Coolerado 5 Ton RTU Performance: Western Cooling Challenge Results

Eric Kozubal and Steven Slayzak

Revised November 2010

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- Figure 5 and Figure 6 on page six were updated to show corrected values.
- Table 2 on page 7 was updated to show surrogate annual conditions.
- All tables in the appendices on page 8 were updated to show values of surrogate annual conditions where appropriate.
- Throughout the report, the term *credited* was inserted to modify terms such as *ventilation* and *cooling* to align with Western Cooling Challenge definitions.

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Acronyms

DX	direct expansion
EA	exhaust air
EER	energy efficiency ratio
HVAC	heating, ventilation, and air-conditioning
NREL	National Renewable Energy Laboratory
OA	outside air
RA	return air
RTU	rooftop unit
SA	supply air
SHR	sensible heat ratio
w.c.	water column
WCC	Western Cooling Challenge
WCEC	Western Cooling Efficiency Center

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1 Introduction

The National Renewable Energy Laboratory (NREL) is tasked, through funding from the U.S. Department of Energy Office of Building Technology, to evaluate the performance of advanced cooling concepts that meet or exceed the performance criteria developed by the Western Cooling Efficiency Center (WCEC) (http://wcec.ucdavis.edu/). The WCEC has developed a set of criteria for test conditions, minimum energy, and water use performance for prototype cooling equipment. The WCEC has identified these conditions as indicative of western state climates. These criteria, named the Western Cooling Challenge (WCC), have been set forth as a challenge to manufacturers to improve the state-of-the-art space cooling products. NREL is to verify these criteria through laboratory testing at its heating, ventilation, and air-conditioning (HVAC) test facility (www.nrel.gov/dtet/lab_capabilities.html) in Golden, Colorado, which is uniquely suited to accurately measure the cooling performance, energy, and water use of advanced cooling systems. The facility provides flexibility to test prototype equipment and develop subsequent test methodology. Data are analyzed and reported to reflect performance at sea level elevation.

This report is intended for individuals with technical understanding of cooling technologies for buildings.

2 Unit Description and Test Method

NREL tested a prototype rooftop unit (RTU) manufactured by the Coolerado Corporation (see Figure 1). The unit, an advanced ultra-cooler that uses the patented “M-cycle” process, is a hybrid indirect evaporative cooling and refrigeration direct expansion (DX) system. An airflow schematic of the RTU is shown in Figure 2. Return air (RA) and outdoor air (OA) are brought into the unit and cooled by an indirect evaporative media. Between 43% and 46% of this air is used as an indirect evaporative cooling stream. The balance is then passed through a refrigerant evaporator coil and supplied to the space by a high-efficiency fan. The exhaust air from the evaporative process is generally cooler than the ambient air and is therefore used for the heat sink air flow going through the refrigerant condenser coil. OA and exhaust air (EA) flow rates were matched during testing. The RA and supply air (SA) flow rates are also equal, thus there is no make-up air (to the space) supplied by the unit. The mode of operation can be described as recirculation and ventilation air cooling with no makeup air.

