Phased Retrofit of Watergate's "Sister"

A catalyst for a new framework based on building resiliency and decarbonization life cycle cost

Outline

1. Introduction
    a. Identification of problem
    b. Thought Process
2. Proposed Solution
    a. Phasing
    b. Details of steps
3. How Much Retrofit Do you Need?
    a. Thermal Resilience
4. REVIVE
    a. Where is this all headed?
5. Conclusion

Affiliated Organizations

1. DOE
2. RMI
   a. Realize
3. ABC (Advanced Building Construction)
   a. ABCC
4. Phius
   a. Brings in passive buildings, building sciences, climate specifics
5. Baumann Consulting
   a. Energy auditor for “Brutus”

Identifying the Problem

1. “Not a crook”

Identifying the Problem

1. “Not a crook”

Identifying the Problem

1. “Not a crook”
2. Got busted for this

Identifying the Problem

1. “Not a crook”
2. Got busted for this
3. At this famous hotel

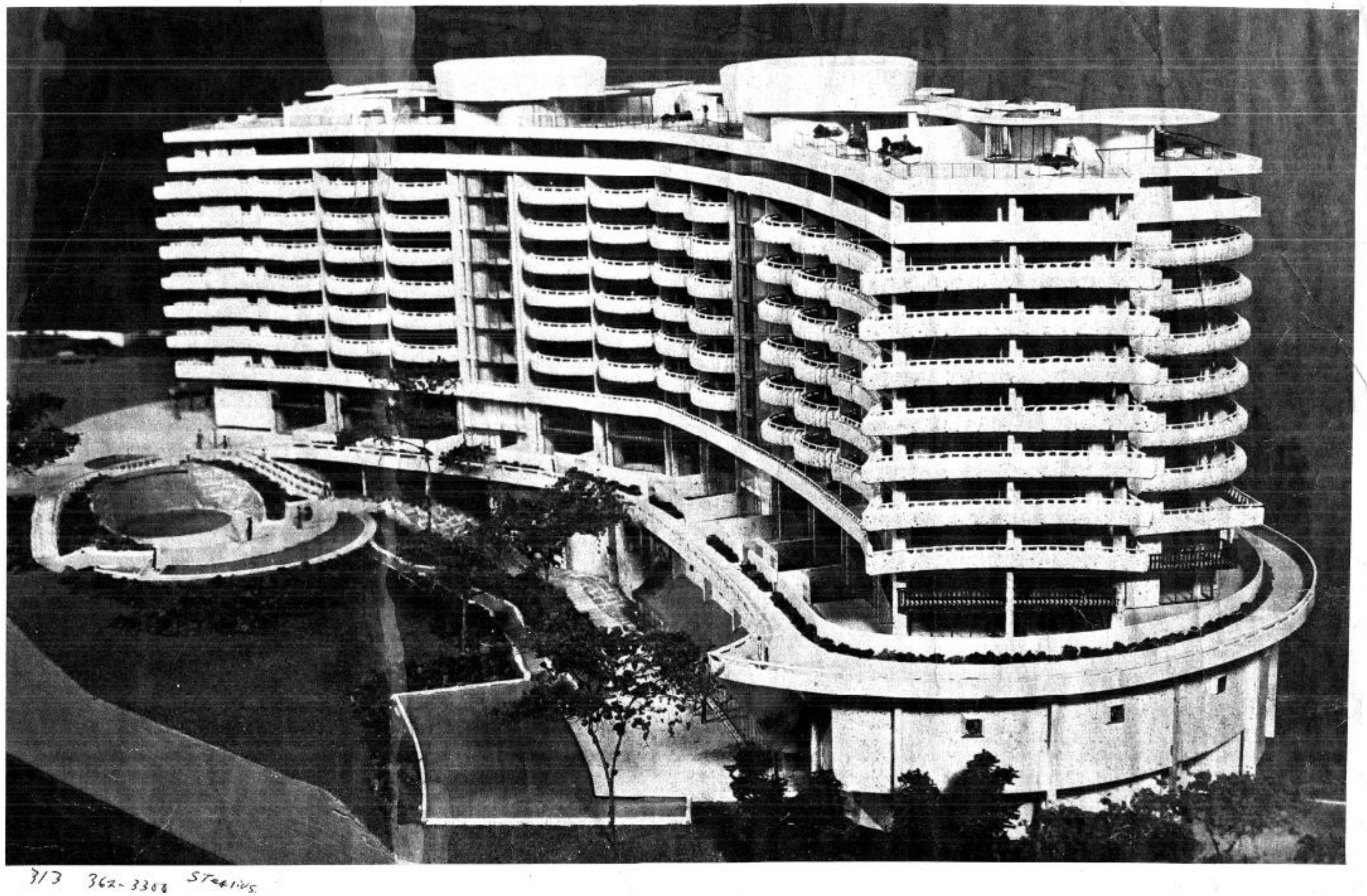
Identifying the Problem

1. “Not a crook”
2. Got busted for this
3. At this famous hotel
4. Architect really liked concrete and glass

Building Overview

"Brutus"

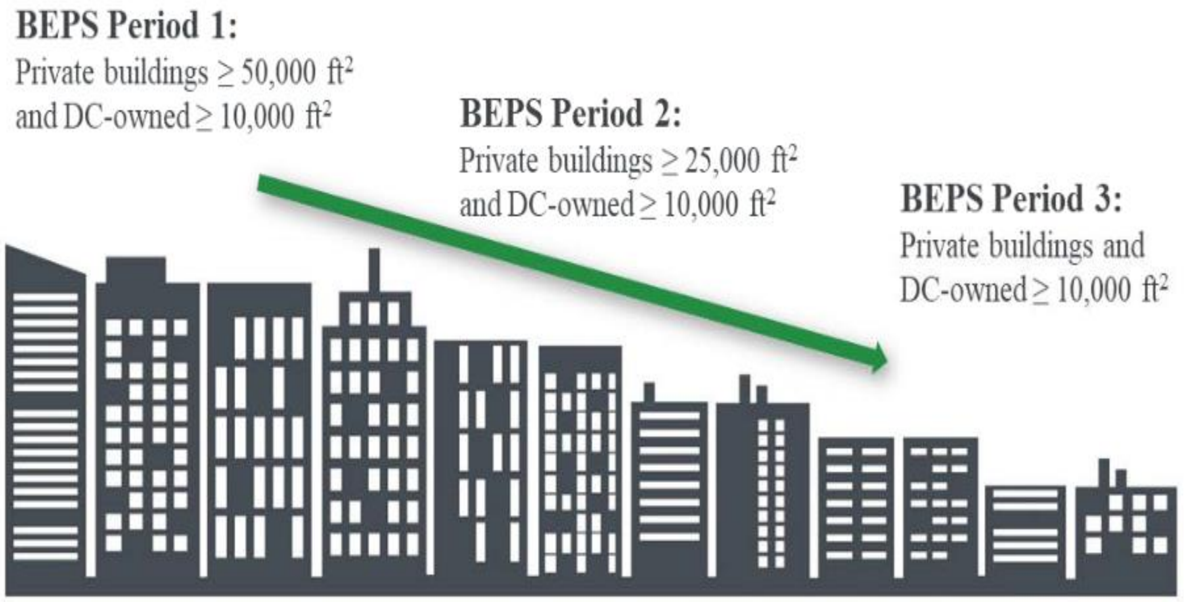
- Washington, DC
- Built 1972
- Fischer and Elmore Architects
- 129 condos
- 242,000 sf
- 10 stories with 3 basements



What's Going Wrong?

- Washington, DC BEPS (Building Energy Performance Standards)
- $2,630,000 fine
  - if no
- 56% reduction in site energy

There is an alternative path for phased compliance



What's Going Wrong?

Original, failing low pressure steam boilers

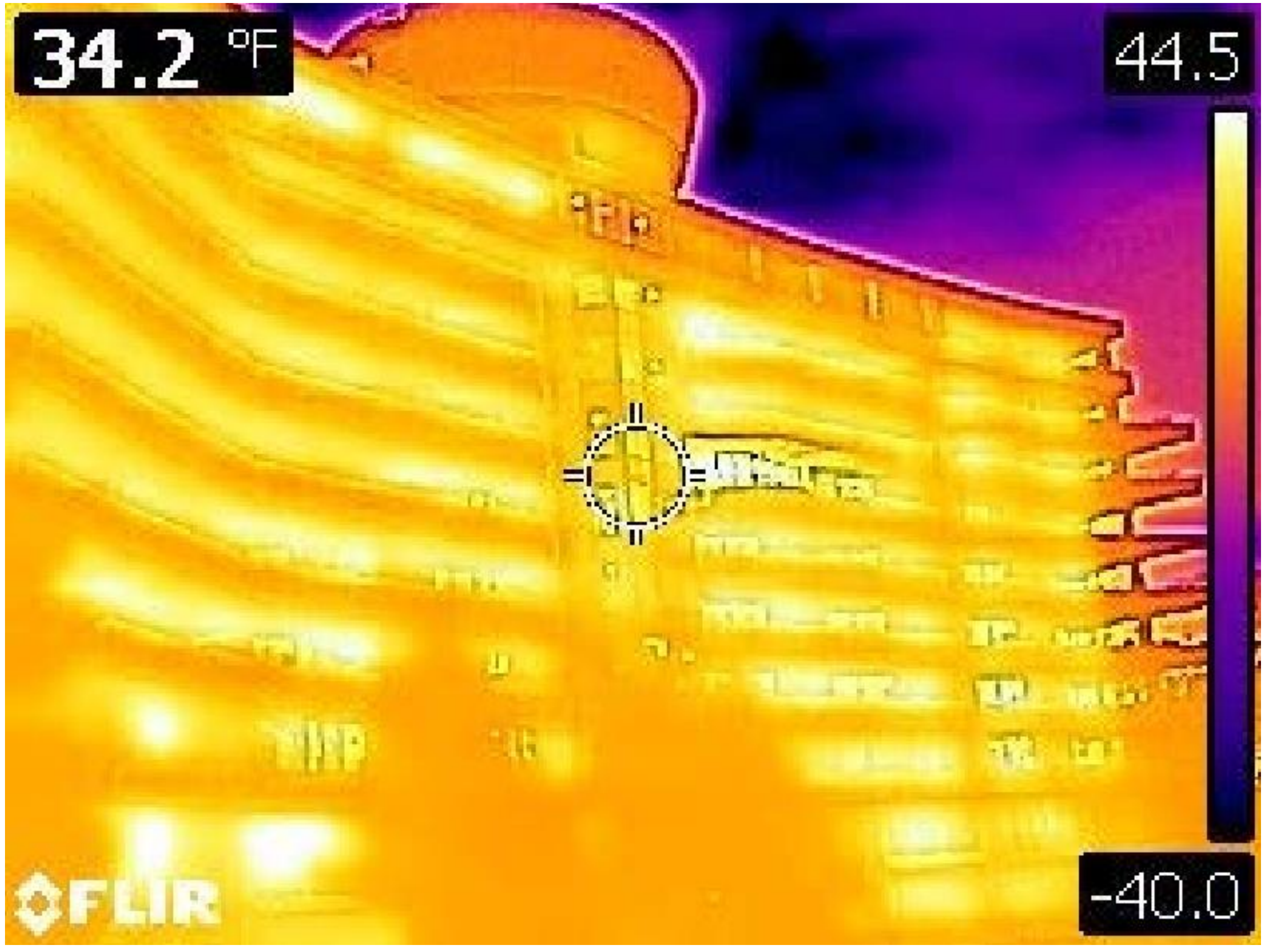
What's Going Wrong?

Drafty, single pane windows

On 31°F day, glass was 37°F

What's Going Wrong?

Concrete balconies have structural damage and are a fin-tube radiator to the outdoors

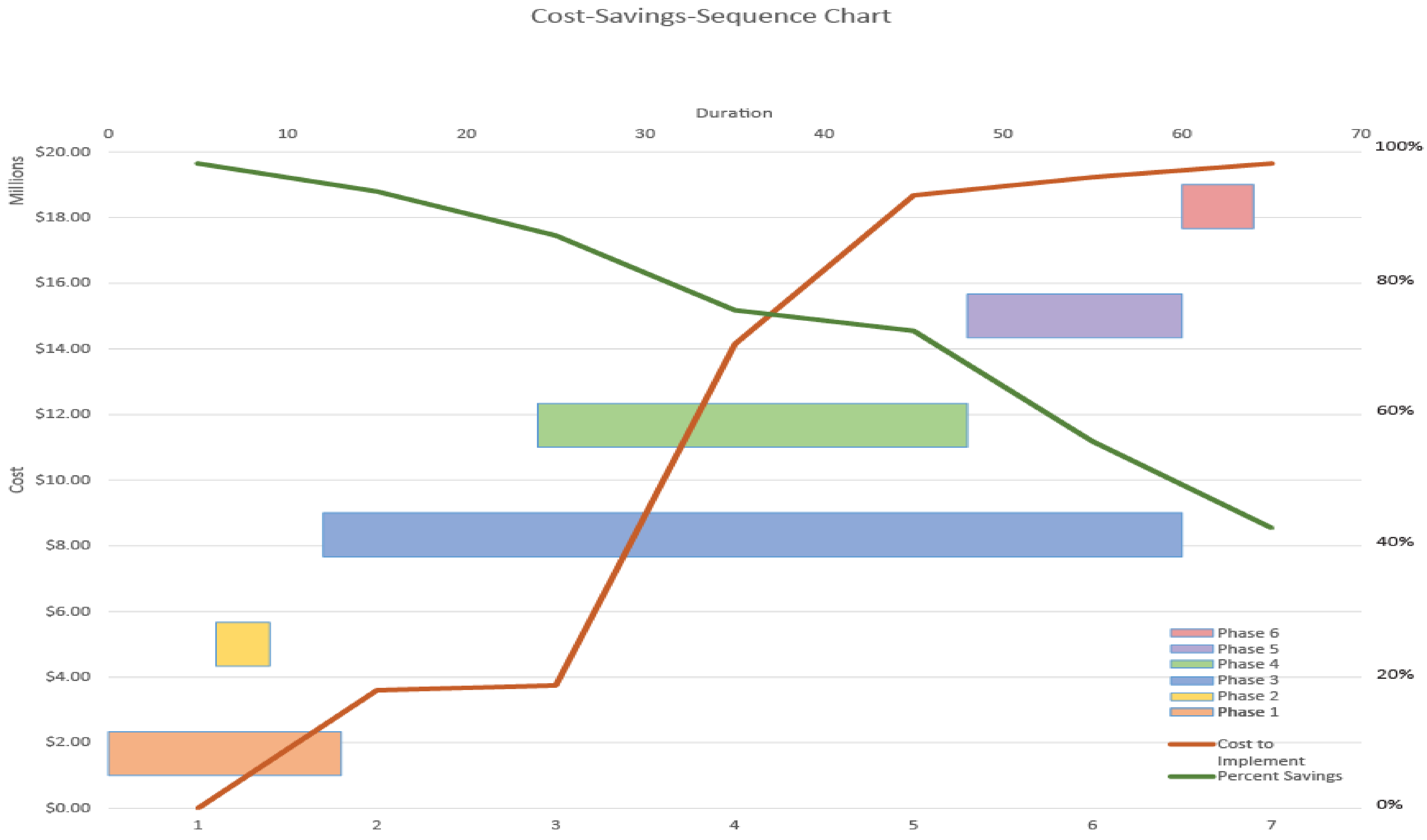


The Solution? Easy!

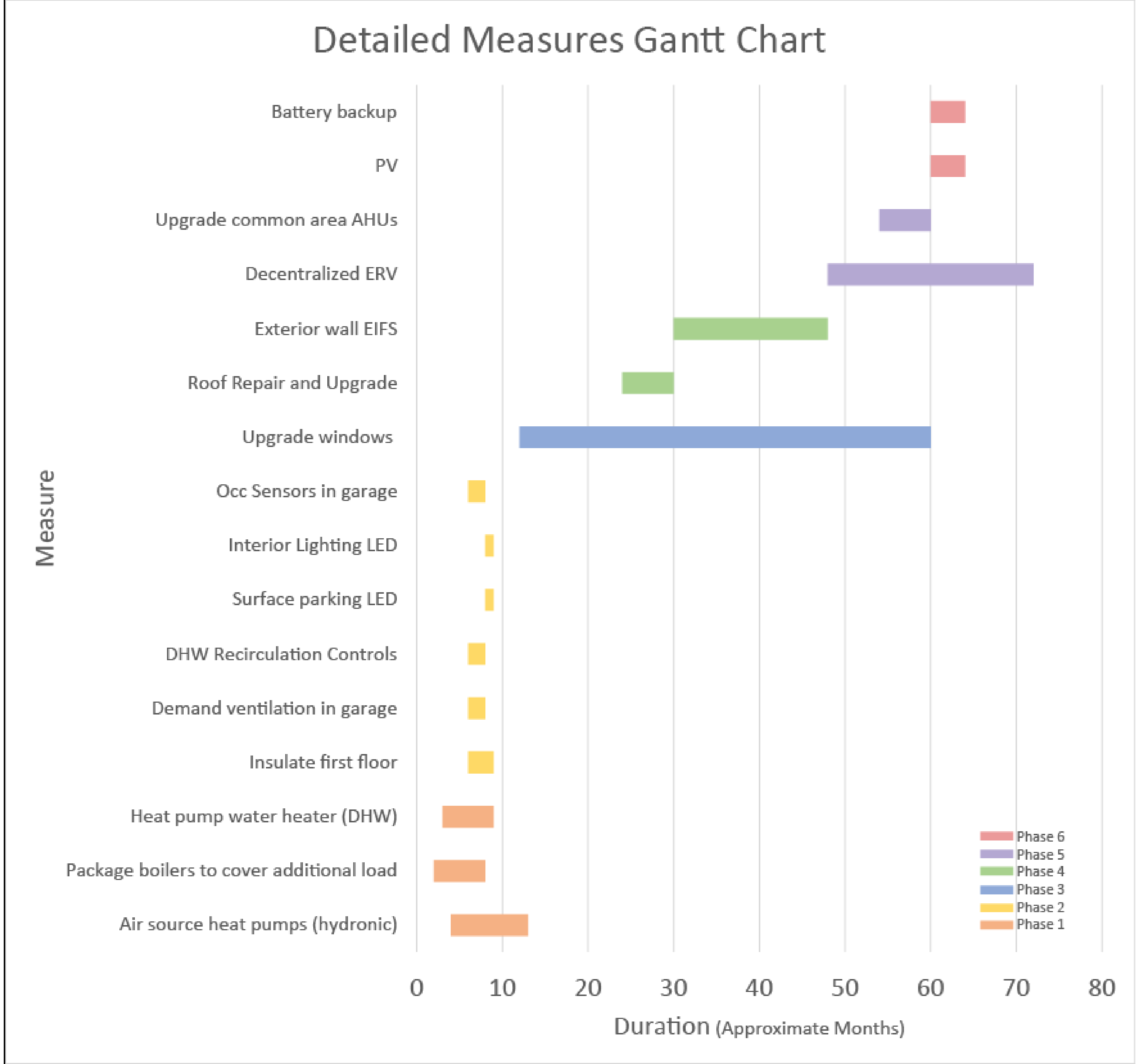
Energy Cost Savings	Electricity Savings	Natural Gas Savings	Net Measure Cost	Simple Payback
$ 347,000	1,491,800 kWh	271,400 Therm	$ 20,914,800	None

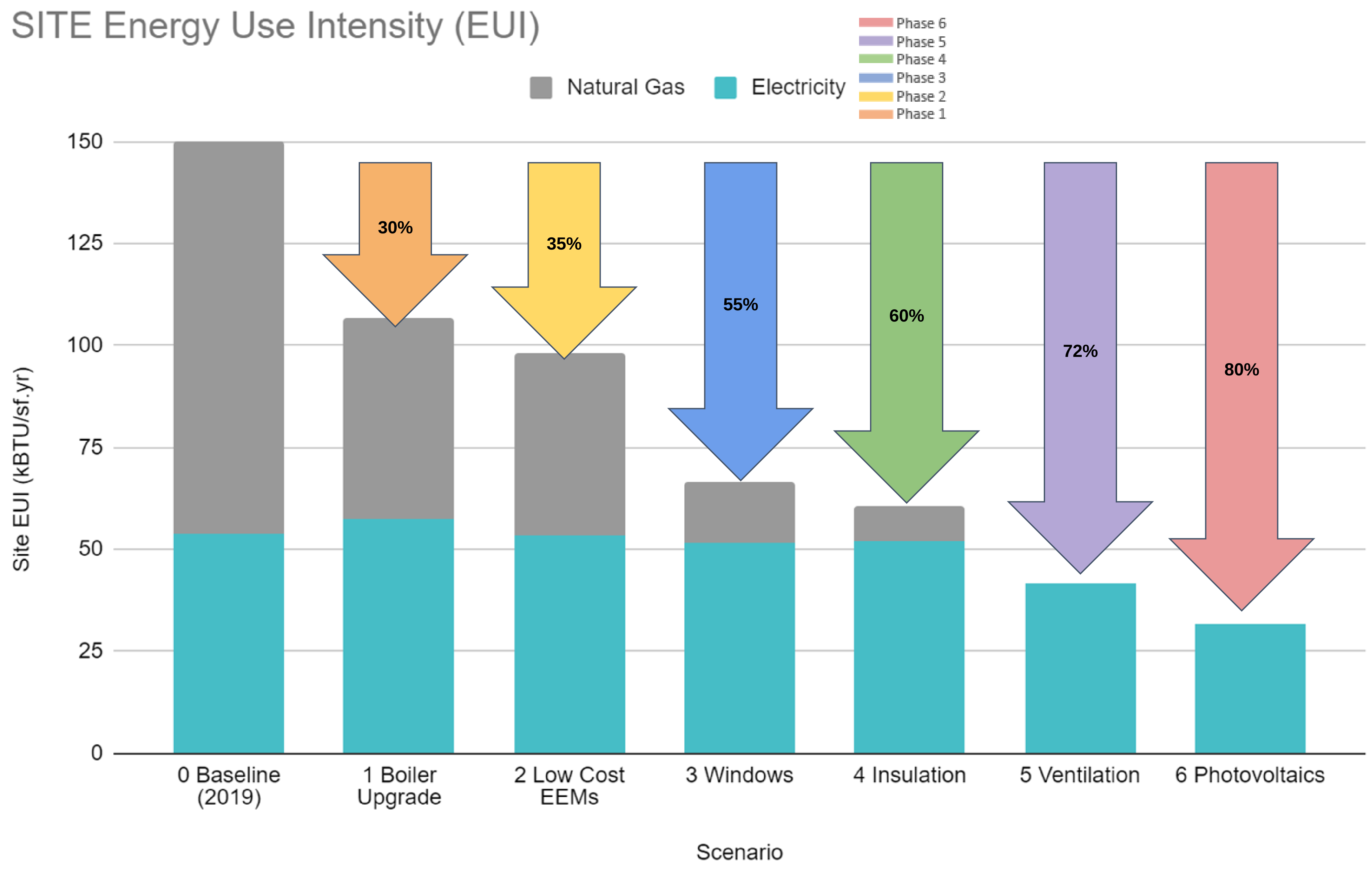
Phasing

- Can be staggered or take Phase at a time
  - Following current sequence would be a 6 year plan
- Trying to spread out large capital costs
- Respond to the existing deficiencies
  - Boilers
  - Windows
  - Roof
  - Balconies
- Response to BEPS Requirements
  - Reduce site energy with mechanical upgrade, 20%
    - Avoids the $2,600,300 fine
  - Long term plan to decrease site energy consumption by 77%
- Build in benefits for owners
  - Maintain balconies
  - Passive Survivability
  - Decreased utility costs



Cost-Savings-Sequence Chart
Duration
0
10
20
30
40
50
60
70
Millions
Cost
$20.00
$18.00
$16.00
$14.00
$12.00
$10.00
$8.00
$6.00
$4.00
$2.00
$0.00
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
Phase 6
Phase 5
Phase 4
Phase 3
Phase 2
Phase 1
Cost to Implement
Percent Savings


Detailed Measures Gantt Chart
Battery backup
PV
Upgrade common area AHUs
Decentralized ERV
Exterior wall EIFS
Roof Repair and Upgrade
Upgrade windows
Occ Sensors in garage
Interior Lighting LED
Surface parking LED
DHW Recirculation Controls
Demand ventilation in garage
Insulate first floor
Heat pump water heater (DHW)
Package boilers to cover additional load
Air source heat pumps (hydronic)
Measure
0
10
20
30
40
50
60
70
80
Duration (Approximate Months)
Phase 6
Phase 5
Phase 4
Phase 3
Phase 2
Phase 1



SITE Energy Use Intensity (EUI)
Natural Gas
Electricity
Phase 6
Phase 5
Phase 4
Phase 3
Phase 2
Phase 1
Site EUI (kBTU/sf.yr)
150
125
100
75
50
25
0
30%
35%
55%
60%
72%
80%
0 Baseline (2019)
1 Boiler Upgrade
2 Low Cost EEMs
3 Windows
4 Insulation
5 Ventilation
6 Photovoltaics
Scenario

- Highlights
  - Fixes mechanical issues first
  - Spread out cost
  - Instant cost savings on boilers, and reduces energy to tackle BEPS Phase 1

