refrigerant low and high pressures are measured using commercial mechanical manifold gauges set (Imperial Manifold Gauge 400 Series, accuracy±3%). The electricity consumption of the air conditioner is measured using clamp on sensor 9661(±0.3%) connected to a digital data logger HIOKI power meter 3169-20 model (V range 150 V to 600 V, accuracy AC±0.2%, AC current ±0.2%). It was recorded at 2-minutes intervals.

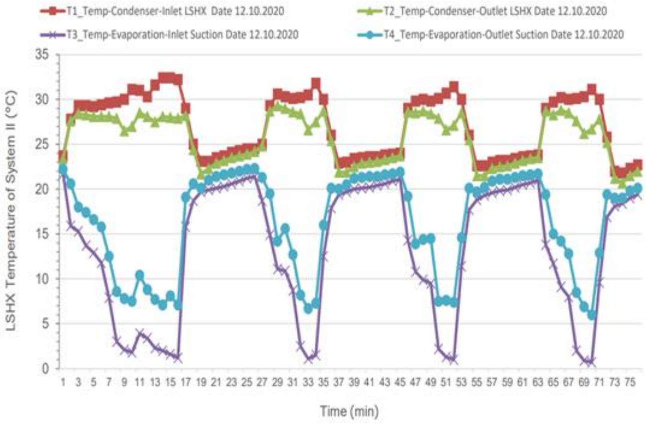
3. RESULTS AND DISCUSSION

First, we conducted a preliminary study to assess the temperature and flowrate of condensed cold water by operating the air conditioner during different days with different ambient conditions and several time periods. The air conditioning was set at 25°C for all systems considered. At the beginning, the temperature of condensed water measured at point 7 decreased continuously from the initial temperature of water retained in the tank then it oscillated between 12 to 14°C. While the amount of condensed cold water varied between 17.8 to 50.0 grams per minutes; with an average of 34.74 g/min. Obviously decreasing the air conditioning setpoint temperature below 25°C will increase the condensed water flowrate and decrease its temperature, however, this in turn will consume more electricity. In this study, tests were repeated several times for each system considered through several days and times periods. Representative and average data are reported and analyzed. Although ambient conditions were not exactly the same, subjective comparison and conclusion could be made using different parameters as it will be discussed in this section.

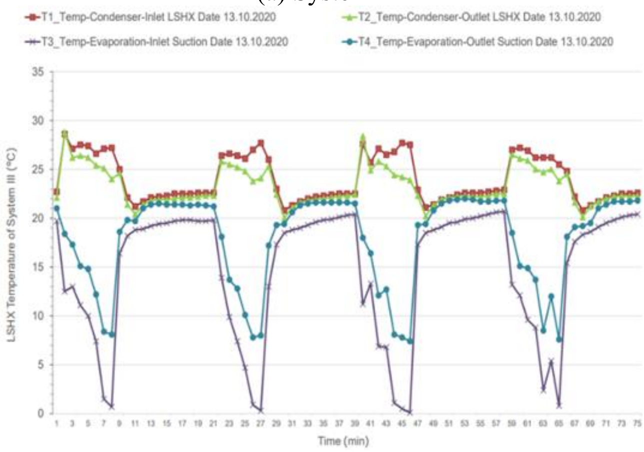
3.1 Effectiveness of LSHX with condensed cold water

The measured variations at the inlet and outlet of the LSHX of the suction line and liquid line are shown in Figure 4 for the air conditioner operated both without (system II, Figure 4.a: LSHX) and with condensed cold water (system III, Figure 4.b: LSHX-CW).

It can be observed that the effectiveness of LSHX (system II) is practically negligible and agrees well with published data [3]. With LSHX-CW (system III), the temperature of liquid line at the inlet of LSHX-CW, point 1, is lower than that of LSHX and remained below 30°C. It is evident that this is due to the continuous flow of condensed cold water through the water tank which improves LSHX efficiency for transferring heat between the liquid and vapor refrigerants. As a consequence, all other measured points were lower than those measured at the same positions with LSHX. Figure 5 shows a comparison between average effectiveness calculated using data from four series of tests of the LSHX and LSHX-CW. The fluctuation of effectiveness follows the operating of air conditioning system. Also, LSHX-CW effectiveness increases with time as water tank is continuously replaced by the cold condensed water and smooth operation of the air conditioning. Therefore, it is well demonstrated that the use of LSHX-CW lead to a non negligeable performance improvement. Under test conditions, the maximum calculated effectiveness is 7.67%.



