Rating Water-Source Heat Pumps Using ARI Standard 320 and ISO Standard 13256-1

W. Vance Payne and Piotr A. Domanski
National Institute of Standards and Technology
Building and Fire Research Laboratory
Gaithersburg, Maryland USA 20899-8230

Telephone: 301-975-4623
Telefax: 301-975-8973
Email: Vance.Payne@NIST.GOV
Web Site: www.bfrl.nist.gov/863/refrig.html

International Appliance Technical Conference, March 25-27, 2002, Lexington, KY, USA

ABSTRACT

This investigation compares performance ratings obtained when testing water-source heat pumps using the Air-Conditioning and Refrigeration Institute (ARI) Standard 320 and the International Organization for Standardization (ISO) Standard 13256-1. Multiple tests included a ducted 1.75 kW (0.5 ton) unit and a non-ducted 3.52 kW (1.0 ton) unit. Air external static pressure and water flow were varied at the ISO conditions to determine the correction in capacity and total power mandated by the ISO standard. ISO cooling capacity for the first and second units were 0.1 % higher and 1.1 % lower than the ARI capacity, respectively. ISO cooling energy efficiency ratio (EER) for the first and second units were 4.5 % higher and 3.9 % lower than the ARI EER, respectively. ISO heating capacity for the first and second units were 4.8 % lower and 2.9 % lower than the ARI capacity, respectively. ISO heating coefficient of performance (COP) for the first and second units were 6.2 % higher and 1.0 % lower than the ARI COP, respectively.

INTRODUCTION

Globalization of economies creates new marketing opportunities and increases the importance of international standards. The adoption of an international standard offers substantial economic benefits, but the transition from a national to an international standard poses a question of whether the ratings obtained by using these standards are equivalent.

This study was concerned with the rating obtained for water-source heat pumps tested using two standards: the standard developed by the Air-Conditioning and Refrigeration Institute (ARI), ARI Standard 320 (1998), and the standard developed by the International Organization for Standardization (ISO), ISO Standard 13256-1 (1998). On January 1, 2000, the ARI adopted the ISO standard as the basis for its certification programs. The standard developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE Standard 90.1 (1999), references both the ARI standard and the ISO until October 29, 2001, with the ISO standard designated as the exclusive standard starting at this date. The goal of this study was to evaluate the differences in rated energy efficiency ratio (EER) for cooling operation and coefficient of performance (COP) for heating operation obtained when using these two test methods.

The test and rating results obtained when using the ARI standard and ISO standard are expected to be somewhat different because of three inherent differences between these standards:

(1) The first difference is the slightly different dry-bulb and dew-point temperatures. These different operating conditions are related to different temperature scales (Fahrenheit vs. Celsius) and do not

represent a significant difference in the test operating temperatures.

(2) The second difference between the ARI standard and the ISO standard is the external air static pressure applied during the test. Under the ARI standard, the unit must be tested while operating against the external air static pressure that is specified by the standard for a given system's capacity. Under the ISO standard, the unit must be tested against static pressure specified by the manufacturer. After completion of the test, a credit is given for the indoor fan power to the total energy input, and the system capacity is adjusted for the heat added by the indoor fan.

(3) The third difference is the treatment of the energy input to the water pump. Under the ARI standard, this energy input is not included in the calculation of the total energy input, and the standard specifies the water flow rate that results in a 5.6 °C (10.0 °F) temperature change across the heat exchanger. Under the ISO standard, the test must be performed at the mass flow rate specified by the manufacturer, and the energy input to the water pump is measured and included in the total energy input.

The following sections present the experimental apparatus, systems tested, and laboratory test results obtained by the ARI and ISO standards. Tests of one ducted and one non-ducted water-source heat pump provided comparison data for these two test procedures. In addition to "standard" testing carried out using the two standards, expanded testing was performed under ISO testing conditions with varied air external static pressure and water flow rates. These tests provided information regarding the effect on the rating of these two parameters that are specified by the manufacturer of the heat pump. Payne and Domanski (2001) presented a full report of this study.

