TEST OF CONDENSATE SUBCOOLING COILS FOR AIR CONDITIONERS

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ABSTRACT

A two-ton compact air conditioner was developed for a shelter environmental control application. The cooling capacity requirement was 2 tons at an outdoor ambient temperature of 110°F (43°C) and an indoor dry-bulb temperature of 80°F (27°C), a wet-bulb (WB) temperature of 67°F (19°C), and a sensible heat ratio of 0.8. A serpentine coil was installed at the bottom of the drain pan to take advantage of cool condensate for improved cooling capacity. The coil was arranged in the prototype unit such that three different condensate reuse options can be tested by either connecting the coil to the condenser exit or compressor inlet (desuperheating) or by cutting the coil completely out of the system operation. The added coil did increase the cooling capacity by 5.5% to 8.8% and lower the discharge pressure by 5 to 10 psi (35 to 70 kPa) at a 95°F (35°C) outdoor temperature compared with the test data when the coil was not used at all. The coil worked best when it was used as a subcooling coil for refrigerant liquid. This paper presents some quantitative test results for the performance of the unit when the additional coil was used as a subcooling coil or a desuperheating coil or not used at all.

INTRODUCTION

Boosting the capacity of an air conditioner has conventionally been accomplished by incorporating a liquid-suction-line heat exchanger to increase refrigerant subcooling. This method will, however, also increase the suction gas superheat. The condensate from the evaporator of an air conditioner can also be used to boost the cooling capacity without modification of, or adverse effects on, any component. For most air conditioners, the condensate is either drained out or scooped up by the condenser fan and thrown onto the condenser coil. While the latter design did take advantage of the condensate, more can be accomplished if a coil is added at the bottom of the drain pan. The added coil can be used to further subcool the liquid or to desuperheat the vapor.

In this project, a two-ton compact air conditioner was developed. One of the requirements was that the unit be small and lightweight. However, the unit needed to be rated at a 110°F (43°C) outdoor temperature and a 80°F (27°C) dry-bulb (DB) indoor temperature and have a 0.8 sensible heat ratio, which was much more than two-ton capacity at ARI rating conditions. Therefore, a unit was built to have a 2.25- to 2.5-ton capacity at the ARI-rated operating conditions. To boost the cooling capacity, a coil was added at the bottom of the drain pan. The unit was then tested both at ARI-rated indoor conditions (80°F [27°C] DB and 67°F [19°C] WB) and at indoor conditions required by the specifications, with the outdoor temperature varied from around 75°F to 110°F (24°C to 43°C). This paper discusses how the added coil affects the cooling capacity and performance of the unit. The added coil could be connected to the compressor exit (desuperheating) or condenser exit (extra subcooling) or could be eliminated completely. This arrangement enabled us to study the effects of the added coil by comparing the test results of all three coil connections.

It was found that the added coil did increase the cooling capacity by about 5% to 10% in the outdoor temperature range variation mentioned above and lowered the compressor discharge pressure if used for extra subcooling. When the coil was used as a desuperheater, the cooling capacity still increased, but the head pressure also increased.

TEST SETUP

Prototype Unit

Figure 1 shows the schematic of the prototype unit. Six valves were added to control the application of the added coil. A turbine meter is connected to the liquid line for refrigerant mass flow rate measurement. Thermocouples and pressure transducers were used to measure temperature and pressure at various locations, as shown in the schematic. The added copper coil placed at the bottom of the drain pan is 0.3125 in. (0.8 cm) in outside diameter and 8 ft (2.4 m) long.

Airflow Rate Measurements

For both indoor and outdoor airflow rate measurements, ductworks were connected to the indoor inlets and outlets of the fans. Two variable-speed fans were added to the ductworks to compensate for the pressure loss caused by the ductworks. Average-velocity heads were measured for the volumetric flow rate calculation. Figure 2 shows the schematic of airflow rate measurements.

Evaporator Inlet and Exit Air Dew-Point Measurements

Two dew-point hygrometers were used for indoor evaporator inlet and exit air dew-point measurements. With measured dry-bulb temperatures, relative humidities and wet-bulb temperatures can be calculated. From that information, latent and sensible loads can be calculated. All tests were performed in a two-room environmental chamber, with one room to simulate indoor operating conditions and the other to simulate outdoor conditions.

