



Technology Performance Exchange™
Confidence through data.

BPA: VRF Modeling Study

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Project Objectives

- Validate end-to-end TPEX workflow:
 - Data → TPEX → EnergyPlus Model → Predicted Performance
- Compare how different datasets impact predicted performance
 - Manufacturer-provided data
 - Lab test data

Approach

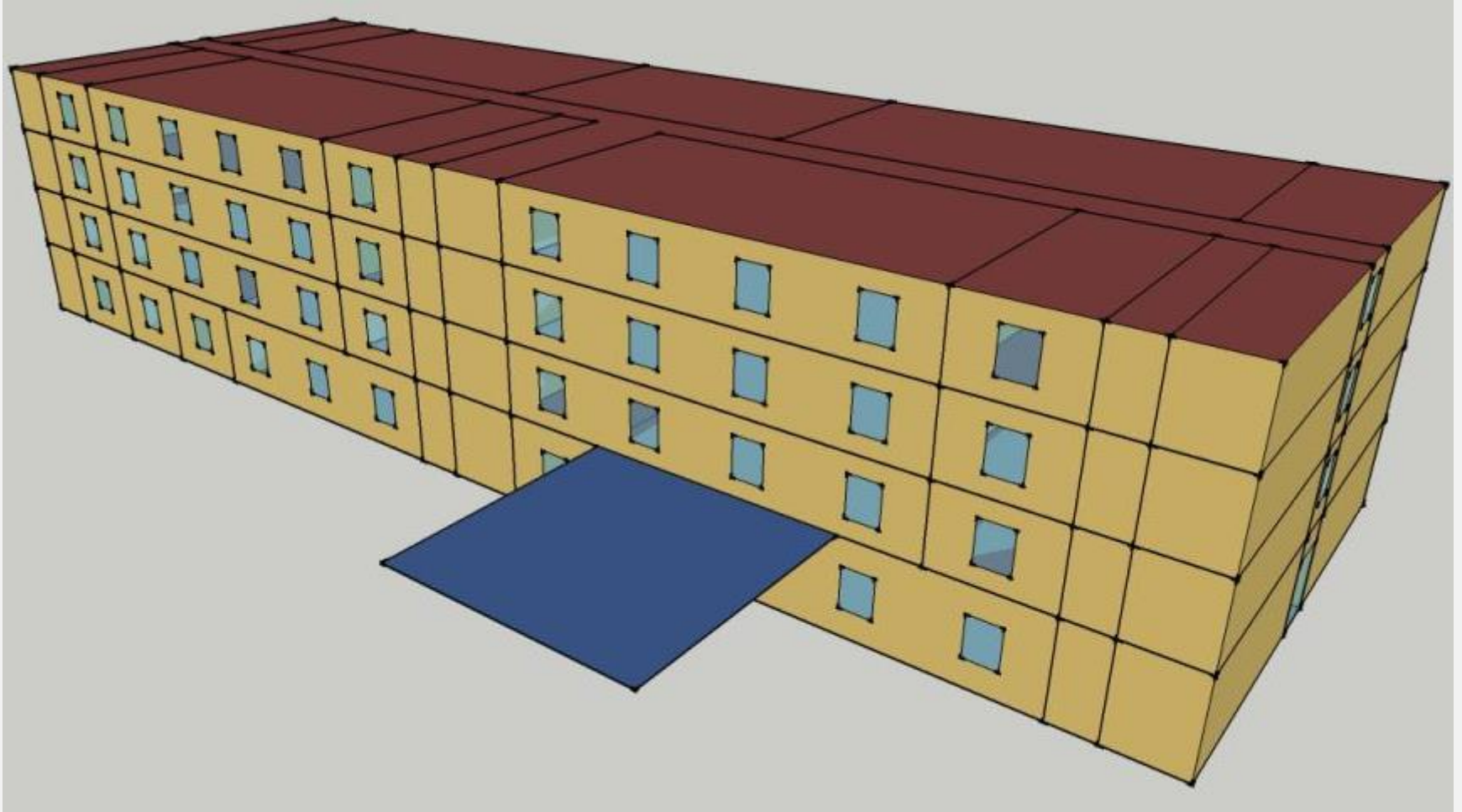
- Start with an existing EnergyPlus VRF model
- Upload two different datasets to TPEX representing the same VRF system
 - Manufacturer (LG) published performance data
 - EPRI lab-test data¹
- One at a time, insert the translated EnergyPlus objects into the existing model
- Evaluate the process and compare the results