EXPERIMENTAL SETUP

The main components of the experimental apparatus included the tested heat pump, the nozzle chamber, and the pull-thru fan. The water-source heat pump was supplied with distilled water at the appropriate temperature and flow rate. All measurements were collected according to ASHRAE Standard 37-1988.

EXPERIMENTAL PROCEDURE AND TEST CONDITIONS

For both cooling (Tables 1 and 2) and heating (Tables 3 and 4) tests, the refrigeration chamber was maintained within 0.3 °C (0.5 °F) of a constant dry-bulb temperature and dew-point temperature. In the cooling mode, the water flow rate was adjusted to give a 5.6 °C (10.0 °F) temperature increase for the ARI standard and as specified by the manufacturer for the ISO standard.

Table 1: ARI cooling conditions

Location	Setpoint	Tolerance
Indoor Dry-bulb Temperature	26.7 °C (80.0 °F)	±0.3 °C (±0.5 °F)
Indoor Dew-point Temperature	15.8 °C (60.4 °F)	±0.3 °C (±0.5 °F)
Inlet Water Temperature	29.4 °C (85.0 °F)	±0.3 °C (±0.5 °F)
Outlet Water Temperature	35.0 °C (95.0 °F)	±0.3 °C (±0.5 °F)

Table 2: ISO cooling conditions

Location	Setpoint	Tolerance
Indoor Dry-bulb Temperature	27.0 °C (80.6 °F)	±0.3 °C (±0.5 °F)
Indoor Dew-point Temperature	14.7 °C (58.5 °F)	±0.3 °C (±0.5 °F)
Inlet Water Temperature	30.0 °C (86.0 °F)	±0.3 °C (±0.5 °F)
Water Flow	Specified by the manufacturer	

Table 3: ARI heating conditions

Location	Setpoint	Tolerance
Indoor Dry-bulb Temperature	21.1 °C (70.0 °F)	±0.3 °C (±0.5 °F)
Inlet Water Temperature	21.1 °C (70.0 °F)	±0.3 °C (±0.5 °F)
Water Flow	Same water flow as in the cooling test	

In the heating mode, all fan settings and water flow rates were maintained the same as the respective cooling tests. For the ISO standard, the fan power correction was added to the heating capacity and to the total power.

Table 4: ISO heating conditions

Location	Setpoint	Tolerance
Indoor Dry-bulb Temperature	20.0 °C (68.0 °F)	±0.3 °C (±0.5 °F)
Maximum Dew Point	11.7 °C (53.1 °F)	±0.3 °C (±0.5 °F)
Inlet Water Temperature	20.0 °C (68.0 °F)	±0.3 °C (±0.5 °F)
Water Flow	Same as in the cooling test above	

UNITS TESTED, TESTS PERFORMED AND DATA REDUCTION

Unit 1 was a ducted design with a nominal cooling capacity of 1.75 kW (0.5 ton). Unit 2 was a non-ducted console type design with a nominal cooling capacity of 3.52 kW (1.0 ton). Neither unit included a pump for circulating water through the water coil. For the non-ducted unit, the air static pressure at the exit of the unit was maintained at zero for all tests. Table 5 below summarizes the tests performed on each unit for the cooling and heating modes. The tests designated as "Modified ISO" were performed with increased and decreased air static pressure and water coil pressure drop to examine their effects upon EER and COP.