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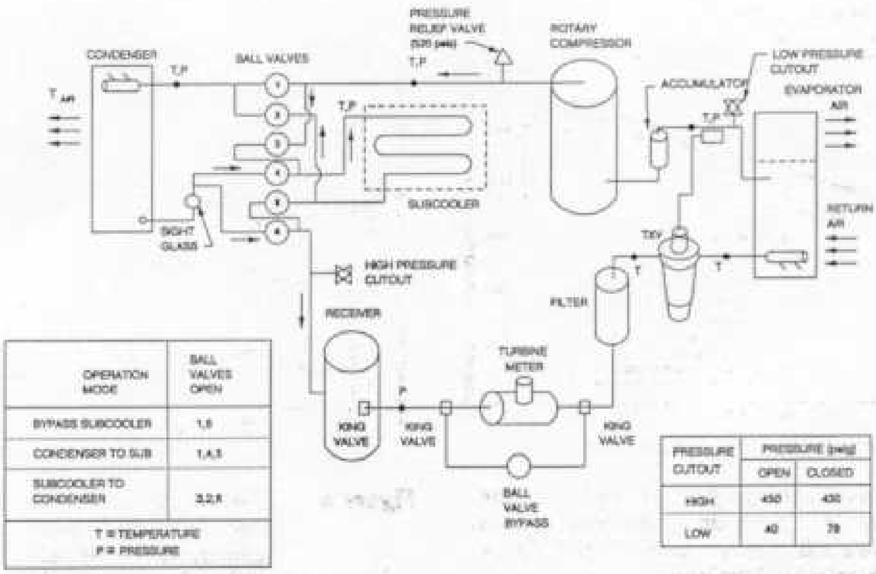

Figure 1 Schematic of prototype unit and refrigerant-side test setup

TEST RESULTS AND DISCUSSION

Figure 3 shows the cooling capacity as a function of outdoor ambient temperatures with indoor conditions maintained at 80°F DB and 67°F WB (52% relative humidity [RH]). The base run (for which the added coil was not in use) has the lowest cooling capacities at all outdoor temperatures. At a 110°F (43°C) outdoor temperature, the base run has a cooling capacity of 25,200 Btu/h (7.38 kW), and the added coil used for extra liquid subcooling has the highest cooling capacity, 27,200 Btu/h (7.97 kW). The added coil increased the cooling capacity by 2,000 Btu/h (0.59 kW). The desuperheating coil has a capacity between those two at 26,400 Btu/h (7.74 kW). The cooling capacity difference decreases as outdoor ambient temperature decreases. At an 80°F (27°C) outdoor temperature, the capacity gap decreased to 1,000 Btu/h (0.29 kW). When the indoor relative humidity was lowered to 37%, the unit operated with a sensible heat ratio of 0.8. The cooling capacity was drastically reduced for all three cases, as shown in Figure 4. At an outdoor ambient temperature of 110°F (43°C), the base run capacity dropped to 23,200 Btu/h (6.80 kW). Again, the additional coil used as a subcooler had the highest cooling capacity at 25,600 Btu/h (7.50 kW), a 10.3% difference. With the desuperheating coil, the capacity is 24,700 Btu/h (7.24 kW). These test results indicated that adding a coil at the bottom of the drain pan did increase the unit's cooling capacity.

Figures 5 and 6 show the discharge pressure as a function of outdoor ambient temperature with two sets of

