2. SUMMARY AND RECOMMENDATIONS

The heat pump tested in these experiments yielded heating-mode performance data that agreed well with the rated values published by the Air-Conditioning and Refrigeration Institute (ARI). The ARI ratings and observed COP of the unit are shown in Table 1. The observed values are from tests in which 0.6 m^3/s (1273 cfm) of air was supplied to the indoor unit at 21.1°C (70°F) during both high- and low-temperature tests. The outdoor air was conditioned to 8.3°C (47°F) during the high-temperature tests and to −8.3°C (17°F) during the low-temperature tests. The outdoor air relative humidity was maintained at 70% for both tests.

Under dry-coil conditions, the overall efficiency of the compressor and motor increased from 46% at −8.3°C (17°F) to 53.5% at 8.3°C (47°F). See Appendix A for a detailed display of steady-state system peformance.

Table 1. Observed steady-state performance compared with Air-Conditioning and Refrigeration Institute ratings

	Observed	Rated
Coefficient of performance[a]	2.95	3.1
Coefficient of performance[b]	2.15[c]	2.1
Heating capacity,[a] kW (Btu/h)	9.6 (32,750)	9.96 (34,000)
Heating capacity,[b] kW (Btu/h)	5.3 (18,146)	5.27 (18,000)

[a]At 8.3°C (47°F).
[b]At −8.3°C (17°F).
[c]Averaged over an 80-min frosting cycle; does not include losses due to defrosting.

2.1 Heat Pump Performance Observed Using a Wet Evaporator Coil

Under nonfrosting dehumidifying conditions at the outdoor coil, a small improvement in heat pump COP was observed as the moisture content of the outdoor air was increased. The time-averaged COP, which was approximately 2.9 for the 8.3°C (47°F), 60% relative humidity condition, increased to 2.95 and 3.0 as the relative humidity was increased to 70 and 80% for subsequent test runs. The corresponding heating capacities improved from 9083 W (31,000 Btu/h) to 9596 W (32,750 Btu/h) to 9962 W (34,000 Btu/h) as the relative humidity was increased from 60 to 70 to 80%. Increasing the ambient relative humidity yielded higher rates of mass transfer of moisture and thus higher latent heat contributions to the outdoor coil, which produced the improvement in COP and heating capacity.

2.2 Performance Observed at 4.4°C (40°F) Ambient Temperature

The heat pump COP and heating capacity, measured at 4.4°C (40°F) as a function of time after system start-up, decreased with time due to frost accumulation on the outdoor heat exchanger. However, the heat pump COP and capacity both improved by increasing the ambient relative humidity above 70%. The COP improved from 2.75, observed at 60% relative humidity, to values above 2.9 as the relative humidity was increased for subsequent test runs (Table 2). Similar trends were also observed in the heating capacity.

Table 2. Performance observed at 4.4°C (40°F)

Relative humidity (%)	COP	Heating capacity [kW (Btu/h)]	Initial evaporator wall temperature [°C (°F)]	Onset of frosting[a] (min)
50	2.75	8.2 (27,846)	−1.72 (28.9)	nonfrosting
70	2.82	8.5 (29,200)	−2.22 (28.0)	34
80	2.86	9.0 (30,808)	−0.33 (31.4)	87
90	2.92	9.1 (31,168)	0.88 (36.6)	155

[a]Onset of frosting was observed for a wall temperature of approximately −2.7°C (27°F) for the 4.4°C (40°F) test runs.

The increase in mass transfer, due to higher moisture content of the air, yielded greater latent heat contributions to the outdoor heat exchanger. The latent heat gain increased the total heat transfer to the outdoor heat exchanger and produced the observed improvement in system performance. The higher latent heat contribution also caused the evaporator tube wall temperature to increase, which delayed the onset of frosting (Table 2).

2.3 Frosting Performance for Ambient Temperatures Less Than 4.4°C (40°F)

System performance did not improve when the relative humidity was increased for test runs conducted at ambient temperatures less than 4.4°C (40°F). Increasing the relative humidity resulted in higher rates of frost accumulation and therefore increased the rate of COP and capacity degradation for relative humidities of 70% and greater (Table 3). Reductions of COP and heating capacity were on the order of 15 and 20%, respectively, for the −1.1 and 1.7°C (30 and 35°F) tests conducted at 80 and 90% relative humidity.

Frosting of the outdoor heat exchanger was observed at 70% relative humidity for ambient temperatures ranging from 4 to −1°C (40 to 30°F). For relative humidities greater than 80%, frosting of the outdoor heat exchanger was observed for all temperatures investigated.

Typical frosting data and system performance observed for the 1.7°C (35°F) tests are tabulated in Appendix A as a function of run time.

Table 3. Degradation of system performance due to frosting of the outdoor heat exchanger

Ambient temperature [°C (°F)]	Relative humidity (%)	COP		Heating capacity (Btu/h)		Duration of test (min)
		Initial	Final	Initial	Final	
1.67 (35)	70	2.73	2.13	27,740	19,000	140
1.67 (35)	80	2.76	2.18	28,977	19,900	65
1.67 (35)	90	2.61	2.15	27,782	19,900	55
−1.11 (30)	70	2.54	2.16	23,800	19,500	163
−1.11 (30)	80	2.75	2.11	27,502	19,300	54
−1.11 (30)	90	2.63	2.04	26,138	18,000	54
−6.67 (20)	70	2.23	2.15	20,399	19,500	158
−6.67 (20)	80	2.19	2.17	20,954	18,800	91
−6.67 (20)	90	2.32	1.81	21,672	15,000	84