Laboratory Test Report for Six ENERGY STAR® Dehumidifiers

Jon Winkler, Ph.D., Dane Christensen, Ph.D., and Jeff Tomerlin

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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Executive Summary

This report documents the measured performance of six residential ENERGY STAR® vapor compression dehumidifiers. The performance of each was measured over a wide range of inlet air conditions and fit to a numerical model with an R-squared value greater than 0.995 for both water removal rate and energy factor (i.e. capacity and efficiency). Performance curve coefficients were also developed for use in EnergyPlus. Test data from all six dehumidifiers were fit to a generic performance curve for water removal rate and energy factor. These curves accurately represented all the test data with an average relative error of 5.9% in both estimated water removal rate and estimated energy factor.

Definitions

AHAM	American Home Appliance Manufacturers
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
cfm	cubic feet per minute
DB	dry-bulb
DOE	U.S. Department of Energy
DP	dew point
EPA	U.S. Environmental Protection Agency
GE	General Electric, Inc.
HVAC	heating, ventilating, and air-conditioning
NREL	National Renewable Energy Laboratory
RH	relative humidity
WG	water gauge

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1 Overview

Six residential vapor compression cycle dehumidifiers spanning the available range of capacities and efficiencies were tested in the National Renewable Energy Laboratory's (NREL) Heating, Ventilating, and Air-Conditioning (HVAC) Systems Laboratory. Each was tested under a wide range of indoor air conditions to facilitate the development of performance curves for use in whole-building simulation tools. Table 1 lists the manufacturer specifications. The energy factor for a dehumidifier is defined as the amount of energy required to remove a specified volume of water from the incoming air. The two ducted Ultra-Aire dehumidifiers can be used in a standalone system with unique ductwork or the ductwork can be incorporated into a HVAC system. The remaining dehumidifiers are standalone units.

Table 1. Dehumidifier Manufacturer Specifications

Brand Name	Model #	Capacity[1] (pints/day)	Energy Factor[1] (L/kWh)	Airflow Rate (cfm)
Ultra-Aire	XT150H	150	3.7	415[2]
Ultra-Aire	70H	70	2.32	160[2]
Santa Fe[3]	Compact	70	2.37	170[2]
General Electric (GE)	ADER65LP	65	1.8	195/175/155
Soleusair	SG-DEH-45-1	45	1.5	103/91/81
Comfort Aire	BHD-301-G	30	1.4	N/A
Frigidaire	FAD251NTD	25	1.2	N/A

[1] Performance at the rated inlet condition of 80°F, 60% relative humidity (RH)
[2] Flow rate specified at 0 in. water gauge (WG)
[3] Unit was not tested under all operating conditions due to nearly identical performance with the Ultra-Aire 70H

Sources: Therma-Stor 2007, Therma-Stor 2010, Therma-Stor 2011, GE 2011, Soluesair 2011, EPA 2011

Table 1 lists seven dehumidifiers. The Santa Fe Compact and Ultra-Aire 70H are manufactured by Therma-Stor, LLC. During setup these two units were observed to have nearly identical designs. The Santa Fe Compact dehumidifier was tested under a limited number of operating conditions and the results were compared to the Ultra-Aire 70H performance model. The Ultra-Aire 70H model predicted the Santa Fe Compact performance with an average 3.2% error. Thus, testing of the Santa Fe Compact was discontinued and the results are not included in this report. Test results for the six remaining dehumidifiers are reported.

All six dehumidifiers satisfied the ENERGY STAR® efficiency criteria (see Figure 1). The two Ultra-Aire dehumidifiers well exceeded ENERGY STAR requirements; the remaining four barely met the necessary efficiency level. All dehumidifiers listed in the ENERGY STAR product directory are included in Figure 1. We intended to test a dehumidifier below ENERGY STAR efficiency requirements, but could not find such a unit available for purchase at the time of testing. However, the performances of several non-ENERGY STAR dehumidifiers were found in the literature and are included in Figure 1 for reference.

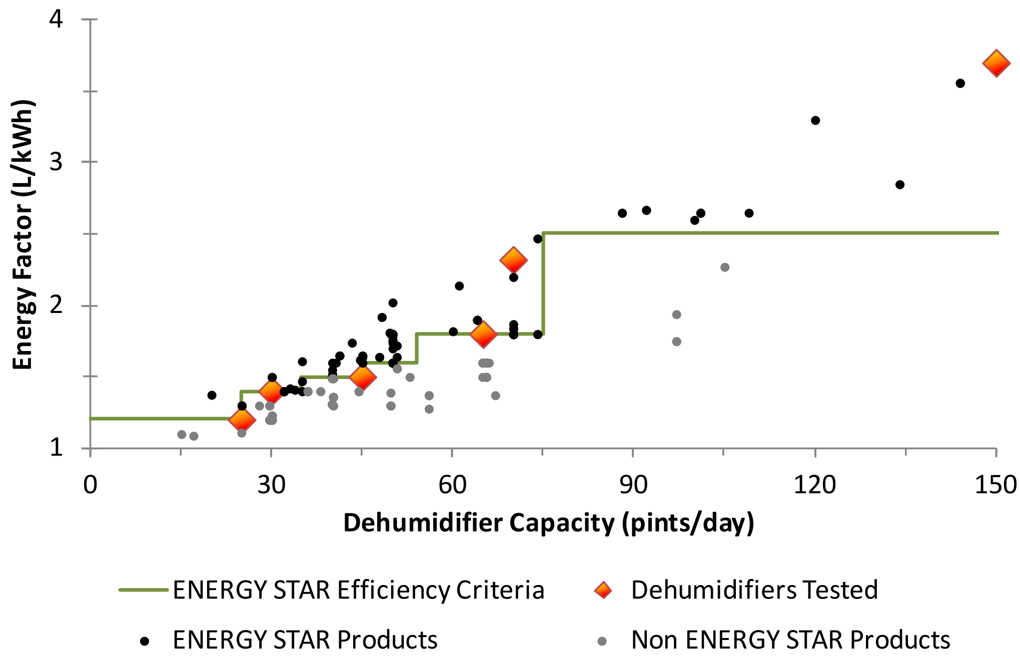


Figure 1. Dehumidifier ENERGY STAR efficiency criteria

Sources: Therma-Stor 2007, Therma-Stor 2010, GE 2011, Soluesair 2011, EPA 2011

2 Test Description

All six dehumidifiers were tested in NREL's HVAC Systems Laboratory with funding from the U.S. Department of Energy (DOE) for the Building America program. The test method followed ANSI/AHAM DH-1-2008, except as described below (ANSI/AHAM 2008). Air was supplied at tightly controlled psychrometric states and the performance was measured over approximately 5–10 minutes of steady-state operation. Steady-state operation was determined by observing the unit's power consumption and outlet air temperature and humidity. Tightly sealed, insulated plenums were constructed around the supply and return grilles of the four standalone dehumidifiers. The supply and return ducts for the two Ultra-Aire dehumidifiers were directly connected to the laboratory's inlet and outlet ducts.

The test matrix evolved over time. The Ultra-Aire XT150 was tested in summer 2009 and reported by Christensen and Winkler (2009). The unit was tested at 12 test conditions, which were chosen to represent typical operating conditions and to bracket those conditions for more accurate interpolation modeling. The Comfort Aire dehumidifier was tested in summer 2010 under 21 operating conditions. The laboratory test data were used to create the test matrix for the four remaining dehumidifiers tested in summer 2011. The final test matrix was created to minimize testing time and still test enough points to create accurate performance-based models. The dehumidifiers with multiple fan speeds were tested at the high fan speed only. A summary of the test matrices is shown on the psychrometric diagram in Figure 2.

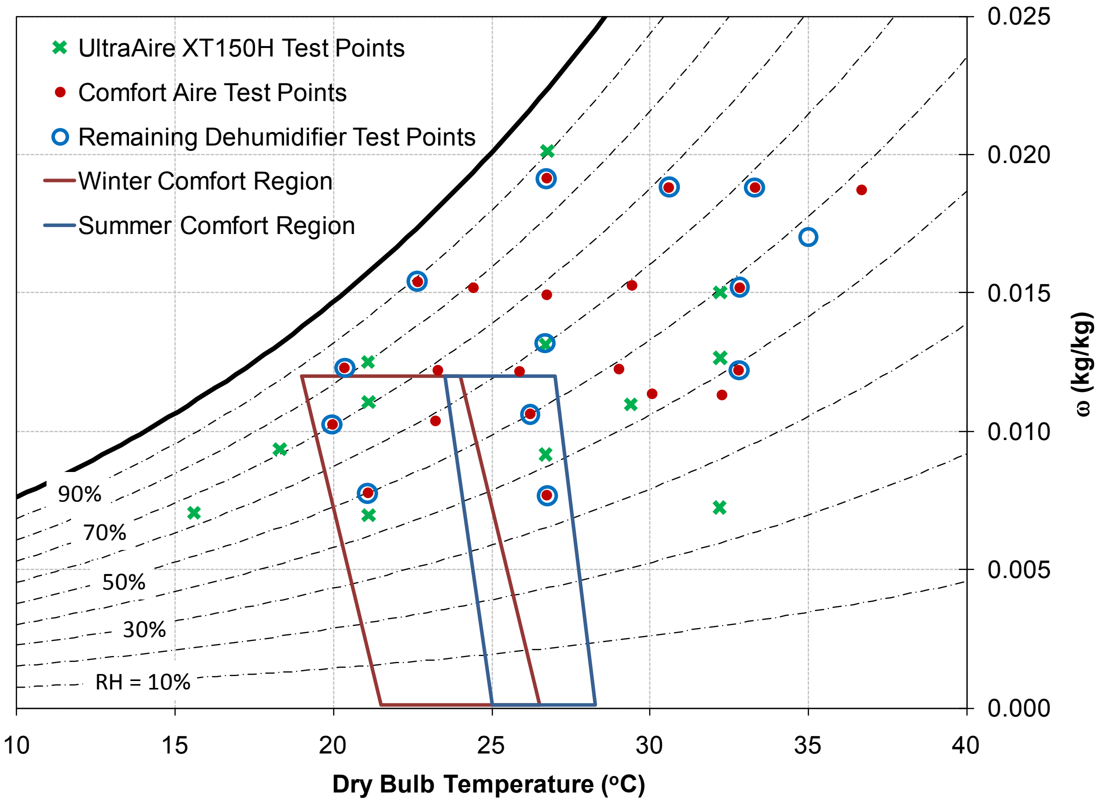


Figure 2. Psychrometric chart showing dehumidifier test points Winter and Summer Comfort Regions from ASHRAE (2004)

The final version of the test matrix used in testing the last four dehumidifiers is listed in Table 2.

Table 2. Finalized Test Matrix

Dry-Bulb		Humidity Ratio		Dew Point		Relative Humidity (%)
(°C)	(°F)	(kg/kg)	(grains)	(°C)	(°F)	
20	68.6	0.01229	86	17.2	63.0	82.1
21	69.9	0.00777	54	10.3	50.5	50.0
20	67.9	0.01025	72	14.5	58.0	70.5
23	72.8	0.01542	108	20.8	69.4	89.1
27	80.1	0.00767	54	10.1	50.2	35.1
26.7	80.0	0.01319	92	18.3	65.0	60.1
26	79.2	0.01062	74	15.0	59.0	49.9
27	80.1	0.01914	134	24.2	75.6	86.2
31	87.1	0.01883	132	24.0	75.1	67.8
33	91.0	0.01222	86	17.1	62.8	39.2
33	91.1	0.01520	106	20.5	69.0	48.5
33	91.9	0.01882	132	23.9	75.1	58.1
35	95.0	0.01702	119	22.3	72.2	48.0

Laminar flow elements were used to measure inlet and outlet airflow rates (see Table 3). Each dehumidifier was initially tested at a set static pressure to determine the blower volumetric flow rate. For subsequent tests, the laboratory's inlet fan provided the appropriate air mass flow rate that would be encountered at sea level to the dehumidifier's return duct or return grille. The dehumidifier's outlet pressure was controlled to ambient pressure by the laboratory's outlet fan to minimize air leakage from the experimental apparatus. Air mass balance (ε_{Mass}) was defined as the ratio of instantaneous inlet air mass flow rate to instantaneous outlet air mass flow rate. All dehumidifiers were tested at a single airflow rate. Thus, the effect of airflow rate on the performance was not captured.