¹ EPRI data was uploaded to the TPEX development server to ensure data privacy

Model Description

- EnergyPlus V8.1 baseline model based on *actual plans* for a 43,200 ft², 4-story hotel
- Nominally ASHRAE 90.1-2013 compliant (CZ 5A)
 - Upgraded wall insulation
- Efficient plug loads (laundry, appliances, elevators)
- Variable refrigerant flow and dedicated outside air systems
 - Some zones served by natural gas unit heaters

Model Description



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VRF Details

- Outdoor Unit: LG Multi V Sync II ARUB076BT2
 - 22.4 kW cooling / 25.2 kW heating
- Indoor Unit: ARNU243B2G2
 - 7.1 kW cooling / 8.0 kW heating
- Rated values from AHRI Directory of Certified Product Performance
- System parameters for all models from engineering manuals
- Some EnergyPlus fields allowed to default
- Performance curves derived from:
 1. LG published performance maps
 2. EPRI laboratory test data



Preprocessing Lab Data

- Not all EPRI test points corresponded with the TPEX performance map template
- EPRI data were interpolated (some in two dimensions):
 - Indoor dry bulb temperatures (heating)
 - Indoor wet bulb temperatures (cooling)
 - 70%, 100%, & 130%¹ combination ratios (CR)
- Resulting data inserted into performance map templates
- TPEX translator run (ignored data threshold) to generate EnergyPlus objects

¹Data extrapolated for 130% CR

EPRI IDU Cooling Performance Map

Performance Map																						
Outdoor Air Dry-Bulb Temperature	Indoor Air Wet-Bulb Temperature																					
	13.9°C			16.1°C			17.8°C			19.4°C			21.1°C			22.8°C			24.4°C			
	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	
-5.0°C																						
-3.9°C																						
-1.1°C																						
1.7°C																						
4.4°C																						
7.2°C																						
10.0°C																						
12.8°C																						
15.6°C																						
18.3°C																						
21.1°C																						
23.9°C																						
26.7°C																						
29.4°C				3.84	3.01	0.08	4.53	3.37	0.08	5.10	3.63	0.08	5.57	3.80	0.08							
32.2°C																						
35.0°C				3.79	2.97	0.08	4.49	3.34	0.08	4.88	3.47	0.08	5.43	3.71	0.08							
37.8°C																						
40.6°C				3.63	2.85	0.08	4.30	3.19	0.08	4.57	3.25	0.08	4.82	3.29	0.08							
43.3°C																						



LG IDU Cooling Performance Map

Performance Map																						
Outdoor Air Dry-Bulb Temperature	Indoor Air Wet-Bulb Temperature																					
	13.9°C			16.1°C			17.8°C			19.4°C			21.1°C			22.8°C			24.4°C			
	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	CC	SC	EI	
-5.0°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
-3.9°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
-1.1°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
1.7°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
4.4°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
7.2°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
10.0°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
12.8°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.14	5.36	0.08	
15.6°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	9.08	5.33	0.08	
18.3°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	8.94	5.24	0.08	
21.1°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	8.79	5.16	0.08	
23.9°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.44	5.36	0.08	8.58	5.04	0.08	
26.7°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.94	5.42	0.08	8.23	5.33	0.08	8.38	5.01	0.08	
29.4°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.88	5.36	0.08	7.94	5.10	0.08	8.09	4.83	0.08	
32.2°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.74	5.27	0.08	7.79	5.01	0.08	7.94	4.75	0.08	
35.0°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.59	5.24	0.08	7.74	4.98	0.08	7.88	4.72	0.08	
37.8°C	4.69	3.87	0.08	5.68	4.45	0.08	6.39	4.75	0.08	7.09	5.04	0.08	7.44	5.16	0.08	7.59	4.95	0.08	7.74	4.66	0.08	
40.6°C	4.69	3.87	0.08	5.39	4.22	0.08	6.09	4.54	0.08	6.80	4.83	0.08	6.94	4.83	0.08	7.30	4.78	0.08	7.44	4.57	0.08	
43.3°C	4.54	3.75	0.08	5.10	3.98	0.08	5.68	4.22	0.08	6.39	4.54	0.08	6.53	4.54	0.08	6.94	4.54	0.08	7.24	4.42	0.08	