Phase	Measure	Cost	Phase Cost	Utility Cost	Cost savings
BASELINE:				$ 569,661	
1	Air source heat pumps (hydronic)	$ 2,508,000	$ 3,600,650	$ 544,826	$ 24,835
	Package boilers to cover additional load	$ 847,650			
	Heat pump water heater (DHW)	$ 245,000			
2	Insulate first floor	$ 75,200	$ 144,600	$ 505,986	$ 38,839
	Demand ventilation in garage	$ 25,200			
	Temperature/ demand control of DHW recirculation	$ 2,000			
	Surface parking LED	$ 25,800			
	Interior Lighting LED	$ 7,500			
	Occ Sensors in garage	$ 8,900			
3	Upgrade windows (based on resiliency/ comfort)	$ 10,394,550	$ 10,394,550	$ 440,004	$ 65,983
4	Roof Repair and Upgrade	$ 2,366,400	$ 4,535,550	$ 421,810	$ 18,194
	Exterior wall EIFS	$ 2,169,150			
5	Decentralized ERV	$ 332,500	$ 551,422	$ 324,091	$ 97,719
	Upgrade common area AHUs	$ 218,922			
6	PV	$ 220,500	$ 420,500	$ 247,672	$ 76,419
	Battery Backup	$ 200,000			

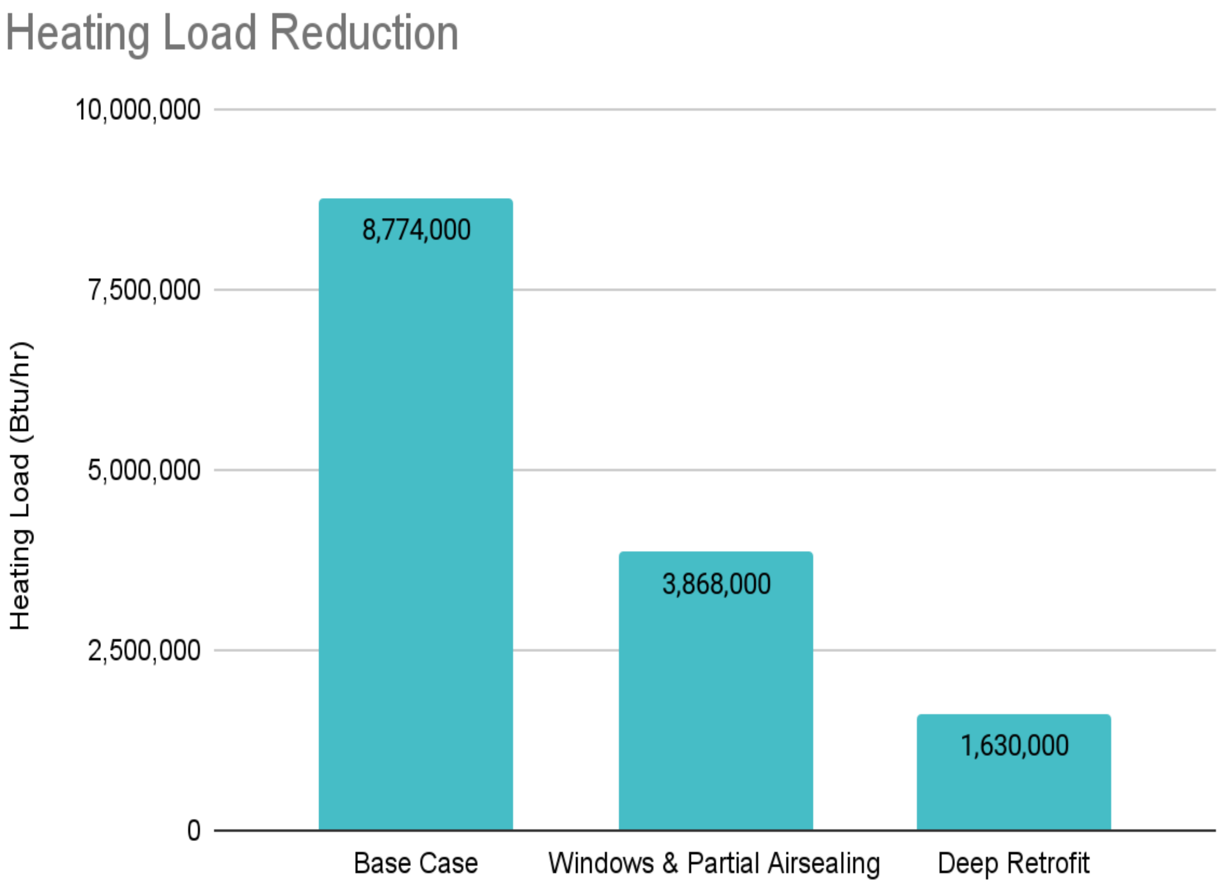
Phasing Details

Phase 1: Tackling the Major Deficiency

1. High Efficiency Air Source Heat Pump Chillers
2. Packaged Boilers
3. CO_2 Heat Pump Water Heaters

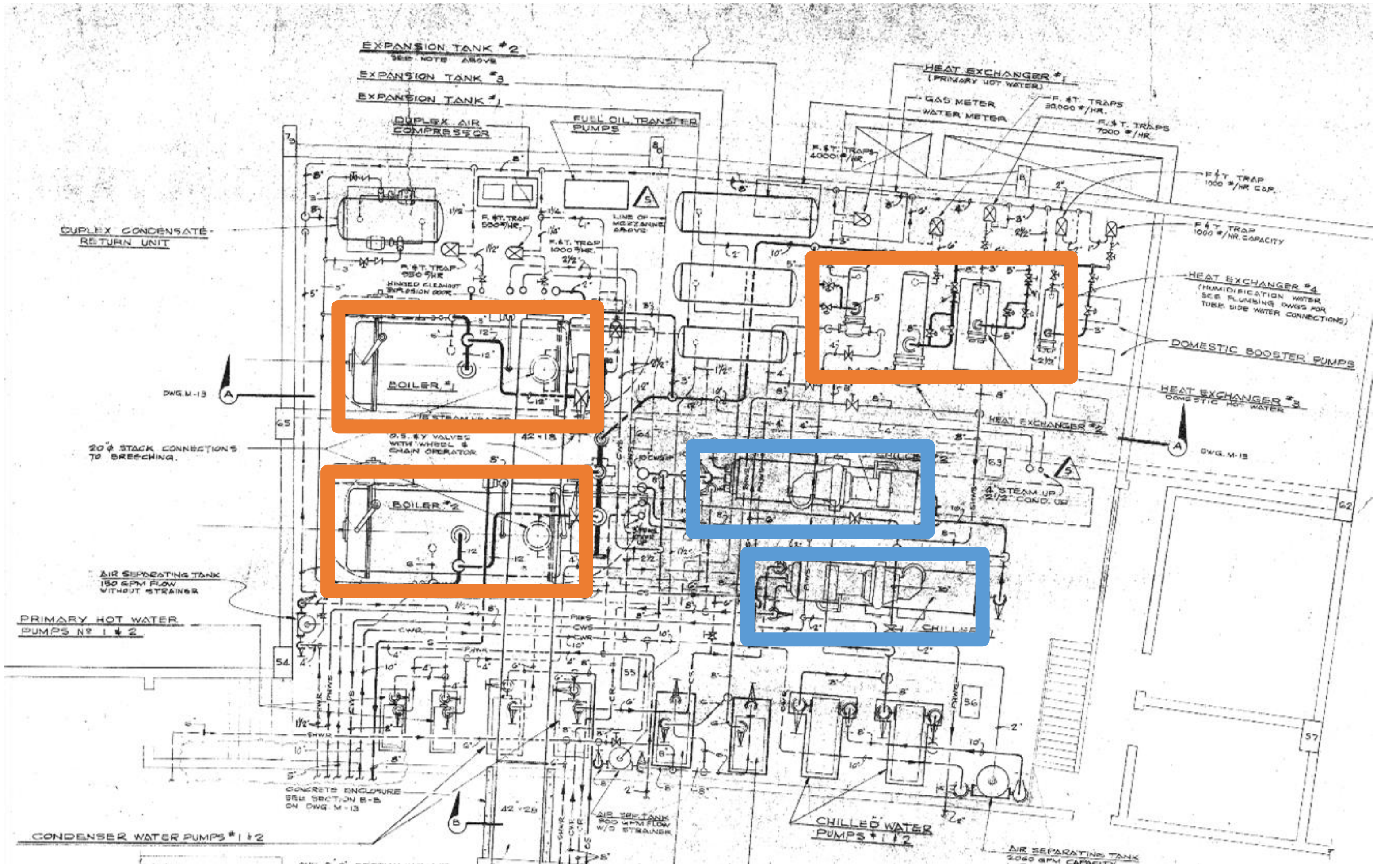
Phase 1: Details

1. High Efficiency Air Source Heat Pump Chillers
   a. Coverage 20% of heating load
2. Packaged Boilers
   a. Coverage 78% of heating load
   b. Stop gap equipment (to be decommissioned)



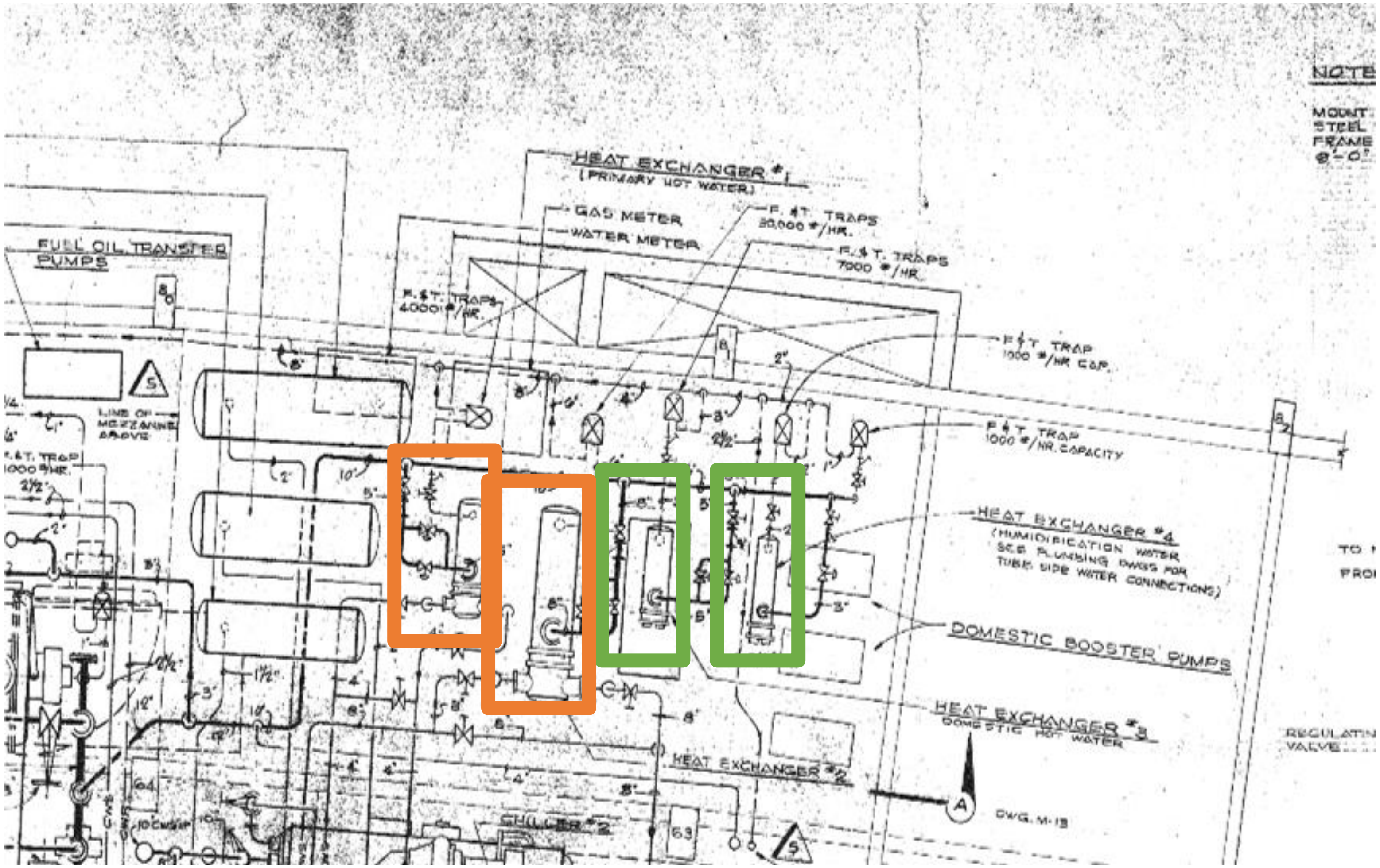
Phase 1: Details

- Two low pressure steam boilers
  - 10,000 MBH ea
  - 15 PSIG
  - ~52% efficiency
- Two centrifugal chillers
  - 300 tons ea



Phase 1: Details

- HX1: Primary
- HX2: Secondary
- HX3: DHW
- HX4: Humidification



Phase 1: Details

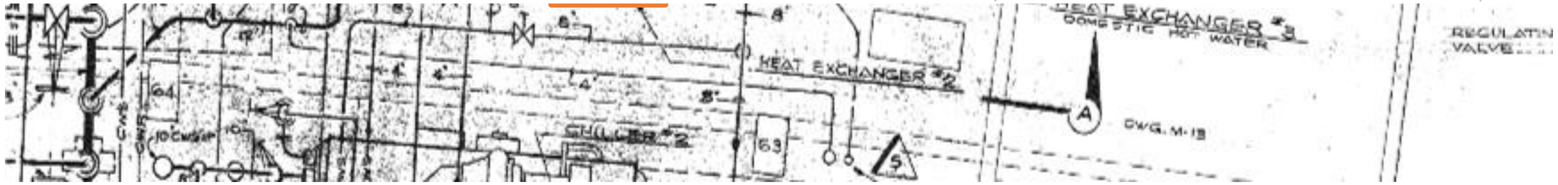
HEAT EXCHANGER SCHEDULE

ITEM	LOAD MBH	SHELL SIDE STEAM PRESS.	SHELL SIDE STEAM FLOW LBS/HOUR	TUBE SIDE WATER GPM	TUBE SIDE EWT	TUBE SIDE LWT	TUBE SIDE MAX. P.D.	CONSTRUCTION DATA SHELL DIA.	CONSTRUCTION DATA TUBE LENGTH	CONSTRUCTION DATA No. OF PASSES	CONSTRUCTION DATA HTG. SURF SQ FT.	LOCATION	REMARKS
HEAT EXCHANGER No 1	1500	5 PSIG	1500 #/HR.	150	180°	200°	3 FT.					BOILER ROOM	PRIMARY HOT WATER
HEAT EXCHANGER No 2	11,300	5 PSIG	12,000 #/HR.	900	160°	185°	3 FT.					BOILER ROOM	SECONDARY HOT WATER
HEAT EXCHANGER No 3	2300	5 PSIG	2400 #/HR.	SEE PLUMBING DETAIL SHEET DWG M-51								BOILER ROOM	DOMESTIC HOT WATER
HEAT EXCHANGER No 4	450	5 PSIG	470 #/HR.	18	40°	90°	3 FT.					BOILER ROOM	HUMIDIFICATION WATER

NOTES:

1- FOR DOMESTIC HOT WATER CONVERTOR SEE PLUMBING DETAIL SHEET, DWG. M-51

2- MAX. TUBE VELOCITY 4 FPS



Phase 1: Details

A I R H A N D L I N G U N I T

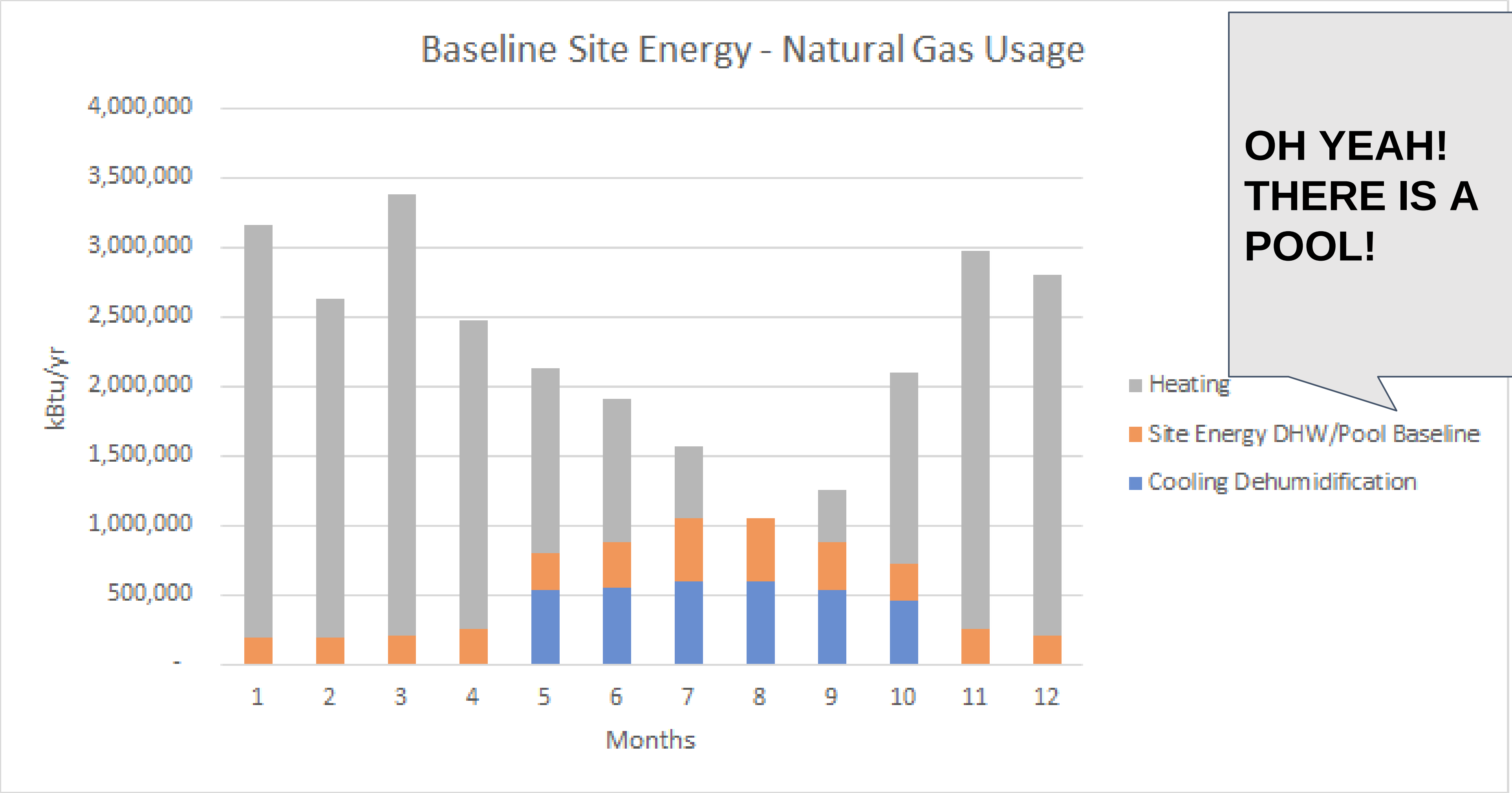
UNIT No	FAN DATA CFM	EXT. S.P.	MAX. O.V. FPM	MAX. RPM	MOTOR H.P.	MIN. O.A.	PREHEAT COIL DATA AIR EDB	AIR LDB	STEAM PRESS.	STEAM RATE	WATER EWT	WATER GPM	WATER P.D.
A.H.U # 1	22,110	1.50"	1600	620	20	22,110	0°	60°	5 PSIG	1500#/HR	—	—	—
A.H.U # 2	22,270	1.50"	1600	620	20	22,270	0°	60°	5 PSIG	1500#/HR	—	—	—
A.H.U # 3	5500	1.0"	1500	995	7½	5500	0°	60°	5 PSIG	375#/HR	—	—	—
A.H.U # 4	10700	1.0"	1520	1060	10	5350	38°	55°	5 PSIG	570#/HR	—	—	—

UNIT No	COOLING COIL DATA AIR EDB	AIR EWB	AIR LDB	AIR LWB	WATER EWT	WATER GPM	WATER P.D.	SPRAY PUMP H.P.	MAX. FV FPM	MIN. ROWS	MAX. S.P.	REHEAT COIL DATA AIR EDB	AIR LDB	STEAM PRESS.	STEAM RATE
A.H.U # 1	95°	78°	55°	54°	44°	375	15 FT	½HP	450	6	1.0"	60°	85°	5 PSIG	630#/HR
A.H.U # 2	95°	78°	55°	54°	44°	375	15 FT	½HP	450	6	1.0"	60°	85°	5 PSIG	630#/HR
A.H.U # 3	95°	78°	56°	54°	44°	90	15 FT	—	500	6	1.1"	60°	95°	5 PSIG	220#/HR
A.H.U # 4	87.5°	72.5°	57°	54°	44°	130	15 FT	—	400	8	1.00"	75°	100°	5 PSIG	310#/HR

NOTES
1- ALL UNITS SHALL HAVE VARIABLE SPEED DRIVE
2- UNITS SHALL BE MOUNTED ON SPRING VARIATIONS ISOLATORS W/ SOUND PADS.
3- FANS SHALL HAVE AIRFOIL BLADES
4- MAX. S.P. LOSS FOR COOLING COILS INCLUDES SPRAYS & ELIMINATORS.
5- STEAM COILS TO BE MIN. 2 ROWS. NON-FREEZE TYPE.

- 60,580 cfm total, 100% OA.
- Tempered to 70°F
- 55,000 cfm direct exhaust

Phase 1: Details



OH YEAH! THERE IS A POOL!

Phase 2: Low Cost Efficiency Measures

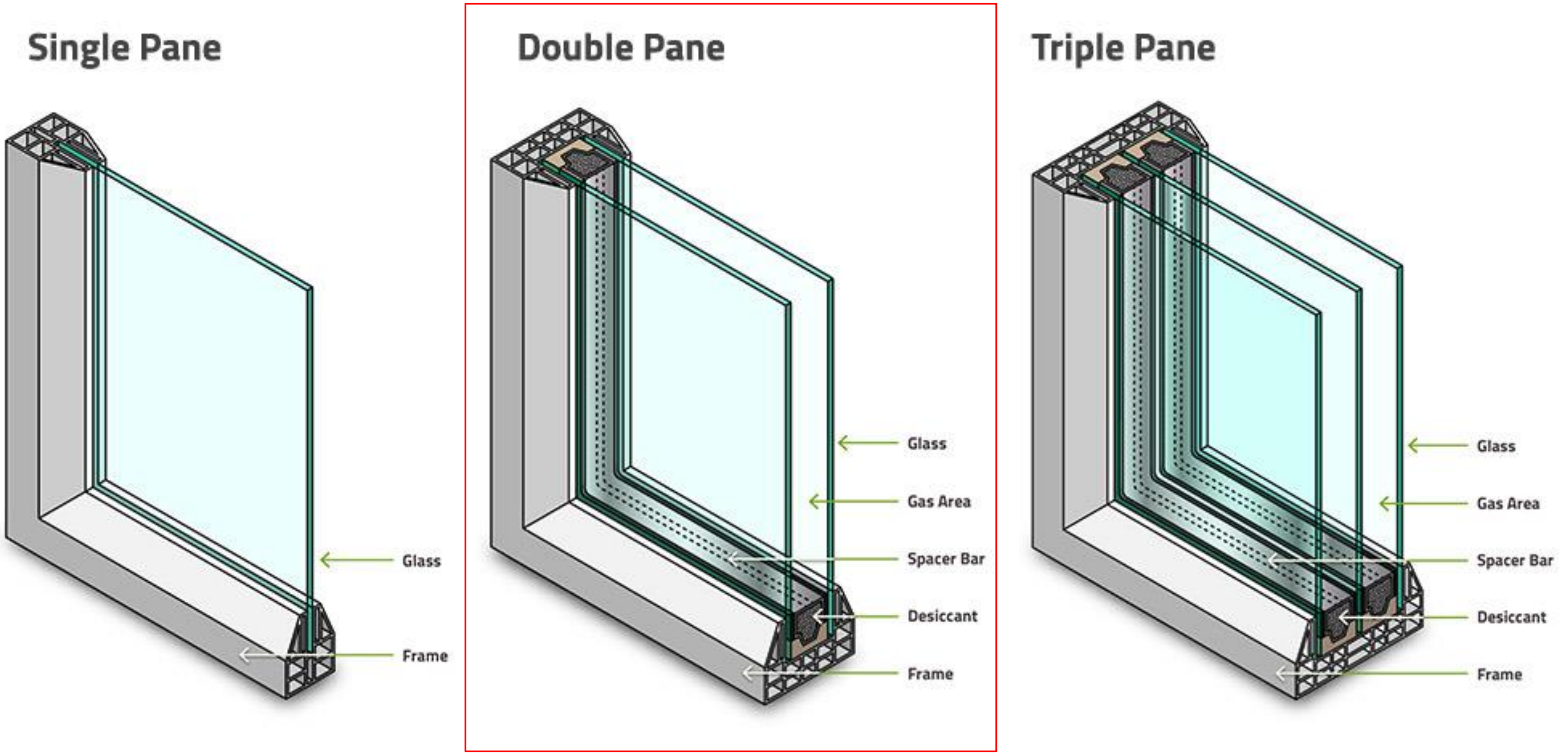
1. Insulate garage ceiling
2. Demand control ventilation in garage
3. Upgraded DHW controls (
4. Surface parking LED
5. Interior LED lighting
6. Occupancy sensor in garage