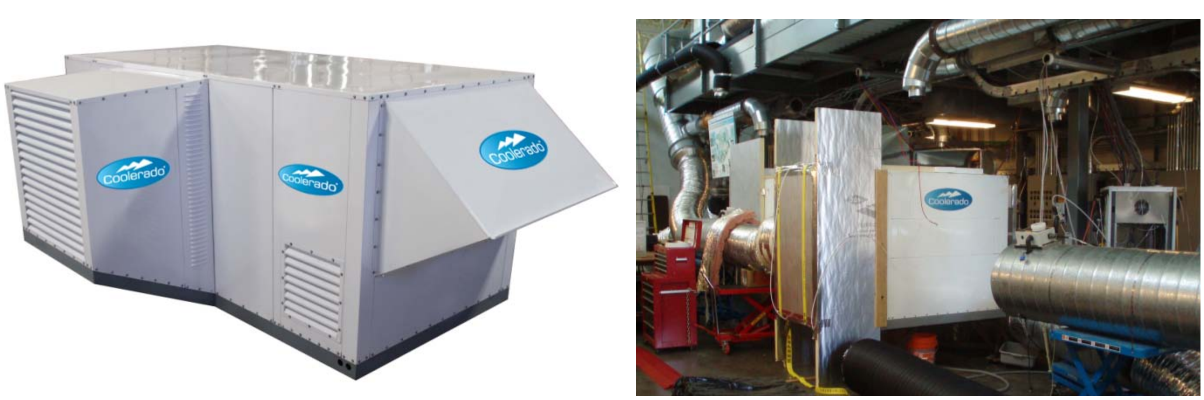

Figure 1. The prototype RTU and the unit being tested at the NREL HVAC laboratory

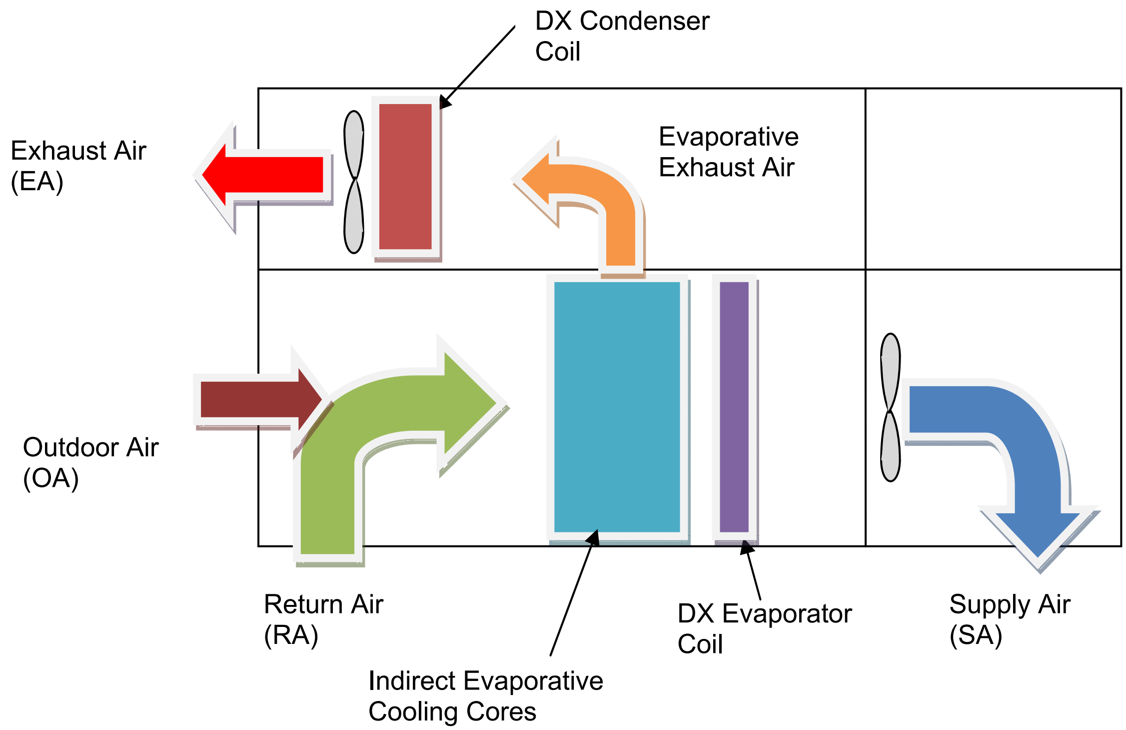

Figure 2. Coolerado RTU air flow schematic

The unit brings in OA and mixes it with RA to create a fresh air rate shown in equations (1) and (2).