Table 3. Measured Airflow Rates

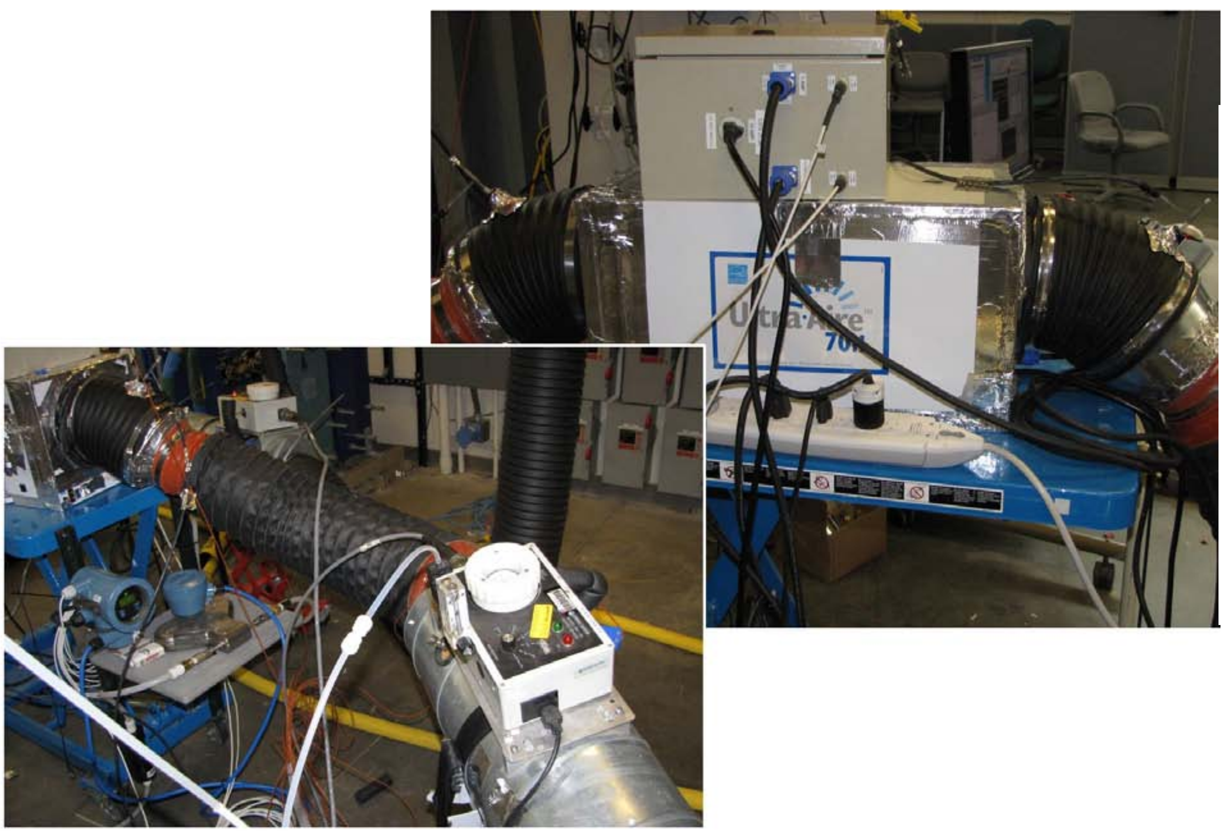
Dehumidifier	Manufacturer Reported Capacity (pints/day)	Airflow Rate	
		Measured Value (cfm)	Manufacturer Reported (cfm)
Ultra-Aire XT150H	150	330	415
Ultra-Aire 70H	70	165	160
General Electric	65	193	195
Soleusair	45	107	103
Comfort Aire	30	179	N/A
Frigidaire	25	88	N/A

Sources: Therma-Stor 2007, Therma-Stor 2010, GE 2011, Soluesair 2011, EPA 2011

Chilled mirror hygrometers, with an accuracy of 0.15°C, were used to measure inlet and outlet dew point temperatures; a coriolis flow meter was used to measure condensate drain mass flow rate. A moisture mass balance (ε_{Water}) was defined as the ratio of instantaneous inlet air moisture mass flow rate to the sum of outlet air moisture mass flow rate and condensate flow rate.

A thermocouple array in the ductwork near the unit was used to measure well-mixed inlet and outlet temperatures. Static pressure was measured at the inlet and outlet. Standard American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) formulas were used to calculate enthalpy for each air stream. Total unit power and fan power were individually measured using two power meters. An energy balance (ε_{Energy}) was defined as the ratio of the sum of inlet air energy rate and electric power to the outlet air energy rate.

Two photographs of the Ultra-Aire 70H are included in Figure 3. A stand was constructed to elevate the unit so condensate flow could be measured and collected. The gray box atop the dehumidifier houses power meters measuring the fan power and the total unit power. The photo on the lower left shows the condensate coriolis mass flow meter and the outlet dew point hygrometer. Appendix A contains additional photographs of the experimental setups.



NREL/PIX 19737 (top, right), 19738 (bottom, left)
Credit: Bethany Sparn, NREL

Figure 3. Photograph of the Ultra-Aire 70H test setup

3 Test Results

Appendix B includes detailed test results for the dehumidifiers tested. The test data in Appendix B were adjusted to sea level using appropriate coil bypass factors.

Experimental mass, water, and energy balances are also listed in Appendix B. A balance value of 1 is achieved by inlet and outlet parameters being equal. Energy balances for the ducted units were better than for nonducted units because the nonducted units lost compressor heat through the walls of dehumidifier casing that was unaccounted for in the air-side measurements. This heat loss resulted in cooler outlet air temperatures but did not affect the performance parameters of interest; namely, water removal rate and energy factor because the compressor energy was directly measured. Water balances were better for the larger capacity dehumidifiers because a more continuous water stream flowed through the condensate coriolis flow meter.

Table 4 compares the manufacturer reported and experimentally determined performance values for the standard rated operating condition of 80°F, 60% RH return air (ANSI/AHAM 2008). Generally, manufacturers report performance only at the standard rating point. Thus, a direct comparison to manufacturer-provided data can be conducted only at this specific point of operation. The capacities of all units met or exceeded manufacturer-reported values and, in general, the units operated more efficiently than reported.

Table 4. Comparison of Rated Performance Values

Dehumidifier	Manufacturer Rated Performance		Measured Performance	
	Capacity (pints/day)	Energy Factor (L/kWh)	Capacity (pints/day)	Energy Factor (L/kWh)
Ultra-Aire - XT150H[1]	150	3.7	150	3.8
Ultra-Aire - 70H	70	2.3	77.1	2.6
General Electric	65	1.8	70.4	1.9
Soleusair	45	1.5	48.3	1.6
Comfort Aire[1]	30	1.4	43.1	1.7
Frigidaire	25	1.2	26.9	1.1

[1] Performance at the rated inlet condition of 80°F, 60% RH was not directly tested. Results were determined from the corresponding regression model (minimum R^2 of 0.996).

The primary objective of the experimental testing was to develop a library of performance curves for a broad range of dehumidifiers. Biquadratic equations are commonly used to simulate HVAC equipment. Equation 1 shows that the entering dry-bulb temperature (T_{in} ,°C) and relative humidity (RH_{in}, 0-100%) are used to estimate the water removal rate and energy factor.

$$Parameter = a + b \cdot T_{in} + c \cdot T_{in}^2 + d \cdot RH_{in} + e \cdot RH_{in}^2 + f \cdot T_{in} \cdot RH_{in} \quad (1)$$

The experimental data were fit to Equation 1 for water removal rate and energy factor. Tables 5 through 7 contain curve fit coefficients for each dehumidifier tested. Nearly all variables of interest (outlet temperature, outlet humidity, power consumption, etc.) can be calculated using curve outputs for capacity and energy factor at the provided inlet condition and the corresponding dehumidifier air mass flow rate.

Table 5. Curve Fit Coefficients for the Ultra-Aire XT150H and Ultra-Aire 70H

	Ultra-Aire XT150H Capacity (pints/day)	Ultra-Aire XT150H Energy Factor (L/kWh)	Ultra-Aire 70H Capacity (pints/day)	Ultra-Aire 70H Energy Factor (L/kWh)
a	–159.67	–5.7925	–214.02	–7.6527
b	3.0539	0.20741	7.2025	0.26475
c	–0.17396	–0.002560	–0.076992	–0.0026446
d	3.6126	0.13525	2.9293	0.14117
e	–0.017796	–0.00056207	–0.0098773	–0.00048381
f	0.054811	–0.00016617	0.0078233	–0.0010876
r^2	0.998	0.998	0.999	0.999

Table 6. Curve Fit Coefficients for the GE ADER65LP and Soleusair SG-DEH-45-1

	General Electric Capacity (pints/day)	General Electric Energy Factor (L/kWh)	Soluesair Capacity (pints/day)	Soluesair Energy Factor (L/kWh)
a	–204.85	–6.6341	–55.879	–3.4599
b	8.0645	0.28560	1.9880	0.15364
c	–0.088482	–0.0032936	–0.021802	–0.0019053
d	3.1486	0.12026	0.92351	0.063237
e	–0.011160	–0.00041373	–0.0028202	–0.00020780
f	–0.015386	–0.0015161	0.013010	–0.00043861
r^2	0.999	0.997	0.999	0.997

Table 7. Curve Fit Coefficients for the Comfort Aire BHD-301-G and Frigidaire FAD251NTD

	Comfort Aire Capacity (pints/day)	Comfort Aire Energy Factor (L/kWh)	Frigidaire Capacity (pints/day)	Frigidaire Energy Factor (L/kWh)
a	–76.137	–3.9653	–49.473	–3.1461
b	1.9674	0.12833	1.4527	0.11619
c	–0.019527	–0.0013985	–0.018538	–0.0014438
d	1.1442	0.074793	0.63326	0.048822
e	–0.0044646	–0.00026754	–0.0020335	–0.00015523
f	0.017640	–0.00017376	0.012741	–0.00010357
r^2	0.998	0.995	0.999	0.999

Appendix C shows plots that compare the predicted and experimental water removal rates and energy factors. All models accurately predicted the experimental results, as indicated by all points being in close proximity to the line of ideal fit (represented by the line y = x).

EnergyPlus, an annual whole-building simulation tool, uses Equation 1 to simulate the thermal performance and electric power of a direct-expansion dehumidifier (DOE 2010). The EnergyPlus dehumidifier component model uses two biquadratic curves to scale the rated performance. The user must enter the water removal rate (L/day), energy factor (L/kWh), and volumetric airflow rate (m^3/s) at the AHAM rated operating point. The normalized performance curves entered into EnergyPlus scale the rated performance to determine the performance at off-rated conditions. Thus, the curves must equal a value of 1 at the rated operating condition (80°F DB, 60% RH). Tables 8 and 9 contain the normalized water removal rate and energy factor performance curve coefficients for use in EnergyPlus. The R-squared values indicate the performance curves have accurately captured the experimental performance. Plots comparing the normalized model predictions to the experimental values have not been provided, because normalizing the data does not change the model's accuracy. The comparison plots in Appendix C apply to the normalized model as well. Appendix D includes graphical representations of the normalized performance curves using the coefficients in Tables 8 and 9.