#	Measure Description	Financial			BEPS 1			BEPS 2
		Measure Cost	Annual Cost Savings	Simple Payback (yrs)[10]	% of recommended Target[11]	Avoided BEPS Penalty[12]	Simple Payback after avoided Penalty (yr)	% of Target Source EUI Reduction Cycle 2
Low-Cost and No-Cost Recommendations								
5.1.1	Evaluate Garage Ventilation System and Install Garage CO/NO2 Controlled Ventilation	$ 25,200	$ 8,000	3.1	3%	$ 93,800	Immediate	2%
5.1.2	Install Temperature Control on DHW-Recirculation Pump	$ 2,000	$ 600	3.3	1%	$ 10,200	Immediate	<1%
5.1.3	Install Low-Flow Fixtures	$ 148,600	$ 3,000	None	4%	$ 53,400	32.0	3%
5.1.4	Calibrate Thermostats in Residential Units	$ 7,800	$ 300	25.8	<1%	$ 4,700	10.2	<1%
5.1.5	Upgrade Surface Parking Lighting to LED	$ 25,800	$ 5,900	4.4	2%	$ 69,100	Immediate	1%
5.1.6	Upgrade Lighting to LED	$ 7,500	$ 2,800	2.7	<1%	$ 28,300	Immediate	<1%
5.1.7	Retro Commission the Chiller Plant	$ 10,000	$ 23,100	0.4	7%	$ 268,900	Immediate	5%
5.1.8	Install Occupancy Sensors in Covered Parking Areas	$ 8,900	$ 6,000	1.5	2%	$ 68,700	Immediate	1%

4.75 year ROI

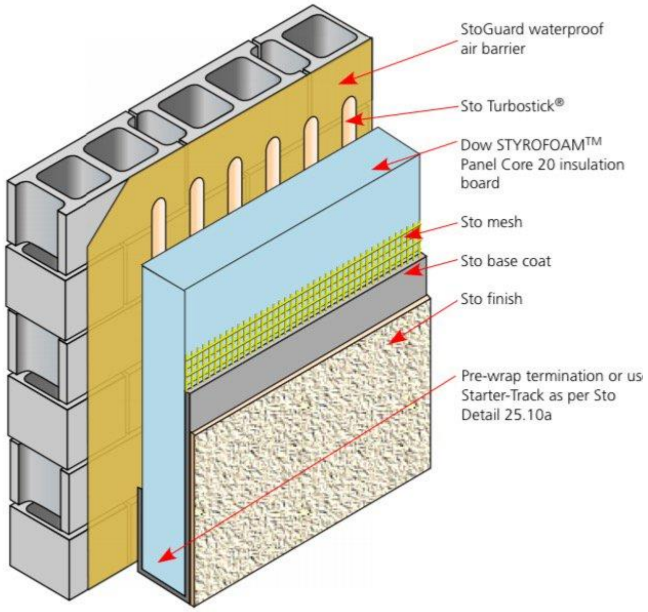
Phase 3: Replacing the Windows

- Replace all exterior windows
- U-0.25 (Good Double Pane)
- Window overlaps other phases



Phase 4: Finishing the Envelope Upgrades

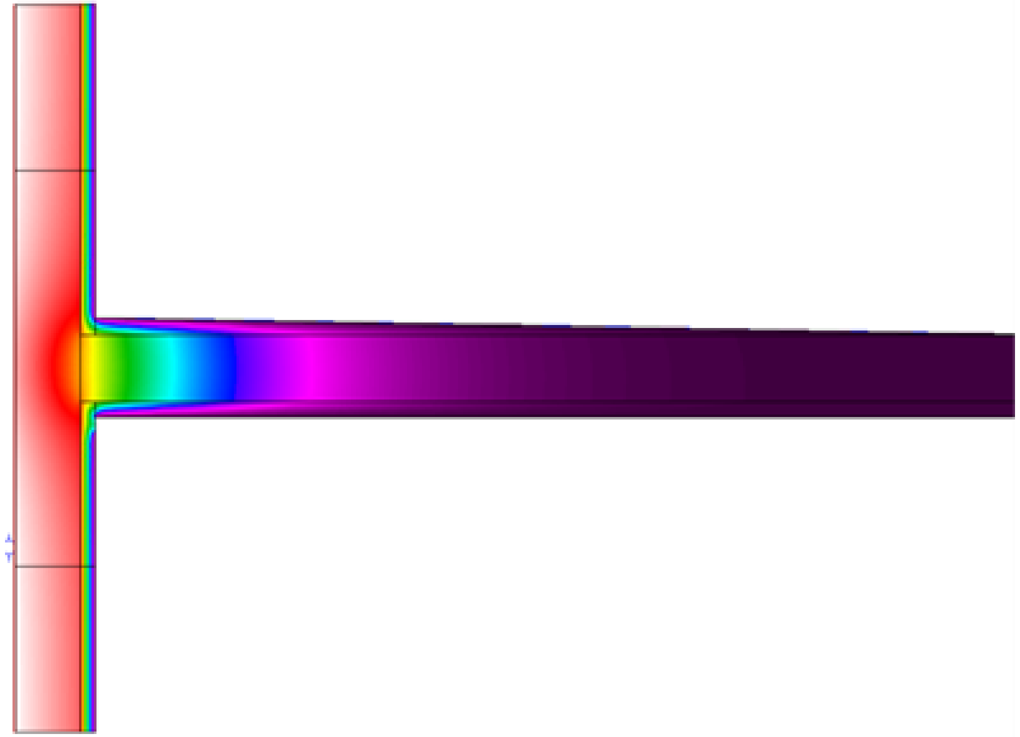
1. Replace and upgrade roof
2. Insulate exterior walls
3. Mitigate balcony thermal bridging



Balcony Thermal Bridge Mitigation

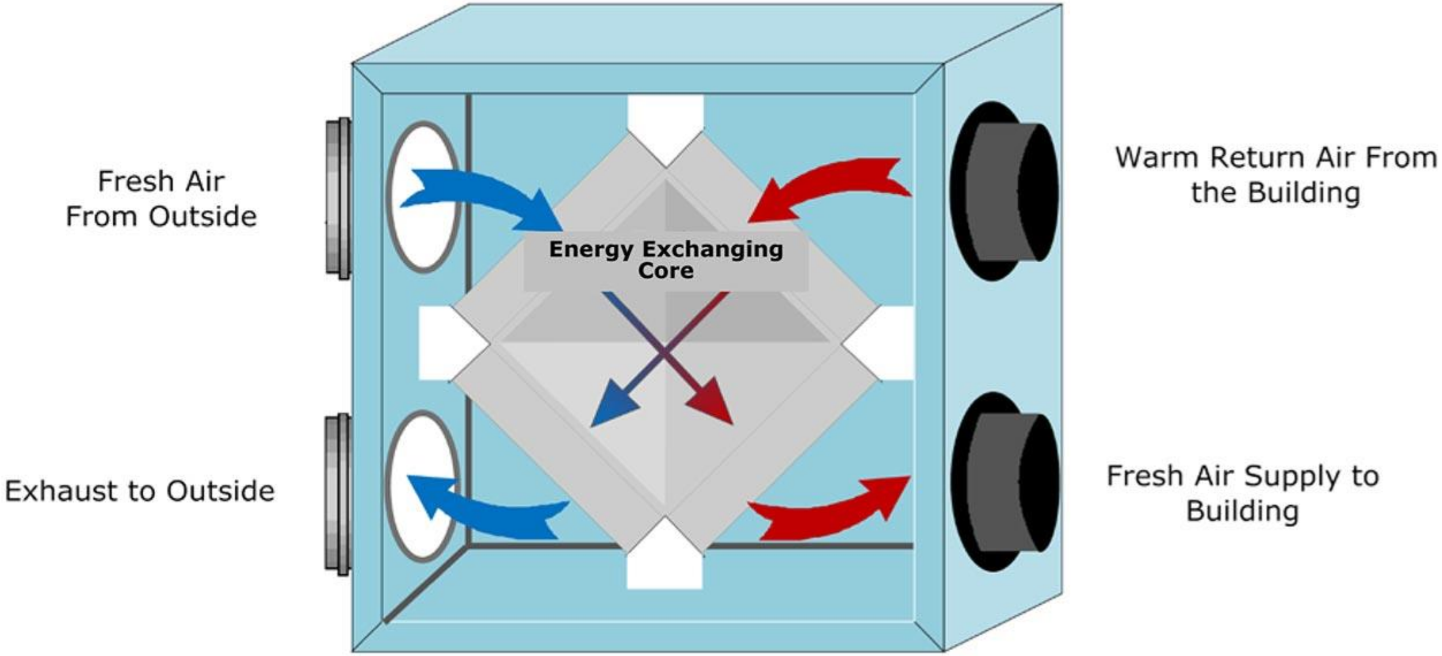
psi: 0.401 Btu/hr ft °F

psi: 0.125 Btu/hr ft °F



Phase 5: Improved Ventilation

1. Energy recovery ventilation (unit or floor level)
2. Replace and upgrade common area air handlers



Phase 6: Renewables and Battery Backup

1. Photovoltaic panels on roof
2. Battery backup

How Much Retrofit Do You Need?

Let’s look at resiliency

Is it passive?

Phius 2021
Performance Criteria Calculator v3.1

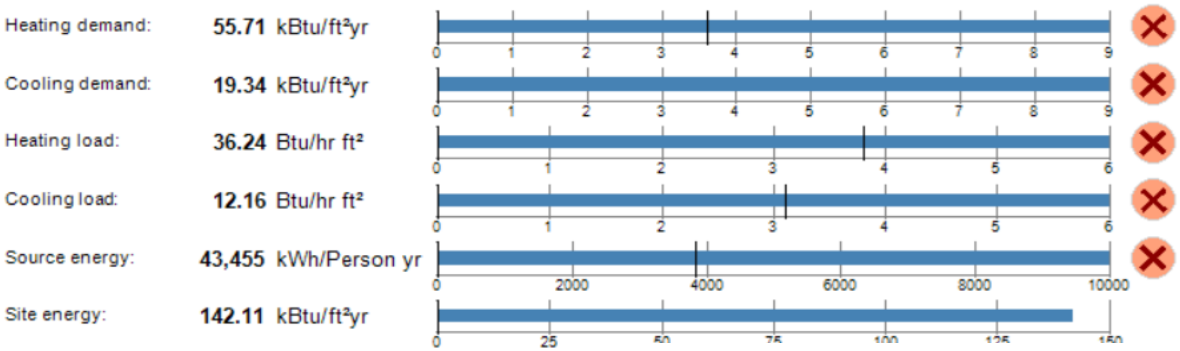
UNITS:	IMPERIAL (IP)
BUILDING FUNCTION:	RESIDENTIAL
PROJECT TYPE:	NEW CONSTRUCTION
STATE/ PROVINCE	VIRGINIA
CITY	WASHINGTON DC REAG
Envelope Area (ft²)	210,296.1
iCFA (ft²)	242,122.0
Dwelling Units (Count)	129
Total Bedrooms (Count)	158

Space Conditioning Criteria

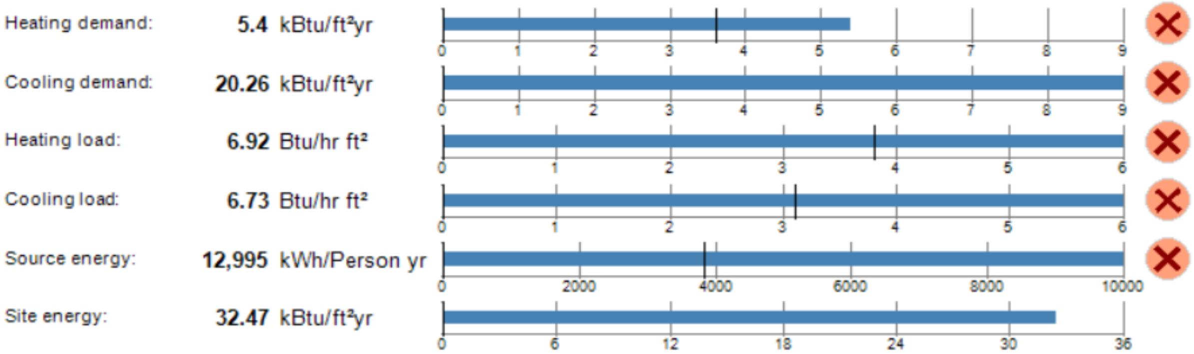
Annual Heating Demand	4.0	kBtu/ft²yr
Annual Cooling Demand	9.7	kBtu/ft²yr
Peak Heating Load	4.0	Btu/ft²hr
Peak Cooling Load	3.1	Btu/ft²hr

Source Energy Criteria

Phius CORE	5800	kWh/person.yr
Phius ZERO	0	kWh/person.yr



Base case



Phase 6 Completed

Is it passive?

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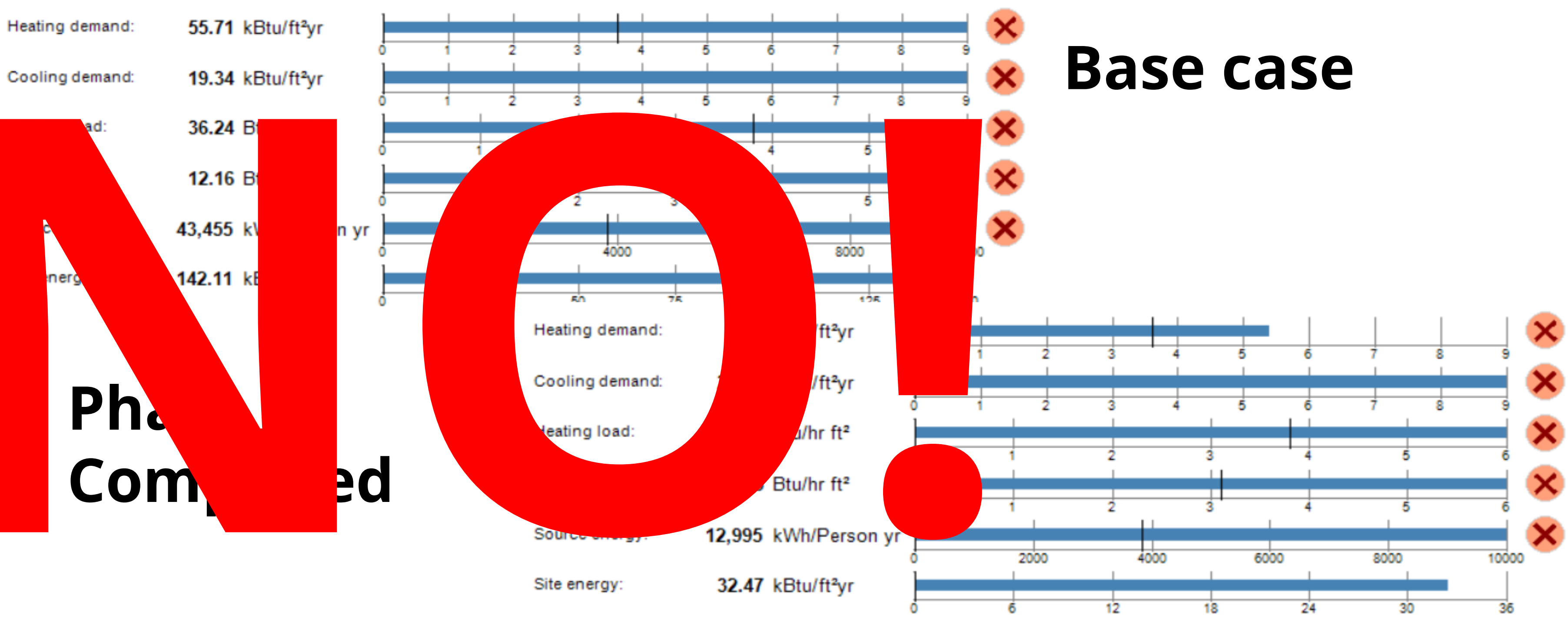
Phius ZERO	0	kWh/person.yr



Base case

NO!

Pha
Com ed

Winter Outage Resilience

- Passive building measures help keep heat in:
  - Airtight enclosure
  - Superinsulation
- They also keep CO_2 in:
  - Need ERV/HRV 5 cfm/person (2.4 l/s)
  - Cracked Window (no heat recovery)

Winter Outage Resilience

Metrics/criteria:

- Hours below 2°C (35.6° F) = 0.
- Heating SET Hours, basis 12.2°C (54°F) ≤ 216 F-hours.

  - ASHRAE 55-2010 defines SET as “the temperature of an imaginary environment at 50% relative humidity, <0.1 m/s [0.33 ft/s] average air speed, and mean radiant temperature equal to average air temperature, in which total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity level”

Summer Outage Resilience

- Though passive measures alone may not suffice, **they remain crucial**.

- **We want to find combinations of passive measures that can lower the load to the point where rooftop PV + mechanical cooling can keep a place livable.**
  - Passive enclosure can keep the active cooling in

Summer Outage Resilience

Metrics/criteria
- Heat index, hours in Danger = 0
- Battery capacity
- Demand limit setback to 90°F HI

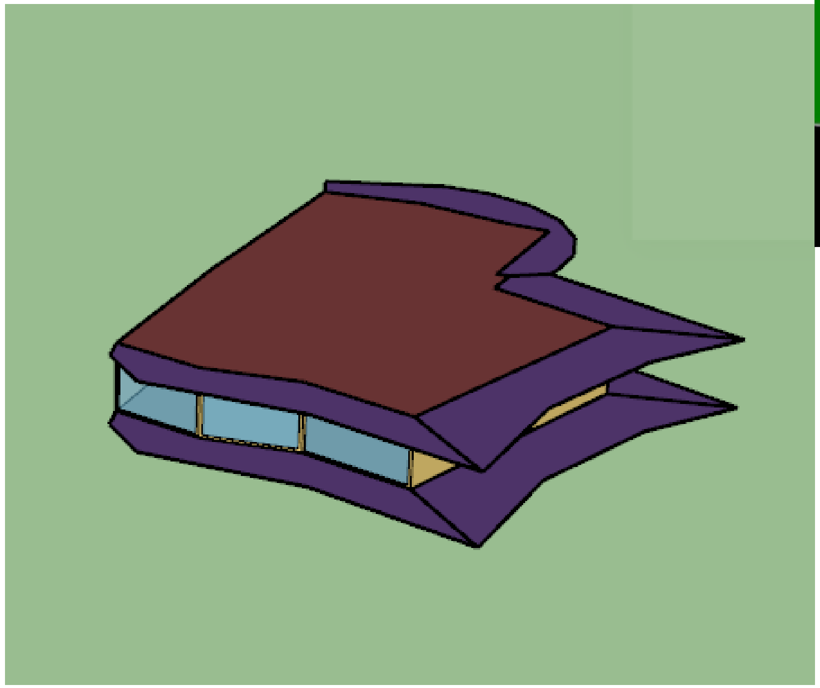
NOAA national weather service: heat index

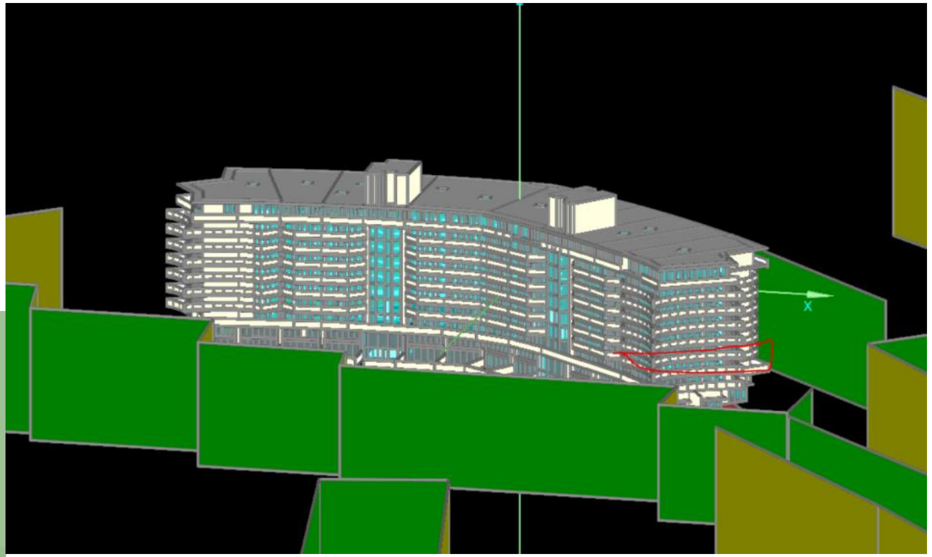
Relative humidity \ Temperature	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	86 °F (30 °C)	88 °F (31 °C)	90 °F (32 °C)	92 °F (33 °C)	94 °F (34 °C)	96 °F (36 °C)	98 °F (37 °C)	100 °F (38 °C)	102 °F (39 °C)	104 °F (40 °C)	106 °F (41 °C)	108 °F (42 °C)	110 °F (43 °C)
40%	80 °F (27 °C)	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	94 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	105 °F (41 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	136 °F (58 °C)
45%	80 °F (27 °C)	82 °F (28 °C)	84 °F (29 °C)	87 °F (31 °C)	89 °F (32 °C)	93 °F (34 °C)	96 °F (36 °C)	100 °F (38 °C)	104 °F (40 °C)	109 °F (43 °C)	114 °F (46 °C)	119 °F (48 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)	
50%	81 °F (27 °C)	83 °F (28 °C)	85 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	99 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	113 °F (45 °C)	118 °F (48 °C)	124 °F (51 °C)	131 °F (55 °C)	137 °F (58 °C)		
55%	81 °F (27 °C)	84 °F (29 °C)	86 °F (30 °C)	89 °F (32 °C)	93 °F (34 °C)	97 °F (36 °C)	101 °F (38 °C)	106 °F (41 °C)	112 °F (44 °C)	117 °F (47 °C)	124 °F (51 °C)	130 °F (54 °C)	137 °F (58 °C)			
60%	82 °F (28 °C)	84 °F (29 °C)	88 °F (31 °C)	91 °F (33 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	110 °F (43 °C)	116 °F (47 °C)	123 °F (51 °C)	129 °F (54 °C)	137 °F (58 °C)				
65%	82 °F (28 °C)	85 °F (29 °C)	89 °F (32 °C)	93 °F (34 °C)	98 °F (37 °C)	103 °F (39 °C)	108 °F (42 °C)	114 °F (46 °C)	121 °F (49 °C)	128 °F (53 °C)	136 °F (58 °C)					
70%	83 °F (28 °C)	86 °F (30 °C)	90 °F (32 °C)	95 °F (35 °C)	100 °F (38 °C)	105 °F (41 °C)	112 °F (44 °C)	119 °F (48 °C)	126 °F (52 °C)	134 °F (57 °C)						
75%	84 °F (29 °C)	88 °F (31 °C)	92 °F (33 °C)	97 °F (36 °C)	103 °F (39 °C)	109 °F (43 °C)	116 °F (47 °C)	124 °F (51 °C)	132 °F (56 °C)							
80%	84 °F (29 °C)	89 °F (32 °C)	94 °F (34 °C)	100 °F (38 °C)	106 °F (41 °C)	113 °F (45 °C)	121 °F (49 °C)	129 °F (54 °C)								
85%	85 °F (29 °C)	90 °F (32 °C)	96 °F (36 °C)	102 °F (39 °C)	110 °F (43 °C)	117 °F (47 °C)	126 °F (52 °C)	135 °F (57 °C)								
90%	86 °F (30 °C)	91 °F (33 °C)	98 °F (37 °C)	105 °F (41 °C)	113 °F (45 °C)	122 °F (50 °C)	131 °F (55 °C)									
95%	86 °F (30 °C)	93 °F (34 °C)	100 °F (38 °C)	108 °F (42 °C)	117 °F (47 °C)	127 °F (53 °C)										
100%	87 °F (31 °C)	95 °F (35 °C)	103 °F (39 °C)	112 °F (44 °C)	121 °F (49 °C)	132 °F (56 °C)										