For the ISO standard, a correction to the air-side capacity and total power were calculated based on the external static air pressure drop of the air coil and the water pressure drop across the water coil. This correction

Table 5: Test matrix summary for cooling and heating modes

	External Air Static Pressure*	Water Coil Pressure Drop
ARI 320	Normal	Normal
ISO 13256-1	Normal	Normal
Modified ISO	High	Normal
	Low	Normal
	Normal	High
	Normal	Low

* The non-ducted unit was maintained at zero exit static pressure for all tests.

was calculated by Equation 1 with the Δp being the static pressure drop of the fluid considered, air or water. The fan power correction was added to the total power consumption and subtracted from the total capacity for the cooling tests. The fan power correction was added to the total power consumption and capacity for the heating tests. Pumping power was added to the total power for all heating and cooling tests.

$$\Phi_{pa} = \frac{q\Delta p}{\eta} \qquad (1)$$

Φ_{pa} is the pump or fan power adjustment (watts), q is the fluid flow rate (L/s), Δp is the measured pressure drop (Pa), and η is $0.3 \cdot 10^3$ as specified by ISO Standard 13256-1.

Total power was measured by a wattmeter during the test period, which was never shorter than 30 min. The total power measurement was combined with the water coil capacity as a secondary calculation of the air-side capacity. For the ARI standard, the reported capacity is based on the air-side measurements. For the ISO standard, the reported capacity is the average of the air-side and secondary method capacities.

UNIT 1: COOLING TEST RESULTS

Table 6 summarizes the cooling test results for Unit 1, the ducted 1.75 kW (0.5 ton) nominal cooling capacity system. For the ISO test, the table presents detailed information; the uncorrected capacity, power, and EER are presented first. The following entries are system operating parameters, ISO corrections for capacity and power, and the corrected capacities and EERs. These corrected values are the reported capacities and EERs when tests are performed using the ISO method. The last entries are the results of the ARI tests.

Under the ARI cooling conditions, air-side capacity and EER were 2352 W (8024 Btu/h) and 13.21, respectively. For the ISO 13256-1 cooling conditions, air-side capacity and EER were 2353 W (8028 Btu/h) and 13.80. Correcting the capacity and power for the fan and pump, according to Equation 1, changed the EER from 12.89 (the uncorrected value in Table 6) to 13.80 (an increase of 7.1 %).

Variation in air static pressure has the greatest effect upon capacity and EER due to the capacity correction and fan power correction required by the ISO standard. For the low and high air static pressure tests, air-side capacity changed by 0.3 % and –3.6 %, respectively, as air volume flow changed by +30 % and –30 %. EER change due to the changes in air volume flow rate were –0.7 % and –2.2 %. As water flow was varied by –10 % and +10 %, ISO air-side capacity changed by –1.6 % and +0.1 %, respectively. EER changed by –1.4 % and +0.7 %.

ARI capacity was 1.6 % higher than the ISO uncorrected capacity. ARI EER was 1.6 % higher than the ISO uncorrected EER. These differences were due to the differences in test conditions (dry bulb and dew point). ISO capacity increased by 1.6 % due to correcting for fan heat input according to Equation 1. ISO EER increased by 7.0 % due to the corrections for fan heat, fan power, and pump power. The pump power correction was 1.5 % of the total power for all tests.

UNIT 1: HEATING TEST RESULTS

Table 7 summarizes the heating test results for Unit 1. Under the ARI heating conditions air-side capacity and COP were 3270 W (11157 Btu/h) and 4.81, respectively. For the ISO 13256-1 heating conditions air-side capacity and COP were 3114 W (10624 Btu/h) and 5.11.

Variations in air static pressure had the greatest effect upon capacity and efficiency due to the capacity correction and fan power correction. For the low and high air static pressure tests, air-side capacity changed by 1.8 % and -1.6 %, respectively, as air volume flow changed by +30 % and -30 %. COP change due to the changes in air volume flow rate were 1.7 % and -2.3 %. As water flow was varied by -10 % and +10 %, ISO air-side capacity changed by -0.8 % and +0.7 %, respectively. ISO COP changed by +0.2 % and +0.0 %.