$$OA\ Fraction = \frac{\dot{V}_{OA}}{\dot{V}_{OA} + \dot{V}_{RA}} \qquad (1)$$

$$\dot{V}_{Ventilation} = OA\ Fraction\ \times \dot{V}_{SA} \qquad [\text{cfm}] \qquad (2)$$

The nominal cooling capacity is given by equation (3) when tested at peak conditions. This number should not be confused with the total credited cooling defined later in equation (11). Rather, this number is used as a baseline to determine ventilation cooling capacity and a nominal specific cooling rate in cfm/ton. The cfm/ton calculation is also used to determine the static pressure imposed during the test, which is set at 0.7 in. w.c. at 350 cfm/ton. (See the WCC test specification for further details.)

$$\text{Capacity} = \dot{m}_{SA} \times (31.5\ - h_{SA}) \qquad [\text{Btu/h}] \qquad (3)$$

The RTU utilizes a high ventilation rate to provide air to the evaporative process. The specification states that ventilation cooling credit is limited to a specified OA flow. The nominal cooling capacity is used to determine the credited ventilation cooling and is calculated with equation (4).

$$\dot{V}_{Ventilation,Credited} = 0.01\ \times \text{Capacity} \qquad [\text{cfm}] \qquad (4)$$

Given the constraint:

$$\dot{V}_{Ventilation,Credited} \leq \dot{V}_{Ventilation}$$

The unit was given a single air flow at the OA inlet location. The RA and OA were psychrometrically mixed at the test facility rather than inside the RTU. Cooling capacity at the WCC test conditions is calculated with equations (5–13).

Space (Recirculation) Air Cooling:

$$\text{Total Space Cooling} = \dot{m}_{SA} \times (h_{RA} - h_{SA}) \quad [\text{Btu/h}] \quad (5)$$

$$\text{Sensible Space Cooling} = \dot{m}_{SA} \times C_p \times (T_{RA} - T_{SA}) \quad [\text{Btu/h}] \quad (6)$$

$$\text{Latent Space Cooling} = \text{Total Space Cooling} - \text{Sensible Space Cooling} \quad [\text{Btu/h}] \quad (7)$$

Credited Ventilation Air Cooling:

$$\text{Total Credited Ventilation Cooling} = \dot{m}_{OA,Credited} \times (h_{OA} - h_{RA}) \quad [\text{Btu/h}] \quad (8)$$

$$\text{Sensible Credited Ventilation Cooling} = \dot{m}_{OA,Credited} \times C_p \times (T_{OA} - T_{RA}) \quad [\text{Btu/h}] \quad (9)$$

$$\text{Latent Credited Ventilation Cooling} = \text{Total Credited Ventilation Cooling} - \text{Sensible Credited Ventilation Cooling} \quad [\text{Btu/h}] \quad (10)$$

Credited Cooling:

$$\text{Total Credited Cooling} = \text{Total Space Cooling} + \text{Total Credited Ventilation Cooling} \quad [\text{Btu/h}] \quad (11)$$

$$\text{Sensible Credited Cooling} = \text{Sensible Space Cooling} + \text{Sensible Credited Ventilation Cooling} \quad [\text{Btu/h}] \quad (12)$$

$$\text{Latent Credited Cooling} = \text{Latent Space Cooling} + \text{Latent Credited Ventilation Cooling} \quad [\text{Btu/h}] \quad (13)$$

Testing was done at nominal peak and surrogate annual conditions. The psychrometric conditions for the cooling challenge are shown in Table 1. RA conditions apply to the peak and annual tests.

Table 1. WCC Psychrometric Conditions

	T_{db}	T_{wb}	Unit
Nominal Peak OA Conditions	105	73	°F
Surrogate Annual OA Conditions	90	64	°F
RA Conditions	78	64	°F

The unit has three primary modes of operation that are labeled as stages 0 to 2. Stage 2 has a higher OA fraction to provide additional air to the condensing coil.