Key to colors: Caution, Extreme caution, Danger, Extreme danger

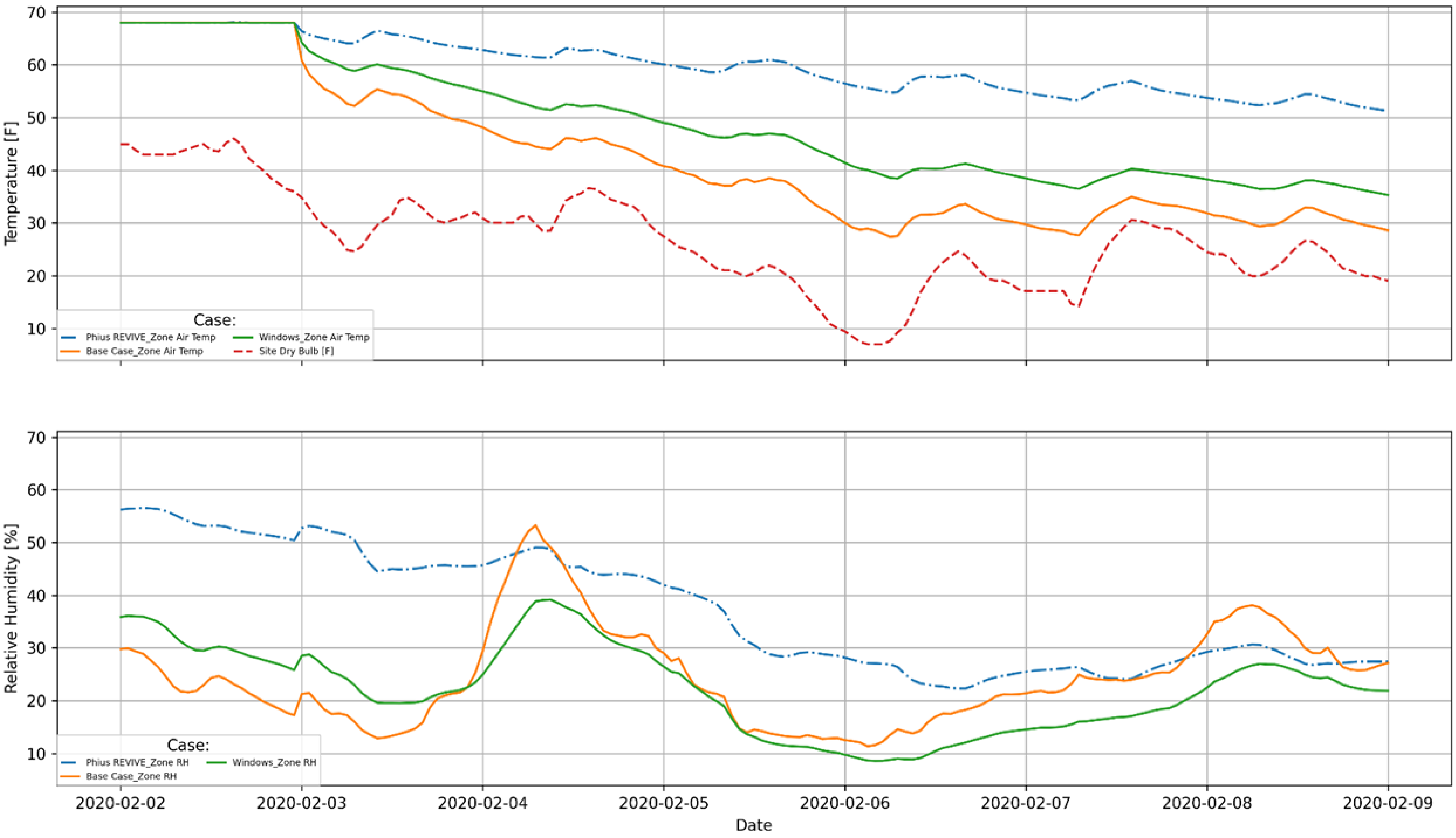
Test Unit

- End unit
- Lots of glazing
- 3 Beds, 2,700 SF
  - Not Dense

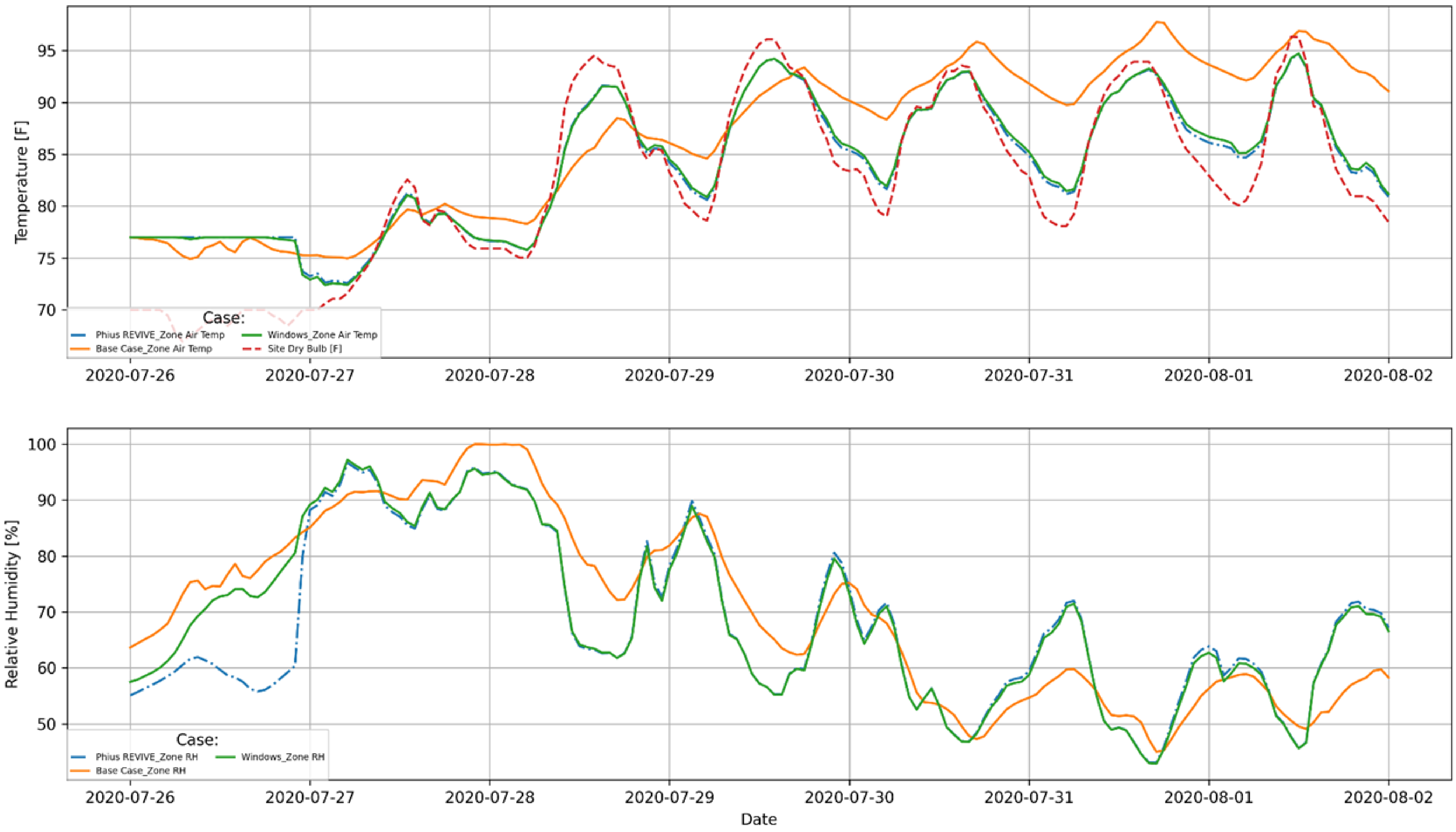


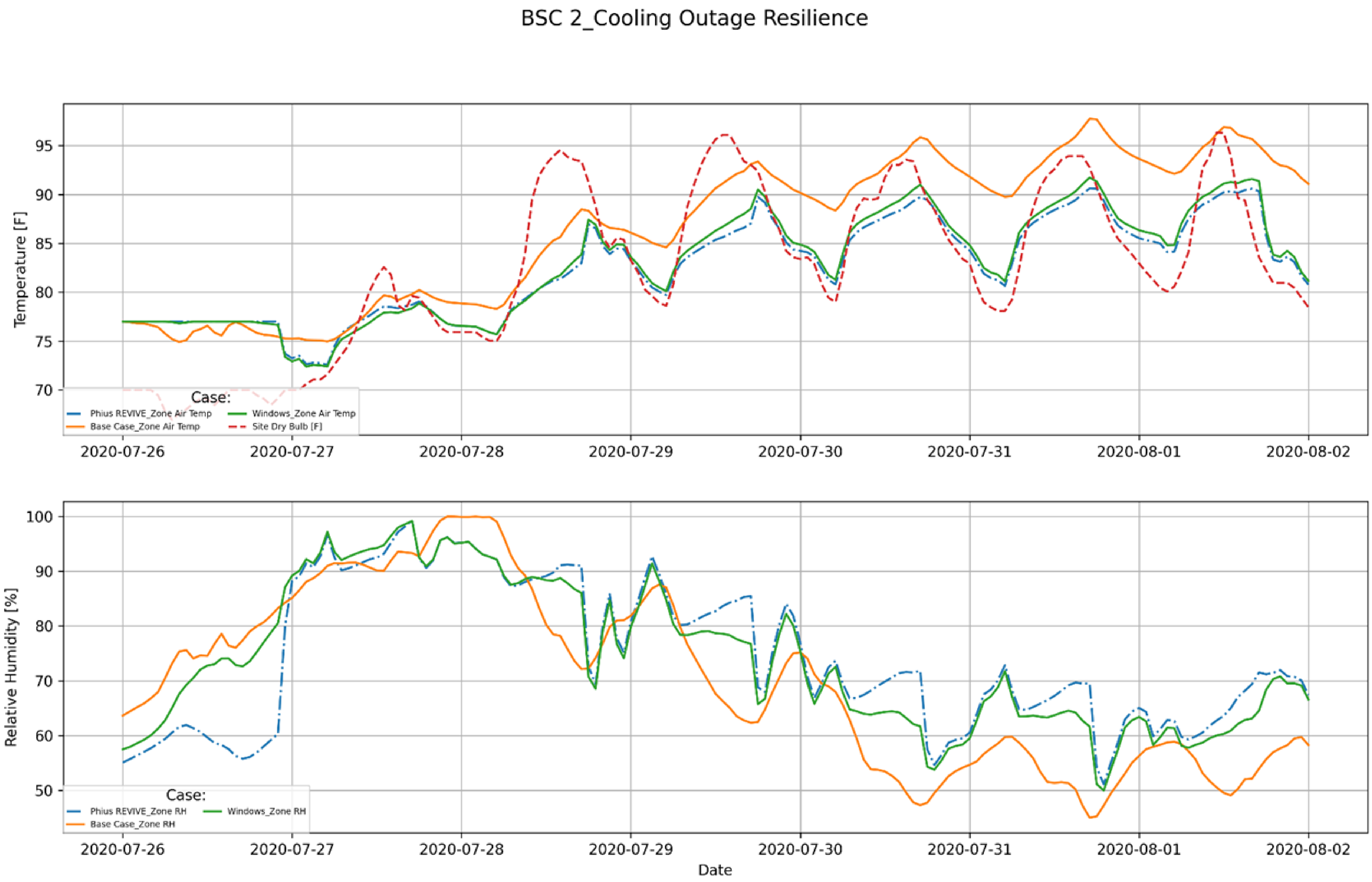


BSC 2_Heating Outage Resilience

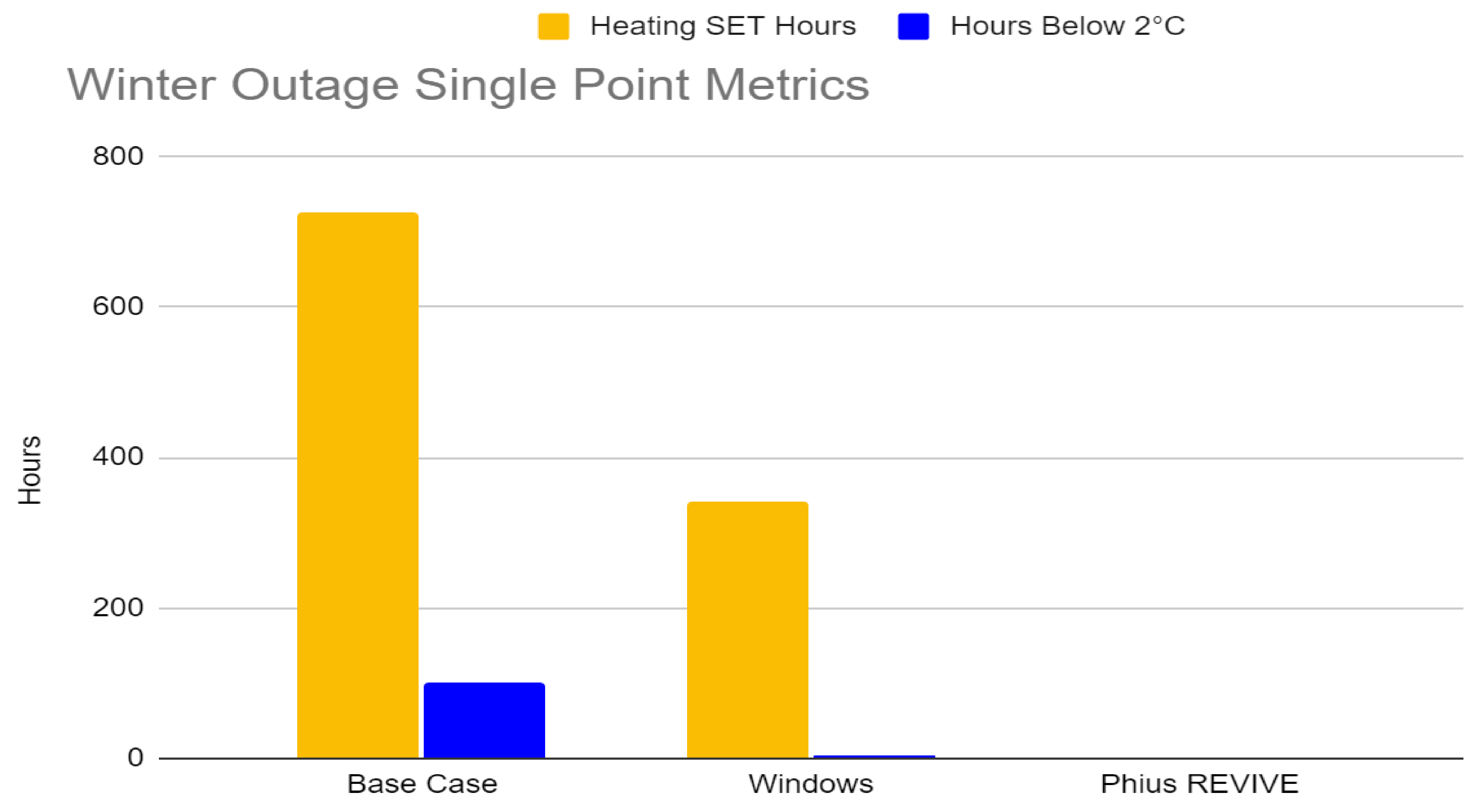


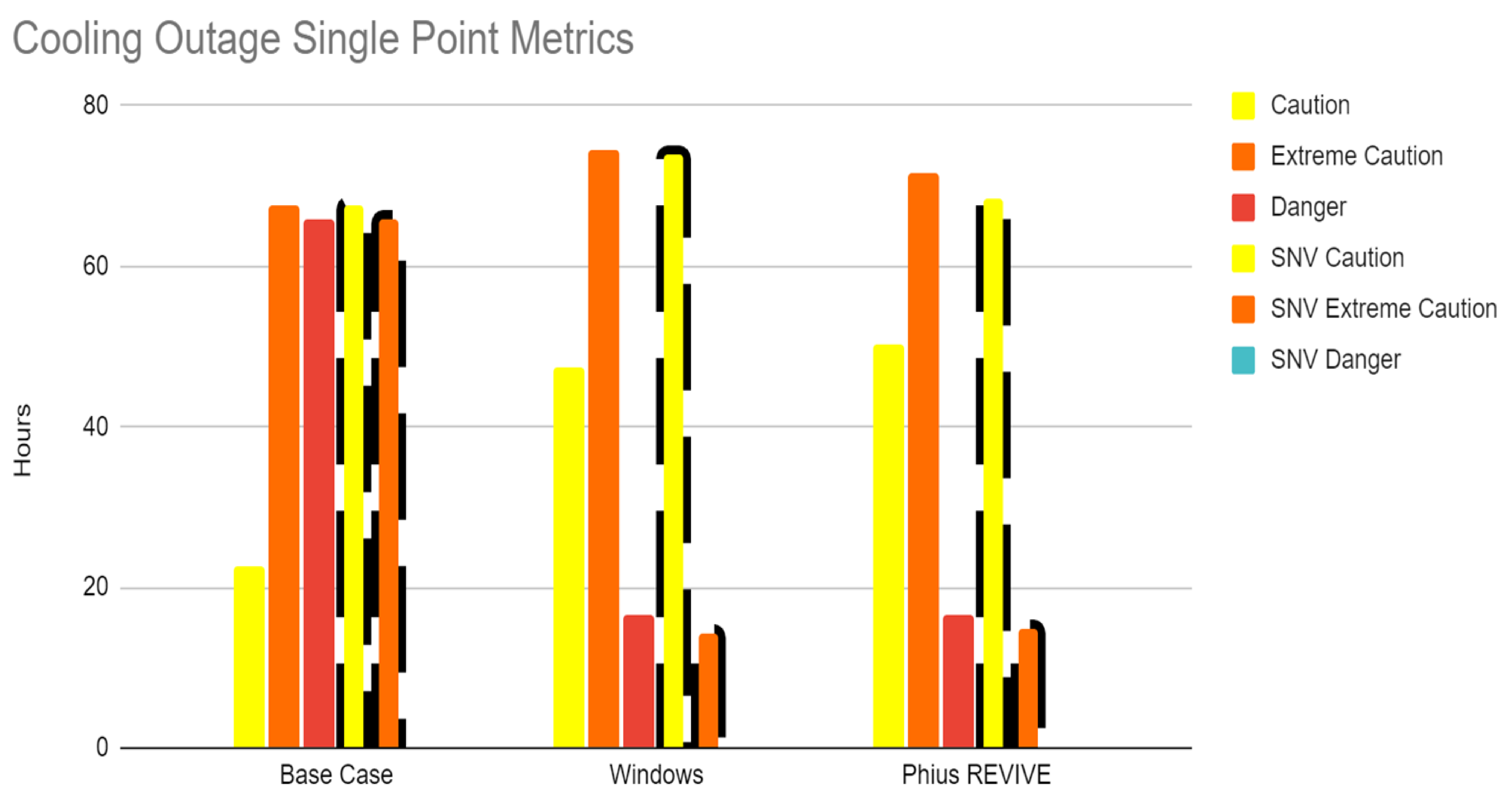
BSC 2_Cooling Outage Resilience





BSC 2_Cooling Outage Resilience
Temperature [F]
95
90
85
80
75
70
Case:
Phius REVIVE_Zone Air Temp
Base Case_Zone Air Temp
Windows_Zone Air Temp
Site Dry Bulb [F]
2020-07-26
2020-07-27
2020-07-28
2020-07-29
2020-07-30
2020-07-31
2020-08-01
2020-08-02
Relative Humidity [%]
100
90
80
70
60
50
Case:
Phius REVIVE_Zone RH
Base Case_Zone RH
Windows_Zone RH
Date


Heating SET Hours
Hours Below 2°C
Winter Outage Single Point Metrics
800
600
400
200
0
Hours
Base Case
Windows
Phius REVIVE


Cooling Outage Single Point Metrics
Hours
80
60
40
20
0
Base Case
Windows
Phius REVIVE
Caution
Extreme Caution
Danger
SNV Caution
SNV Extreme Caution
SNV Danger

Where is This All Headed?

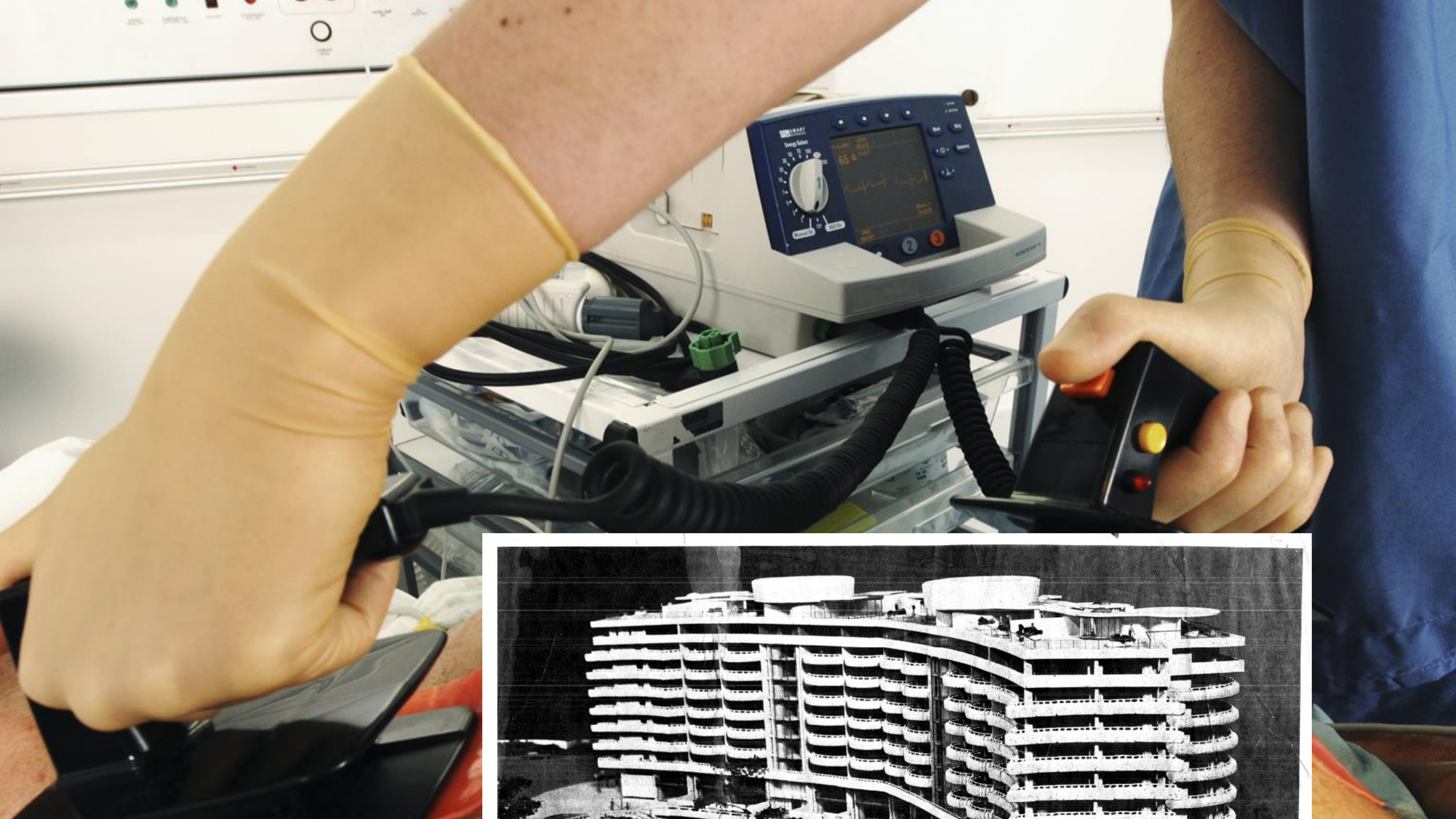
Phius REVIVE *Pilot* Framework

~~Retrofit-Gate~~

REVIVE = Phius' existing retrofit program
REVIVE *Pilot* = Retrofit program in development

New Framework:

1. Use outage **resilience** as the guiding principle for enclosure upgrades (rather than cost optimization, how the existing program is framed)
2. **Phase in** a retrofit plan over time (optional)
    - Electrify first, to final capacity
    - Make envelope improvements
    - Decommission stop gap assets
3. Do this at the best life-cycle cost, including cost of carbon, operating and embodied. (**ADORB** cost)



Summary: REVIVE Pilot program

Key requirements

- A quality assurance process covers all phases.
- Direct emissions cease soon.
- Critical loads are covered by locally-generated renewable generation / storage

Scope

- Land use
- Decarbonization
- Cost/Finance/Equity
- Resilience
- Quality and Health
- Phase planning

- *GOOD FOR YOUR BUILDING*
- *GOOD FOR THE PLANET*
- *QUALITY ASSURED RESULTS*

ADORB Cost Includes Embodied Carbon

Annualized **D**ecarbonization **O**f **R**etrofitted **B**uilding **Cost**

ADORB Cost = sum of the following components, each an annual cost:

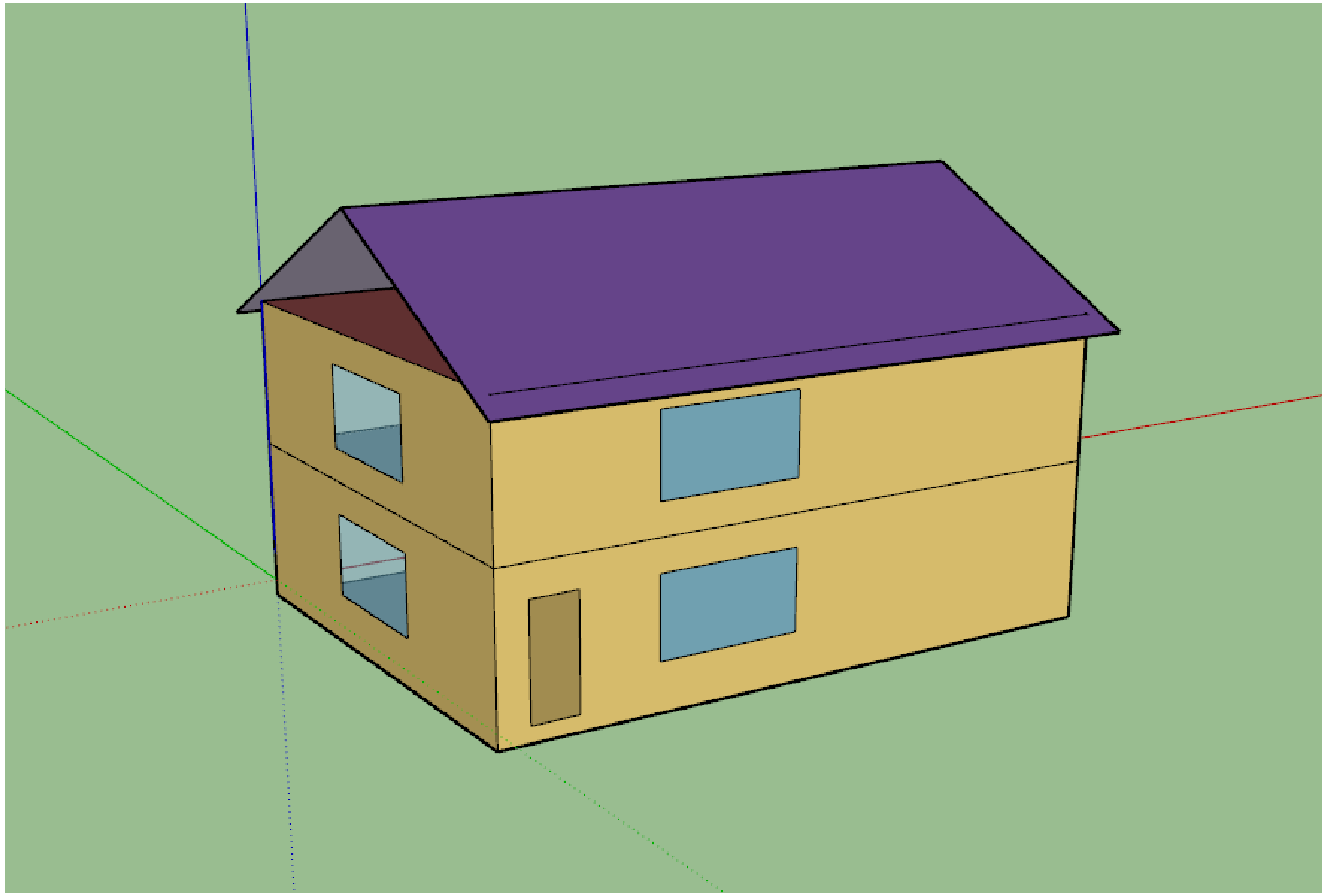
- Direct energy cost. E.g. site kWh * $/kWh = $
- Direct building retrofit measures cost (material & labor) including building-level electrification cost. E.g. ft3 of stuff * $/ft3 = $
- Cost of carbon, upfront / embodied. CO2e kg * $/kg = $
- Cost of carbon, operating. CO2e kg * $/kg = $
- Energy system transition cost (e.g. new solar + storage). $/MW * MW = $

INCLUDES LABOR, NOT JUST MATERIALS -- PERSONAL & BUSINESS CHOICES COUNT

ADORB Cost should not exceed baseline and preferably is minimized.