ARI capacity was 1.2 % higher than the ISO uncorrected capacity. COP was 1.0 % lower than the ISO uncorrected COP. These differences were due to the differences in test conditions (dry bulb and dew point). ISO capacity decreased by 0.3 % due to correcting the tests for fan capacity. The combined effects of fan heat, fan power, and pump power increased ISO COP by 5.0 %.

UNIT 2: COOLING TEST RESULTS

Unit 2 was a non-ducted 3.52 kW (1.0 ton) nominal cooling capacity, console heat pump designed for wall mounting with no ductwork; therefore, air static pressure was maintained at zero for all tests to simulate free discharge to the indoor space.

Table 8 summarizes the cooling test results for Unit 2. Under the ARI cooling conditions, air-side capacity and EER were 3085 W (10528 Btu/h) and 14.18, respectively. For the ISO 13256-1 cooling conditions, air-side capacity and EER were 3051 W (10412 Btu/h) and 13.63.

ARI capacity was 1.1 % higher than the ISO uncorrected capacity.

EER was 2.4 % higher than the ISO uncorrected EER. These differences were due to the differences in test conditions (dry-bulb and dew-point temperatures). The pump power was less than 2.8 % of the total power for all tests. ISO EER decreased with respect to the ISO raw results by 1.6 %. Changes in water flow rate through the water coil produced a small effect upon the ISO cooling test results. As water flow was varied by –20 % and +20 %, ISO averaged capacity changed by –1.3 % and –0.3 %, respectively. EER changed by –2.8 % and +0.2 %.

UNIT 2: HEATING TEST RESULTS

Table 9 summarizes the heating test results for Unit 2. Table 9 does not include tests at a low water flow rate. Two tests were performed at a lowered water flow rate, but they were excluded due to unacceptable variations (pulses) in water flow rate through the water coil.

ARI air-side capacity and COP were 4668 W (15927 Btu/h) and 4.94. For the ISO 13256-1 normal airflow heating conditions air-side capacity and COP were 4534 W (15469 Btu/h) and 4.89. When water flow rate was increased by 16.9 %, ISO capacity increased by 0.8 % and ISO COP decreased by 1.6 %. For the high water flow rate case, the pump power correction was 3.5 % of the total power. ARI capacity was 1.2 % higher than the ISO uncorrected capacity. ARI COP was 2.6 % lower than the ISO uncorrected COP. The pump power correction was less than 2.8 % of the total power.

SUMMARY

The purpose of this experimental investigation was to examine differences in ratings obtained from tests according to ARI Standard 320 and ISO Standard 13256-1. This investigation included tests at different volumetric flow rates of air and water to examine the effect of capacity and power corrections on the rating obtained by the ISO test procedure.