- Stage 0: Indirect evaporative cooling only, with 43% OA fraction.
- Stage 1: Indirect evaporative cooling + low stage DX cooling, with 43% OA fraction.
- Stage 2: Indirect evaporative cooling + high stage DX cooling, with 46% OA fraction.

See the WCEC Web site (http://wcec.ucdavis.edu/) to view the complete WCC test specifications.

3 Results

The following graphs illustrate the cooling process of the Coolerado RTU on a psychrometric chart for all cooling stages. Figure 3 and Figure 4 show the mixed air and SA conditions at WCC nominal peak and surrogate annual conditions, respectively. The figures show the progression of cooling capacity and supply conditions as the unit ramps up from stage 0 to stage 2. At nominal peak conditions, the RTU provides space cooling with a sensible heat ratio (SHR) between 0.92 and 1.25. Stage 2 is used to rate the system at nominal peak conditions.

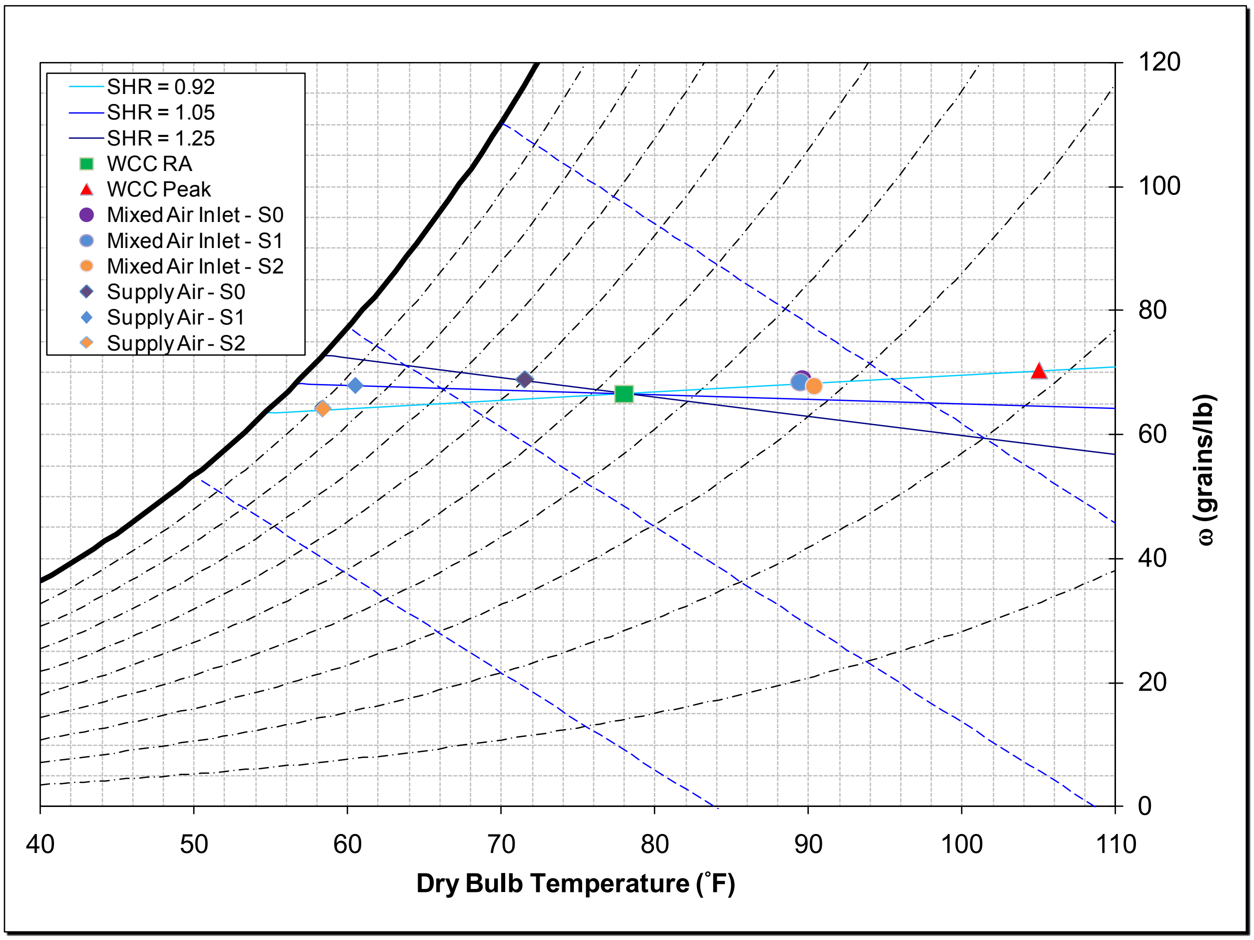

Figure 3. Psychrometric chart of RTU performance at nominal peak conditions (Shown at 0 ft elevation. S0, S1, and S2 denote stages 0, 1, and 2, respectively)

At surrogate annual test conditions, the RTU provides space cooling with an SHR between 0.68 and 0.81. The large dehumidification capacity is primarily due to the large OA flow provided by the unit. For surrogate annual conditions, only stages 0 and 1 are used to rate the system.