Cost of Carbon = $0.25 [$/kg]

Test building



US DOE Prototypical Single Family House

- 2 Stories
- 3 beds (4 occ)
- 2,128 sqft (198 sqm)
- 13.5% WWR
- slab on grade

Packages and summer modes

Retrofit Packages:

0 - Baseline, typical existing condition

1 - Equipment & appliances, electrification

1 - but better ERV

2 - add DOE "Market ready envelope"

2 - but better ERV

3 - IECC 2021

4 - Phius 2021 excl. subslab insul.

4 - Phius 2021 incl. subslab insul.

Summer modes

NV - natural vent., temp control

SNV - scheduled nat. vent., temp ctrl.

SNV+Shd - add exterior blinds

HP - heat pump

HP+Shd - heat pump + ext. blinds

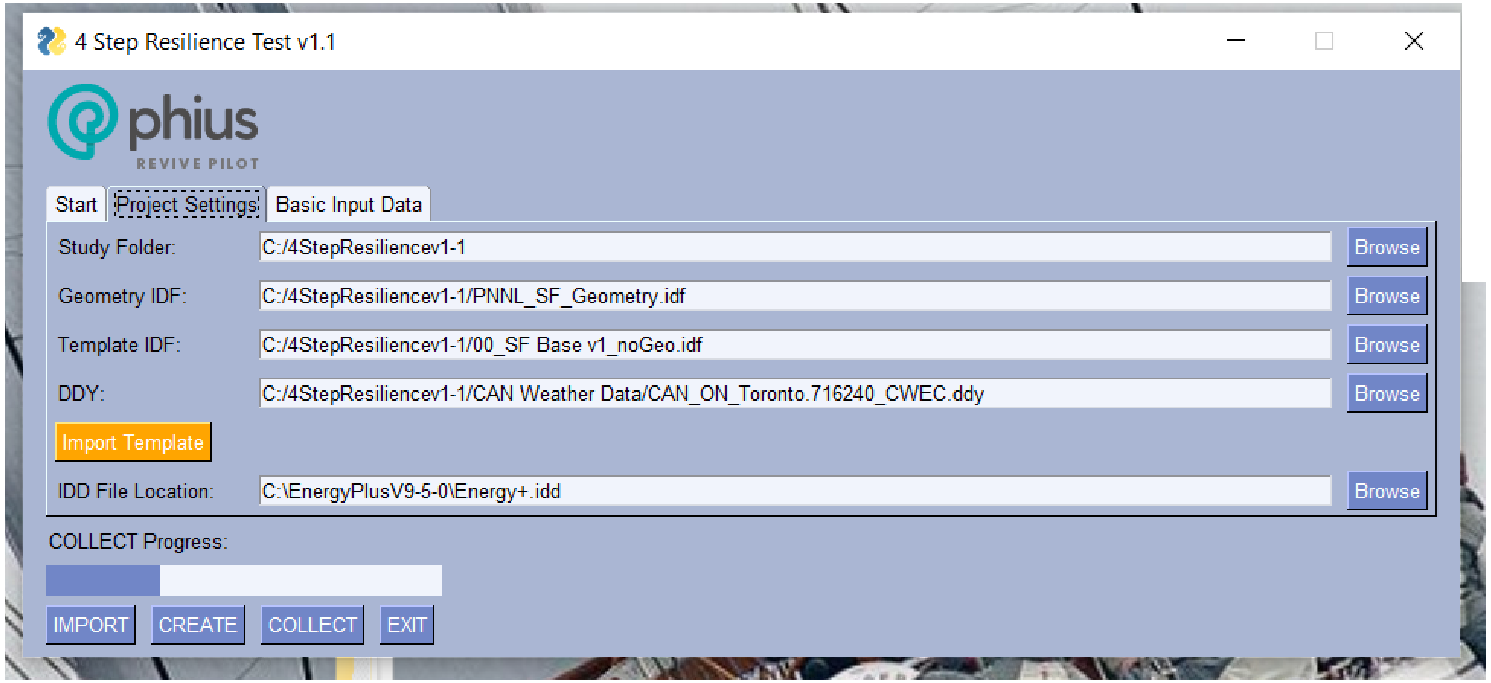
EC - evaporative cooler (B zones)

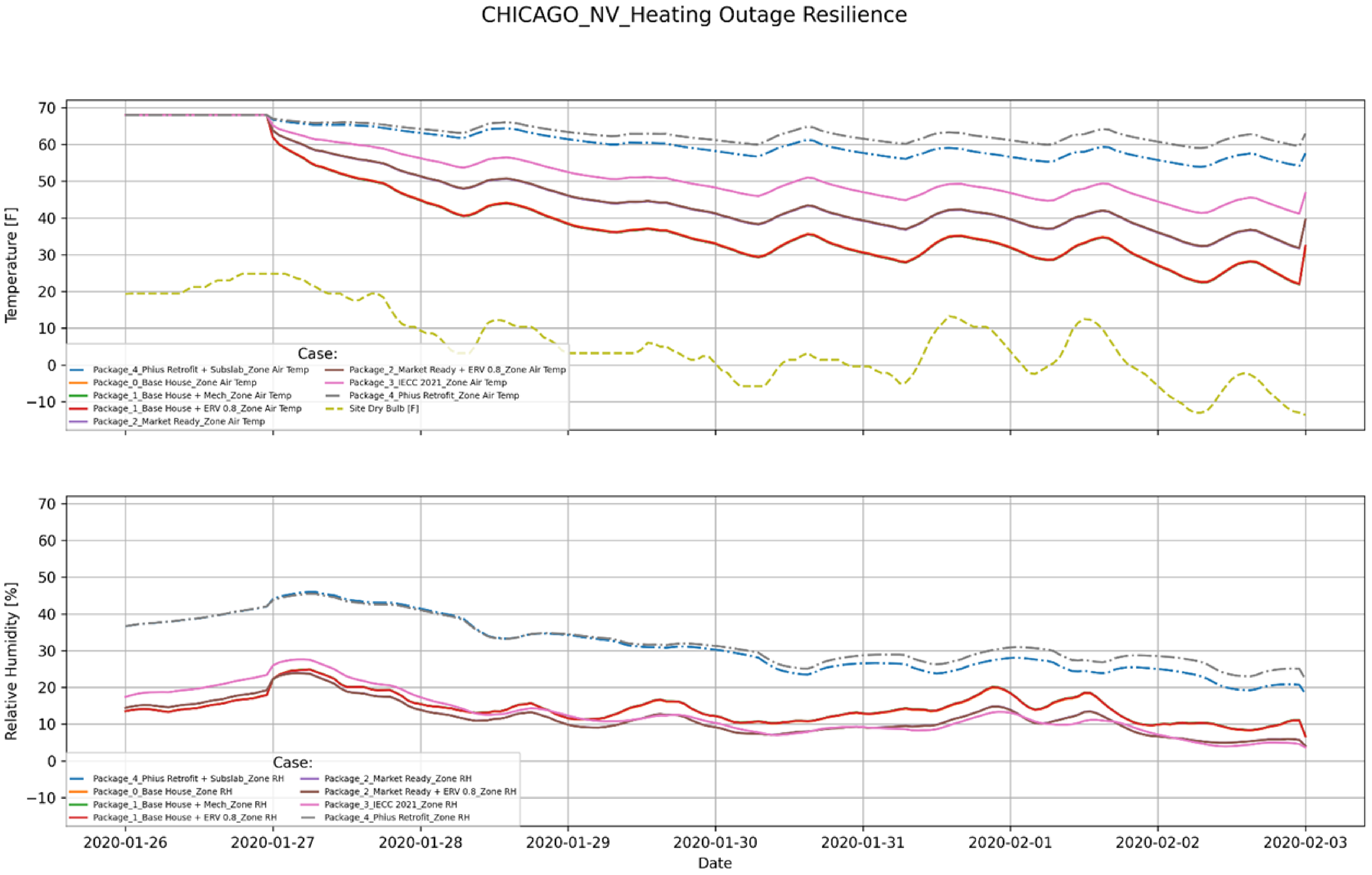
EC+Shd - evap cooler + ext. blinds

Current Results

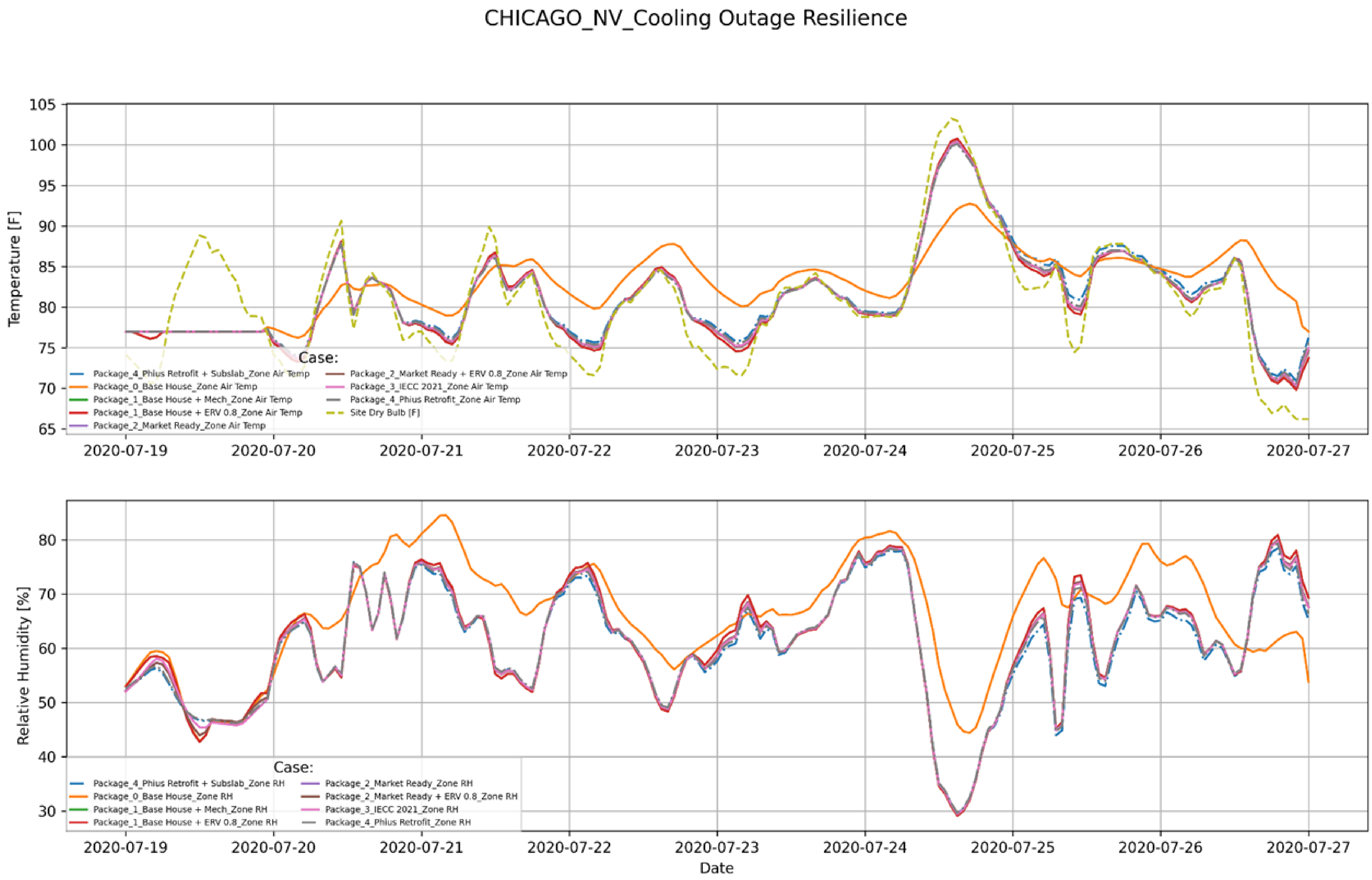
Chicago full results, additional at end of presentation

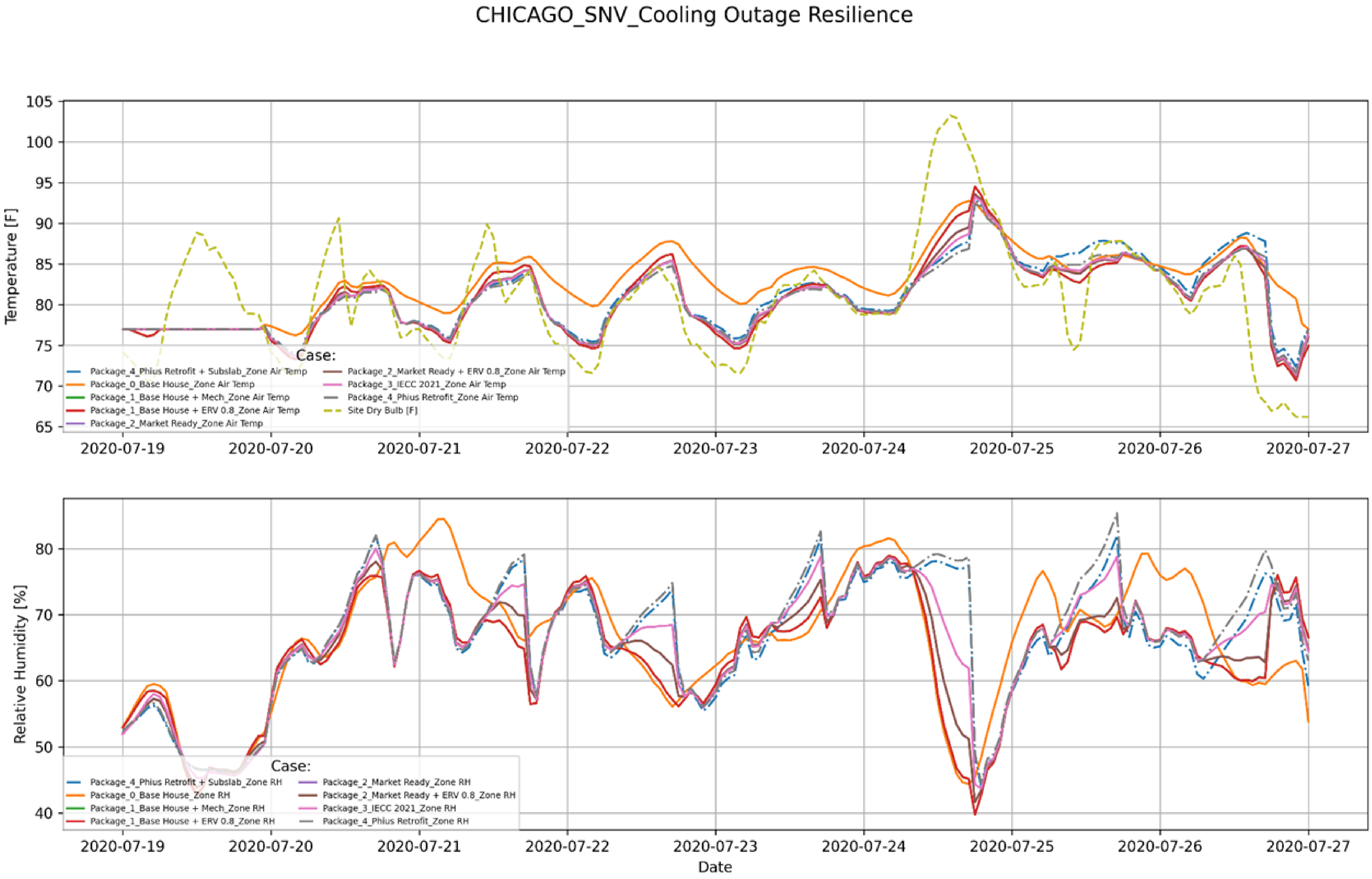
Tool Development



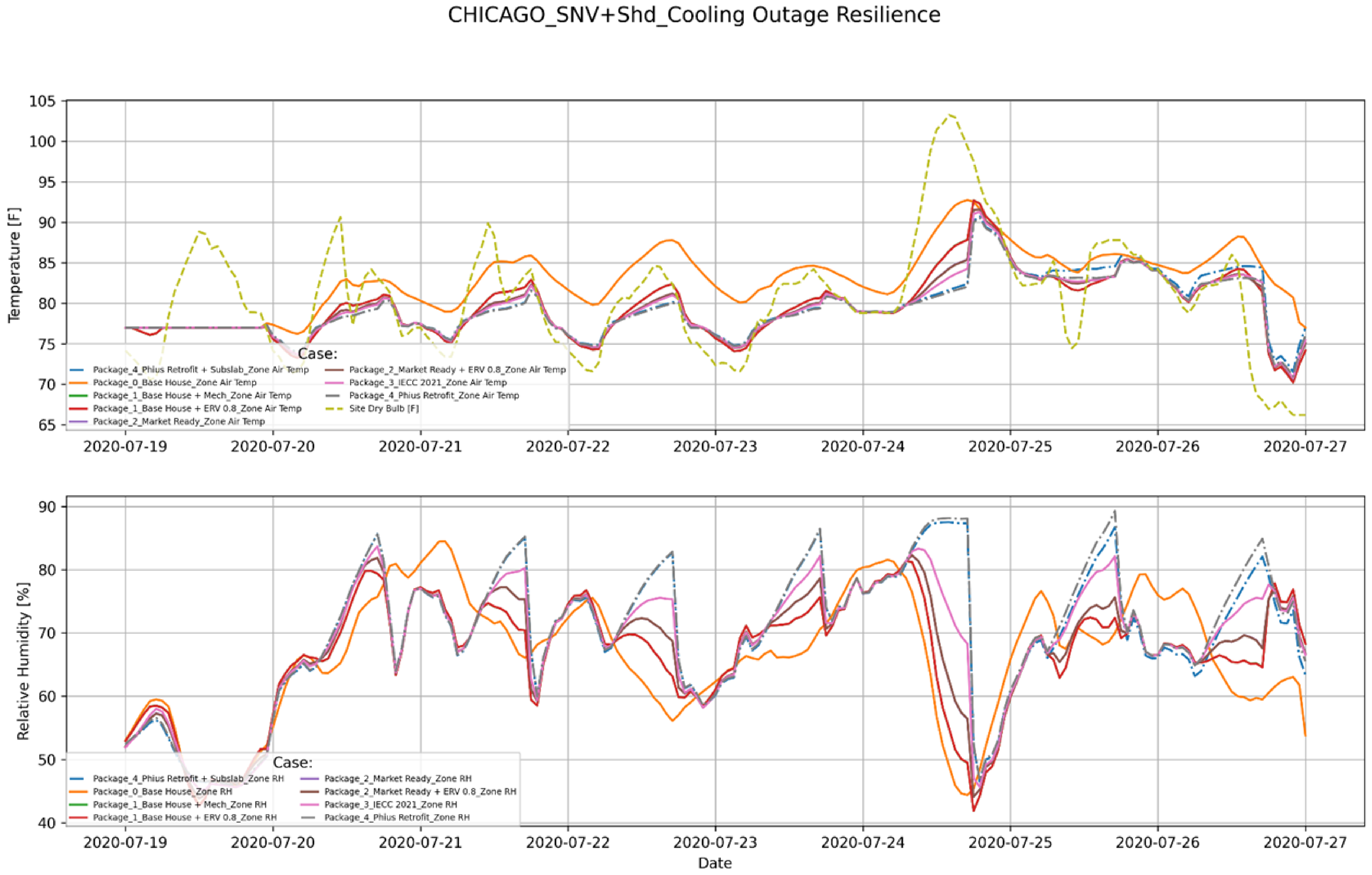


CHICAGO_NV_Heating Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date
2020-01-26
2020-01-27
2020-01-28
2020-01-29
2020-01-30
2020-01-31
2020-02-01
2020-02-02
2020-02-03


CHICAGO_NV_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27

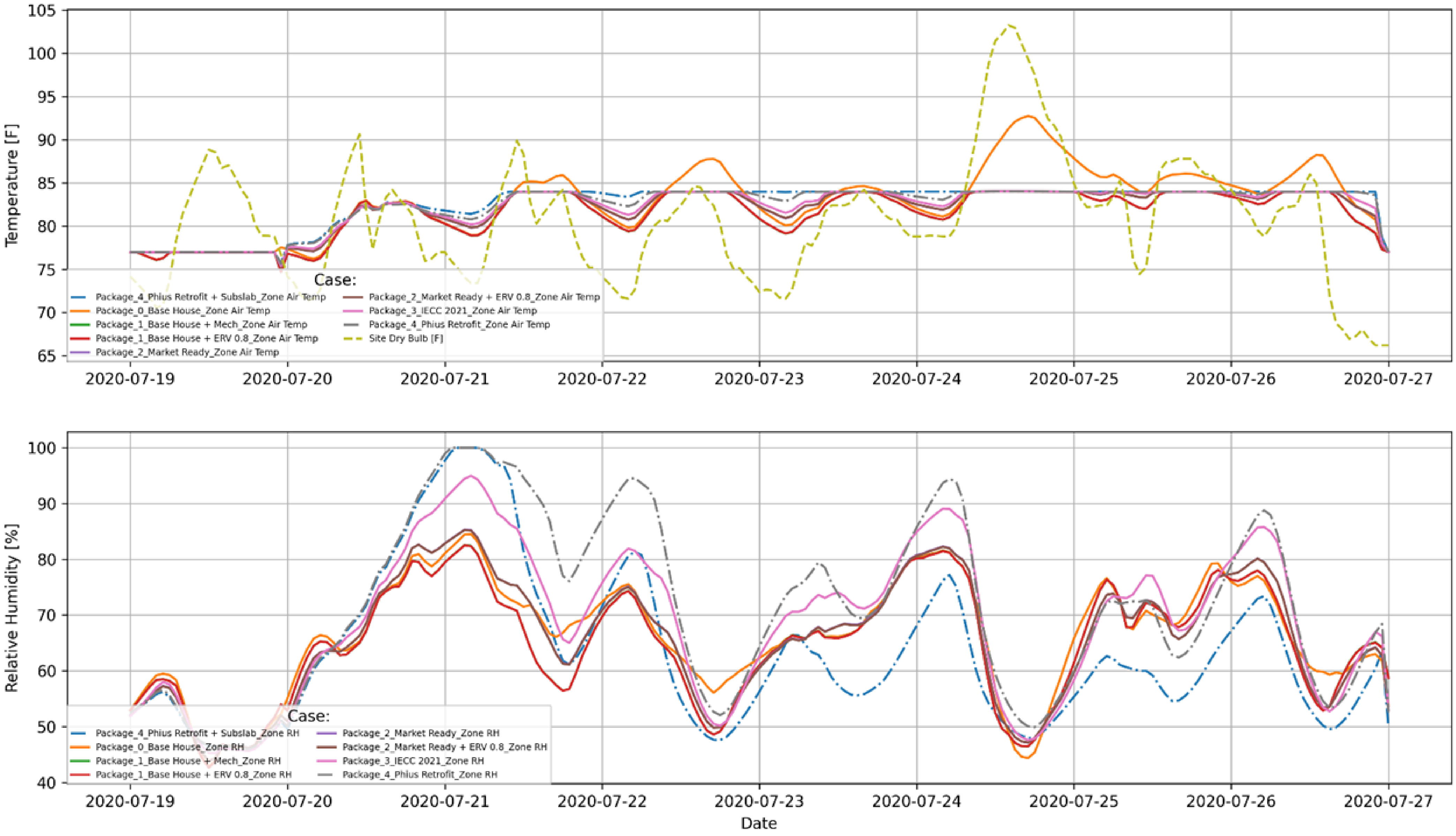


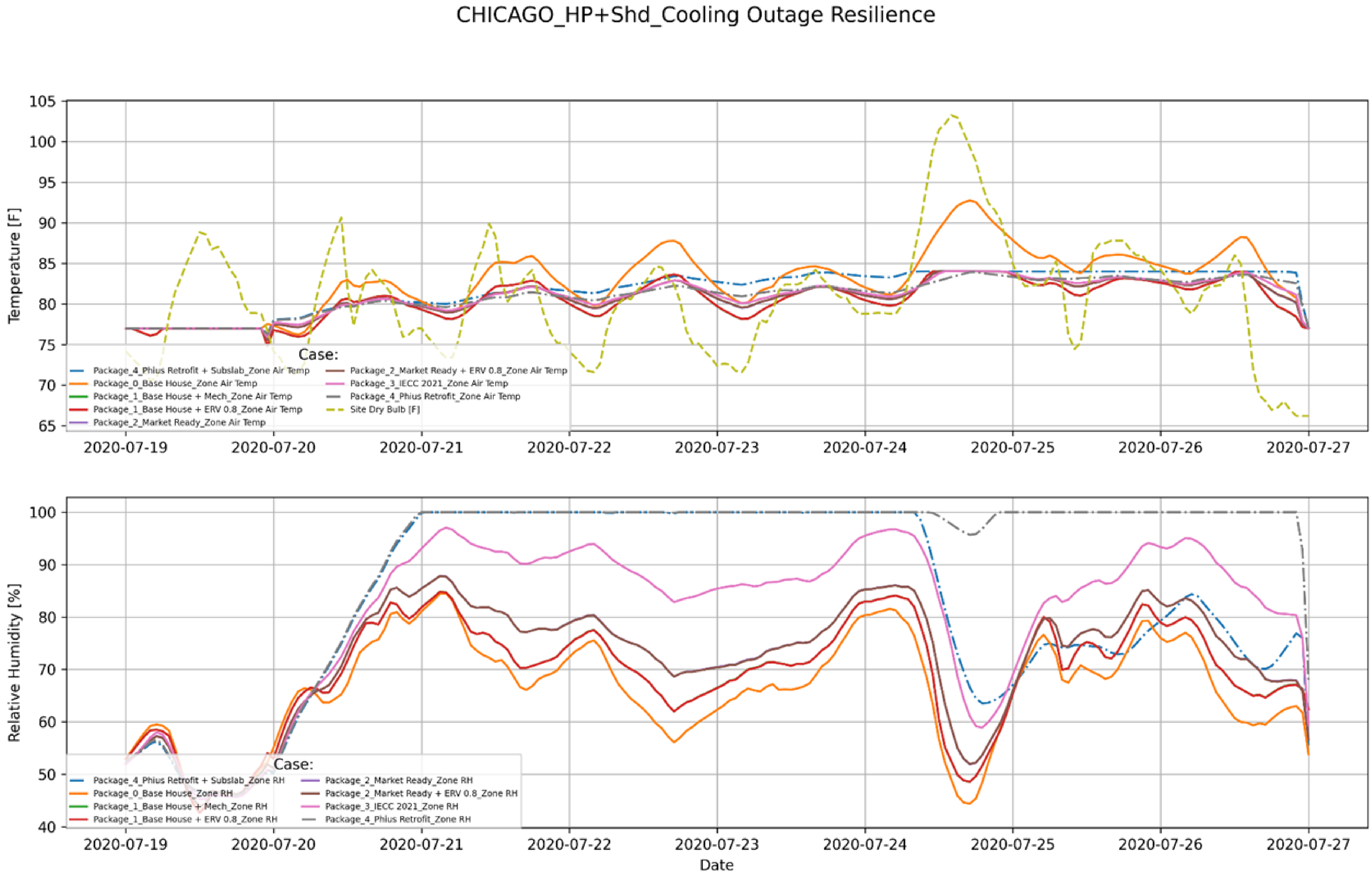
CHICAGO_SNV_Cooling Outage Resilience
Temperature [F]
105
100
95
90
85
80
75
70
65
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Relative Humidity [%]
80
70
60
50
40
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Date