Figures 1 and 2 summarize results for capacity changes. ISO

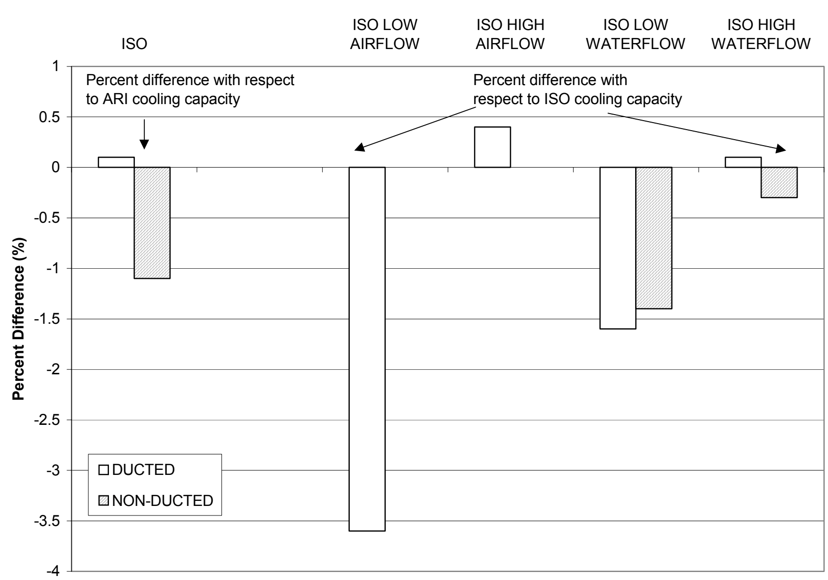

Figure 1: Cooling capacity comparison

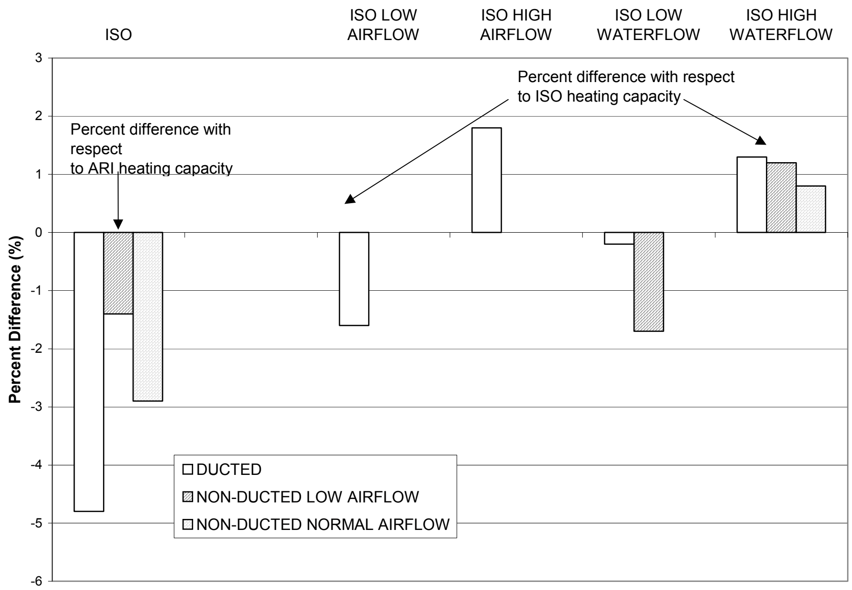

Figure 2: Heating capacity comparison

cooling capacity for the ducted unit and non-ducted unit were 0.1 % higher and 1.1 % lower than the ARI capacity, respectively. In the heating mode, the ISO capacities were 4.8 % lower and 2.9 % lower than the ARI capacities. The range of capacity change was from –3.6 % to 1.8 %.

As shown by Figure 3, the ISO cooling EERs for the ducted unit and the non-ducted unit were 4.5 % higher and 3.9 % lower than the ARI EERs, respectively. The ISO heating COPs (Figure 4) for the first and second units were 6.2 % higher and 1.0 % lower than the ARI COPs, respectively. The range of ISO EER and ISO COP changes due to variation of the external air static pressure and water flow rate was from –2.8 % to 1.8 %.

The uncertainties for NIST test results were calculated applying the uncertainty propagation law and considering the uncertainties of all involved temperature, pressure, and power measurements. For the 95 % confidence level, the maximum uncertainty for EER and COP was found to be 5.2 % and 5.9 %, respectively. Hence, the differences between the ISO and ARI ratings are near or within the limits of uncertainty.