Table 8. Normalized Water Removal Rate Coefficients for the EnergyPlus Component Model

	Ultra-Aire XT150H	Ultra-Aire 70H	General Electric	Soleusair	Comfort Aire	Frigidaire
a	–1.0648	–2.0900	–2.6382	–1.3583	–1.3222	–1.82260
b	0.020365	0.056838	0.10122	0.052320	0.02384779	0.053677265
c	–0.00011600	–0.00051779	–0.0010888	–0.00062497	–0.00022928	–0.00068640
d	0.024090	0.031944	0.041806	0.021215	0.021240	0.023268
e	–0.00011867	–0.00011318	–0.00014986	–6.9291E-05	–9.1570E-05	–7.4699E-05
f	0.00036551	0.00026988	–0.00016050	0.00023933	0.000564439	0.00046914
r^2	0.998	0.999	0.999	0.999	0.997	0.999

Table 9. Normalized Energy Factor Coefficients for the EnergyPlus Dehumidifier Model

	Ultra-Aire XT150H	Ultra-Aire 70H	General Electric	Soleusair	Comfort Aire	Frigidaire
a	–1.5464	–3.0402	–3.4183	–2.1259	–2.3185	–2.7804
b	0.055372	0.10518	0.14716	0.094404	0.075036	0.10268
c	–0.00068342	–0.0010506	–0.0016970	–0.0011707	–0.00081771	–0.0012760
d	0.036107	0.056083	0.061965	0.038855	0.043732	0.043147
e	–0.00015005	–0.00019220	–0.00021318	–0.00012768	–0.00015643	–0.00013718
f	–4.43616E–05	–0.00043206	–0.00078120	–0.00026950	–0.00010160	–9.1532E-05
r^2	0.998	0.999	0.997	0.999	0.995	0.999

4 Generic Performance Curves

A generic set of normalized performance curves to simulate other dehumidifiers would be useful. Generic performance curves could be used in building optimization software to simulate a variety of dehumidifier sizes and efficiency levels. The coefficients in Equation 1 were determined through a linear regression with normalized experimental data from all six dehumidifiers. Nine experimental test points were removed from the Comfort Aire dataset to be consistent with the test matrix from the five other dehumidifiers. Thus, 77 test points were included in the regression.

Coefficients for the generic performance curves are listed in Table 10. These will provide a normalized result (at a given operating condition) that must be scaled by the corresponding rated performance metric for the specific dehumidifier being modeled. The entire experimental dataset was accurately fit to the generic performance curves, as indicated by the R-squared values. The average relative errors in capacity and energy factor predictions were both less than 5.9%. The generic model was able to predict the water removal rate and energy factor of the nine Comfort Aire test points removed from the regression with average relative errors of 2.4% and 2.6%, respectively. Despite subtle differences in the individual performance curves (see Appendix D), a single set of performance curves can accurately predict the performance of all the dehumidifiers tested.

Table 10. Normalized Water Removal Rate and Energy Factor Coefficients for the Generic Model

	Capacity (pints/day)	Energy Factor (L/kWh)
a	–1.1625	–1.9022
b	0.022715	0.063467
c	–0.00011321	–0.00062284
d	0.021111	0.039540
e	–6.9303E-05	–0.00012564
f	0.00037884	–0.00017672
r^2	0.977	0.969

Plots comparing the generic performance curve output to the experimental results are shown in Figure 4 and Figure 5. The dataset used for the regression and the nine points removed from the Comfort Aire dataset used for validation are included in the comparison plots. Appendix E includes graphical representations of the generic curves, which can be visually compared to the curves for the individual performances in Appendix D.

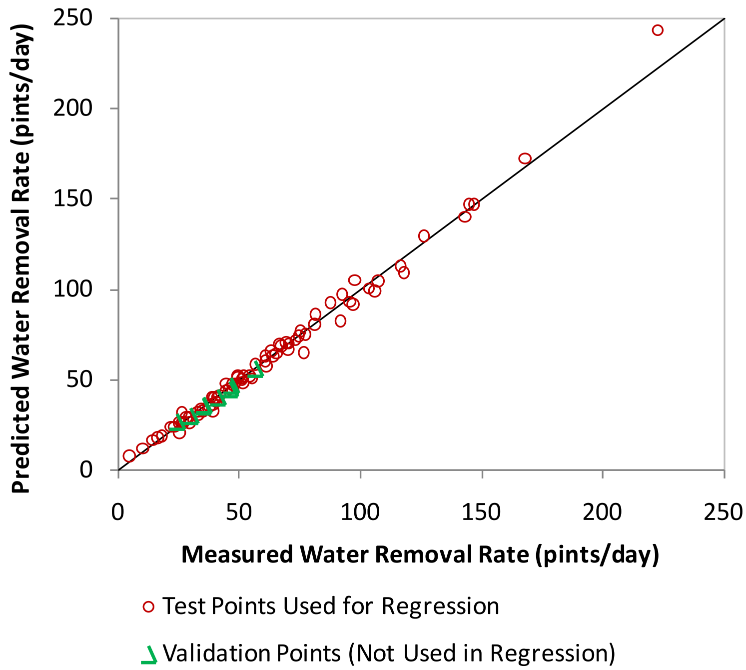


Figure 4. Water removal rate model comparison using the generic performance curve

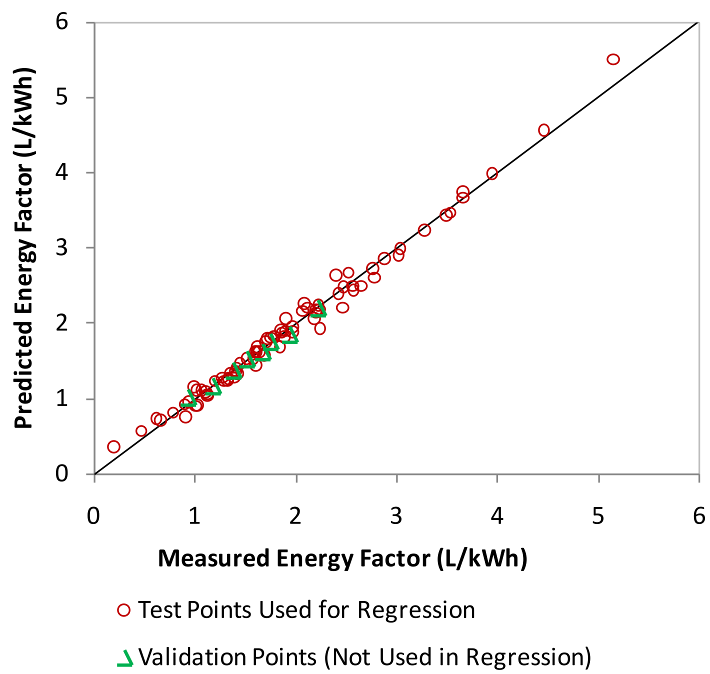


Figure 5. Energy factor model comparison using the generic performance curve

5 Conclusions

Six residential ENERGY STAR vapor compression dehumidifiers were tested in the laboratory over a wide range of operating conditions. The performance of all units met or exceeded manufacturer reported values. The experimental test data were fit to biquadratic performance curves for water removal rate and energy factor. All numerical models accurately represented the test data. Data from all six dehumidifiers were used to develop an accurate generic dehumidifier performance curve.

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Appendix A – Photographs of Experimental Setup

NREL/PIX 19601
Credit: Dane Christensen, NREL

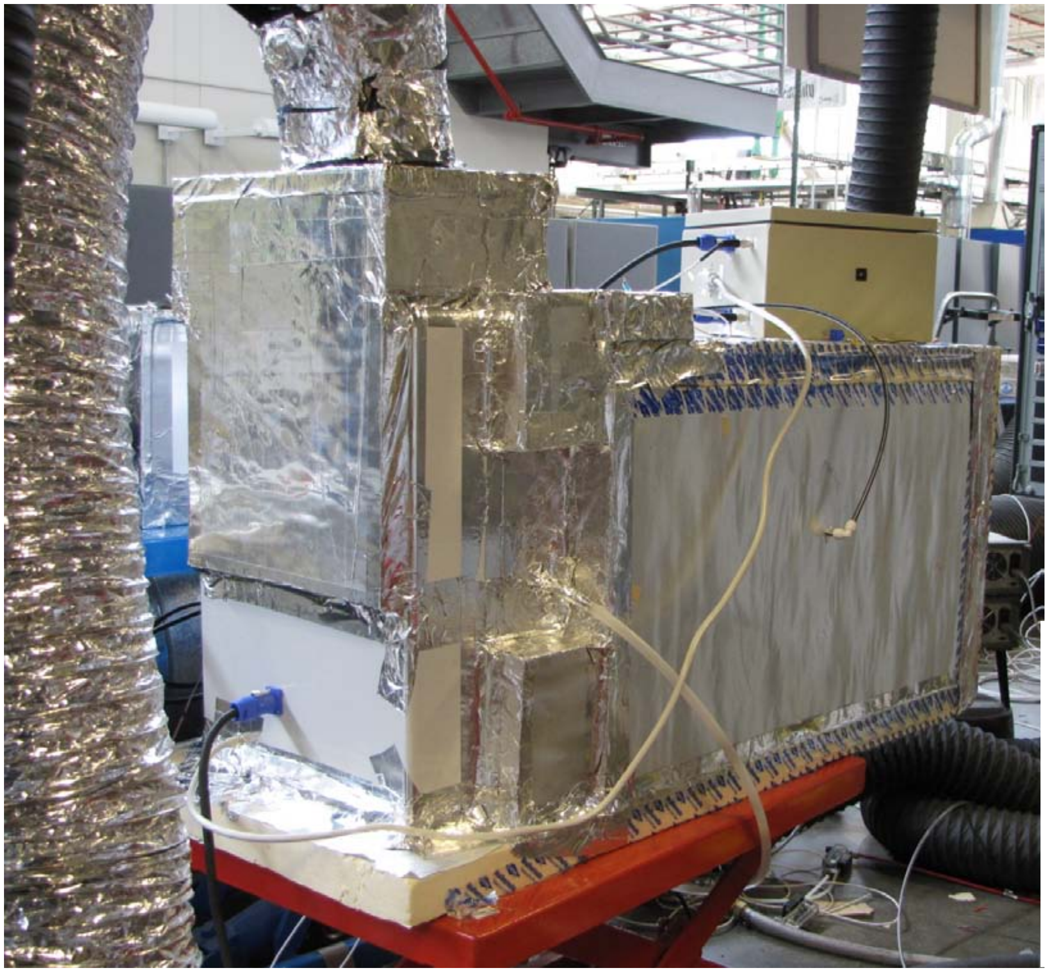
Figure 6. Photograph of the Ultra-Aire XT150H test setup

A stand was constructed to elevate the unit so flow could be measured and collected. The temperature of the flowing condensate was measured in the trap. This piping was insulated to maintain condensate temperature up to a coriolis flow meter. All seams in the XT150H's sheet metal box were sealed with aluminum tape to prevent air leakage and maintain an accurate air mass balance. The gray box atop the dehumidifier is the power meter.