CHICAGO_SNV+Shd_Cooling Outage Resilience
Temperature [F]
105
100
95
90
85
80
75
70
65
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Relative Humidity [%]
90
80
70
60
50
40
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

CHICAGO_HP_Cooling Outage Resilience




CHICAGO_HP+Shd_Cooling Outage Resilience
Temperature [F]
105
100
95
90
85
80
75
70
65
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Relative Humidity [%]
100
90
80
70
60
50
40
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Date

Single Point Metrics

Heating Set Hours (12.2°C)	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	0	0	0	0	0	0	0	0
EL PASO, TX	0	0	0	0	0	0	0	0
SEATTLE, WA	0	0	0	0	0	0	0	0
DENVER, CO	7	8	8	0	0	0	0	0
CHICAGO, IL	817	831	824	315	307	24	0	0
INTL FALLS, MN	1313	1326	1320	646	637	138	0	0

Single Point Metrics

Freezing hours (T<2°C)	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	0	0	0	0	0	0	0	0
EL PASO, TX	0	0	0	0	0	0	0	0
SEATTLE, WA	0	0	0	0	0	0	0	0
DENVER, CO	0	0	0	0	0	0	0	0
CHICAGO, IL	92	96	94	14	13	0	0	0
INTL FALLS, MN	151	151	151	71	67	0	0	0

Single Point Metrics

Natural Ventilation - Extreme Caution	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	119	97	97	98	99	99	104	115
EL PASO, TX	36	8	8	6	6	12	6	12
SEATTLE, WA	0	0	0	0	0	0	0	0
DENVER, CO	0	3	3	2	2	2	1	2
CHICAGO, IL	89	31	31	33	33	33	34	37
INTL FALLS, MN	18	0	0	0	0	0	0	0

Single Point Metrics

Natural Ventilation -Caution	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	13	57	57	61	61	68	95	104
EL PASO, TX	115	89	89	91	92	88	92	88
SEATTLE, WA	28	13	13	13	13	13	13	15
DENVER, CO	101	53	53	54	54	54	54	54
CHICAGO, IL	70	80	80	80	80	80	80	77
INTL FALLS, MN	78	44	44	44	44	44	42	42

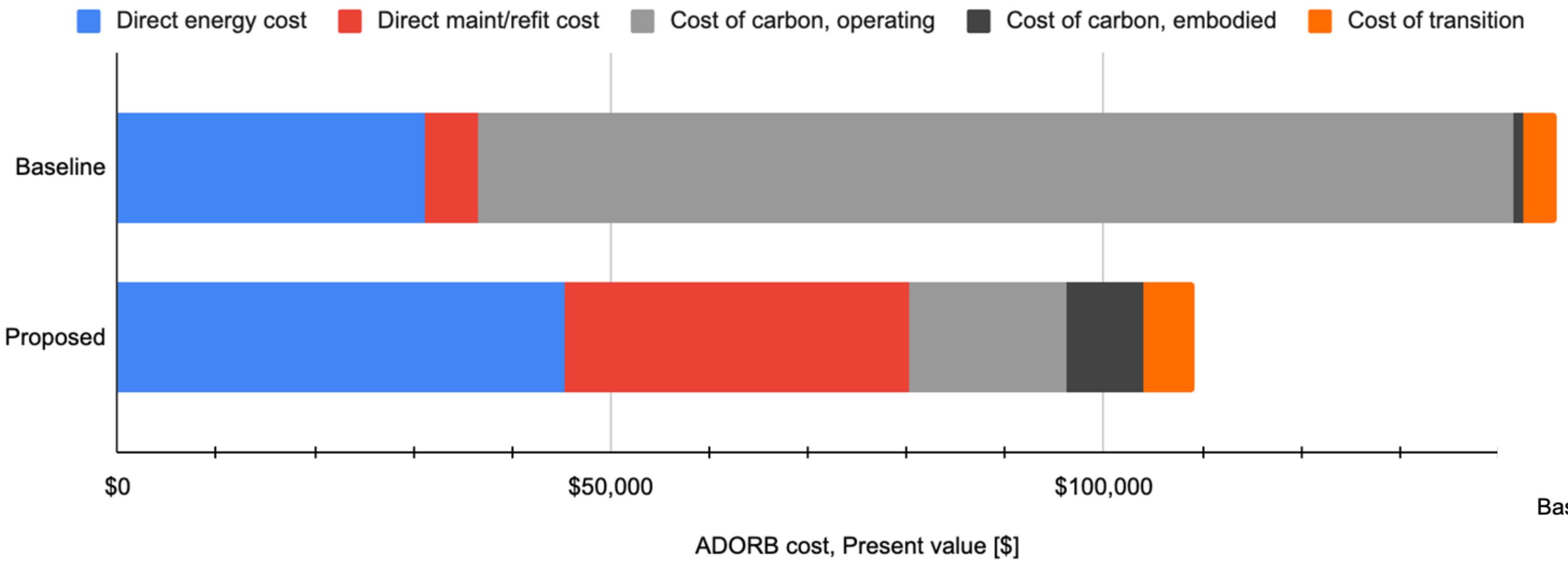
Single Point Metrics

Scheduled Natural Ventilation - Extreme Caution	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	119	87.5	87.5	87.83	88	72.5	76	79.83
EL PASO, TX	36.17	1.33	1.33	0	0	24.83	10.33	26.17
SEATTLE, WA	0	0	0	0	0	0	0	0
DENVER, CO	0	3	3	2.33	2.33	2.33	1.33	2
CHICAGO, IL	89.17	40.17	40.17	40.83	41	48.83	48.33	51.17
INTL FALLS, MN	18.17	0	0	0	0	2	2	0.83

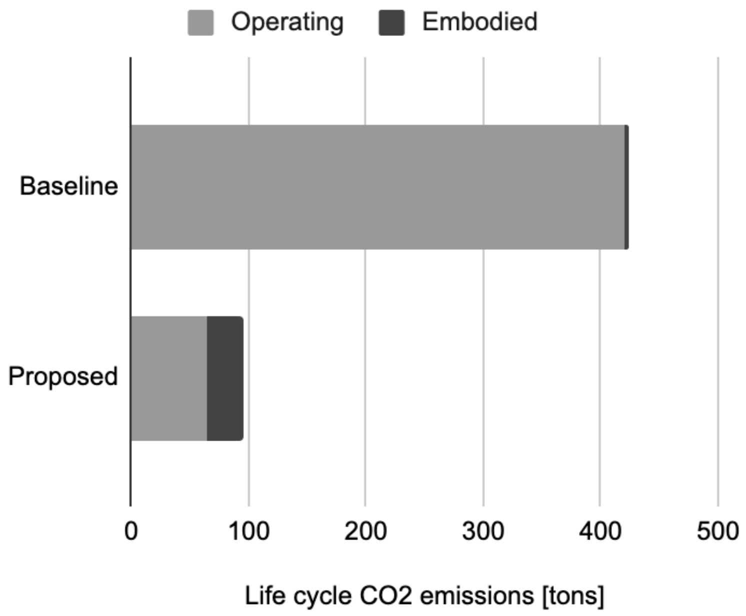
Single Point Metrics

Scheduled Natural Ventilation -Caution	Package_0 Base House	Package_1 Base House + Mech	Package_1 Base House + ERV 0.8	Package_2 Market Ready	Package_2 Market Ready + ERV 0.8	Package_3 IECC 2021	Package_4 Phius Retrofit	Package_4 Phius Retrofit + Subslab
MIAMI, FL	13.33	63.17	63.17	68.17	68.67	75.17	103.83	106.5
EL PASO, TX	114.5	97	97.17	98.67	98.67	76.83	90	75.67
SEATTLE, WA	28	7.5	7.33	4.67	4.67	5	4.83	8.33
DENVER, CO	100.67	53	53	53.67	53.67	53.83	53.83	54.33
CHICAGO, IL	69.83	76	76	75.67	75.5	67.67	69.67	60.83
INTL FALLS, MN	78	34.83	34.83	33.83	33.83	32.5	32.67	31.83

ADORB Cost Example: Electrification of Apartment in Portland, OR

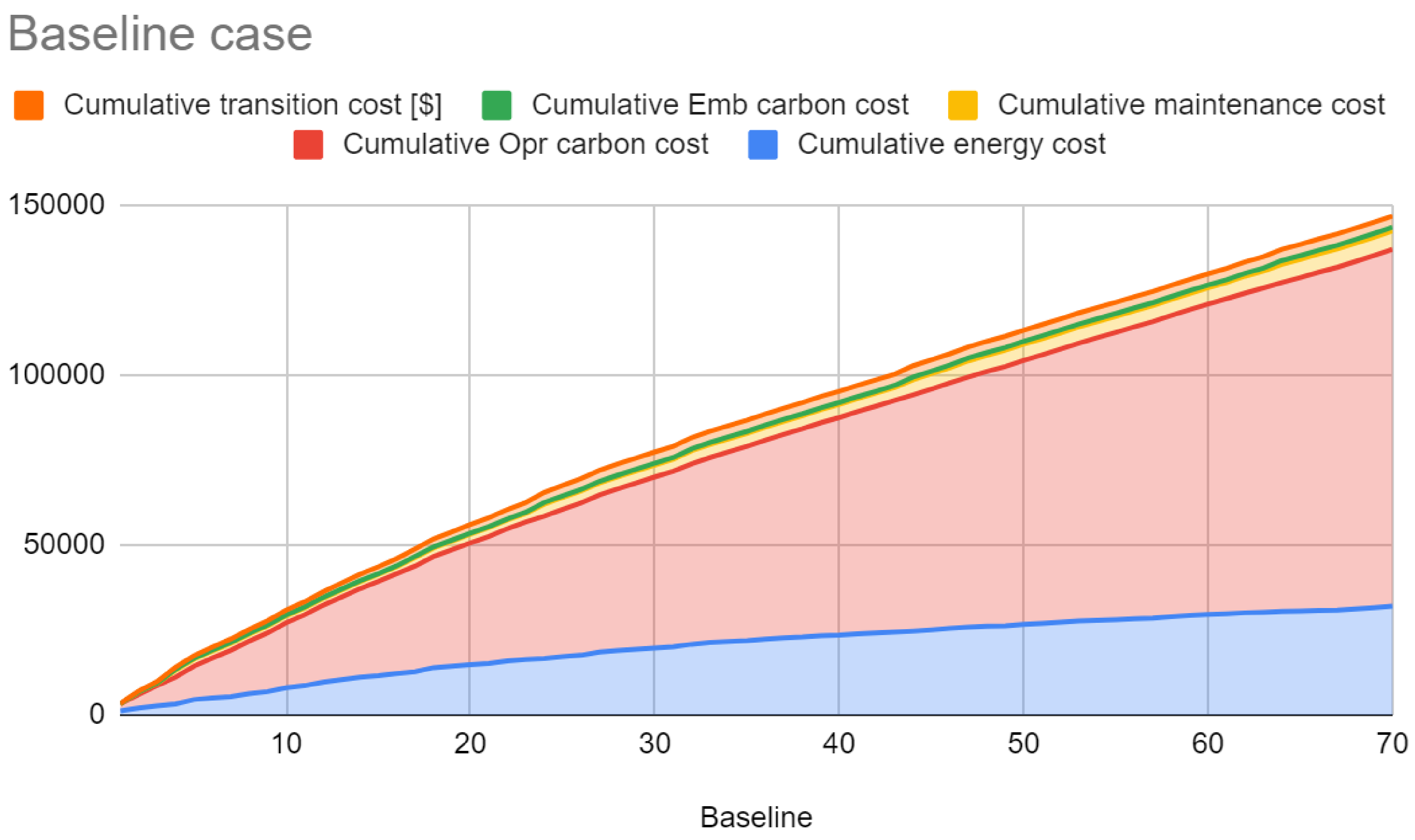


Summary, CO2 emissions [tons]			
	Baseline	Proposed	change
Operating	420	64	-85%
Embodied	4	31	612%
	424	95	-78%

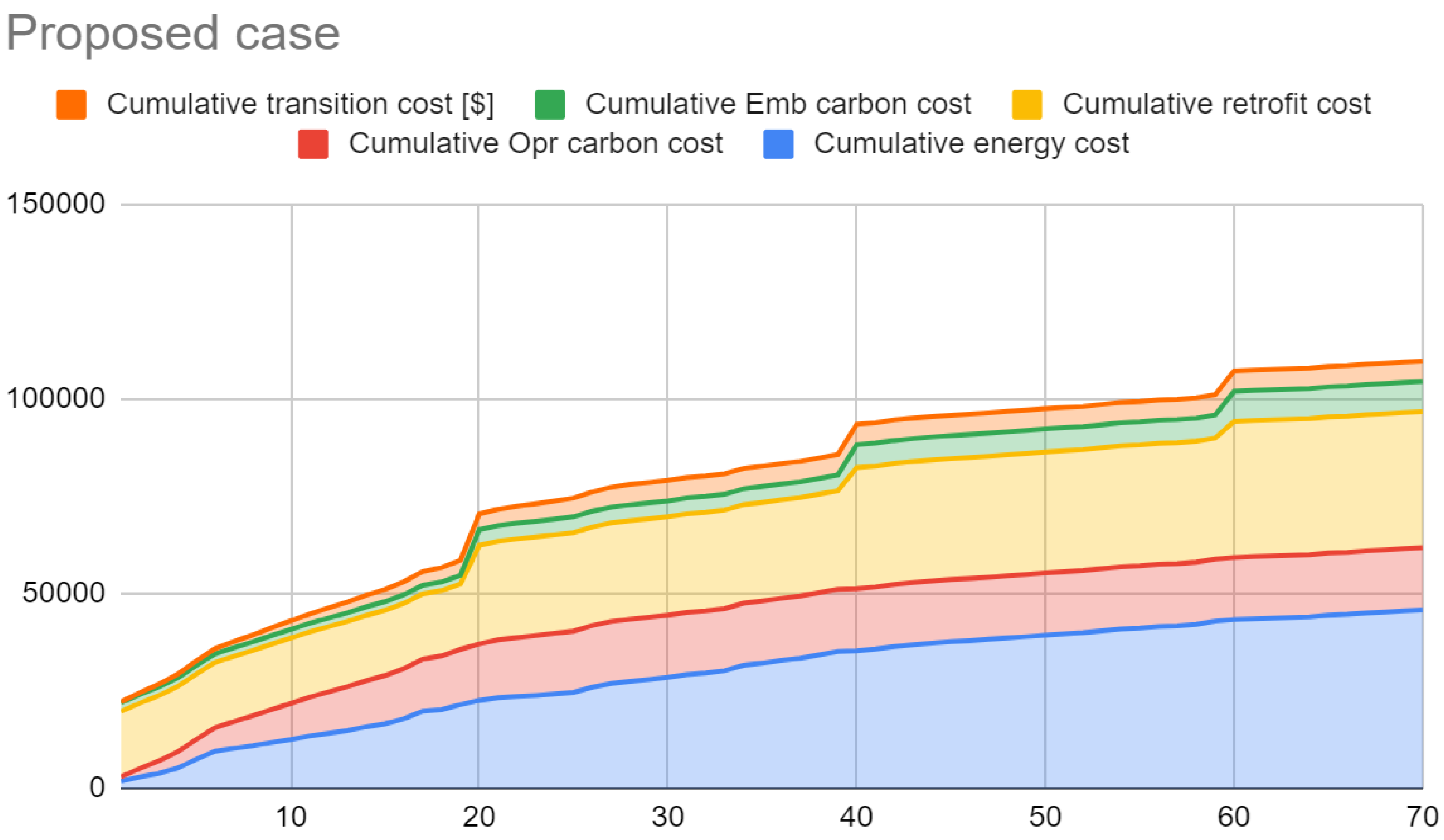


Time horizon [years]	70		
Grid decarb date (1)	2050		
emission factor.			
Summary, present values [$]			
	Baseline	**Proposed**	**change**
Direct energy cost	$31,137	$45,397	46%
Direct maint/refit cost	$5,394	$34,934	548%
Cost of carbon, operating	$104,926	$15,958	-85%
Cost of carbon, embodied	$1,088	$7,743	612%
Cost of transition	$3,310	$5,236	58%
	$145,854	$109,267	-25%

Lifecycle Cost



Lifecycle Cost



Questions?

Graham Wright, PhD
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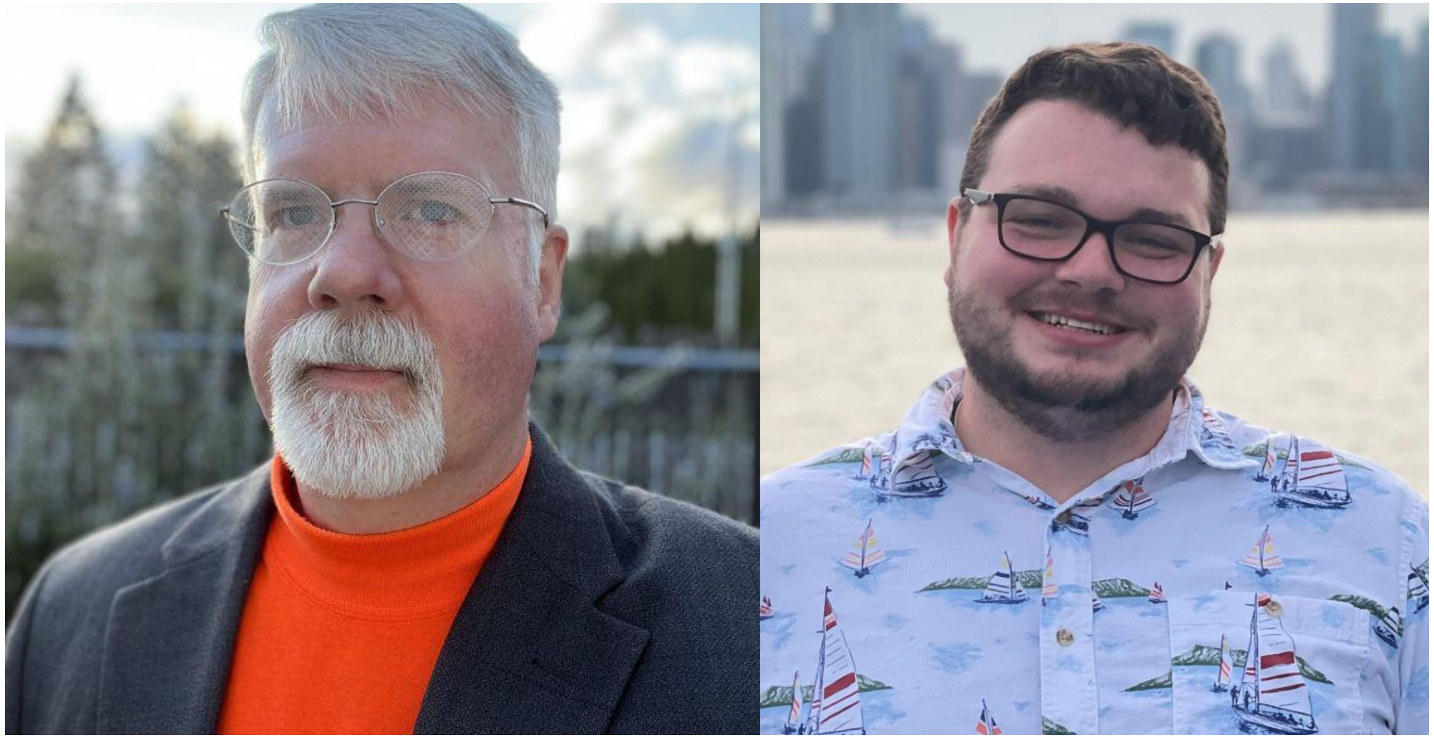
Al Mitchell, EIT, CPHC
Technical Staff, Phius
amitchell@phius.org



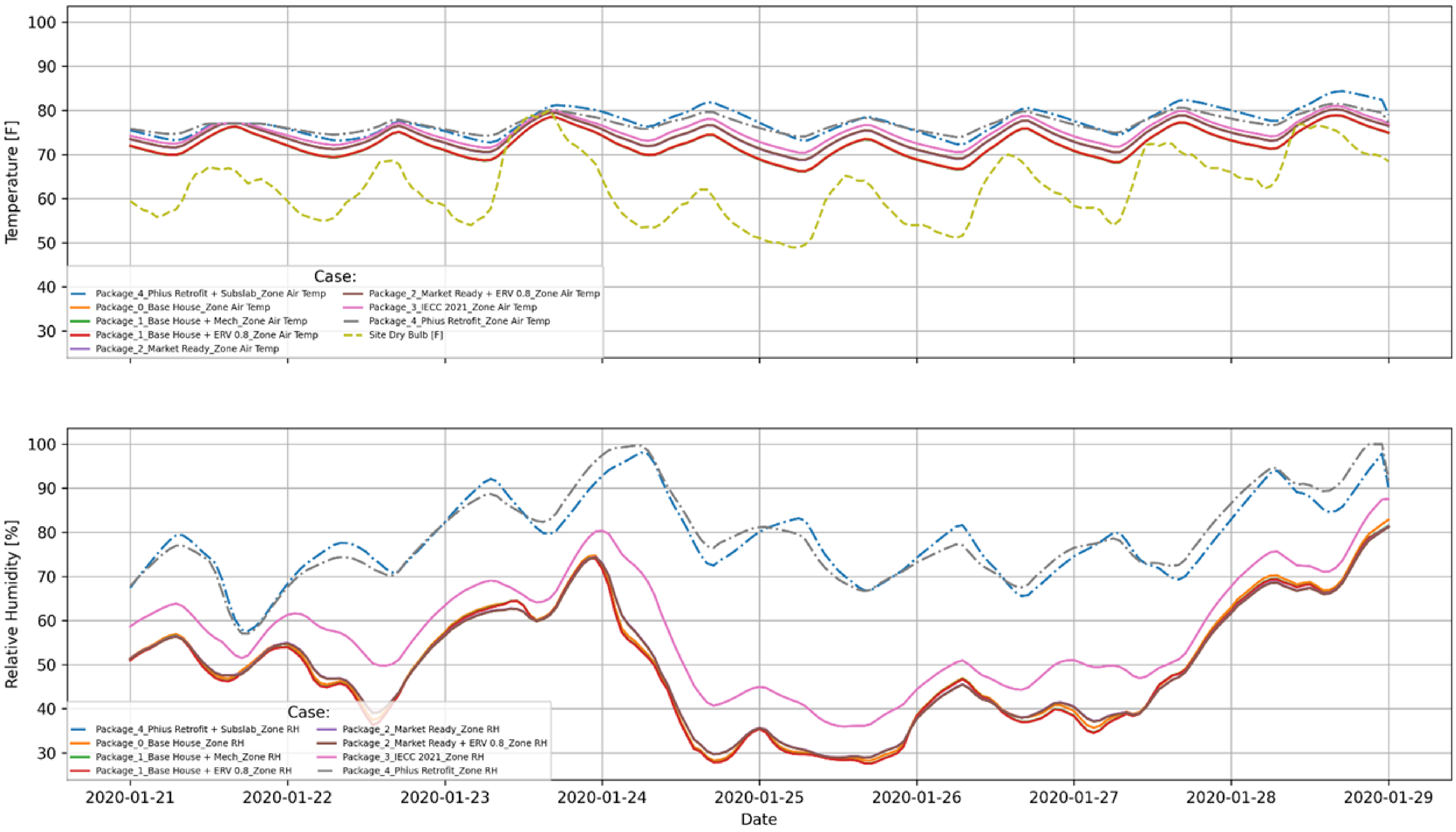
Appendix

Full graph results for:

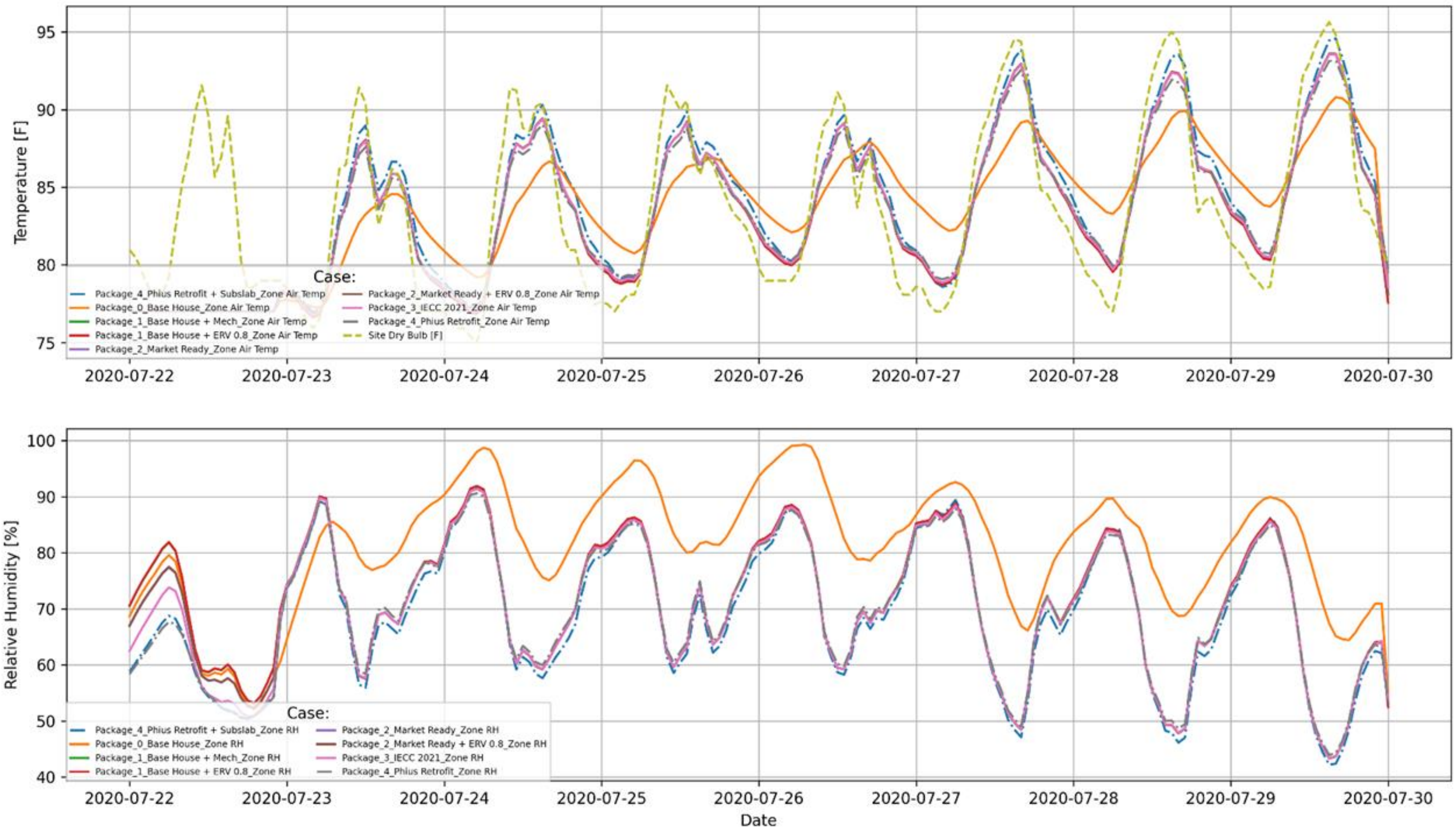
- Miami, FL
- El Paso, TX
- Seattle, WA
- Denver, CO
- International Falls, MN

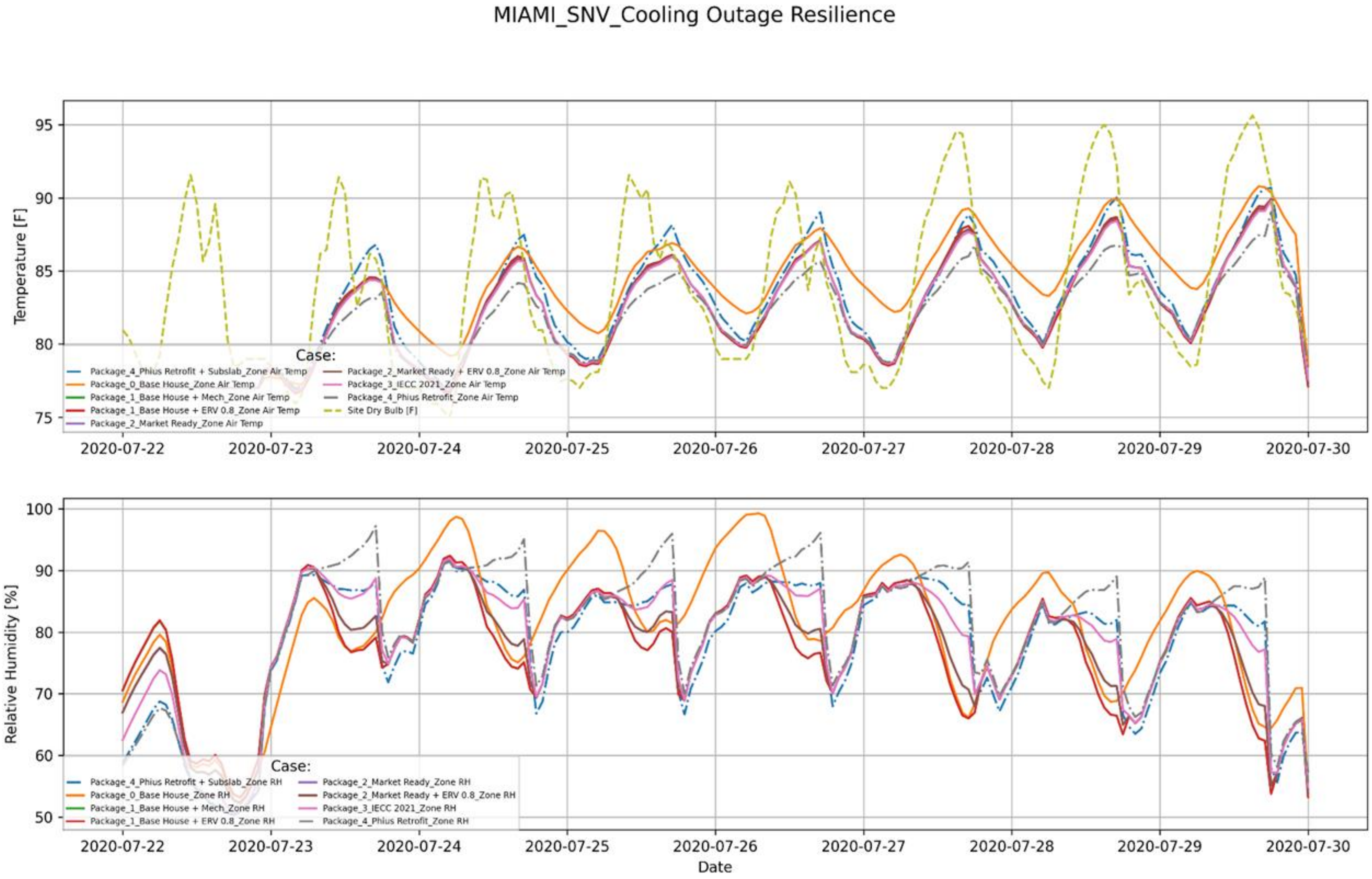
Miami, FL

MIAMI_NV_Heating Outage Resilience



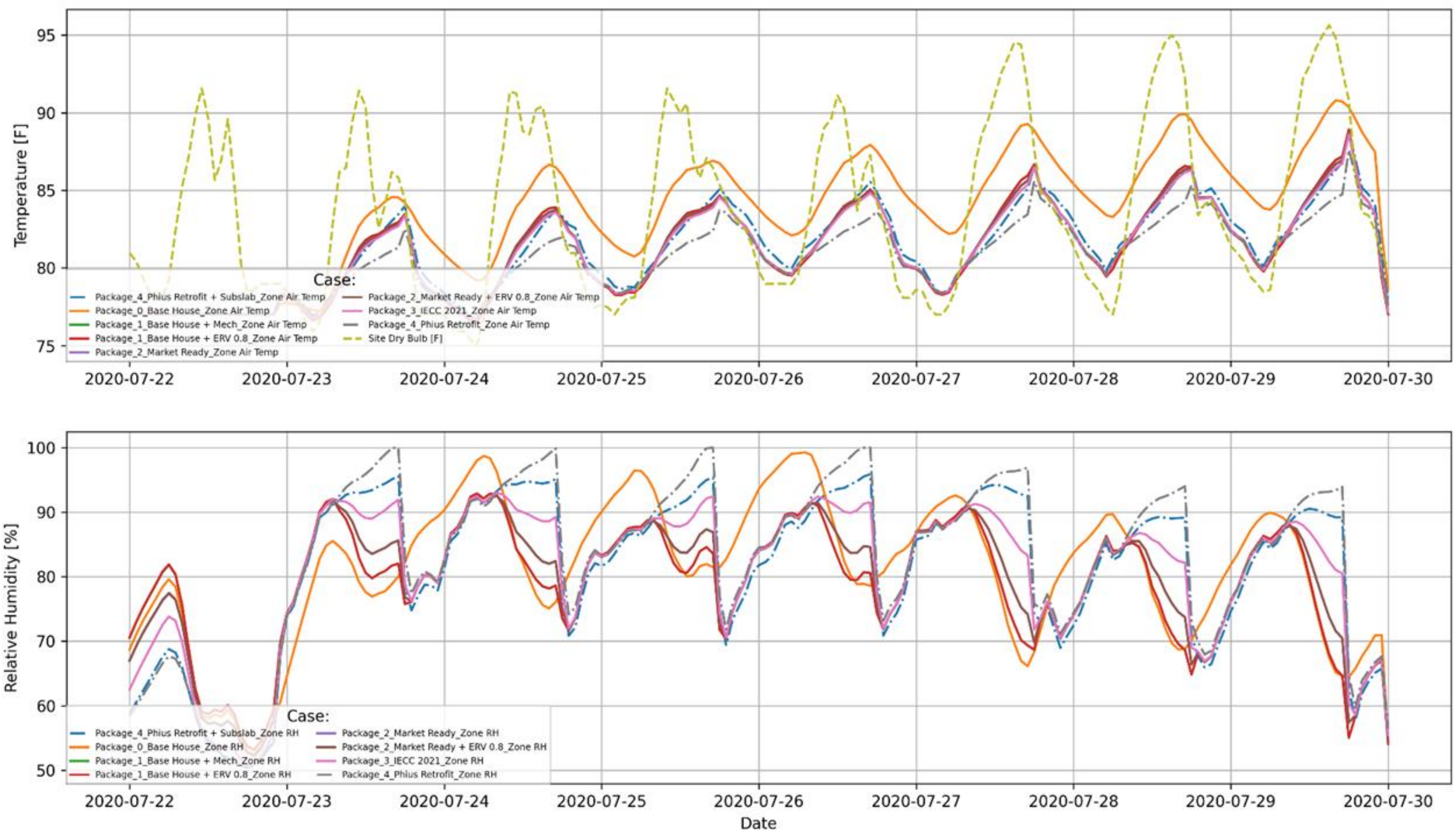
MIAMI_NV_Cooling Outage Resilience

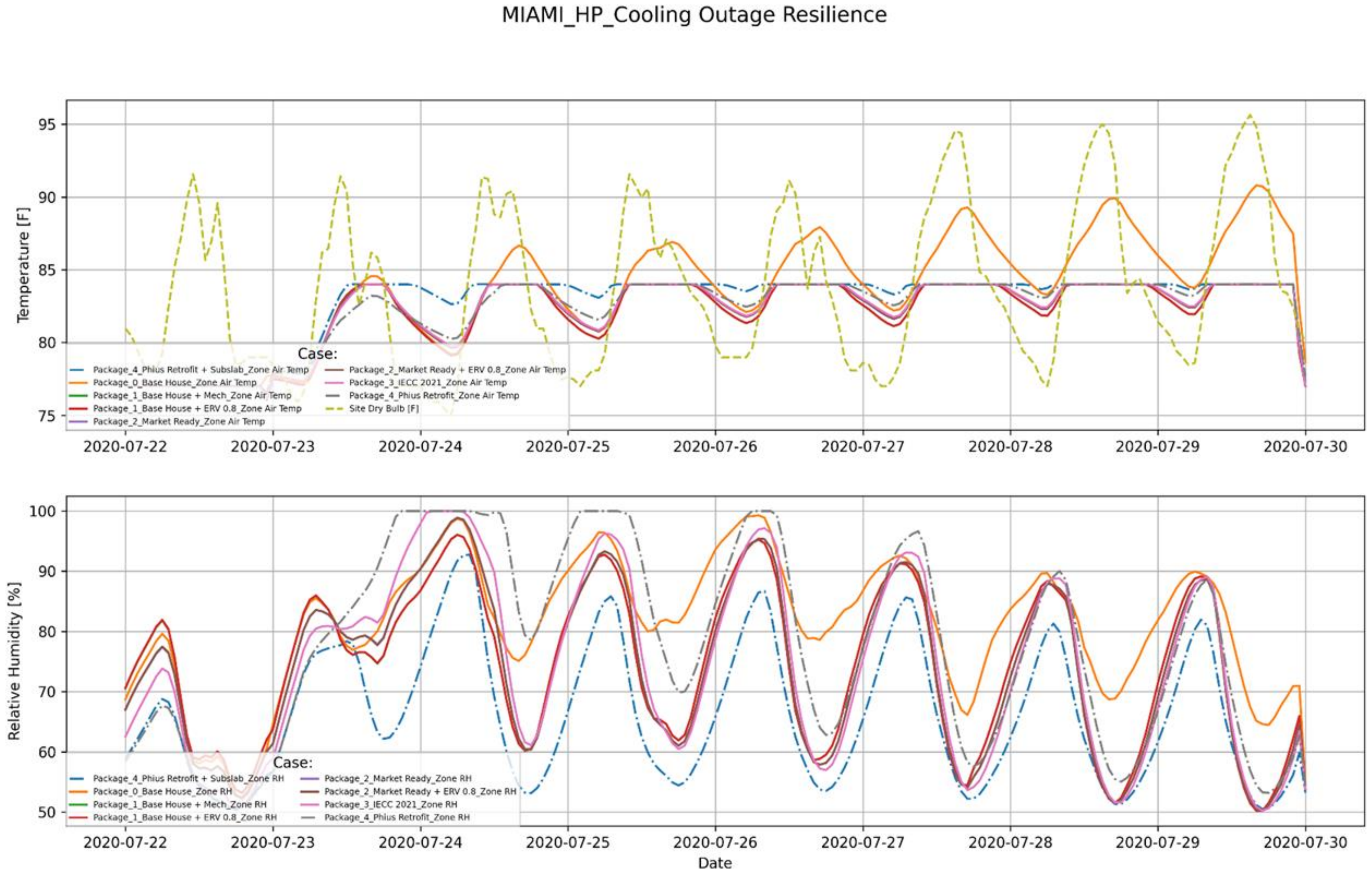




MIAMI_SNV_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
2020-07-28
2020-07-29
2020-07-30
Date

MIAMI_SNV+Shd_Cooling Outage Resilience





MIAMI_HP_Cooling Outage Resilience
Temperature [F]
95
90
85
80
75
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
2020-07-28
2020-07-29
2020-07-30
Relative Humidity [%]
100
90
80
70
60
50
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
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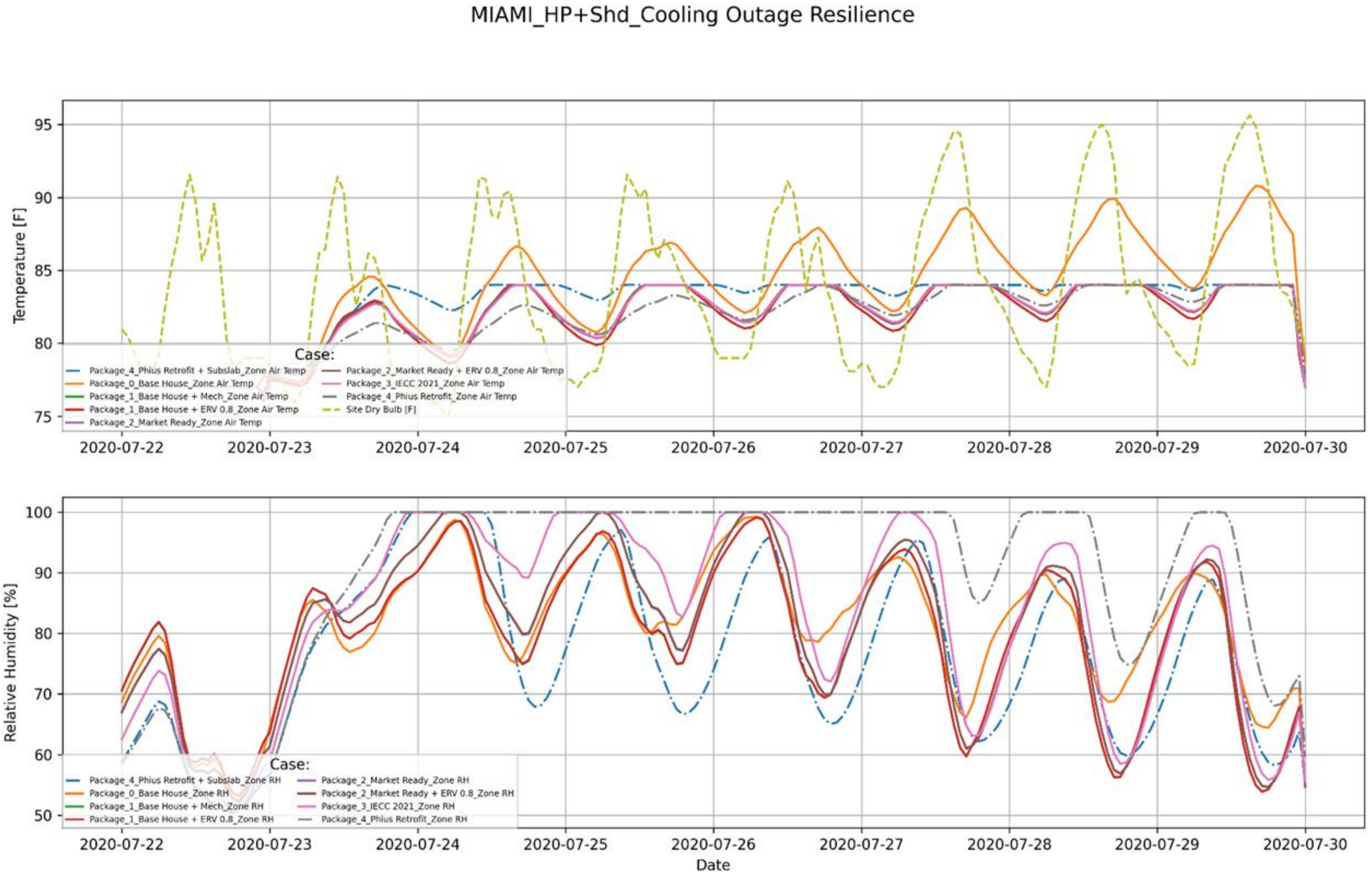
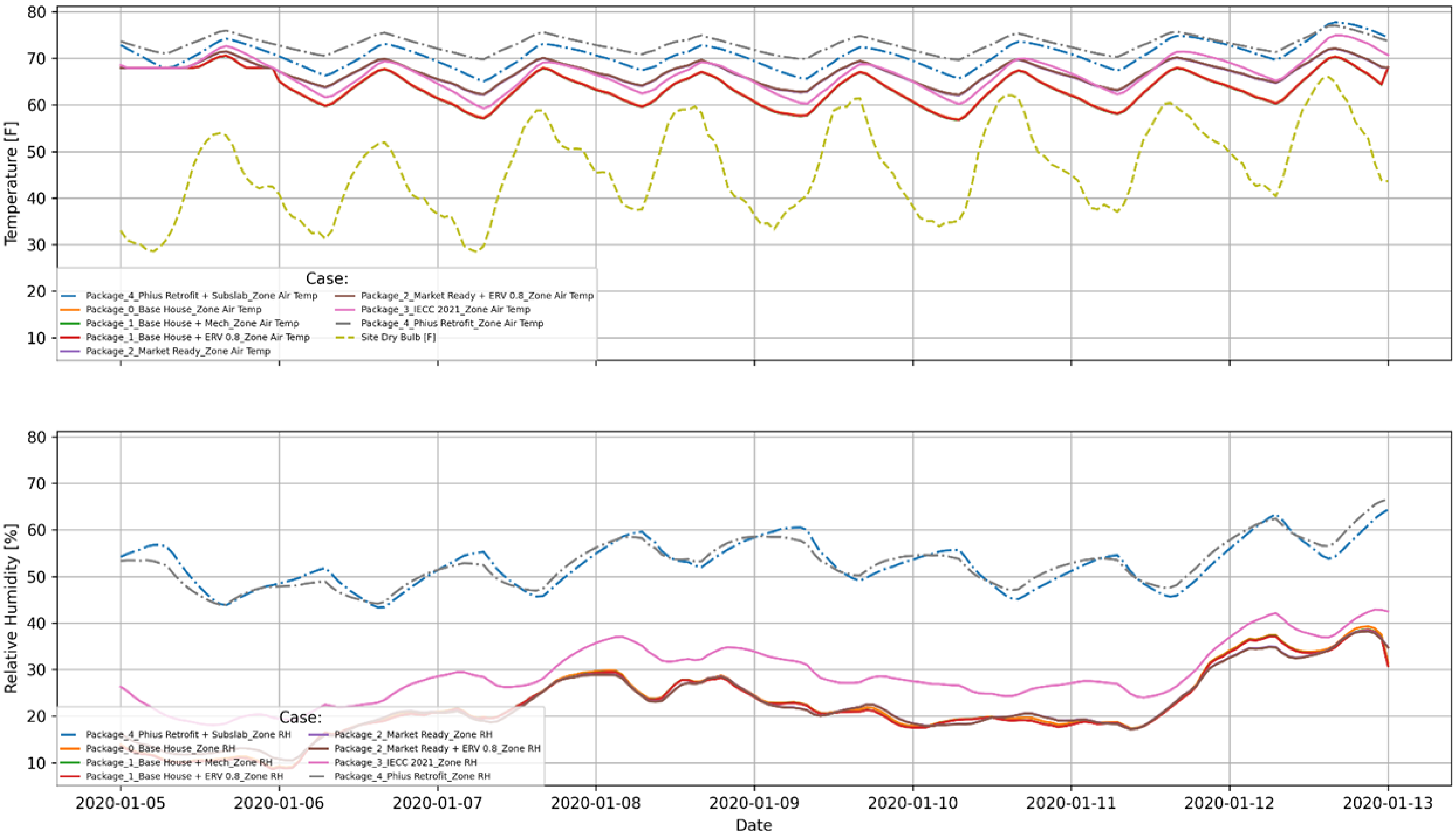
2020-07-28
2020-07-29
2020-07-30
Date