VRF Data Representation

- Translated VRF performance tables prohibit extrapolation
 - Conscious decision, not an EnergyPlus limitation
- Ran three models instead of two
 - LG data
 - EPRI data
 - EPRI data extrapolated to template boundaries
- Third model necessary due to the sparseness of the measured data compared to the expected operating range

Results Overview

Parameter	LG Data	EPRI Data	EPRI Data (Extrapolate)
Heating Energy (Electricity, GJ)	248.33	253.99	259.22
Cooling Energy (GJ)	75.76	1,561.17	695.98
Fan Energy (GJ)	85.93	91.77	93.23
ODU Cooling Capacity (kW)	228.2	254.9	268.1
ODU Heating Capacity (kW)	257.0	287.0	301.9
Occ. Cooling Set Point Not Met (hours)	2.75	2.75	2.75
Occ. Heating Set Point Not Met (hours)	146.75	146.75	146.75

Conclusions - Workflow

- Workflow implementation was straightforward and rapid
- Estimate that rerunning this workflow for a new system would require approximately one week
 - Less if you are already familiar with the baseline model
- Subbing in new performance tables and rerunning the models is trivial
 - Less than one day of work

Conclusions – Analysis Results

- No consensus on cooling performance
 - Lab models deviate from LG model by 819% and 1,961%
 - Lab measurements showed significantly degraded cooling performance compared to manufacturer data
 - Unclear if this was due to an operational issue, or if the system truly is less efficient
- Good agreement on performance in heating mode
 - Lab models within 4.4% of LG model
- Provides (limited) evidenced-based support for the use of manufacturers' data in technology analysis

Recommendations

- Compare normalized metrics (cooling kBtu/ft²/year) to existing VRF systems in the Pacific NW
 - 1.79, 14.67, and 35.12 kBtu/ft²/year
- Pilot data substitution workflow with BPA engineering staff/subcontractors to validate resource requirements



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Questions?

EPRI IDU heating performance map:

Outdoor Air Temperature Dry-Bulb / Wet-Bulb		Performance Map													
		Indoor Air Dry-Bulb Temperature													
		15.0°C		16.1°C		17.8°C		19.4°C		21.1°C		22.8°C		24.4°C	
		HC	EI	HC	EI	HC	EI	HC	EI	HC	EI	HC	EI	HC	EI
-20.0°C	-20.2°C														
-17.8°C	-18.0°C														
-15.0°C	-15.3°C														
-12.2°C	-12.8°C														
-9.4°C	-10.0°C														
-6.7°C	-7.2°C														
-3.9°C	-5.0°C														
-1.1°C	-2.2°C														
1.7°C	0.0°C														
4.4°C	2.2°C														
7.2°C	5.0°C														
8.3°C	6.1°C							9.34	0.08	8.94	0.08				
10.0°C	7.8°C														
12.8°C	10.6°C							9.44	0.08	9.28	0.08	7.37	0.08		
15.6°C	13.3°C														

LG IDU heating performance map:

Outdoor Air Temperature Dry-Bulb / Wet-Bulb		Performance Map													
		Indoor Air Dry-Bulb Temperature													
		15.0°C		16.1°C		17.8°C		19.4°C		21.1°C		22.8°C		24.4°C	
		HC	EI	HC	EI	HC	EI	HC	EI	HC	EI	HC	EI	HC	EI
-20.0°C	-20.2°C	5.36	0.08	5.36	0.08	5.36	0.08	5.36	0.08	5.27	0.08	5.27	0.08	5.27	0.08
-17.8°C	-18.0°C	5.51	0.08	5.51	0.08	5.51	0.08	5.51	0.08	5.51	0.08	5.45	0.08	5.45	0.08
-15.0°C	-15.3°C	6.24	0.08	6.15	0.08	6.07	0.08	6.07	0.08	6.07	0.08	6.07	0.08	6.07	0.08
-12.2°C	-12.8°C	6.48	0.08	6.48	0.08	6.48	0.08	6.39	0.08	6.39	0.08	6.39	0.08	6.39	0.08
-9.4°C	-10.0°C	6.89	0.08	6.89	0.08	6.89	0.08	6.89	0.08	6.89	0.08	6.89	0.08	6.80	0.08
-6.7°C	-7.2°C	7.27	0.08	7.27	0.08	7.27	0.08	7.27	0.08	7.09	0.08	7.09	0.08	7.00	0.08
-3.9°C	-5.0°C	7.59	0.08	7.59	0.08	7.59	0.08	7.59	0.08	7.59	0.08	7.44	0.08	7.35	0.08
-1.1°C	-2.2°C	7.76	0.08	7.76	0.08	7.76	0.08	7.76	0.08	7.76	0.08	7.59	0.08	7.35	0.08
1.7°C	0.0°C	8.00	0.08	8.00	0.08	8.00	0.08	8.00	0.08	7.91	0.08	7.76	0.08	7.35	0.08
4.4°C	2.2°C	8.32	0.08	8.32	0.08	8.32	0.08	8.32	0.08	8.00	0.08	7.76	0.08	7.35	0.08
7.2°C	5.0°C	8.64	0.08	8.64	0.08	8.64	0.08	8.41	0.08	8.00	0.08	7.76	0.08	7.35	0.08
8.3°C	6.1°C	8.97	0.08	8.88	0.08	8.79	0.08	8.41	0.08	8.00	0.08	7.76	0.08	7.35	0.08
10.0°C	7.8°C	9.61	0.08	9.20	0.08	8.79	0.08	8.41	0.08	8.00	0.08	7.76	0.08	7.35	0.08
12.8°C	10.6°C	9.79	0.08	9.29	0.08	8.79	0.08	8.41	0.08	8.00	0.08	7.76	0.08	7.35	0.08
15.6°C	13.3°C	9.79	0.08	9.29	0.08	8.79	0.08	8.41	0.08	8.00	0.08	7.76	0.08	7.35	0.08

EPRI ODU cooling performance (sub)map:

		Performance Map																					
CR	Outdoor Air Dry-Bulb Temperature	Indoor Air Temperature Dry-Bulb / Wet-Bulb																					
		20.0°C / 13.9°C			22.8°C / 16.1°C			26.1°C / 17.8°C			26.7°C / 19.4°C			29.4°C / 21.1°C			31.1°C / 22.8°C			32.8°C / 24.4°C			
		CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	
70%	-5.0°C																						
	-3.9°C																						
	-1.1°C																						
	1.7°C																						
	4.4°C																						
	7.2°C																						
	10.0°C																						
	12.8°C																						
	15.6°C																						
	18.3°C																						
	21.1°C																						
	23.9°C																						
	26.7°C																						
	29.4°C											10.91	8.46	0.00	12.82	8.95	0.00						
	32.2°C																						
	35.0°C											12.13	9.11	0.00	13.26	10.23	0.00						
	37.8°C																						
40.6°C											10.85	10.04	0.00	12.17	11.02	0.00							
43.3°C																							
46.1°C																							
47.8°C																							
50.0°C																							

LG ODU cooling performance (sub)map:

Performance Map																						
CR	Outdoor Air Dry-Bulb Temperature	Indoor Air Temperature Dry-Bulb / Wet-Bulb																				
		20.0°C / 13.9°C			22.8°C / 16.1°C			26.1°C / 17.8°C			26.7°C / 19.4°C			29.4°C / 21.1°C			31.1°C / 22.8°C			32.8°C / 24.4°C		
		CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP	CC	CP	FP
70%	-5.0°C	10.35	1.19	0.00	12.54	1.48	0.00	14.10	1.71	0.00				17.55	2.23	0.00	18.64	2.38	0.00	20.22	2.67	0.00
	-3.9°C	10.35	1.22	0.00	12.54	1.52	0.00	14.10	1.74	0.00				17.55	2.26	0.00	18.64	2.41	0.00	20.22	2.71	0.00
	-1.1°C	10.35	1.26	0.00	12.54	1.56	0.00	14.10	1.78	0.00				17.55	2.30	0.00	18.64	2.45	0.00	20.22	2.75	0.00
	1.7°C	10.35	1.30	0.00	12.54	1.60	0.00	14.10	1.82	0.00				17.55	2.34	0.00	18.64	2.49	0.00	20.22	2.78	0.00
	4.4°C	10.35	1.37	0.00	12.54	1.67	0.00	14.10	1.89	0.00				17.55	2.41	0.00	18.64	2.56	0.00	20.22	2.86	0.00
	7.2°C	10.35	1.41	0.00	12.54	1.71	0.00	14.10	1.93	0.00				17.55	2.45	0.00	18.64	2.60	0.00	20.22	2.89	0.00
	10.0°C	10.35	1.44	0.00	12.54	1.74	0.00	14.10	1.97	0.00				17.55	2.48	0.00	18.64	2.65	0.00	20.22	2.92	0.00
	12.8°C	10.35	1.47	0.00	12.54	1.77	0.00	14.10	2.01	0.00				17.55	2.53	0.00	18.64	2.71	0.00	20.22	2.99	0.00
	15.6°C	10.35	1.52	0.00	12.54	1.84	0.00	14.10	2.09	0.00				17.55	2.64	0.00	18.64	2.82	0.00	20.22	3.12	0.00
	18.3°C	10.35	1.54	0.00	12.54	1.87	0.00	14.10	2.13	0.00				17.55	2.69	0.00	18.64	2.89	0.00	20.22	3.18	0.00
	21.1°C	10.35	1.57	0.00	12.54	1.91	0.00	14.10	2.18	0.00				17.55	2.75	0.00	18.64	2.96	0.00	20.22	3.34	0.00
	23.9°C	10.35	1.61	0.00	12.54	1.96	0.00	14.10	2.27	0.00				17.55	2.99	0.00	18.64	3.25	0.00	20.22	3.68	0.00
	26.7°C	10.35	1.67	0.00	12.54	2.08	0.00	14.10	2.43	0.00				17.55	3.22	0.00	18.64	3.50	0.00	20.22	3.95	0.00
	29.4°C	10.35	1.90	0.00	12.54	2.39	0.00	14.10	2.80	0.00				17.55	3.70	0.00	18.64	4.04	0.00	20.22	4.57	0.00
	32.2°C	10.35	2.02	0.00	12.54	2.55	0.00	14.10	2.99	0.00				17.55	3.98	0.00	18.64	4.33	0.00	20.22	4.91	0.00
	35.0°C	10.35	2.15	0.00	12.54	2.72	0.00	14.10	3.20	0.00				17.55	4.26	0.00	18.64	4.65	0.00	20.22	5.27	0.00
	37.8°C	10.35	2.30	0.00	12.54	2.90	0.00	14.10	3.42	0.00				17.55	4.56	0.00	18.64	4.98	0.00	20.22	5.65	0.00
40.6°C	10.35	2.49	0.00	12.54	3.12	0.00	14.10	3.67	0.00				17.55	4.94	0.00	18.64	5.38	0.00	20.22	6.09	0.00	
43.3°C	10.35	2.52	0.00	12.54	3.15	0.00	14.10	3.71	0.00				17.55	4.97	0.00	18.64	5.42	0.00	20.22	6.10	0.00	
46.1°C																						
47.8°C																						
50.0°C																						

EPRI ODU heating performance (sub)map:

Performance Map																										
CR	Outdoor Air Dry-Bulb / Wet-Bulb Temperature	Indoor Air Dry-Bulb Temperature																								
		15°C			16.1°C			17.8°C			19.4°C			21.1°C			22.8°C			24.4°C			26.7°C			
		HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	
70%	-20.0°C / -20.2°C																									
	-17.8°C / -18.0°C																									
	-15.0°C / -15.3°C																									
	-12.2°C / -12.8°C																									
	-9.4°C / -10.0°C																									
	-6.7°C / -7.2°C																									
	-3.9°C / -5.0°C																									
	-1.1°C / -2.2°C																									
	1.7°C / 0.0°C																									
	4.4°C / 2.2°C																									
	7.2°C / 5.0°C																									
	8.3°C / 6.1°C												17.91	6.89	0.00	16.56	6.09	0.00								
	10.0°C / 7.8°C																									
	12.8°C / 10.6°C												18.68	7.03	0.00	18.07	6.99	0.00								
	15.6°C / 13.3°C																									

LG ODU heating performance (sub)map:

Performance Map																									
CR	Outdoor Air Dry-Bulb / Wet-Bulb Temperature	Indoor Air Dry-Bulb Temperature																							
		15°C			16.1°C			17.8°C			19.4°C			21.1°C			22.8°C			24.4°C			26.7°C		
		HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP	HC	CP	FP
70%	-20.0°C / -20.2°C	15.71	6.99	0.00	15.71	6.99	0.00	15.53	7.04	0.00	15.53	7.13	0.00	15.53	7.04	0.00	15.53	6.99	0.00	15.01	7.10	0.00	13.95	6.91	0.00
	-17.8°C / -18.0°C	16.24	7.08	0.00	16.24	7.04	0.00	16.24	7.13	0.00	16.06	7.18	0.00	16.06	7.18	0.00	16.06	7.04	0.00	15.18	7.20	0.00	14.13	6.96	0.00
	-15.0°C / -15.3°C	18.17	7.08	0.00	18.17	6.94	0.00	17.99	7.22	0.00	17.47	7.13	0.00	17.29	7.13	0.00	16.59	7.04	0.00	15.88	6.66	0.00	15.21	6.30	0.00
	-12.2°C / -12.8°C	19.40	6.85	0.00	19.69	6.43	0.00	18.87	6.43	0.00	18.52	6.94	0.00	17.64	6.94	0.00	17.12	6.81	0.00	16.24	6.26	0.00	15.39	5.75	0.00
	-9.4°C / -10.0°C	20.81	6.66	0.00	20.28	6.33	0.00	19.40	6.33	0.00	18.52	6.52	0.00	17.64	6.49	0.00	17.12	6.24	0.00	16.24	5.75	0.00	15.39	5.30	0.00
	-6.7°C / -7.2°C	21.57	6.57	0.00	20.46	6.28	0.00	19.40	6.28	0.00	18.52	6.33	0.00	17.64	6.09	0.00	17.12	5.86	0.00	16.24	5.40	0.00	15.39	4.98	0.00
	-3.9°C / -5.0°C	21.57	6.52	0.00	20.46	6.24	0.00	19.40	6.10	0.00	18.52	5.72	0.00	17.64	5.53	0.00	17.12	5.35	0.00	16.24	4.92	0.00	15.39	4.54	0.00
	-1.1°C / -2.2°C	21.57	6.47	0.00	20.46	6.14	0.00	19.40	5.77	0.00	18.52	5.35	0.00	17.64	5.16	0.00	17.12	4.97	0.00	16.24	4.60	0.00	15.39	4.25	0.00
	1.7°C / 0.0°C	21.51	6.10	0.00	20.46	5.77	0.00	19.40	5.44	0.00	18.52	5.07	0.00	17.64	5.02	0.00	17.12	4.69	0.00	16.24	4.36	0.00	15.39	4.06	0.00
	4.4°C / 2.2°C	21.57	5.98	0.00	20.46	5.58	0.00	19.40	5.21	0.00	18.52	4.88	0.00	17.64	4.83	0.00	17.12	4.50	0.00	16.24	4.17	0.00	15.39	3.87	0.00
	7.2°C / 5.0°C	21.57	5.70	0.00	20.46	5.35	0.00	19.40	5.02	0.00	18.52	4.83	0.00	17.64	4.74	0.00	17.12	4.36	0.00	16.24	4.03	0.00	15.39	3.73	0.00
	8.3°C / 6.1°C	21.57	5.51	0.00	20.46	5.16	0.00	19.40	4.83	0.00	18.52	4.55	0.00	17.64	4.69	0.00	17.12	4.22	0.00	16.24	3.94	0.00	15.39	3.68	0.00
	10.0°C / 7.8°C	21.57	5.37	0.00	20.46	5.02	0.00	19.40	4.69	0.00	18.52	4.41	0.00	17.64	4.22	0.00	17.12	4.08	0.00	16.24	3.80	0.00	15.39	3.54	0.00
	12.8°C / 10.6°C	21.57	5.13	0.00	20.46	4.83	0.00	19.40	4.55	0.00	18.52	4.27	0.00	17.64	4.08	0.00	17.12	3.94	0.00	16.24	3.66	0.00	15.39	3.40	0.00
15.6°C / 13.3°C	21.57	4.99	0.00	20.46	4.69	0.00	19.40	4.41	0.00	18.52	4.13	0.00	17.64	3.99	0.00	17.12	3.85	0.00	16.24	3.56	0.00	15.39	3.30	0.00	