NREL/PIX 19603 (main), 19602 (inset)
Credit: Dane Christensen, NREL

Figure 7. Photograph of the Ultra-Aire XT150H test setup

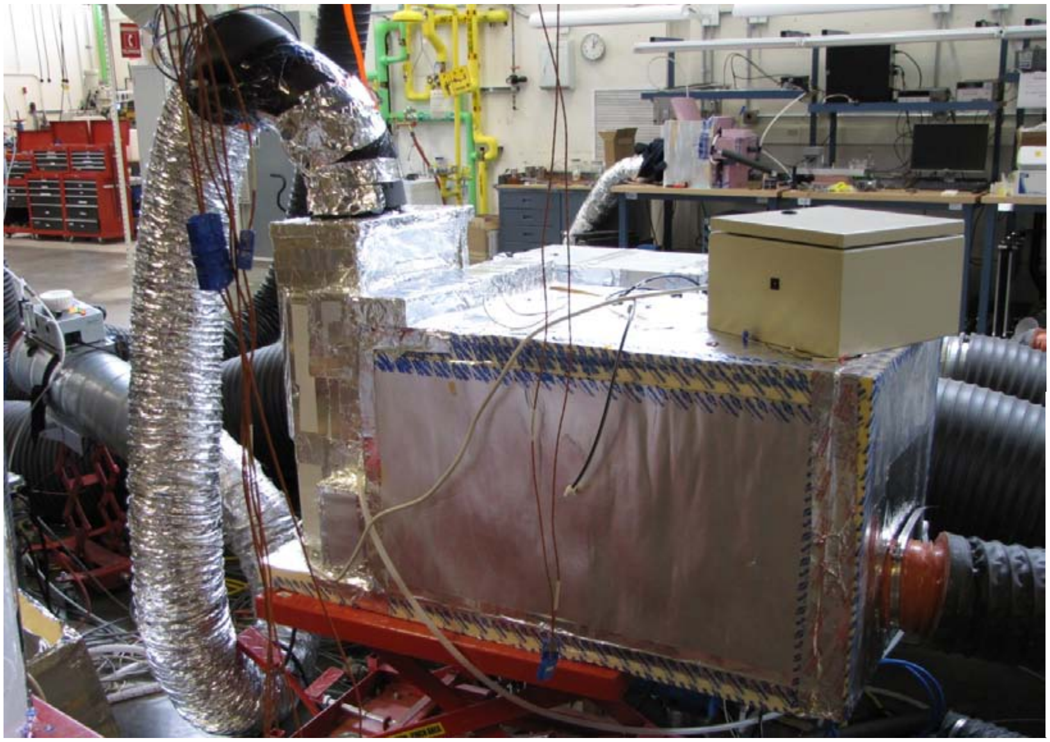
The rigid ductwork (right) is a mixing section, at the end of which temperature and humidity are measured. Thick insulation was applied to the ductwork after that measurement to prevent heat loss and condensation before the dehumidifier inlet. Similarly, insulated ductwork routes the outlet airstream to a mixing section where outlet temperature and humidity are measured. The inset shows pitot tube connections for pressure measurement immediately at the unit’s inlet and outlet. The blue tubing connects the pitot tubes to pressure transducers.



NREL/PIX 19604
Credit: Jon Winkler, NREL

Figure 8. Photograph of the GE dehumidifier test setup

Inlet (right) and outlet (left) plenums were constructed for the four standalone units. Plenums were constructed from 2-in. rigid insulation and tightly sealed with aluminum tape. The gray box atop the inlet plenum houses the power meters. The inlet static pressure was measured in three locations and one static pressure tap is shown in the inlet plenum. The condensate hose flowing to the coriolis flow meter is also shown.



NREL/PIX 19605
Credit: Jon Winkler, NREL

Figure 9. Photograph of the GE dehumidifier test setup

Care was taken to insulate the inlet and outlet ducts. The insulated duct connected to the inlet plenum is on the right; insulated outlet ducts are on the left. Inlet and outlet dew points were measured with chilled mirror hygrometers, shown on the left for the outlet air stream.

Appendix B – Summary of Measured and Calculated Test Data

Summaries of the results are included in Tables 11 through 16. Intended test points were not perfectly achieved in all cases; however, the actual inlet conditions are included in the summary tables and were used in the analysis.

Table 11. Summary of Test Data for the Ultra-Aire XT150H

Inlet Conditions					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
15.60	8.82	0.00875	63.9	0.1867	26.03	1.46	0.0042	20.2	0.1875	97.02	45.91	3.02	634.18	0.995	0.984	1.038
21.10	8.69	0.00869	44.8	0.1851	30.33	3.09	0.0047	17.6	0.1855	76.45	36.17	2.24	672.68	0.997	0.994	1.015
32.20	9.22	0.00899	24.2	0.1856	39.15	6.73	0.0061	13.9	0.1862	39.07	18.49	1.01	766.46	0.997	0.997	0.958
18.30	13.02	0.01161	71.1	0.1869	31.13	5.63	0.0056	20.1	0.1865	126.29	59.76	3.66	680.71	1.002	0.995	1.047
26.70	12.73	0.01142	41.9	0.1877	37.28	7.64	0.0065	16.4	0.1870	91.82	43.44	2.46	735.40	1.004	1.004	1.010
21.10	15.58	0.01380	70.6	0.1869	35.49	8.38	0.0068	19.0	0.1866	144.70	68.47	3.94	723.88	1.002	0.998	1.037
29.40	15.48	0.01371	42.8	0.1867	41.34	10.49	0.0079	16.0	0.1862	105.95	50.13	2.65	788.63	1.003	1.004	0.997
21.10	17.49	0.01565	79.7	0.1868	37.27	9.95	0.0076	19.2	0.1868	168.04	79.51	4.46	743.37	1.000	0.997	1.046
32.20	17.67	0.01583	41.9	0.1877	45.18	12.85	0.0092	15.3	0.1874	117.90	55.79	2.78	837.21	1.002	1.005	1.007
26.71	18.22	0.01632	59.6	0.1864	41.63	12.16	0.0088	17.6	0.1863	146.81	69.47	3.65	792.98	1.001	1.000	1.011
32.21	20.34	0.01867	49.6	0.1863	47.22	15.25	0.0108	16.1	0.1862	143.04	67.68	3.27	862.92	1.000	1.001	0.997
26.75	25.04	0.02500	90.4	0.1912	46.83	18.98	0.0138	20.8	0.1913	222.58	105.32	5.15	852.66	1.000	0.996	1.022

Table 12. Summary of Test Data for the Ultra-Aire 70H

Inlet Conditions					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
26.01	14.33	0.01249	48.4	0.0936	39.00	9.36	0.0073	16.8	0.0932	49.39	23.37	1.78	547.26	1.004	1.007	1.024
26.90	10.87	0.00992	36.6	0.0949	36.13	7.85	0.0066	17.7	0.0949	26.27	12.43	0.99	525.08	1.001	1.000	1.021
32.99	24.17	0.02350	59.9	0.0930	54.09	18.62	0.0134	14.2	0.0925	95.31	45.10	2.76	680.25	1.006	1.024	1.026
30.97	24.16	0.02349	67.2	0.0929	53.23	18.04	0.0130	14.3	0.0923	103.45	48.95	3.03	672.98	1.006	1.024	1.028
27.46	24.05	0.02332	81.7	0.0932	51.40	16.95	0.0121	14.6	0.0927	116.57	55.16	3.49	658.15	1.006	1.021	1.029
35.01	22.29	0.02087	47.8	0.0936	52.88	17.61	0.0126	14.1	0.0927	74.42	35.21	2.20	667.56	1.009	1.026	1.029
32.99	20.93	0.01914	49.2	0.0936	50.48	15.92	0.0113	14.3	0.0927	73.15	34.62	2.23	645.66	1.009	1.025	1.029
22.58	20.62	0.01877	88.6	0.0931	44.61	12.43	0.0090	15.3	0.0927	107.29	50.77	3.53	599.04	1.004	1.013	1.029
26.70	18.36	0.01624	60.2	0.0932	44.27	11.98	0.0087	15.1	0.0929	77.13	36.49	2.56	593.65	1.003	1.012	1.023
32.97	17.29	0.01515	39.2	0.0929	46.71	13.21	0.0094	14.5	0.0922	49.32	23.34	1.59	609.70	1.008	1.021	1.022
21.70	16.87	0.01473	73.9	0.0932	39.45	9.29	0.0073	16.3	0.0931	81.05	38.35	2.87	556.73	1.001	1.003	1.024
21.67	15.03	0.01306	65.8	0.0934	37.20	8.16	0.0067	17.0	0.0933	67.39	31.89	2.47	538.38	1.001	1.001	1.021
21.55	11.59	0.01039	52.9	0.0938	33.32	6.26	0.0059	18.6	0.0945	44.70	21.15	1.75	504.82	0.993	0.984	1.024

Table 13. Summary of Test Data for the GE ADER65LP

Inlet Conditions					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
33.00	23.91	0.02319	59.0	0.1087	51.13	19.89	0.0146	17.8	0.1036	81.39	38.51	1.89	846.83	1.049	1.055	1.061
31.06	23.92	0.02320	65.8	0.1090	49.79	19.56	0.0143	18.6	0.1038	87.56	41.43	2.08	829.75	1.050	1.057	1.067
27.27	23.79	0.02301	81.3	0.1084	47.11	18.79	0.0136	20.3	0.1036	97.68	46.22	2.40	803.13	1.046	1.047	1.068
35.05	22.46	0.02116	48.2	0.1080	51.80	18.74	0.0135	16.0	0.1029	69.38	32.83	1.62	846.44	1.049	1.057	1.069
33.00	20.38	0.01855	47.5	0.1082	48.82	16.43	0.0117	16.0	0.1028	65.26	30.88	1.61	800.30	1.052	1.068	1.064
22.22	20.33	0.01850	89.0	0.1085	40.70	14.43	0.0102	21.4	0.1038	92.50	43.77	2.52	723.74	1.045	1.038	1.087
26.73	18.23	0.01616	59.6	0.1090	42.45	13.32	0.0095	18.2	0.1043	70.44	33.33	1.90	732.67	1.045	1.044	1.062
33.07	17.36	0.01528	39.2	0.1084	46.86	13.68	0.0097	14.8	0.1028	51.50	24.37	1.32	768.31	1.055	1.071	1.063
21.19	16.78	0.01471	75.8	0.1087	36.99	10.88	0.0081	20.7	0.1039	75.25	35.61	2.22	668.46	1.046	1.042	1.085
26.05	14.63	0.01278	49.3	0.1093	39.36	9.90	0.0076	17.1	0.1044	55.17	26.11	1.60	679.84	1.048	1.058	1.091
21.15	14.48	0.01266	65.6	0.1096	35.16	8.82	0.0070	19.9	0.1048	63.96	30.27	1.97	640.67	1.046	1.047	1.073
26.91	10.98	0.01002	36.9	0.1083	37.15	7.55	0.0064	16.4	0.1032	33.09	15.66	1.02	639.93	1.050	1.040	1.046
20.51	10.20	0.00951	51.5	0.1095	31.15	5.73	0.0057	20.2	0.1068	40.69	19.25	1.33	604.56	1.026	0.985	1.096

Table 14. Summary of Test Data for the Soleusair SG-DEH-45-1

Inlet Conditions[1]					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
21.73	14.53	0.01271	63.5	0.0573	41.53	7.07	0.0062	12.6	0.0547	41.86	19.81	1.51	545.97	1.046	1.071	1.066
21.05	10.28	0.00956	50.0	0.0592	36.85	3.86	0.0050	12.9	0.0556	29.28	13.86	1.12	513.70	1.065	1.096	1.062
32.99	24.07	0.02339	59.6	0.0601	56.48	19.01	0.0138	13.0	0.0593	56.54	26.75	1.70	654.03	1.014	1.032	1.045
31.00	24.04	0.02334	66.5	0.0601	55.29	18.53	0.0134	13.3	0.0593	60.60	28.68	1.85	645.11	1.013	1.032	1.044
28.06	24.00	0.02328	78.6	0.0600	53.54	17.83	0.0128	13.9	0.0593	66.47	31.45	2.06	635.27	1.011	1.034	1.037
35.03	22.35	0.02098	47.9	0.0596	56.48	17.76	0.0127	12.0	0.0592	46.82	22.15	1.41	654.48	1.007	1.025	1.040
33.00	20.47	0.01862	47.8	0.0599	53.47	15.59	0.0110	12.1	0.0593	44.51	21.06	1.40	627.34	1.010	1.024	1.044
23.12	20.72	0.01891	86.3	0.0597	47.10	13.45	0.0096	14.4	0.0599	63.15	29.88	2.11	588.76	0.997	1.018	1.012
26.59	18.36	0.01625	60.6	0.0600	47.08	12.21	0.0088	13.3	0.0602	48.33	22.87	1.63	584.24	0.996	1.021	1.011
33.00	17.45	0.01532	39.6	0.0598	50.95	12.98	0.0093	11.5	0.0594	34.66	16.40	1.12	608.31	1.008	1.019	1.039
21.51	16.98	0.01486	75.3	0.0598	42.26	9.55	0.0074	14.3	0.0604	51.83	24.52	1.86	549.81	0.990	1.016	1.007
25.98	15.10	0.01315	51.0	0.0602	43.86	9.12	0.0072	12.8	0.0606	39.11	18.51	1.39	554.38	0.993	1.015	1.021

[1] The 27°C DB, 35.1% RH test point was removed from the data due to difficulty in achieving steady state operation for this particular operating condition.