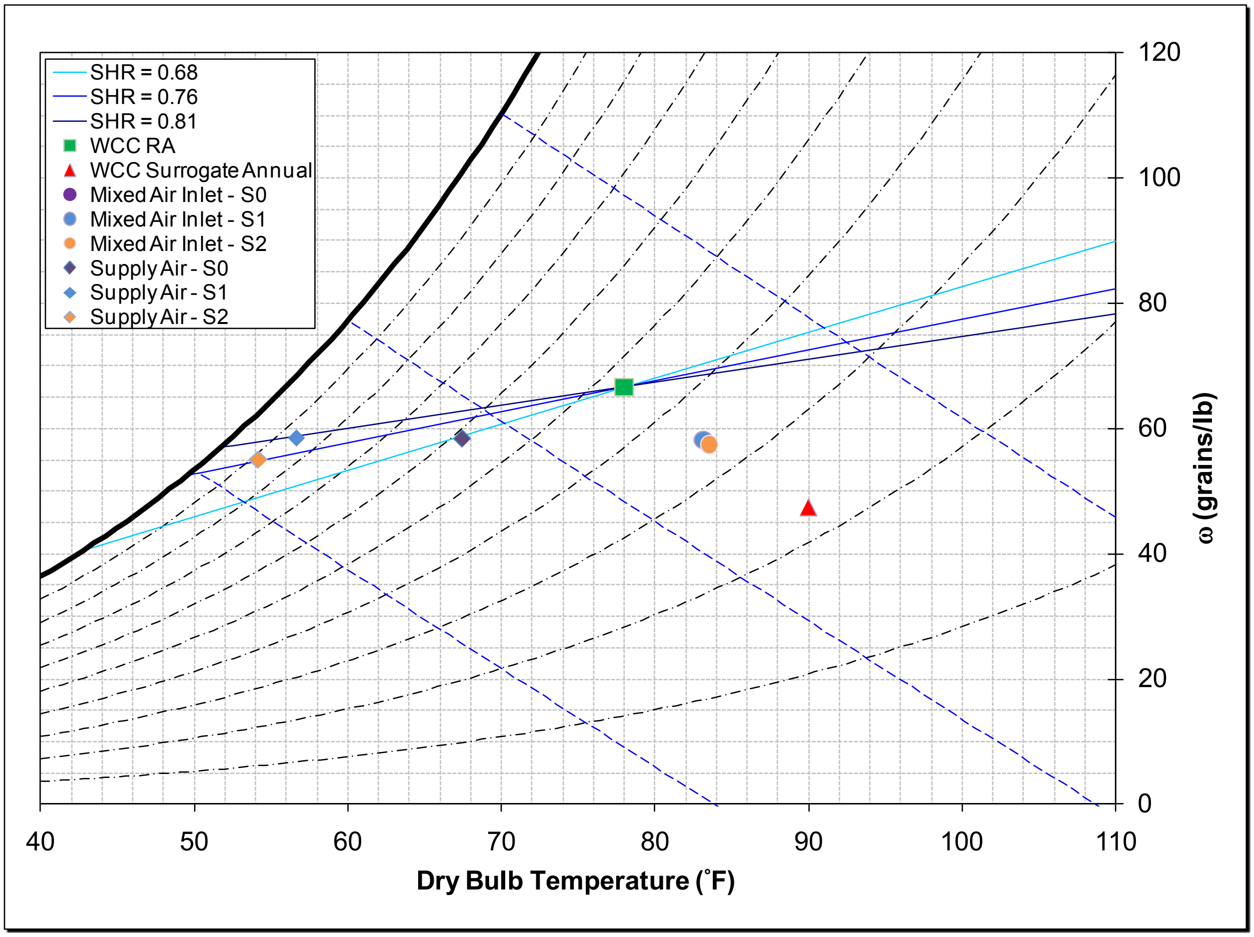

Figure 4. Psychrometric chart of RTU performance at surrogate annual conditions (Shown at 0 ft elevation. S0, S1, and S2 denote stages 0, 1, and 2, respectively)

Figure 5 shows the interpolation of cooling and power at surrogate annual conditions using stages 0 and 1. These data are used to estimate annual cooling performance, assuming that the average building load over a cooling season uses 80% of the measured sensible credited capacity at peak conditions. The interpolated credited capacity and power use are then used to calculate the surrogate annual energy efficiency ratios (EER). The same approach is used for water use. Total water use and water evaporation (in gallons per hour) are interpolated to 80% of the sensible credited capacity (see Figure 6). This number is then used with the surrogate annual credited cooling capacity to determine gallons per credited sensible ton·h.