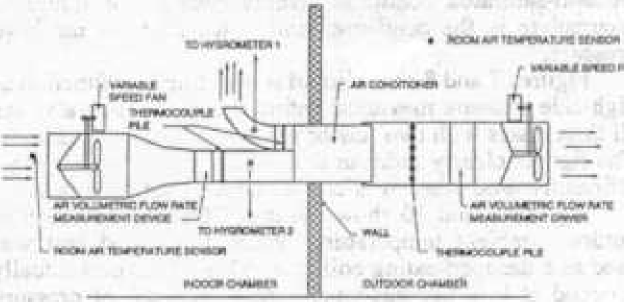

Figure 2 Schematic of air-side test setup

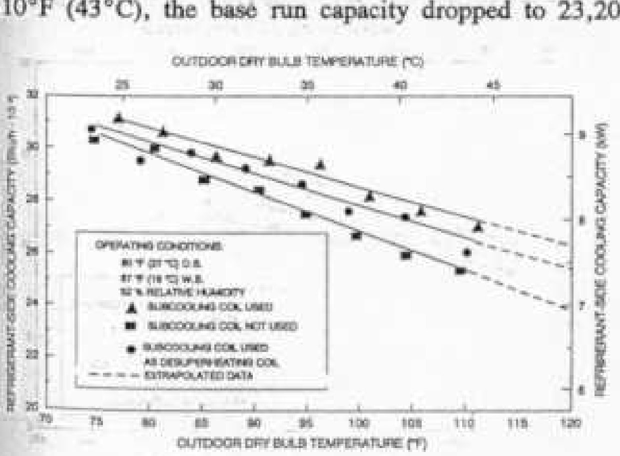

Figure 3 Refrigerant-side cooling capacity as a function of outdoor ambient temperature with indoor at 80°F (27°C) dry-bulb and with 52% relative humidity

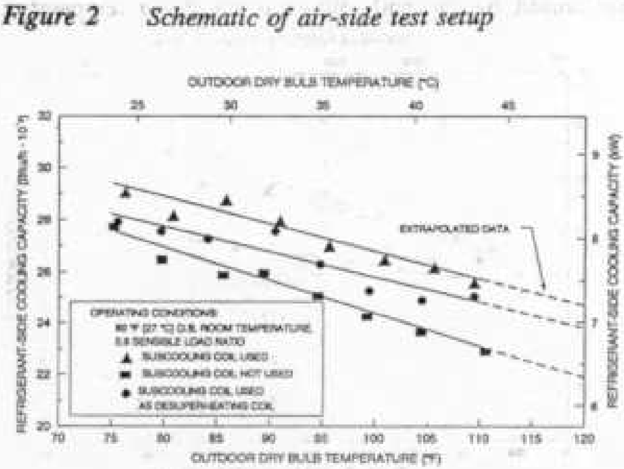

Figure 4 Refrigerant-side cooling capacity as a function of outdoor ambient temperature with indoor at 80°F (27°C) and with a 0.8 sensible load ratio

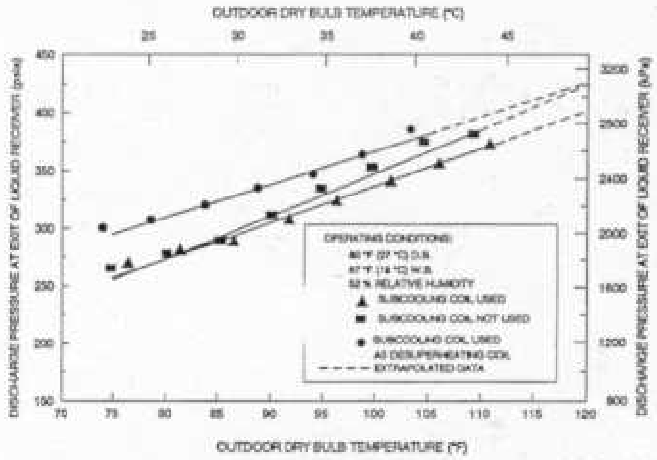

Figure 5 *Compressor discharge pressure before expansion valve as a function of outdoor ambient temperature with indoor at 80°F (27°C) and with 52% relative humidity*