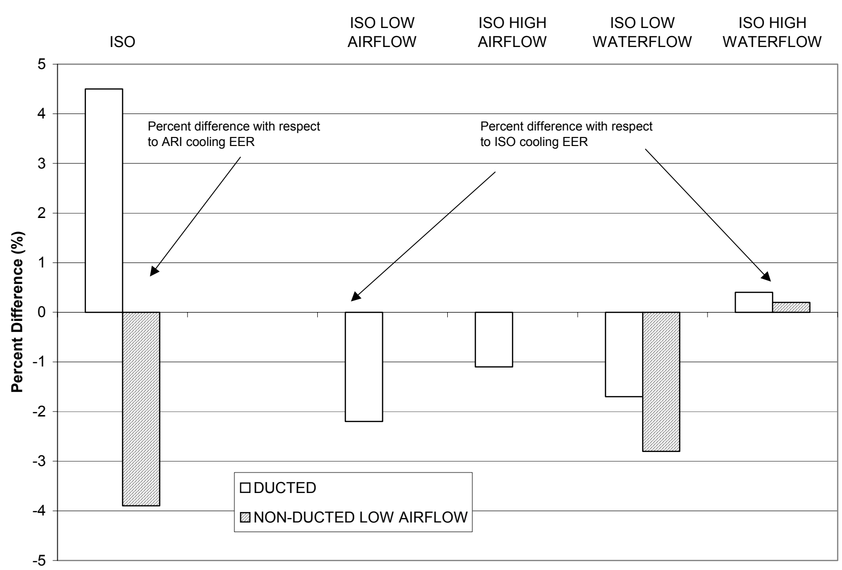

Figure 3: Cooling efficiency comparison

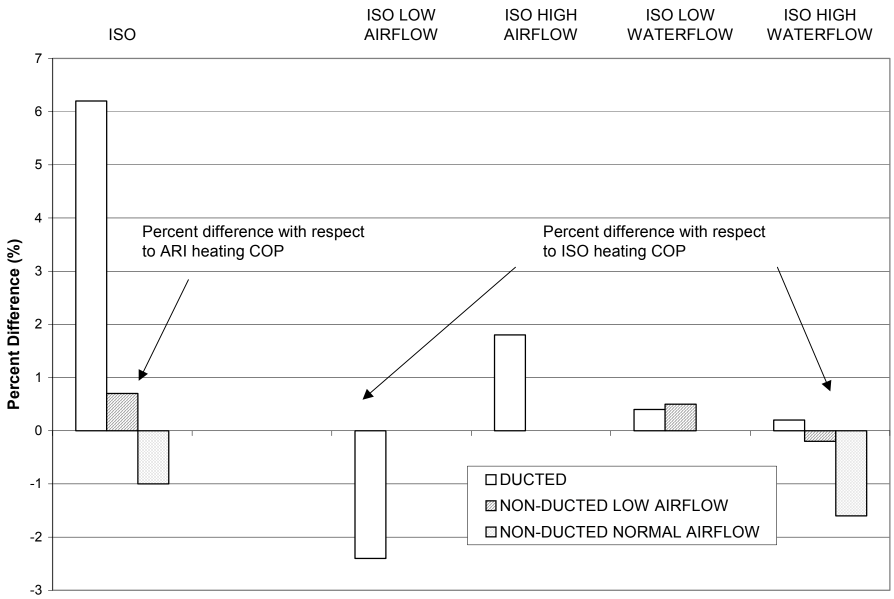

Figure 4: Heating efficiency comparison

REFERENCES

ANSI/ASHRAE Standard 37-1988. *Methods of testing for rating unitary air conditioning and heat pump equipment*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1791 Tullie Circle NE, Atlanta, GA, USA.

ARI Standard 320-1998. *Standard for water-source heat pumps*. Air-Conditioning and Refrigeration Institute. 4301 North Fairfax Drive, Arlington, VA, USA.

ASHRAE Standard 90.1-1999. *Energy Standard for Buildings Except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. 1791 Tullie Circle NE, Atlanta, GA, USA.

ISO 13256-1-1998. *Water-source heat pumps-Testing and rating for performance-Part 1: Water-to-air and brine-to-air heat pumps.* International Organization for Standardization. Case postale 56, CH-1211 Geneva 20, Switzerland.

Payne, W.,V. and Domanski, P.A., 2001. *A Comparison or Rating Water-Source Heat Pumps Using ARI Standard 320 and ISO Standard 13256-1*, NISTIR 6803, National Institute of Standards and Technology, Gaithersburg, MD.