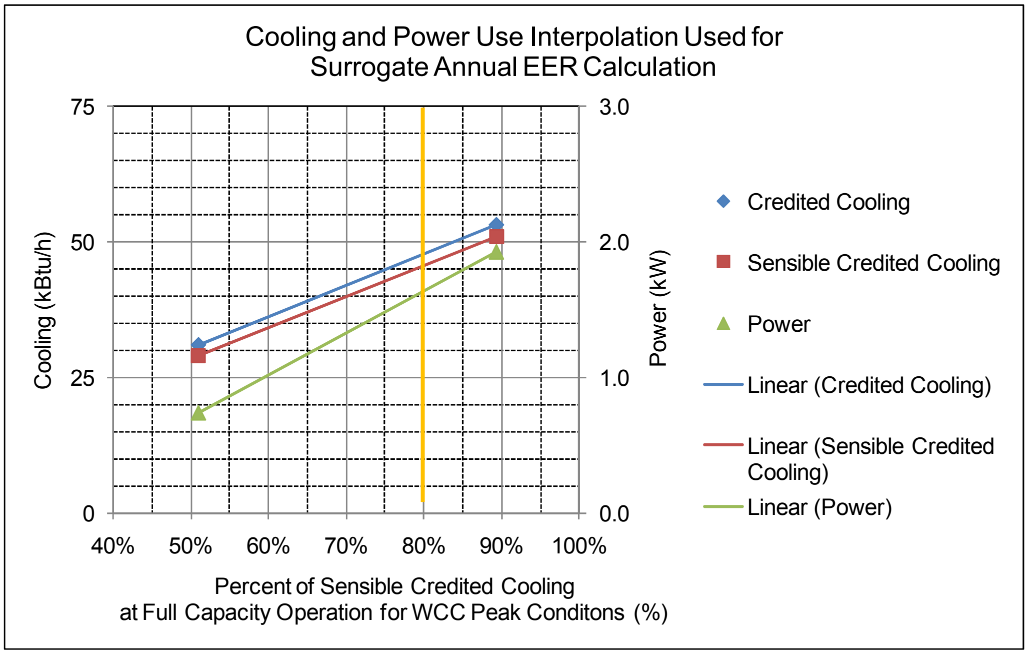

Figure 5. Data used to interpolate surrogate annual EER performance

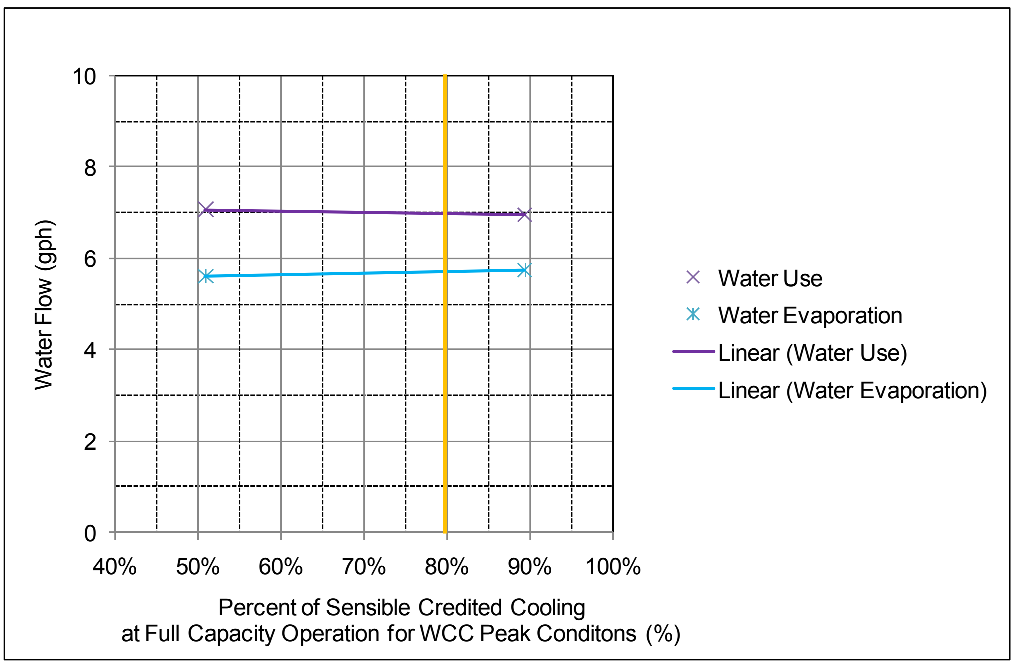

Figure 6. Data used to interpolate surrogate annual water use/evaporation performance

The nominal capacity given by equation (3) for determining credited ventilation rate was calculated to be 60.5 kBtu/h. From this, the credited ventilation rate was then taken to be 600 cfm. The actual ventilation rate was measured to be approximately 800 cfm. The static pressure applied to the unit was 0.7 in. w.c.

The calculated performance of the Coolerado RTU is shown in Table 2. Comparing the calculated performance below to the WCC specifications, the unit meets and exceeds all minimum thermodynamic and water use requirements of the challenge.

Table 2. Western Cooling Challenge Summary

		Specification	Performance	Units
Peak Conditions (105°F/73°F)	Total Credited Cooling	36–360	61.7	kBtu/h
	Sensible Credited Cooling	–	56.9	kBtu/h
	Power	–	2.84	kW
	Credited EER	–	21.7	Btu/Wh
	Sensible Credited EER	≥14.0	20.1	Btu/Wh
	Outlet Humidity	≤0.0092	0.00917	–
	* Water Use	–	1.83	gal/ton·h (sensible credited)
	Water Evaporation	–	1.50	gal/ton·h (sensible credited)
Surrogate Annual Conditions (90°F/64°F)	Total Credited Cooling	–	47.7	kBtu/h
	Sensible Credited Cooling	–	45.6	kBtu/h
	Mean Power	–	1.64	kW
	Credited EER	–	29.1	Btu/Wh
	Sensible Credited EER	≥17.0	27.8	Btu/Wh
	* Water Use	≤4.0	1.84	gal/ton·h (sensible credited)
	Water Evaporation	–	1.50	gal/ton·h (sensible credited)