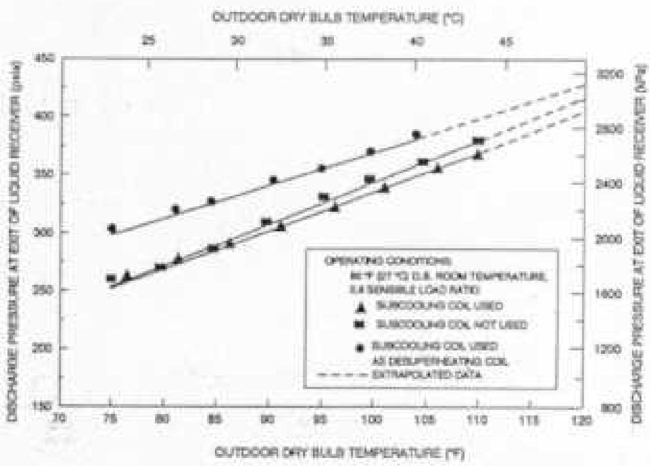

Figure 6 *Compressor discharge pressure before expansion valve as a function of outdoor ambient temperature with indoor at 80°F (27°C) and with a 0.8 sensible load ratio*

indoor operating conditions. The added coil that was used as a desuperheater had the highest discharge pressure, and the added coil that was used as a subcooler had the lowest pressure. When the indoor relative humidity was changed to 37%, the discharge pressure changed very little, as shown in Figure 6. One of the reasons for the high head pressure in desuperheating operation is that the pressure drop, when highly superheated vapor goes through the desuperheater coil, is higher than when the same coil is used as a subcooling coil. Another reason could be that the vapor went through the desuperheater and came out in close-to-saturated condition, which caused the liquid to accumulate in the condenser and, thus, increase the head pressure.

Figures 7 and 8 show liquid subcooling as a function of high-side pressure measured before the expansion valve for all three cases with two sets of indoor operating conditions. The figures clearly indicate that the additional coil is most efficiently used when it is connected as a subcooling coil.

Figures 9 and 10 show the unit COP as a function of outdoor ambient temperature. When the added coil was used as a desuperheating coil, the COPs of the unit actually dropped at low ambient temperatures because of pressure loss caused by the coil. When the ambient temperature increased, the unit COPs were almost identical to those obtained without the coil. When the coil was used as the subcooling coil, the COPs were the highest.

CONCLUSION

A two-ton subcompact air conditioner was built and tested. An additional coil was placed at the bottom of the drain pan so that the cool condensate from the evaporator could be utilized to improve the cooling capacity. The coil was arranged in such a way that it could be connected to the condenser exit to further subcool liquid refrigerant or to the condenser inlet to desuperheat vapor refrigerant from the compressor, or it could be taken completely out of the system operation. After testing the system using a wide range of outdoor ambient temperatures with two sets of indoor operating conditions, it was found that the additional coil did increase the unit's cooling capacity with the coil either used as a subcooling coil or a desuperheating coil. The cooling capacity increased by 1,500 to 2,200 Btu/h (0.44 to 0.64 kW), or 5.5% to 10% at a 95°F (35°C) outdoor ambient temperature, when the added coil was used as a subcooling coil, and the discharge pressure in this case was the lowest as well. When the coil was used to desuper-

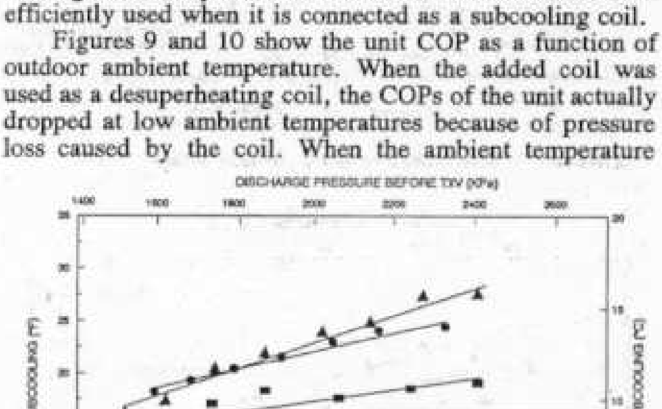

Figure 7 *Liquid subcooling as a function of compressor discharge pressure with indoor at 80°F (27°C) and with 52% relative humidity*

