



Project Summary

An Experimental Evaluation of a Novel Full-Scale Evaporatively Cooled Condenser

Yunho Hwang and Reinhard Radermacher

In this report, the performance of a novel evaporatively cooled condenser is compared with that of a conventional air-cooled condenser for a split-system heat pump. The system was tested in an environmentally controlled test chamber that is able to simulate test conditions as specified by ASHRAE Standard 116-1983. Soft optimizations were conducted to determine optimum charge and short tube restrictor size. Design parameters of the evaporatively cooled condenser were also optimized experimentally to maximize performance. Using these optimum parameters, steady state and cyclic performance tests were conducted.

The experimental results show that the evaporatively cooled condenser has a higher capacity by 1.9% to 8.1%, a compatible coefficient of performance (COP) ranging from 98.0% to 105.6%, and a higher seasonal energy efficiency ratio (SEER) by 11.5% than those of the baseline. Subtracting out the appropriate parasitic power necessitated by the test setup, savings were determined to be 1.8% to 8.1% in capacity, 13.5% to 21.6% in COP, and 14.5% in SEER over the baseline.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Three main types of condensers are used in heat pump systems: air-cooled, water-cooled, and evaporatively cooled. Condensers used in conventional split heat pump systems are mainly air-cooled; they depend on the heat transfer between the coils and the airflow. In this regard, air-cooled condensers need a high airflow rate for higher performance. Used less commonly, water-cooled condensers depend on the heat transfer between the coils and a water flow. Water-cooled condensers have a higher heat transfer coefficient than air-cooled condensers. However, they require a water pump to circulate the water and chemical treatment of the water to reduce fouling of the coils. Evaporatively cooled condensers have been used extensively to enhance heat transfer and improve performance of cooling systems. A popular design for an evaporatively cooled condenser (hereafter called an "evaporative condenser") is to spray water onto the condenser tubes as air is simultaneously blown over them. The water that is not evaporated then drains to the bottom of the condenser unit and is pumped up to the sprayers using a water pump. Cooling is accomplished by the evaporation of the water into the air stream. Thus, the water pumping and chemical treatment requirement of the water-cooled condensers are reduced. The high airflow rate required from the air-cooled condensers is also significantly reduced.

On the other hand, there are some disadvantages of the evaporative condenser.

First, it is more appropriate for central cooling systems than for heat pumps because water freezes in the outside heat exchanger during cold weather home heating. For cooling only, controllers can be provided so that the water drains automatically when the system is shut down for the season. Second, the water pool poses a health hazard as biological growth, such as legionella, may develop. Some minimal amount of water treatment is needed to prevent algae growth. This has always been one of the drawbacks of wet systems for homeowners; they do not want to maintain such a system or will forget to maintain it. For this type of evaporative condenser, however, there is such a small water flow that a package treatment system is available that will not require homeowner maintenance for the life of the unit.

In the design studied in this report, the condenser tubes are immersed in a water bath, as in a water-cooled condenser. Wheel disks, which are partially submerged in the bath, are rotated by a direct-drive motor while air is blown across them. The disks carry a thin water film from the bath to the air stream, and this water film is evaporated into the air stream. The condenser tubes reject heat to the water bath, and the evaporation of the water film rejects heat to the air stream. System reliability is increased in this design because it eliminates the need for a water pump. Also, the airflow rate required is less than that of an air-cooled condenser.

The major advantage of the evaporative condenser is that the condensing temperature is lower than that of an air-cooled condenser. The condensing temperature of this design is limited by the wet bulb temperature of the air rather than the dry bulb temperature. Since the wet bulb temperature is usually 14 to 25 F° (8 to 14 C°) lower than the dry bulb temperature, the condensing temperature is lowered. The lower condensing temperature reduces the pressure across the compressor, reducing the work done by the compressor, thereby increasing the COP. Previous tests have shown that the compressor power consumption is reduced by 11.4% and the COP is increased by 20% as compared to conventional condensers.

The advantages of the evaporative condenser include (a) low cost/light weight (wheel disks are made of plastic); (b) mini-

mal air pressure drop/low fan motor power; (c) great potential for performance improvement, and (d) low condensing and compressor discharge temperature/higher system reliability.