* NREL cannot verify through laboratory testing the unit's ability to withstand scaling caused by water evaporation. The measurements are made available in terms of water use and evaporation in the laboratory. Water use will vary in practice because of system adjustments for water quality.

Appendix – Measured Data Tables

	Stage	Air Flow$_{OA-RA, Mixed}$	Air Flow$_{SA}$	Air Flow$_{EA}$	OA Mass Fraction	T_{OA-RA} Mixed	T_{SA}	T_{EA}	ω_{OA-RA} Mixed	ω_{SA}
	–	scfm	scfm	scfm	%	°F	°F	°F	grains/lb	grains/lb
Peak Conditions	0	3357	1822	1437	43%	89.6	71.5	76.5	68.8	68.8
	1	3354	1834	1422	42%	89.4	60.5	93.4	68.5	67.9
	2	3542	1810	1624	46%	90.4	58.4	96.8	67.9	64.2
Surrogate Annual Conditions	0	3444	1827	1482	43%	83.2	67.5	72.0	58.4	58.4
	1	3383	1826	1451	43%	83.2	56.7	88.3	58.1	58.6
	2	3591	1806	1660	46%	83.6	54.2	91.1	57.4	55.0

	Stage	Water Use	Water Evaporation	Unit Power	Total Space Cooling	Sensible Space Cooling	Latent Space Cooling
	–	gal/sensible-ton·h	gal/sensible-ton·h	kW	kBtu/h	kBtu/h	kBtu/h
Peak Conditions	0	3.17	2.52	0.75	10.44	13.06	-2.62
	1	1.82	1.43	2.01	33.78	35.45	-1.67
	2	1.83	1.50	2.84	42.28	39.19	3.09
Surrogate Annual Conditions	0	2.93	2.32	0.74	31.28	21.21	10.07
	1	1.64	1.35	1.93	53.32	42.96	10.36
	2	1.65	1.38	2.70	62.17	47.40	14.77

	Stage	Total Credited Ventilation Cooling	Sensible Credited Ventilation Cooling	Latent Credited Ventilation Cooling	Total Credited Cooling	Sensible Credited Cooling	Latent Credited Cooling	Credited EER	Sensible Credited EER
	–	kBtu/h	kBtu/h	kBtu/h	kBtu/h	kBtu/h	kBtu/h	Btu/Wh	Btu/Wh
Peak Conditions	0	18.95	17.37	1.57	29.39	30.43	-1.04	39.4	40.8
	1	19.30	17.69	1.61	53.08	53.14	-0.06	26.4	26.4
	2	19.39	17.75	1.63	61.67	56.95	4.72	21.7	20.1
Surrogate Annual Conditions	0	–0.23	7.78	-8.02	31.05	28.99	2.06	41.9	39.1
	1	–0.24	7.93	-8.17	53.09	50.89	2.20	27.5	26.4
	2	–0.24	7.96	-8.20	61.93	55.36	6.57	22.9	20.5

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The Western Cooling Efficiency Center (WCEC) developed a set of criteria for test conditions, minimum energy, and water use performance for prototype cooling equipment and identified these conditions as indicative of western state climates. These criteria, named the Western Cooling Challenge, have been set forth as a challenge to manufacturers to improve the state-of-the-art space cooling products. NREL is to verify these criteria through laboratory testing at its heating, ventilation, and air-conditioning test facility.

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