(a) System II



(b) System III

Figure 4. Temperatures variations at the inlet and outlet of the LSHX of the suction and liquid lines with and without condensed cold water (a) LSHX and (b) LSHX-CW

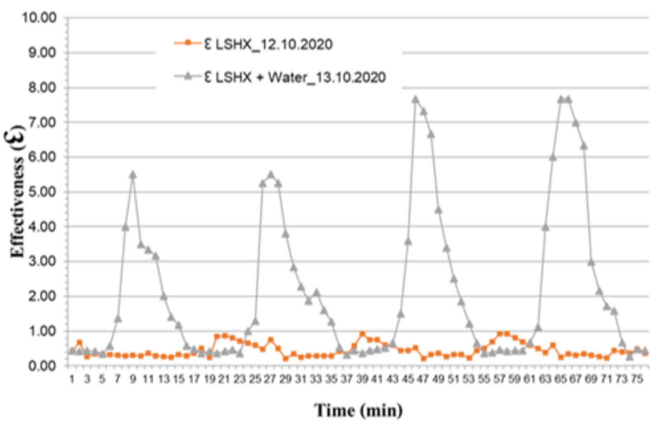


Figure 5. Comparison between the effectiveness of the LSHX with and without condensed cold water

3.2 Fan coil temperature

The measurement of the fan coil temperature of the evaporator is another simple indicator of the air conditioner performance especially when using the same air conditioner for different operation cycles as in it is the case in this paper. Figure 6 shows a comparison between the measured temperature of fan coil (point 9) for the three systems considered. It is well demonstrated that adding the LSHX-CW improves the air conditioner performance as lower fan coil temperature is always observed.

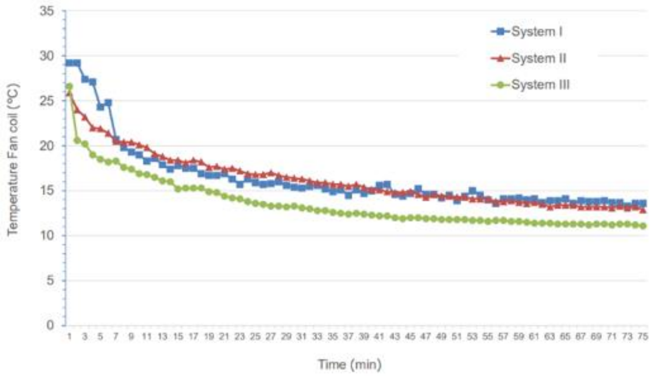


Figure 6. Comparison between the temperature of fan coil of the evaporator for the three systems considered

Table 2. Average data of measured pressure at suction and discharge lines and electrical consumption of the air conditioning for the different systems considered

Table 2a. Pressure Suction Line (PSI)

System	Average	S.D.	%
I (Conventional)	63.00	2.32	-
II (With LSHX)	63.13	1.76	-0.21
III (With LSHX-CW)	64.13	2.86	-1.58

Table 2b. Pressure Discharge Line (PSI)

System	Average	S.D.	%
I (Conventional)	156.23	3.73	-
II (With LSHX)	149.07	1.90	4.59
III (With LSHX-CW)	136.80	3.25	8.23

Table 2c. Electrical Consumption (Watt)

System	Average	S.D.	%
I (Conventional)	2,055.13	33.55	-
II (With LSHX)	1,997.29	37.63	2.80
III (With LSHX-CW)	1,861.00	32.27	9.40

3.3 Performance

Table 2 summarizes the average data of measured pressure at suction and discharge lines and electrical consumption of the air conditioning for the different systems considered. It can be observed that the average measured pressure at the discharge line of system III with LSHX-CW is significantly lower compared to the other two systems whereas that at the suction line is slightly higher. This is due the use of condensed water that improved the subcooling compared to the LSHX alone and limited the superheating. As a consequence, the compressor work is reduced and less electricity is consumed. The corresponding average measured electricity decrease of the air conditioning due the use of LSHX-CW is 9.40%, relatively similar to the precent decrease of pressure at the discharge line, when compared to the conventional system. With LSHX alone, this saving is practically negligible.

Table 3 shows a comparison of average values of coefficient of performance (COP) and energy efficiency ratio (EER) of the air conditioning for the three systems considered. The application of LSHX alone to our air conditioning fitted with R22 didn’t bring any significant improvement. This indicates that the increment of subcooling and superheating are practically similar. This finding agrees well with published data [18]. However, the adoption of LSHX-CW can achieve noticeable improvement meaning that the increment of subcooling is significantly higher compared the superheating. This finding is extremely satisfying with respect to our objective to use LSHX-CW to retrofit installed air conditioning.

Table 3. Comparison of average values of coefficient COP and EER with the percent of improvement for the three systems considered

System	COP	EER (BTU/Watt)	%
I (Conventional)	1.77 ± 0.06	6.04± 0.21	-
II (With LSHX)	1.81 ± 0.05	6.19± 0.18	2.42
III (With LSHX-CW)	1.96 ± 0.05	6.70± 0.15	9.85

4. CONCLUSIONS

Experimental investigation of the performance of a 2-tons split type room air conditioning fitted with R22 installed in a large room of a residential house of 64 m^3 and equipped with a liquid suction heat exchanger (LSHX) with condensed cold-water (LSHX-CW) are reported for different cycles of air conditioning operation. LSHX-CW coaxial design allows to exchange heat between the vapor and liquid refrigerants in the center part and condensed water and the warm liquid refrigerant on the outer part. It was found that the average measured pressure at the discharge line of system with LSHX-CW is significantly lower compared to that with LSHX alone and conventional air conditioning. The maximum calculated effectiveness of LSHX-CW is 7.67% and the average measured electricity saving of the air conditioning is 9.40%. Therefore, the proposed LSHX-CW is an interesting alternative especially appropriate for hot and humid climates to retrofit existing air conditioning as high amount of condensed water is generated continually.

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