Results

An evaporative cooling condenser test unit was fabricated and tested on a commercially available heat pump whose condenser was replaced with the test unit. Tests of the unaltered heat pump system in its original configuration supplied the baseline performance data to which the experimental system was compared. System charge was optimized, using ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Cooling Test B condition. The optimization aimed at balancing the benefit of an evaporative condenser throughout all cooling tests and optimizing seasonal performance. A short tube restrictor size and the amount of refrigerant charge were determined to optimize performance at the Test B condition. Further optimization included balancing the airflow in the duct of the test system and determining the optimum wheel speed of the plastic discs in the condenser.

To determine the overall performance of the system, ASHRAE cooling tests A, B, C, and D were run at the determined optimum amount of refrigerant, short tube restrictor size, airflow balance, and wheel speed determined above and compared to similar tests run with the unmodified heat pump system. In Test A, the evaporative condenser improved cooling capacity by 8.1% and COP by 5.6%, compared to the baseline that used the conventional air condenser. The cooling capacities in Tests B and C were improved by 1.8% and 5.7%, respectively, but the COPs of Tests B and C were degraded by 4.0% and 2.0%, respectively. The cyclic performance of the evaporative condenser, as measured in Test D, was improved by 18.7%, as compared to the baseline. The results of all of these tests were combined, and a seasonal performance was calculated. This seasonal performance was 1.7% lower than that of the baseline.

The power of the outdoor fan in the experimental system was greater than needed in an actual system because the fan motor was oversized to overcome additional flow resistance by the test duct.

The wheel motor consumed more energy because an inverter-driven motor was used in the test facility to easily control the wheel speed. Therefore, it is reasonable to compensate for the parasitic power for a fair comparison of the systems. The parasitic fan and wheel motor power was estimated based on static pressure difference across the wheel, airflow rate, and torque requirement. With these compensations, the COPs were recalculated and compared. The steady state COPs were improved to 11.1% and 21.6%, respectively, in Tests A and B. The improvement in cyclic performance shown by the evaporative condenser was not as great after adjustment (although still improved) because all COPs were improved. The better COPs of the steady state performance and the improvement of cyclic performance improved the seasonal performance by 14.5% above that of the baseline air condenser system.

Conclusions

A novel full-scale evaporative condenser was evaluated experimentally. The final system specification showed improved steady state performance and compatible seasonal performance with the baseline system; cooling capacity ranged from 101.8% to 108.1%, COP ranged from 98.0% to 105.6%, and seasonal energy efficiency was 98%. After accounting for the estimated excessive power consumption by the outdoor fan motor and wheel motor (excess power beyond that needed for normal operation to accommodate additional testing requirements), the evaporative condenser showed significant improvement. The evaporative condenser had a higher capacity by 1.8% to 8.1%, a higher COP by 13.5% to 21.6%, and a higher seasonal energy efficiency by 14.5% than the baseline.

The condensing temperature of the evaporative condenser is limited by the wet bulb temperature of the air. Therefore, the evaporative condenser has the advantage of a lower condensing temperature than that of an air-cooled condenser. The lower condensing temperature reduces the work done by the compressor. The lower compressor power and the lower outdoor fan and wheel motor power increase the COP and the seasonal energy efficiency.

Yunho Hwang and Reinhard Radermacher are with the University of Maryland, College Park, MD 20742.

Robert V. Hendriks is the EPA Project Officer (see below).

The complete report, entitled "An Experimental Evaluation of a Novel Full-Scale Evaporatively Cooled Condenser," (Order No. PB98-100506; Cost: \$21.50, subject to change) will be available only from:

National Technical Information Service

5285 Port Royal Road

Springfield, VA 22161

Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air Pollution Prevention and Control Division

National Risk Management Research Laboratory

U.S. Environmental Protection Agency

Research Triangle Park, NC 27711

United States
Environmental Protection Agency
Center for Environmental Research Information
Cincinnati, OH 45268

Official Business
Penalty for Private Use \$300

EPA/600/SR-97/079

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT NO. G-35