Table 15. Summary of Test Data for the Comfort Aire BHD-301-G

Inlet Conditions					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
20.35	17.44	0.01527	83.2	0.1046	31.45	13.70	0.0098	33.9	0.1010	51.05	24.16	2.19	458.98	1.036	1.037	1.050
21.08	10.44	0.00961	50.5	0.1073	27.97	8.14	0.0067	28.6	0.1008	21.93	10.38	1.02	425.84	1.065	1.047	1.066
19.95	14.64	0.01272	71.3	0.1040	29.43	11.29	0.0083	32.5	0.0989	38.73	18.33	1.72	444.45	1.051	1.039	1.071
23.20	14.84	0.01288	59.2	0.1026	32.46	11.83	0.0086	28.3	0.0980	35.21	16.66	1.51	458.65	1.047	1.063	1.054
23.31	17.30	0.01514	68.9	0.1028	34.08	13.86	0.0099	29.6	0.0989	46.17	21.85	1.94	469.16	1.039	1.067	1.064
22.65	20.96	0.01919	90.1	0.1018	35.90	17.16	0.0122	33.0	0.0948	60.71	28.73	2.42	494.53	1.074	1.091	1.088
24.41	20.72	0.01891	79.9	0.1017	37.18	17.15	0.0122	30.8	0.0953	56.70	26.83	2.22	502.86	1.067	1.085	1.080
26.21	15.16	0.01316	50.5	0.1022	35.31	12.45	0.0090	25.2	0.0976	32.56	15.41	1.35	474.49	1.047	1.080	1.062
25.88	17.28	0.01511	59.0	0.1024	36.19	14.23	0.0101	26.9	0.0981	41.11	19.45	1.67	485.24	1.044	1.074	1.055
26.75	10.26	0.00948	35.5	0.1046	32.97	8.78	0.0070	22.5	0.0987	14.02	6.63	0.62	448.50	1.060	1.088	1.031
26.75	20.44	0.01857	68.3	0.1017	38.81	17.21	0.0123	28.3	0.0953	51.00	24.13	1.97	510.50	1.068	1.092	1.073
26.72	24.40	0.02387	87.1	0.1023	41.54	20.83	0.0155	30.7	0.0958	70.18	33.21	2.57	538.98	1.067	1.092	1.085
29.02	17.35	0.01519	49.3	0.0974	38.95	14.72	0.0104	24.0	0.0974	35.04	16.58	1.38	501.55	1.043	1.082	1.060
29.42	20.78	0.01898	59.7	0.1015	41.07	17.90	0.0128	26.2	0.0949	46.62	22.06	1.75	525.72	1.069	1.097	1.080
30.07	16.19	0.01408	43.1	0.1016	39.05	13.88	0.0099	22.6	0.0972	29.73	14.07	1.17	499.17	1.045	1.088	1.053
30.60	24.13	0.02347	68.5	0.1022	44.34	21.01	0.0157	26.8	0.0963	61.26	28.99	2.18	554.22	1.061	1.092	1.090
32.26	16.11	0.01400	37.9	0.0998	40.76	14.22	0.0101	21.1	0.0952	24.06	11.38	0.93	511.58	1.048	1.083	1.048
32.81	17.31	0.01515	39.6	0.1015	41.78	15.28	0.0108	21.4	0.0966	27.97	13.23	1.06	519.16	1.050	1.089	1.058
32.82	20.70	0.01889	49.0	0.1007	43.71	18.27	0.0131	23.4	0.0940	39.45	18.67	1.44	538.82	1.071	1.108	1.076
33.30	24.12	0.02345	58.7	0.1021	46.21	21.39	0.0160	24.9	0.0959	54.01	25.55	1.89	564.82	1.065	1.099	1.085
36.70	24.04	0.02333	48.4	0.1020	48.65	21.72	0.0164	22.5	0.0959	46.10	21.81	1.58	576.99	1.063	1.104	1.078

Table 16. Summary of Test Data for the Frigidaire FAD251NTD

Inlet Conditions					Outlet Conditions					Performance				Balances		
DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	DB (°C)	DP (°C)	ω (kg/kg)	RH (%)	MFR (kg/s)	Pints/ day	L/ day	L/ kWh	Power (W)	ε_{Mass}	ε_{Energy}	ε_{Water}
26.40	14.47	0.01262	47.8	0.0496	40.40	11.24	0.0083	17.6	0.0484	17.92	8.48	0.78	450.55	1.004	1.031	1.044
28.47	9.23	0.00888	29.9	0.0489	38.43	8.23	0.0068	16.0	0.0496	4.42	2.09	0.20	437.92	0.985	1.006	1.011
22.45	9.29	0.00892	43.0	0.0499	33.42	6.95	0.0062	19.3	0.0499	9.94	4.70	0.47	418.33	0.999	1.000	1.058
32.99	24.32	0.02386	60.5	0.0498	52.85	20.79	0.0154	17.3	0.0486	34.38	16.27	1.28	528.07	1.024	1.060	1.038
31.19	24.18	0.02365	66.4	0.0499	51.65	20.27	0.0149	17.7	0.0488	37.40	17.70	1.42	519.59	1.023	1.062	1.040
25.07	24.20	0.02368	94.9	0.0503	47.70	19.17	0.0139	20.2	0.0496	47.31	22.38	1.84	506.35	1.013	1.041	1.070
22.11	17.08	0.01505	73.0	0.0500	38.95	12.47	0.0090	20.7	0.0492	29.00	13.72	1.27	450.30	1.016	1.026	1.063
35.02	22.13	0.02081	47.3	0.0495	52.44	19.24	0.0140	16.0	0.0479	25.03	11.84	0.94	523.89	1.005	1.038	1.036
33.00	20.14	0.01834	46.8	0.0493	49.57	17.15	0.0122	16.2	0.0484	23.20	10.98	0.90	507.70	1.018	1.048	1.056
22.29	20.67	0.01895	90.5	0.0496	42.77	15.29	0.0108	20.3	0.0489	40.46	19.15	1.69	472.15	1.014	1.039	1.039
27.31	18.46	0.01646	58.5	0.0491	44.77	14.44	0.0102	17.3	0.0465	26.91	12.73	1.11	479.54	0.948	0.979	0.959
33.03	17.10	0.01506	38.6	0.0487	47.71	14.56	0.0103	15.0	0.0471	16.46	7.79	0.66	490.65	1.002	1.040	1.055
19.80	15.10	0.01321	74.2	0.0492	36.03	10.23	0.0077	20.9	0.0484	26.58	12.58	1.19	438.73	1.015	1.023	1.055