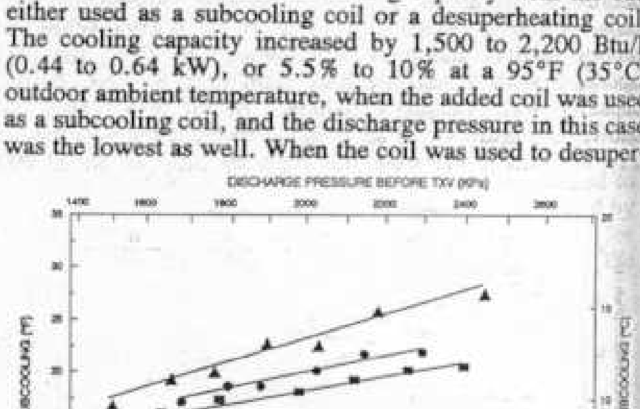

Figure 8 *Liquid subcooling as a function of compressor discharge pressure with indoor at 80°F (27°C) and with a 0.8 sensible load ratio*

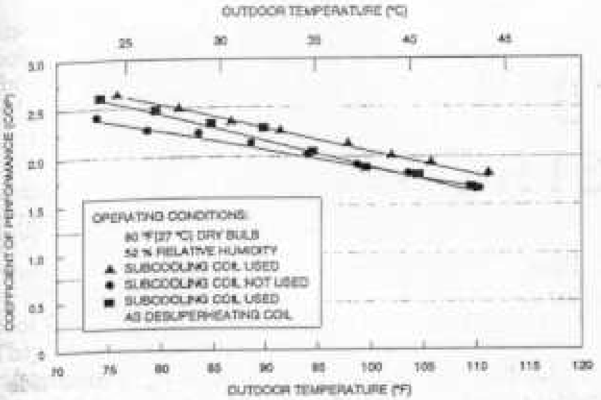

Figure 9 *Coefficient of performance as a function of outdoor ambient temperature with indoor at 80°F (27°C) and with 52% relative humidity*

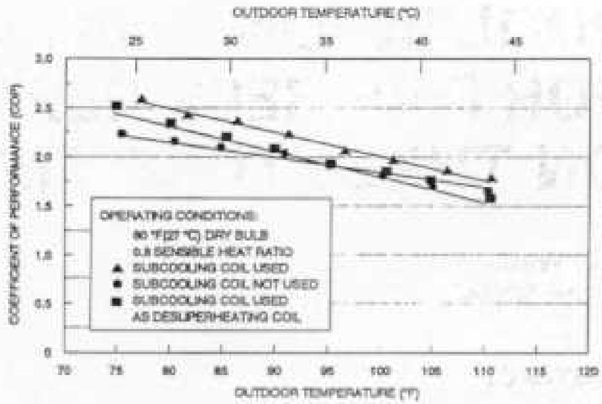

Figure 10 *Coefficient of performance as a function of outdoor ambient temperature with indoor at 80°F (27°C) and with a 0.8 sensible load ratio*

heat the vapor refrigerant, it increased the cooling capacity by 900 to 1,200 Btu/h (0.26 to 0.35 kW), or 3.3% to 4.8%.

The additional coil placed in the condensate drain pan worked best as a subcooling coil rather than as a desuperheater. In the desuperheater mode, the cooling capacity did increase, but unit COP dropped because of additional pressure loss. In the subcooling mode, the unit showed the highest cooling capacity and COP. It is clear that adding a coil to utilize the cool condensate to improve the cooling capacity is effective. The coil works best when used as a subcooling coil at high outdoor ambient temperatures.

ACKNOWLEDGMENTS

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DISCUSSION

Dennis Tiede, Engineer, San Diego Gas & Electric, San Diego, CA: How was the capacity of the unit measured? How much subcooling was produced by the standard condenser coil?

V.C. Mei: The evaporator's cooling capacity was calculated by measuring its inlet and outlet air temperatures, dew points, and inlet air volumetric flow rate. By assuming a constant volumetric airflow rate, the cooling capacity can be calculated for both sensible and latent loads.

The liquid subcooling by the standard coil (no subcooling coil) at 95°F ambient was about 16°F for a 52% RH test. For a 0.8 SHR test, the subcooling at 95°F ambient was slightly higher—about 17°F.