ACKNOWLEDGEMENT

This study was sponsored by the United States Department of Energy, Office of Building Technology, State and Community Programs under contract DE-AI01-99EE27572. The authors thank Dr. Samuel Yana Motta of Honeywell and Mr. David Yashar of NIST for their review and comments on the draft of this report. We also thank Mr. Anthony Downs for his assistance with the testing and analysis of data.

Table 6: ARI and ISO cooling test results for Unit 1

Cooling	External Air Static Pressure			Water Coil Pressure Drop		
	Low	Normal	High	Low	Normal	High
Using ISO 13256-1: Uncorrected Capacity, W (Btu/h)	2326 (7935)	2316 (7902)	2227 (7598)	2276 (7766)	2316 (7902)	2318 (7908)
Uncorrected Total Power, W	620	613	610	617	613	610
Uncorrected EER, Btu/Wh	12.80	12.89	12.46	12.59	12.89	12.97
Water Flow, L/s (gpm)	0.128 (2.0)	0.127 (2.0)	0.127 (2.0)	0.119 (1.9)	0.127 (2.0)	0.135 (2.1)
Water Temp Change, °C (°F)	5.44 (9.8)	5.44 (9.8)	5.38 (9.7)	5.83 (10.5)	5.44 (9.8)	5.17 (9.3)
Water Pressure Drop, Pa (psid)	13807 (2.00)	14134 (2.05)	13578 (1.97)	11038 (1.60)	14134 (2.05)	16368 (2.37)
Air Flow, L/s (cfm)	155 (328)	142 (301)	127 (270)	141 (299)	142 (301)	143 (302)
Air Temp Change, °C (°F)	10.22 (18.4)	10.61 (19.1)	11.0 (19.8)	10.67 (19.2)	10.61 (19.1)	10.72 (19.3)
Air Static, Pa (in H_2O)	69 (0.28)	78.2 (0.31)	99.4 (0.40)	82 (0.33)	78.2 (0.31)	79 (0.32)
ISO Capacity Adjustment: For Fan Heat, W (Btu/h)	36 (122)	37 (126)	42 (144)	39 (132)	37 (126)	37 (128)
ISO Power Adjustment: For Fan Power, W	36	37	42	39	37	37
For Pump Power, W	6	6	6	4	6	7
Corrected Capacity, W (Btu/h)	2361 (8057)	**2353 (8028)**	2269 (7742)	2315 (7898)	**2353 (8028)**	2355 (8036)
Corrected EER, Btu/Wh	13.65	**13.80**	13.50	13.56	**13.80**	13.86
Using ARI 320 Capacity, W (Btu/h)		**2352 (8024)**			**2352 (8024)**	
Total Power, W		608			608	
EER, Btu/Wh		**13.21**			**13.21**	