Appendix C – Plots of Model Comparisons

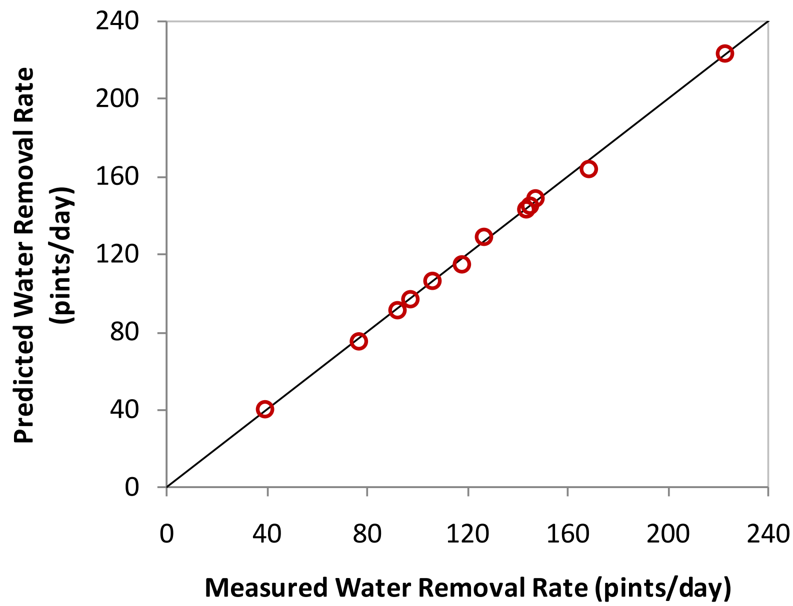


Figure 10. Water removal rate model comparison for the Ultra-Aire XT150H

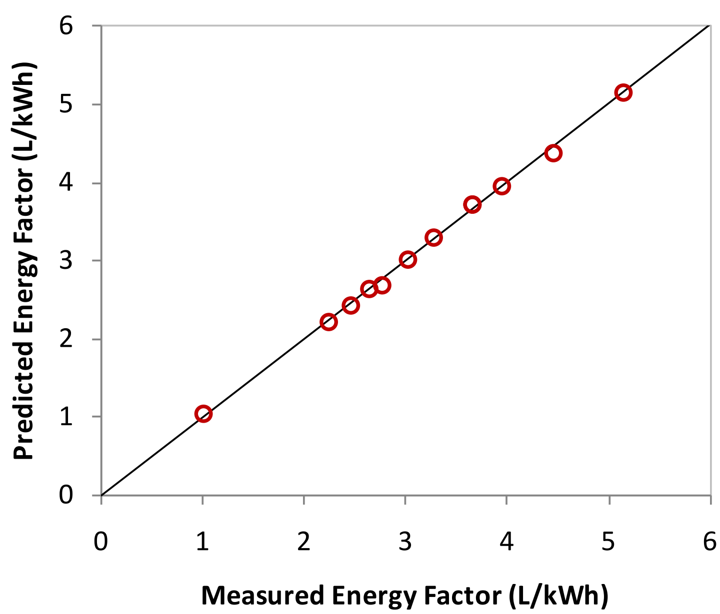


Figure 11. Energy factor model comparison for the Ultra-Aire XT150H

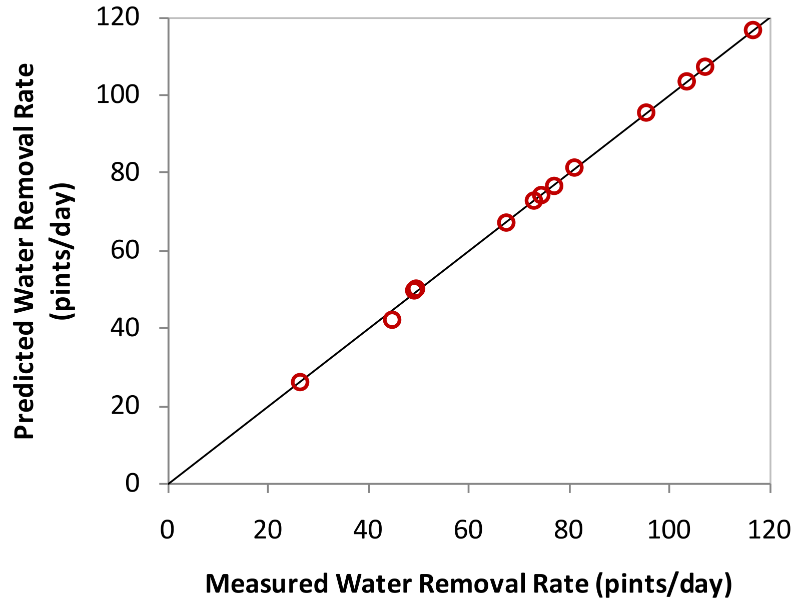


Figure 12. Water removal rate model comparison for the Ultra-Aire 70H

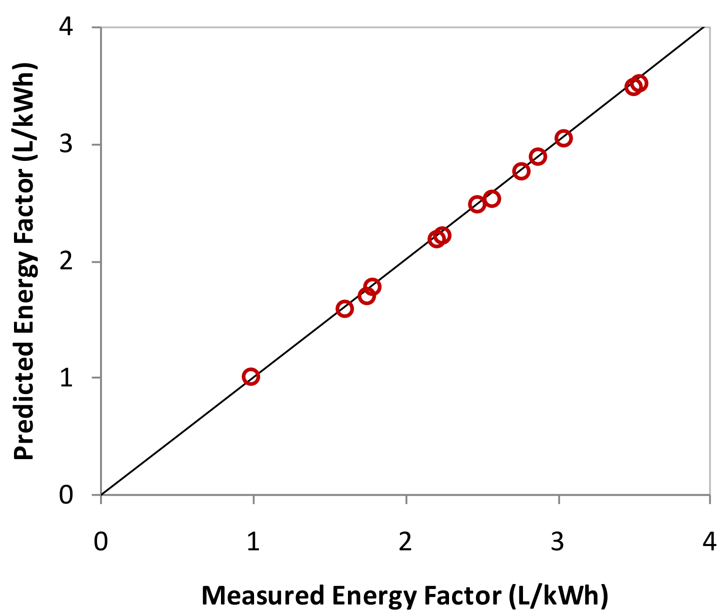


Figure 13. Energy factor model comparison for the Ultra-Aire 70H

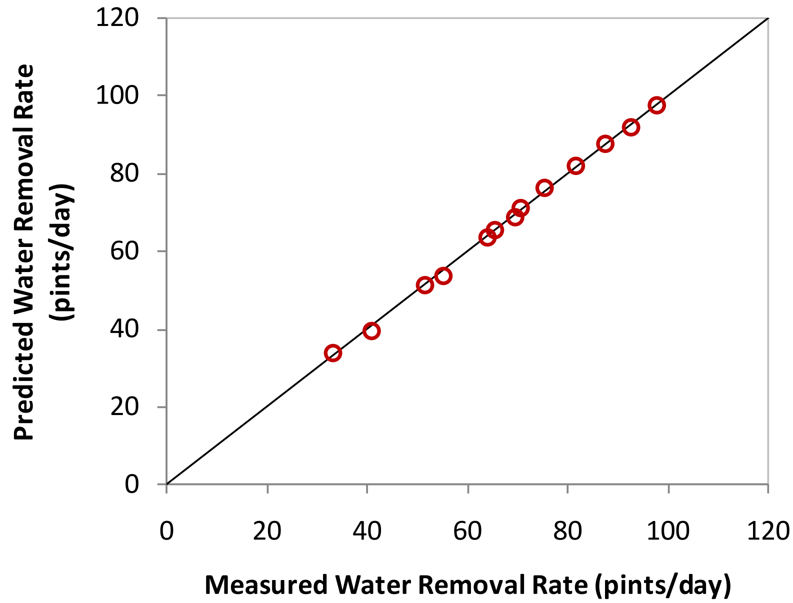


Figure 14. Water removal rate model comparison for the GE ADER65LP

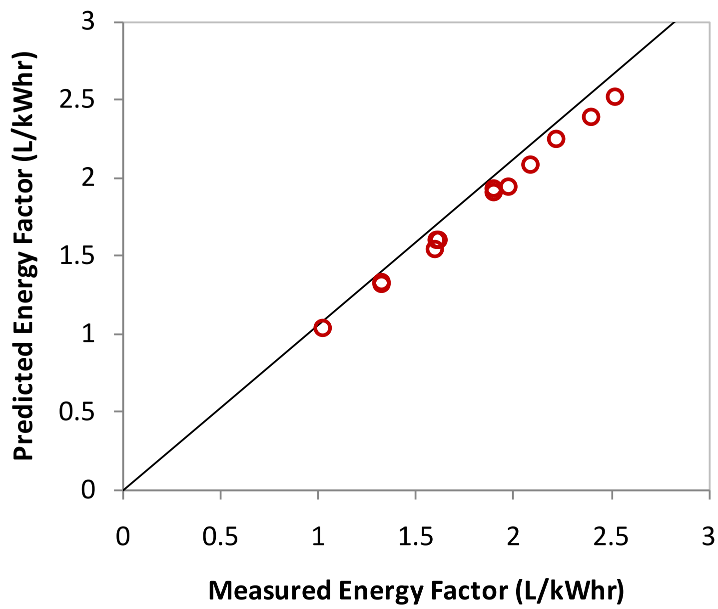


Figure 15. Energy factor model comparison for the GE ADER65LP

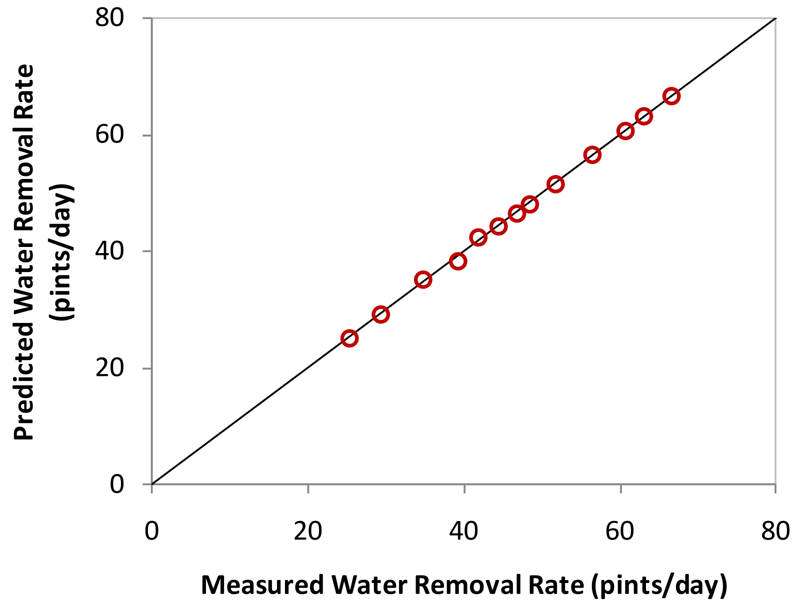


Figure 16. Water removal rate model comparison for the Soleusair SG-DEH-45-1

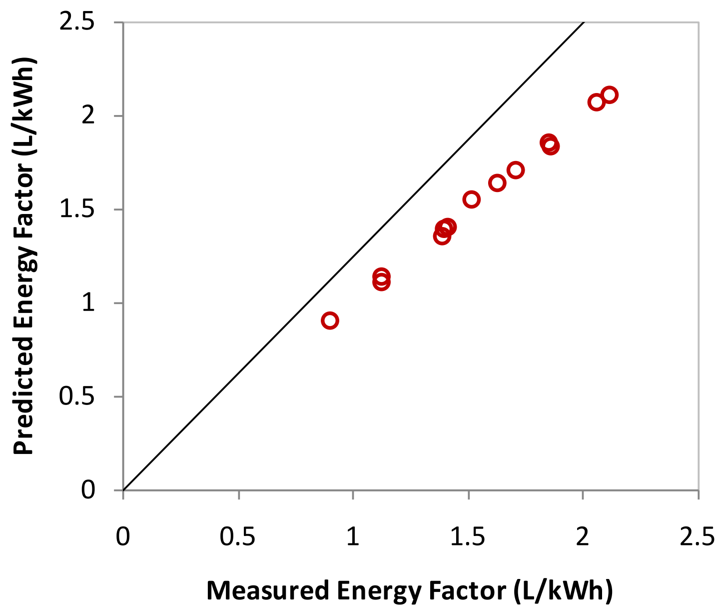


Figure 17. Energy factor model comparison for the Soleusair SG-DEH-45-1

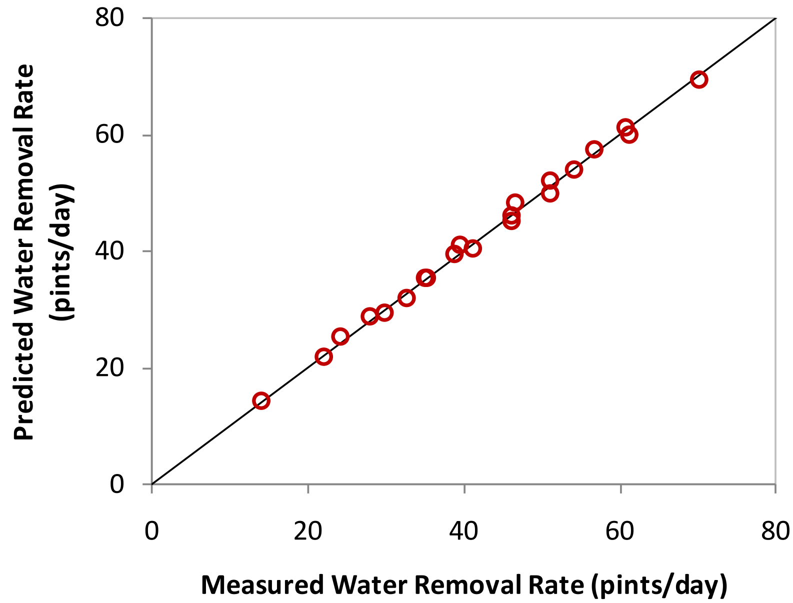


Figure 18. Water removal rate model comparison for the Comfort Aire BHD-301-G

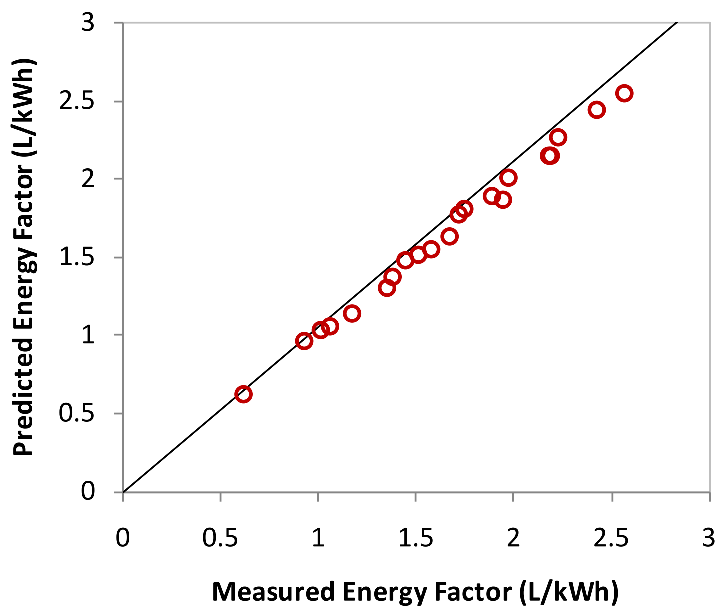


Figure 19. Energy factor model comparison for the Comfort Aire BHD-301-G

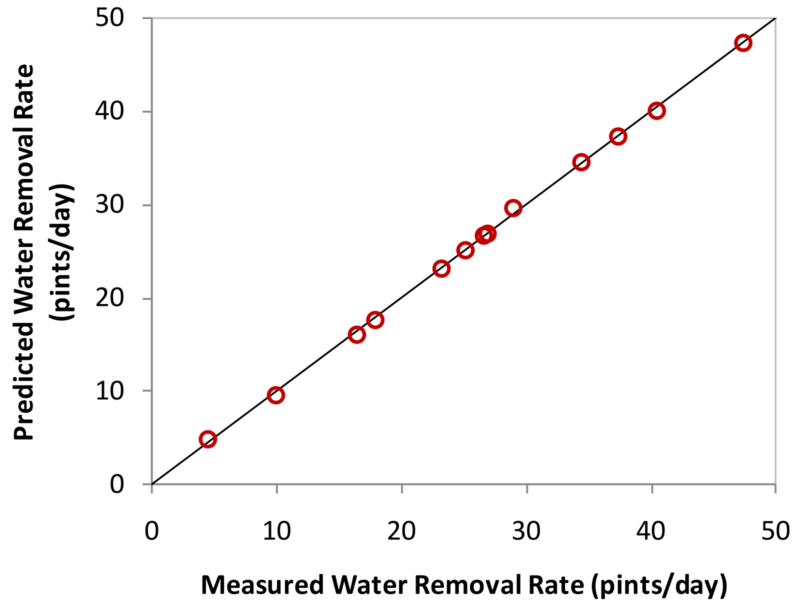


Figure 20. Water removal rate model comparison for the Frigidaire FAD251NTD

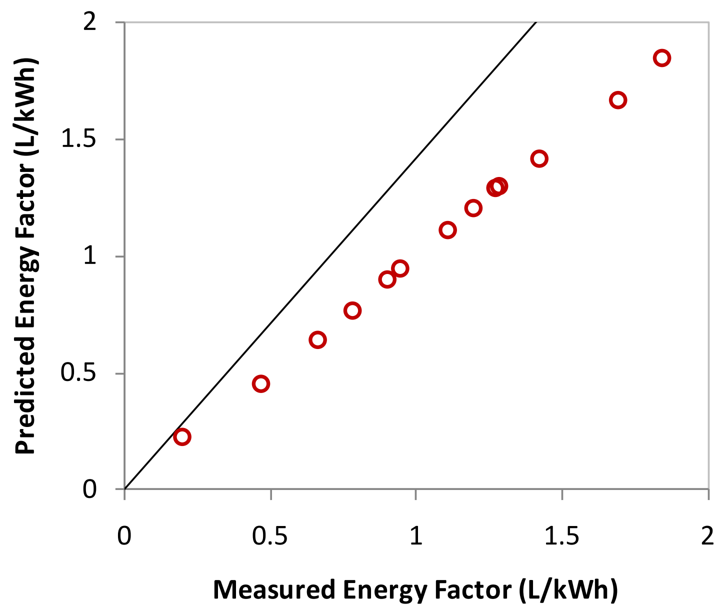


Figure 21. Energy factor model comparison for the Frigidaire FAD251NTD

Appendix D – Normalized Performance Curves

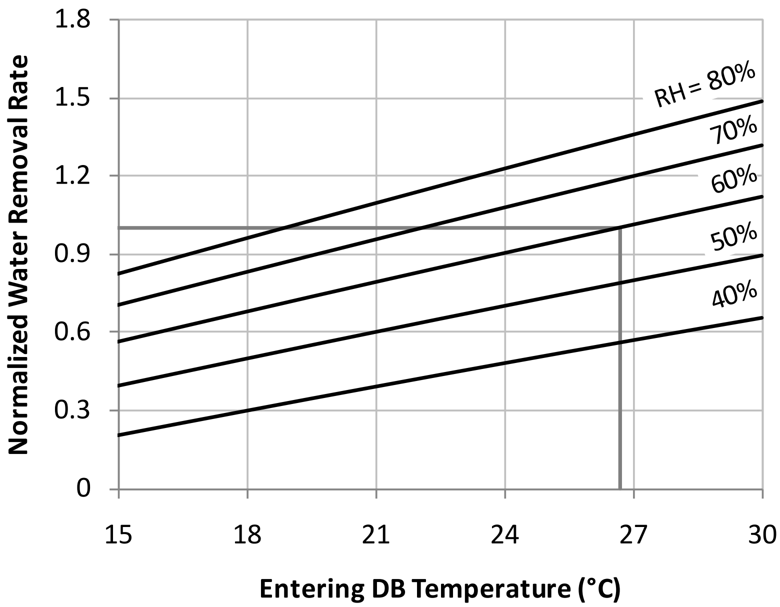


Figure 22. Normalized water removal rate performance curve for the Ultra-Aire XT150H

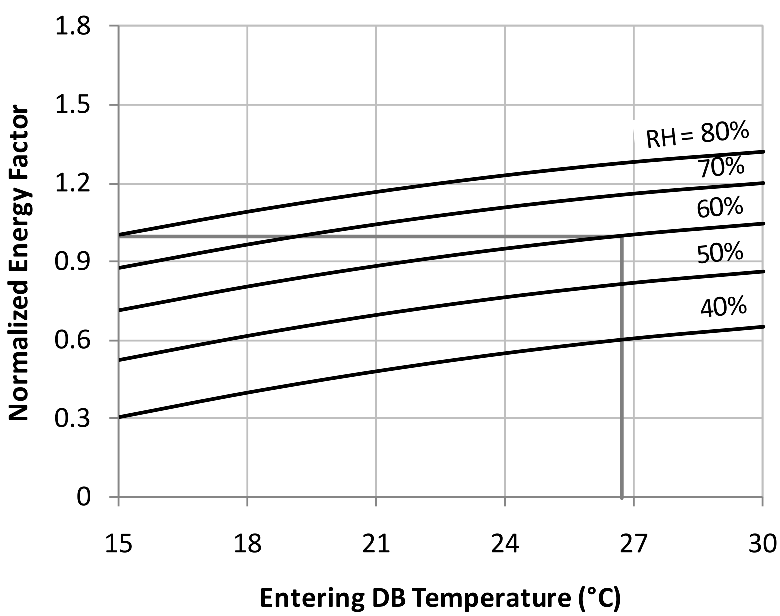


Figure 23. Normalized energy factor performance curve for the Ultra-Aire XT150H

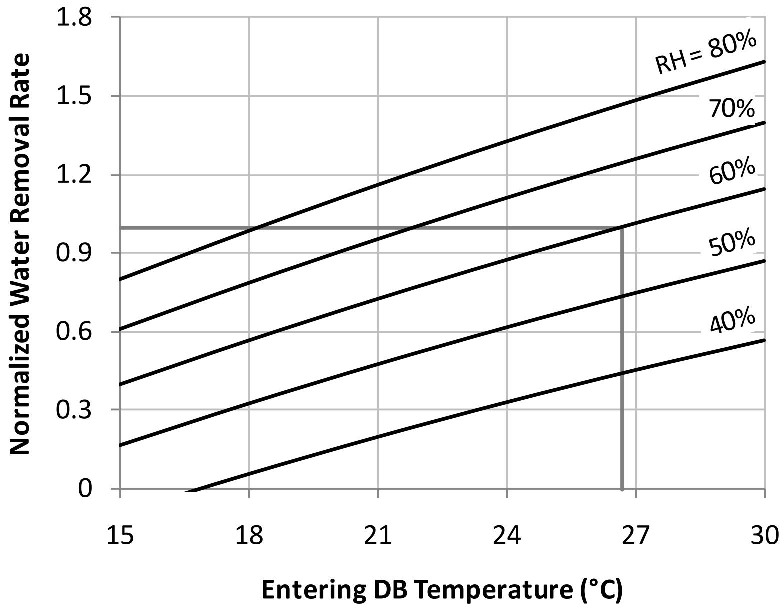


Figure 24. Normalized water removal rate performance curve for the Ultra-Aire 70H

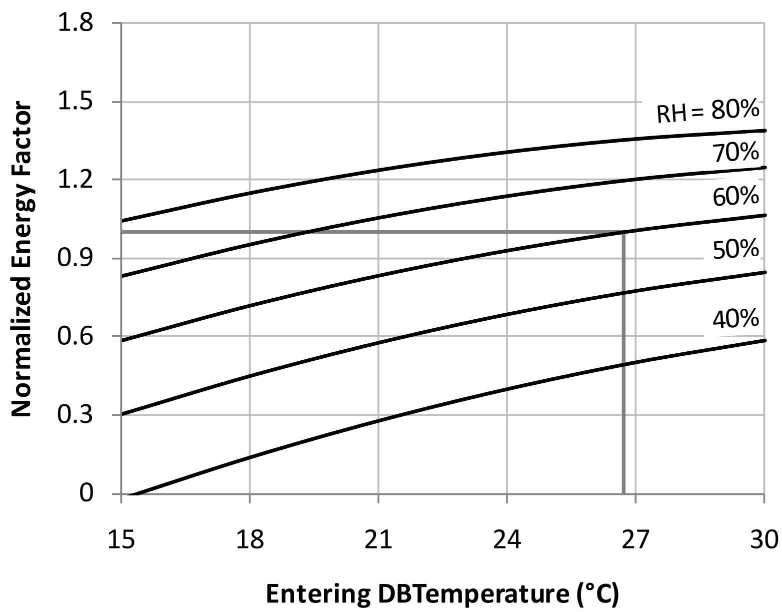


Figure 25. Normalized energy factor performance curve for the Ultra-Aire 70H

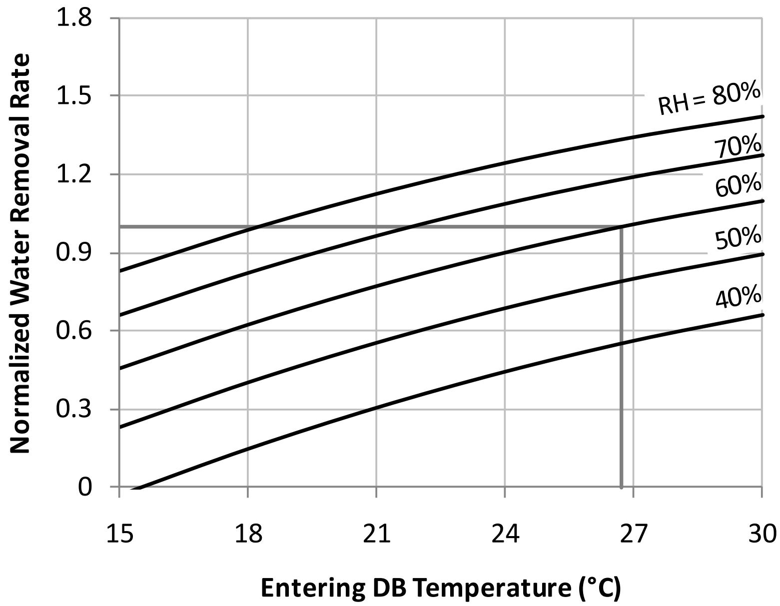


Figure 26. Normalized water removal rate performance curve for the GE ADER65LP

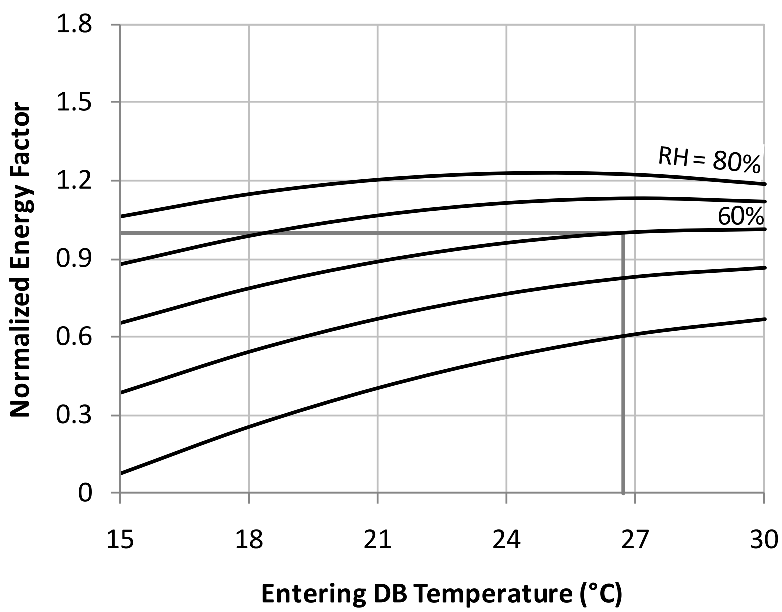


Figure 27. Normalized energy factor performance curve for the GEADER65LP

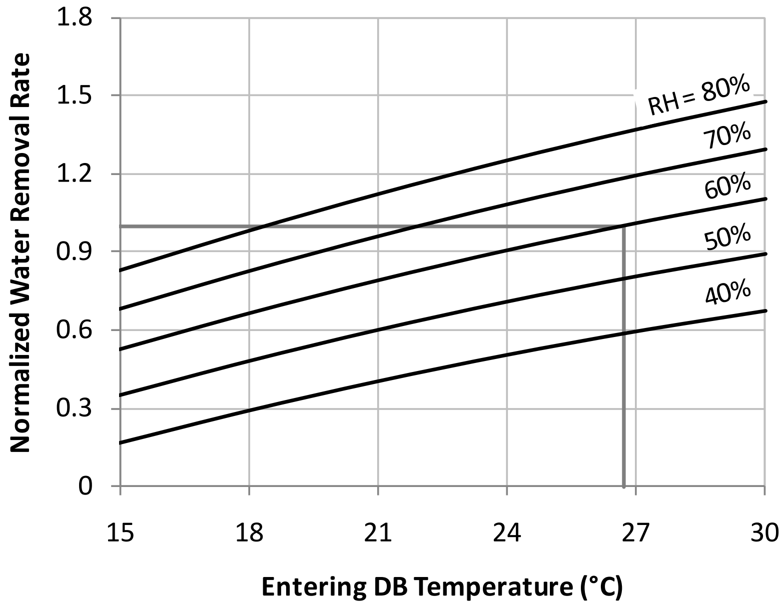


Figure 28. Normalized water removal rate performance curve for the Soleusair SG-DEH-45-1