Table 7: ARI and ISO heating test results for Unit 1

Heating	External Air Static Pressure			Water Coil Pressure Drop		
	Low	Normal	High	Low	Normal	High
Using ISO 13256-1: Uncorrected Capacity, W (Btu/h)	3213 (10964)	3161 (10787)	3112 (10618)	3153 (10757)	3161 (10787)	3198 (10914)
Uncorrected Total Power, W	646	651	656	648	651	654
Uncorrected COP	4.97	4.85	4.74	4.87	4.85	4.89
Water Flow, L/s (gpm)	0.125 (1.982)	0.124 (1.97)	0.125 (1.987)	0.106 (1.684)	0.124 (1.97)	0.136 (2.149)
Water Coil Temp Change, °C (°F)	4.72 (8.5)	4.72 (8.5)	4.67 (8.4)	5.44 (9.8)	4.72 (8.5)	4.39 (7.9)
Water Pressure Drop, Pa (psid)	14107 (2.046)	13600 (1.973)	13983 (2.028)	9990 (1.449)	13600 (1.973)	16237 (2.355)
Air Flow, L/s (cfm)	156 (331)	147 (311)	136 (287)	149 (315)	147 (311)	148 (315)
Air Coil Temp Change, °C (°F)	18.28 (32.9)	19.0 (34.2)	20.0 (36.0)	18.89 (34.0)	19.0 (34.2)	19.11 (34.4)
Air Static, Pa (in H_2O)	82 (0.329)	98 (0.393)	106 (0.427)	91 (0.366)	98 (0.393)	90 (0.362)
ISO Capacity Adjustment: For Fan Heat, W (Btu/h)	43 (146)	48 (163)	48 (164)	45 (154)	48 (163)	45 (152)
ISO Power Adjustment: For Fan Power, W	43	48	48	45	48	45
For Pump Power, W	5.9	5.6	5.8	3.5	5.6	7.3
Corrected Capacity, W (Btu/h)	3170 (10818)	**3114 (10624)**	3064 (10454)	3107 (10603)	**3114 (10624)**	3154 (10761)
Corrected COP	5.20	**5.11**	4.99	5.13	**5.12**	5.12
Using ARI 320 Capacity, W (Btu/h)		**3270 (11157)**			**3270 (11157)**	
Total Power, W		667			667	
EER, Btu/Wh		**4.81**			**4.81**	

Table 8: ARI and ISO cooling test results for Unit 2

Cooling	Water Coil Pressure Drop		
	Low	Normal	High
Using ISO 13256-1: Uncorrected Capacity, W (Btu/h)	3010 (10272)	3051 (10412)	3043 (10382)
Uncorrected Total Power, W	769	752	739
Uncorrected EER	13.36	13.85	14.05
Water Flow, L/s (gpm)	0.136 (2.15)	0.170 (2.694)	0.204 (3.23)
Water Coil Temp Change, °C (°F)	6.67 (12.0)	5.33 (9.6)	4.44 (8.0)
Water Pressure Drop, Pa (psid)	14403 (2.09)	21774 (3.16)	30585 (4.44)
Air Flow, L/s (cfm)	158 (335)	157 (332)	157 (333)
Air Coil Temp Change, °C (°F)	12.39 (22.3)	12.44 (22.4)	12.39 (22.3)
Air Static, Pa (in H_2O)	3.74 (0.015)	2.74 (0.011)	2.74 (0.011)
ISO Capacity Adjustment: For Fan Heat, W (Btu/h)	0	0	0
ISO Power Adjustment: For Fan Power, W	0	0	0
For Pump Power, W	7	12	21
Corrected Capacity, W (Btu/h)	3010 (10272)	**3051 (10412)**	3043 (10382)
Corrected EER	13.25	**13.63**	13.66
Using ARI 320 Capacity, W (Btu/h)		**3085 (10528)**	
Total Power, W		**742**	
EER		**14.18**	

Table 9: ARI and ISO normal airflow heating test results for Unit 2

Heating	Water Coil Pressure Drop	
	Normal	High
<u>Using ISO 13256-1:</u> Uncorrected Capacity, W (Btu/h)	4534 (15469)	4571 (15598)
Uncorrected Total Power, W	911	919
Uncorrected COP	4.98	4.97
Water Flow, L/s (gpm)	0.198 (3.135)	0.231 (3.666)
Water Coil Temp Change, °C (°F)	4.28 (7.7)	3.72 (6.7)
Water Pressure Drop, Pa (psid)	31523 (4.57)	42154 (6.114)
Air Flow, L/s (cfm)	188.6 (400)	188.9 (400)
Air Temp Change, °C (°F)	21.39 (38.5)	21.56 (38.8)
Air Static, Pa (in H_2O)	1.5 (0.006)	1.5 (0.006)
Pump Power Correction, W	21	32
Corrected Capacity, W (Btu/h)	**4534 (15469)**	4571 (15598)
Corrected COP	**4.89**	4.81
<u>Using ARI 320</u> Capacity, W (Btu/h)	**4668 (15927)**	
Total Power, W	946	
COP	**4.94**	