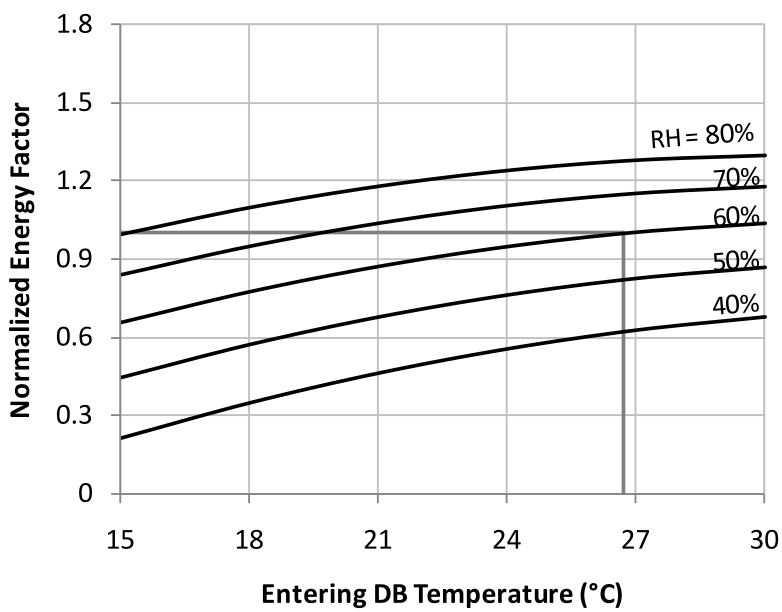


Figure 29. Normalized energy factor performance curve for the Soleusair SG-DEH-45-1

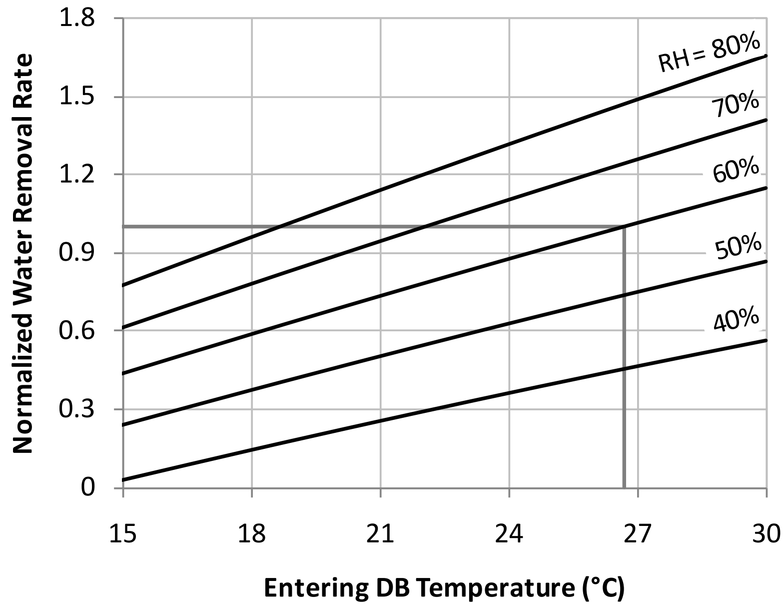


Figure 30. Normalized water removal rate performance curve for the Comfort Aire BHD-301-G

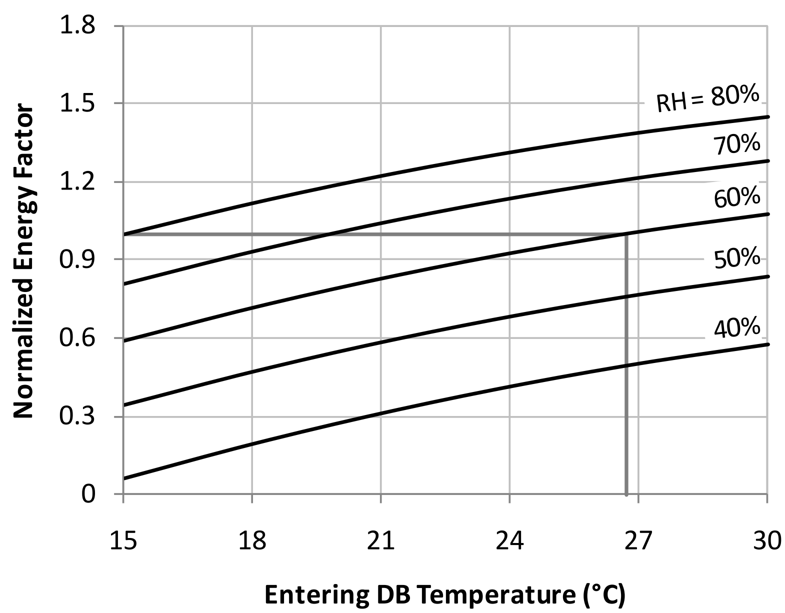


Figure 31. Normalized energy factor performance curve for the Comfort Aire BHD-301-G

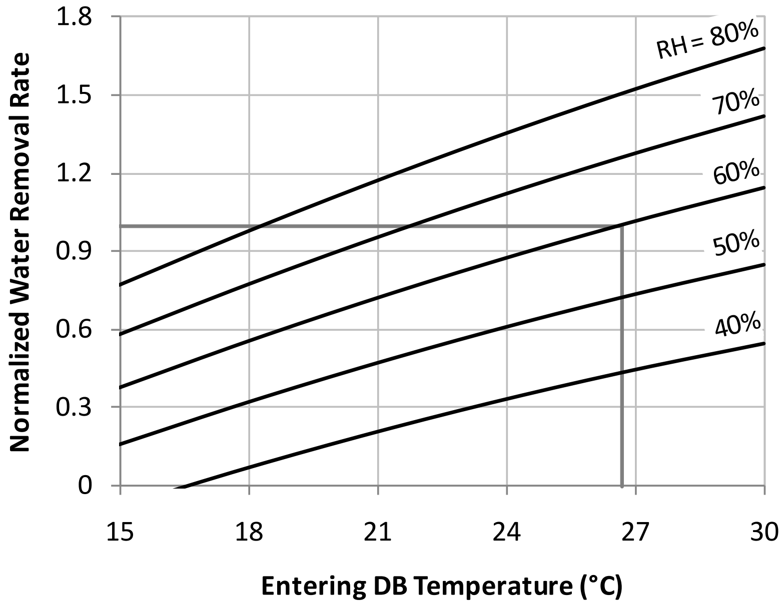


Figure 32. Normalized water removal rate performance curve for the Frigidaire FAD251NTD

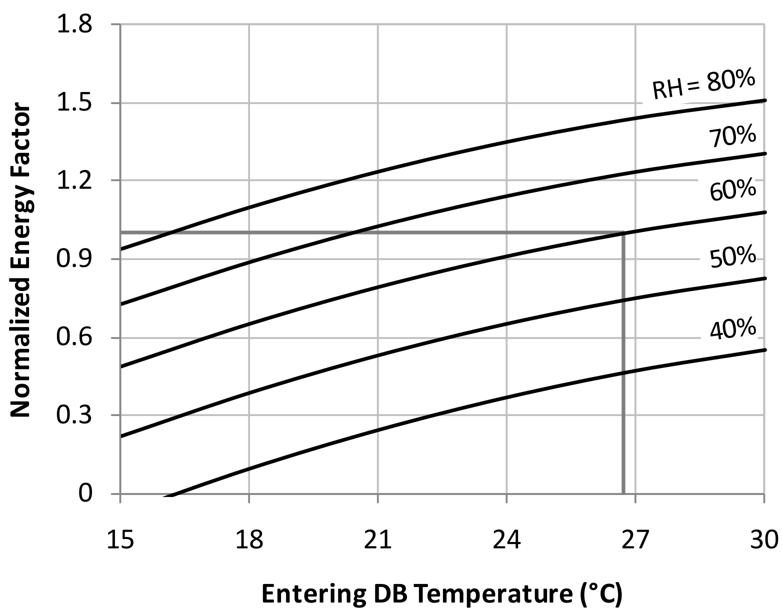


Figure 33. Normalized energy factor performance curve for the Frigidaire FAD251NTD

Appendix E – Generic Performance Curves

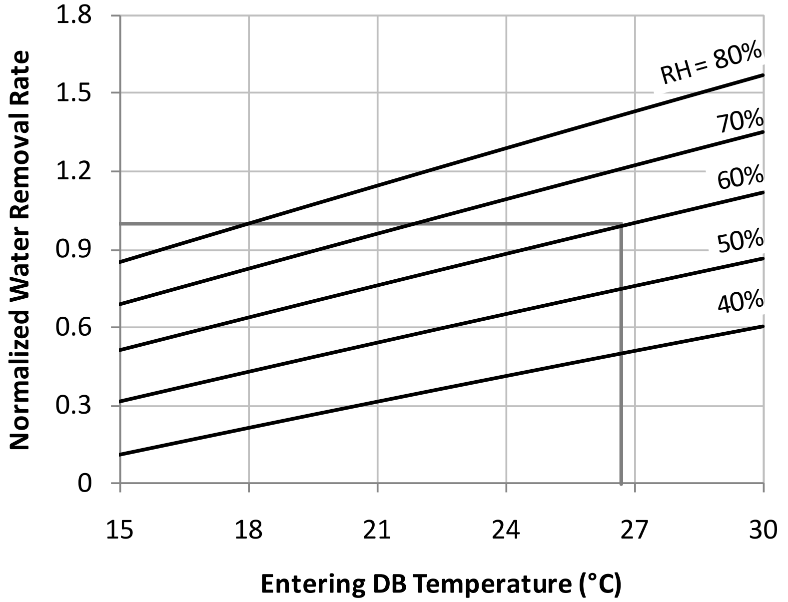


Figure 34. Generic water removal rate performance curve

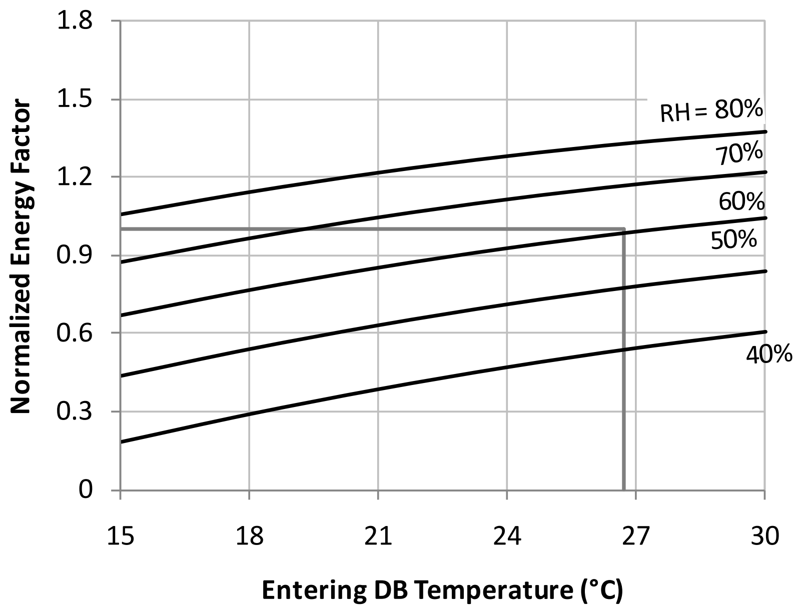


Figure 35. Generic energy factor performance curve