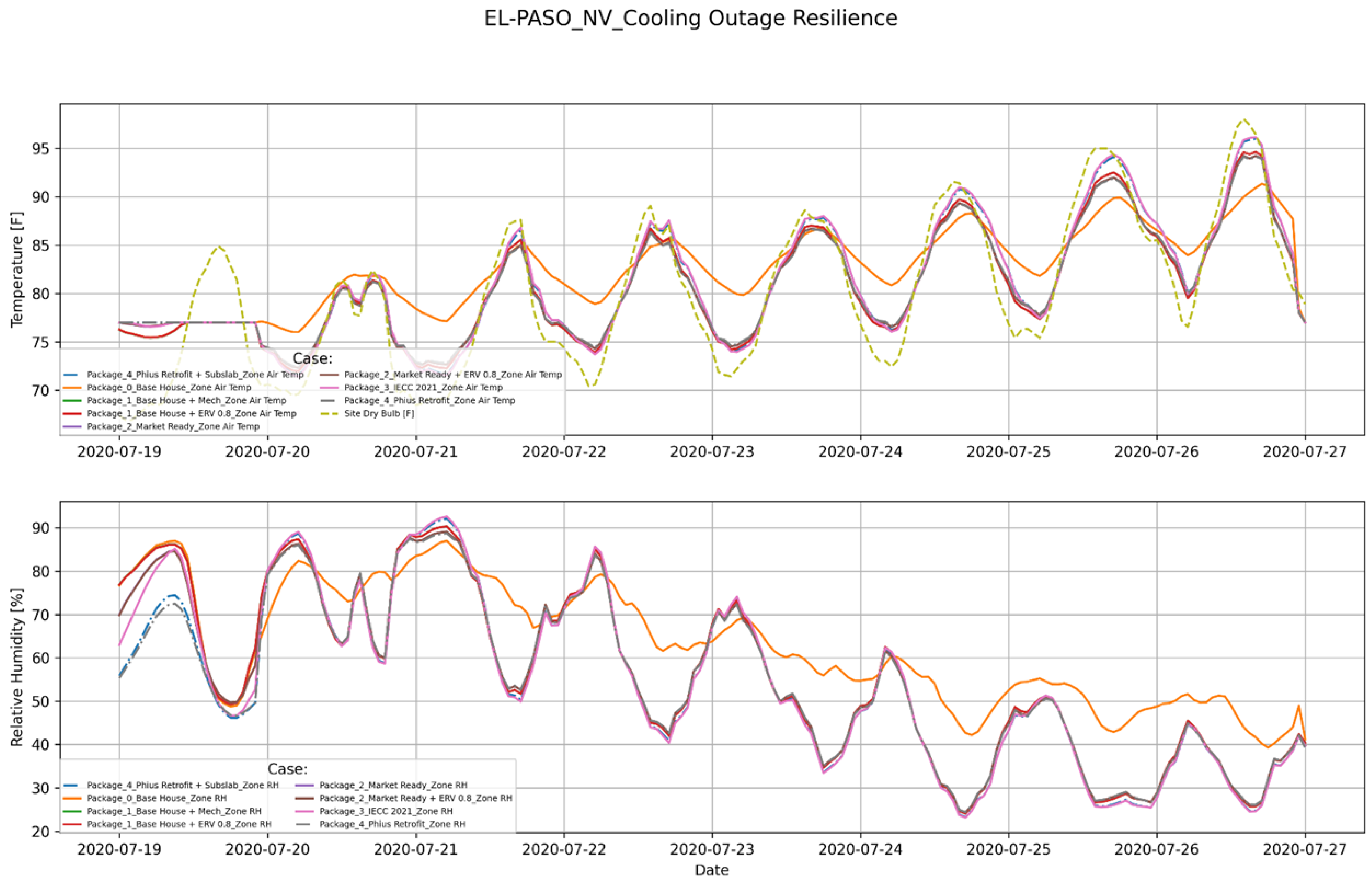


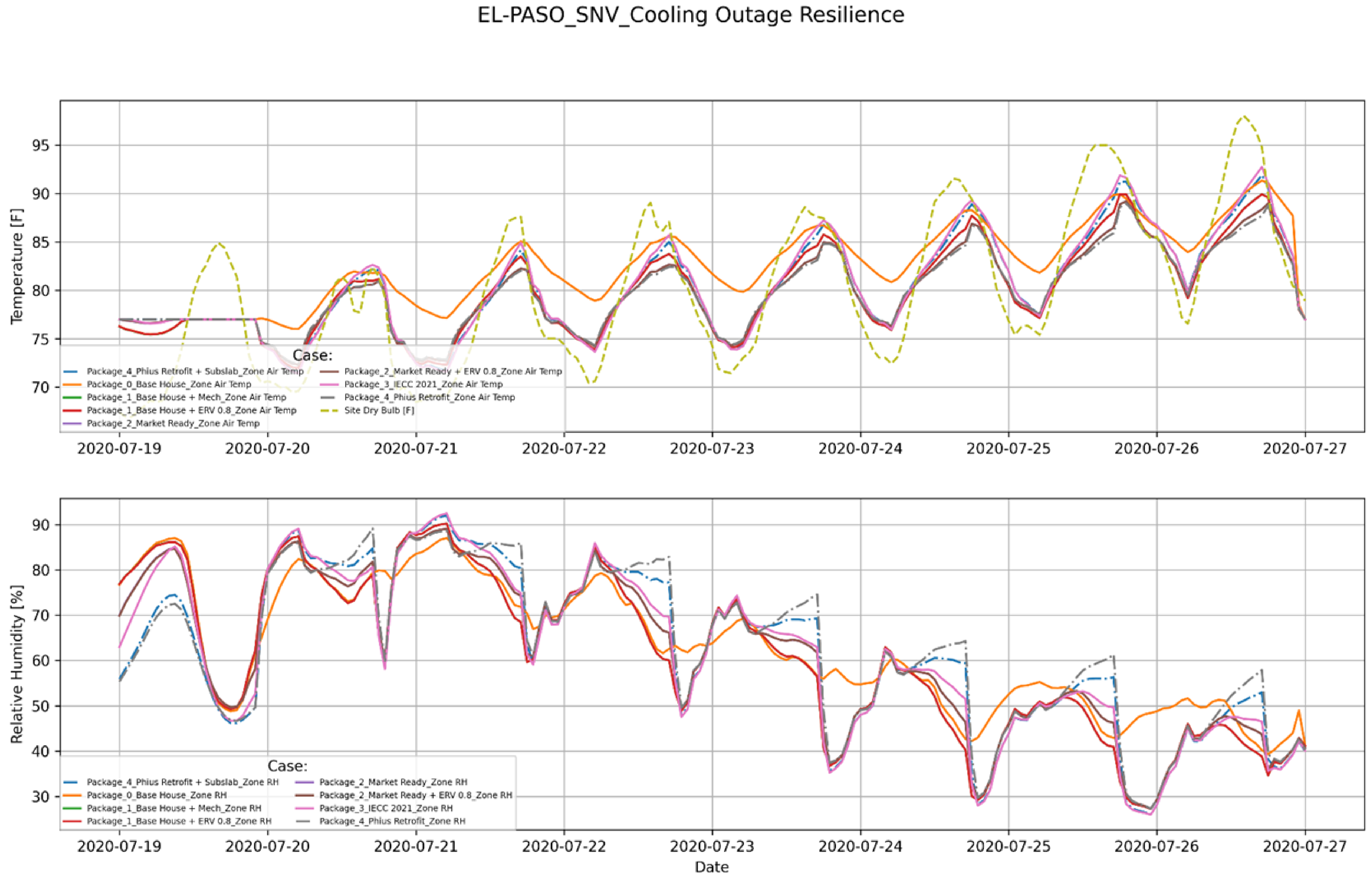
MIAMI_HP+Shd_Cooling Outage Resilience
Temperature [F]
95
90
85
80
75
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
2020-07-28
2020-07-29
2020-07-30
Relative Humidity [%]
100
90
80
70
60
50
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
2020-07-28
2020-07-29
2020-07-30
Date

El Paso, TX

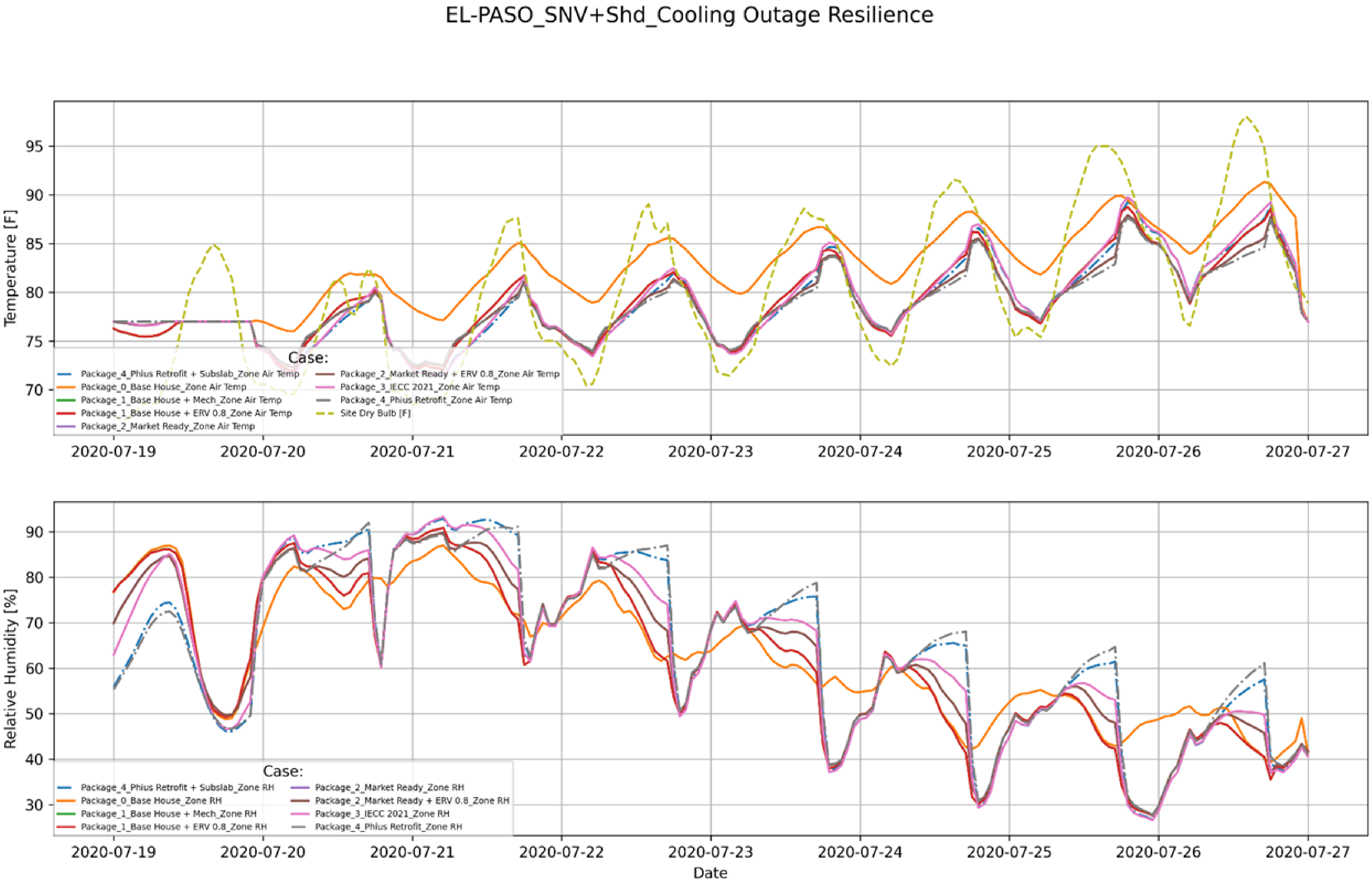
EL-PASO_NV_Heating Outage Resilience



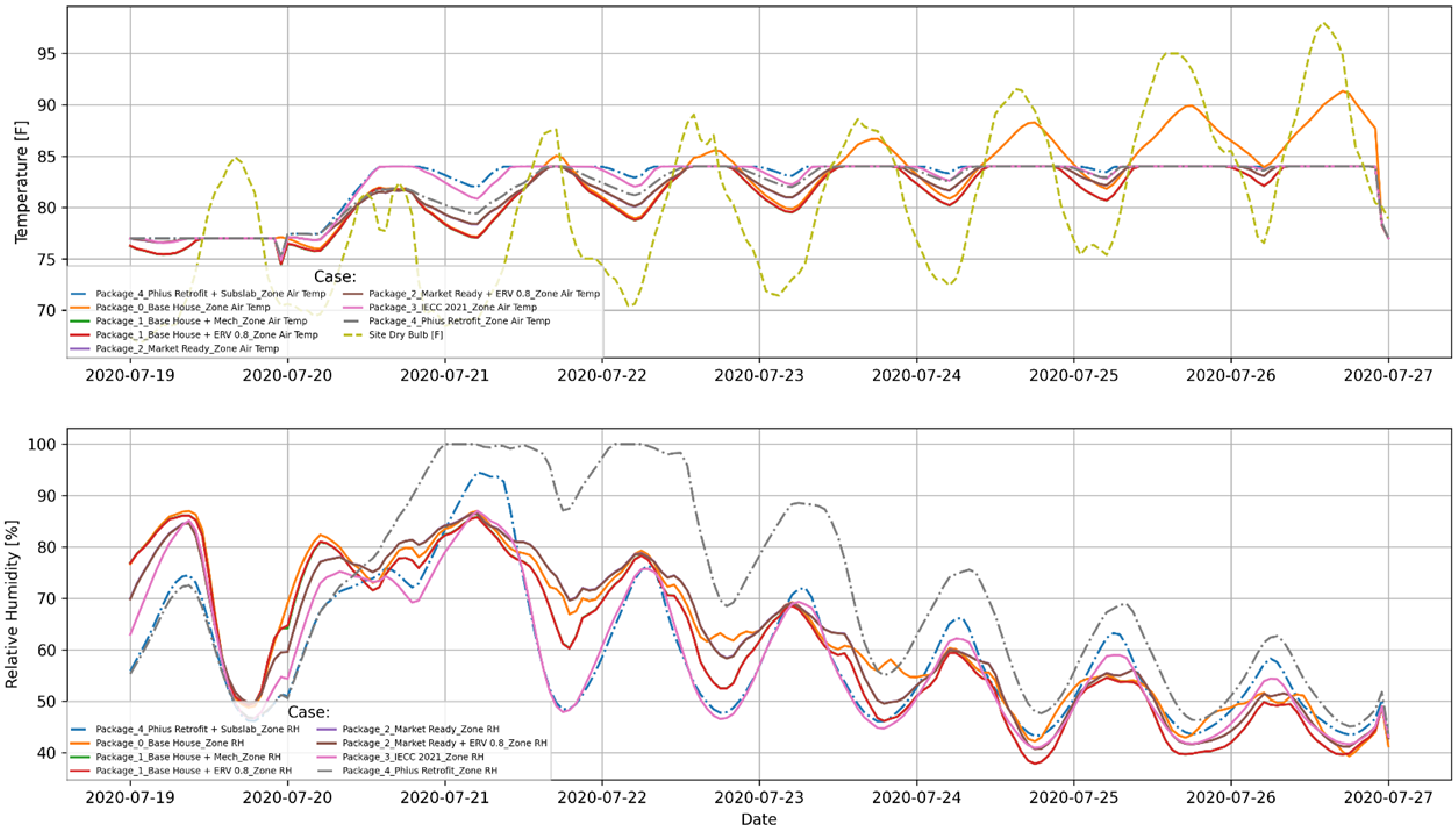

EL-PASO_NV_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

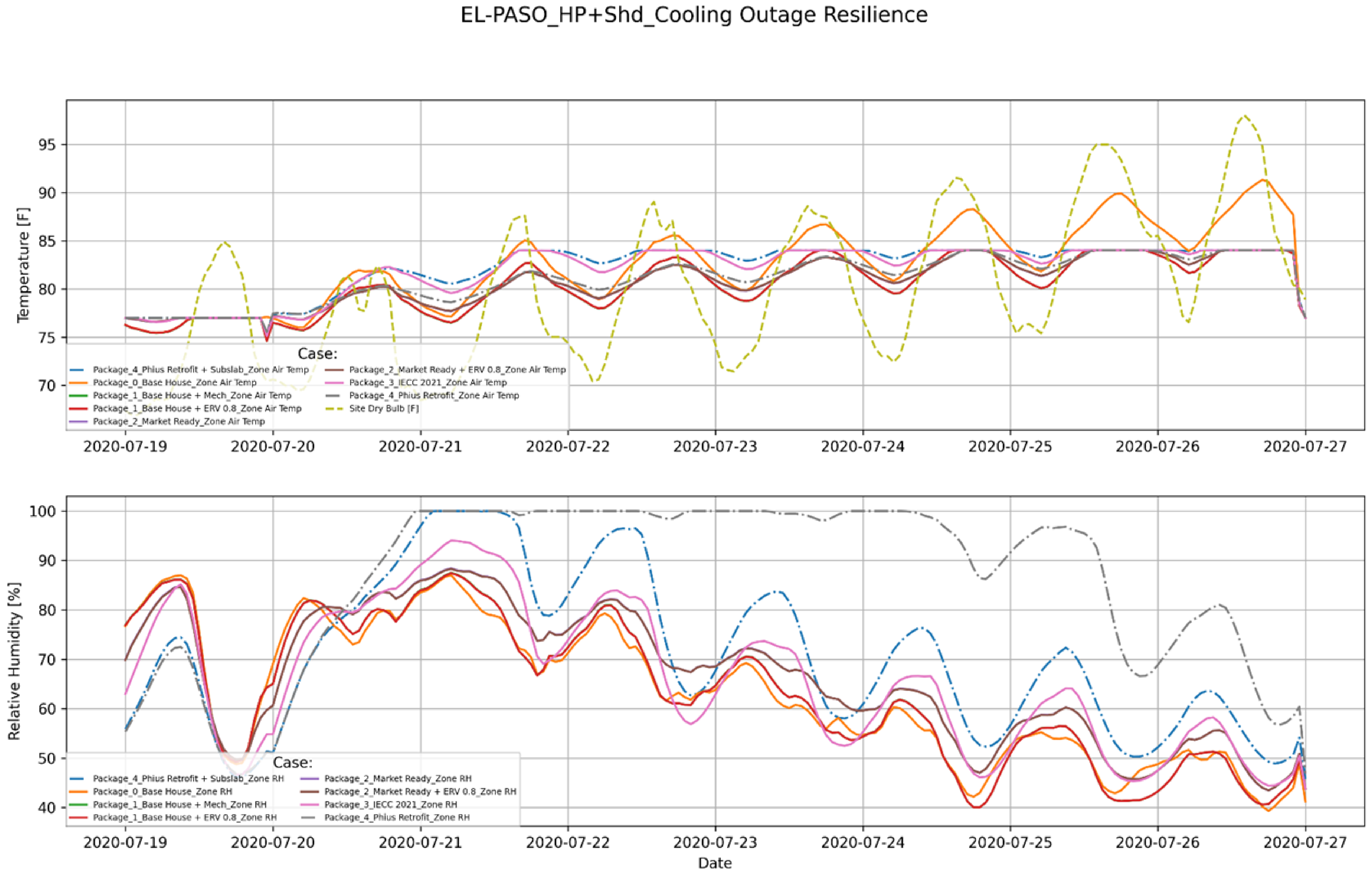


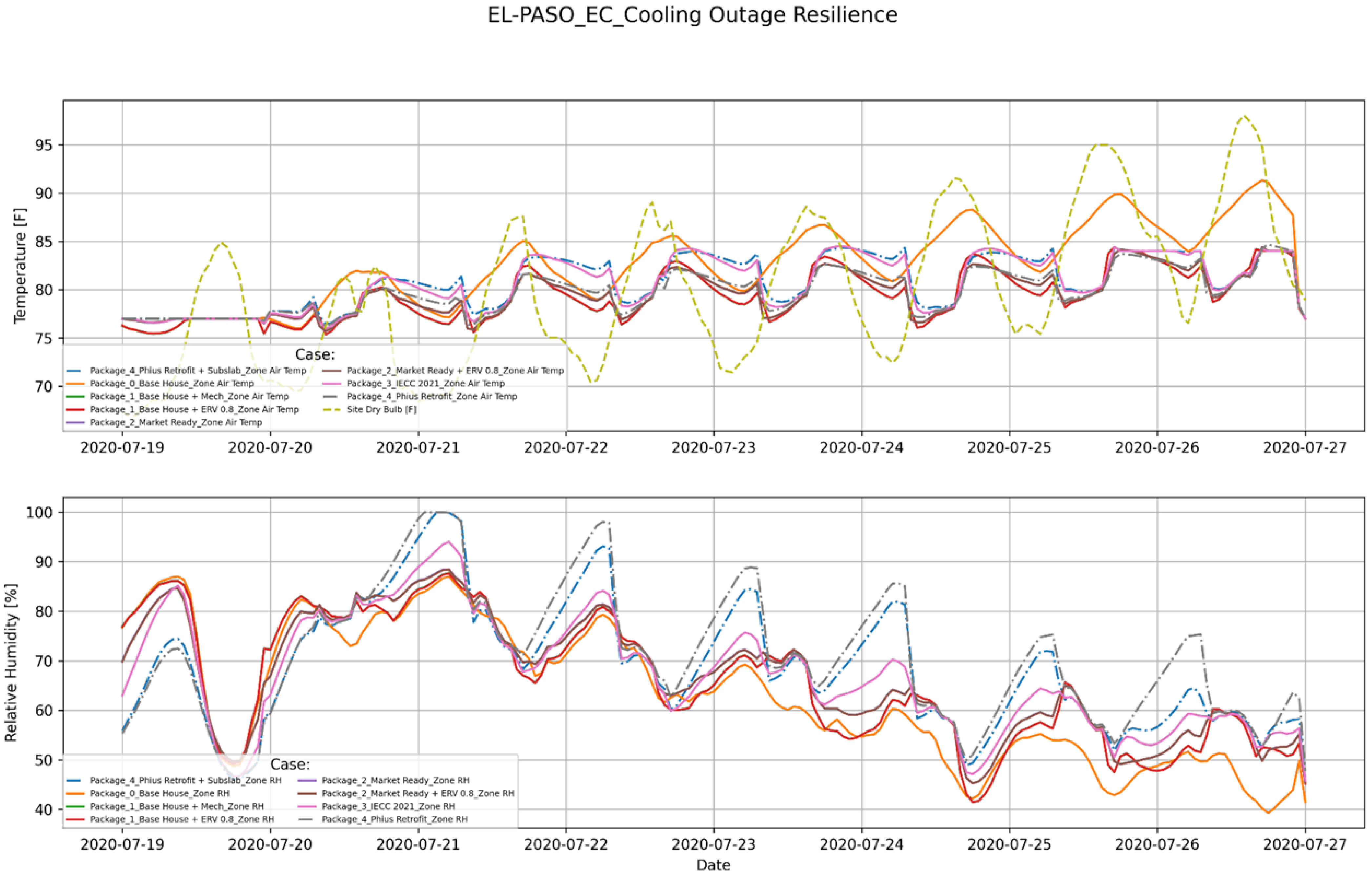
EL-PASO_SNV_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date


EL-PASO_SNV+Shd_Cooling Outage Resilience
Temperature [F]
95
90
85
80
75
70
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Relative Humidity [%]
90
80
70
60
50
40
30
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Date

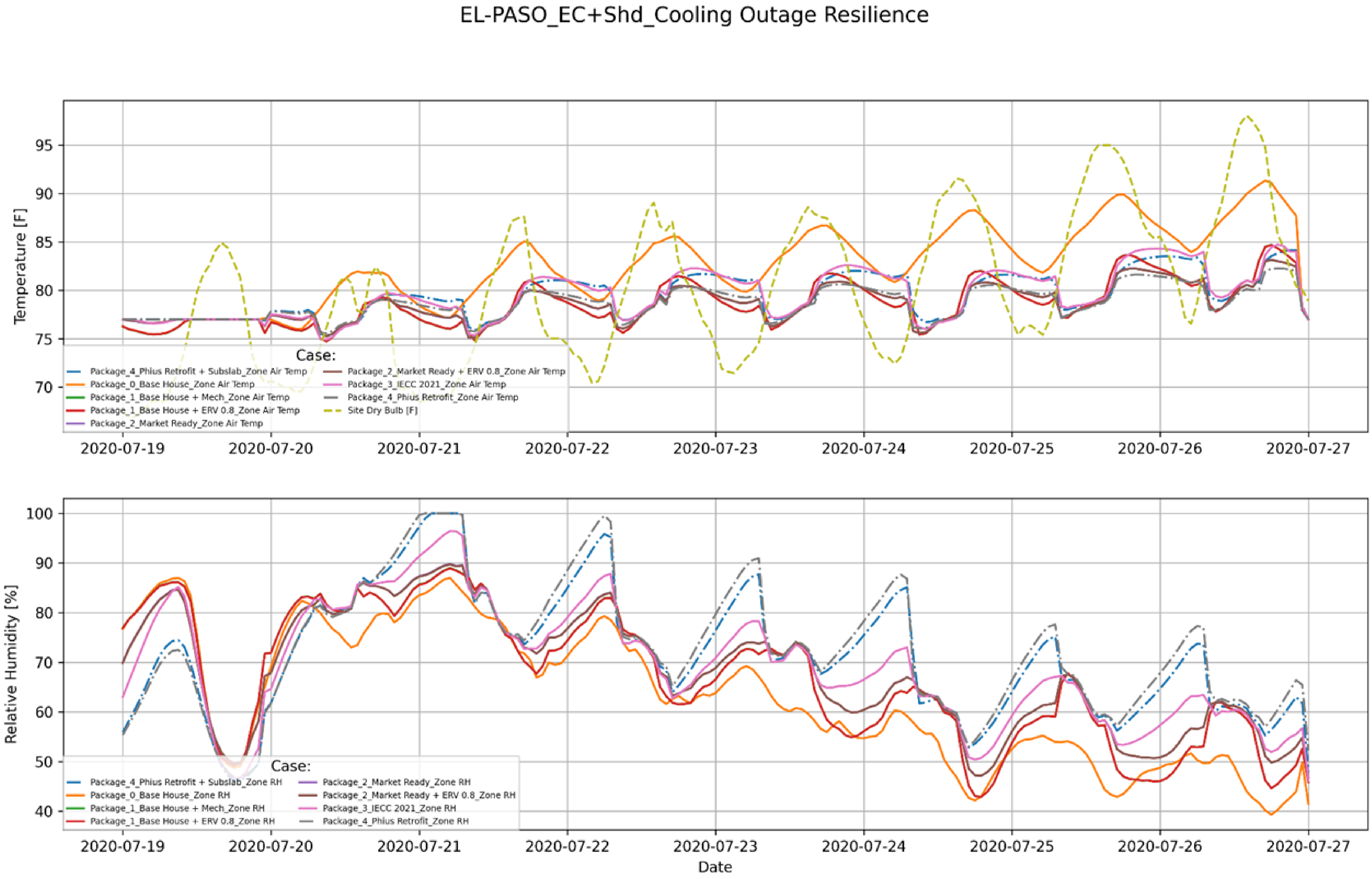
EL-PASO_HP_Cooling Outage Resilience



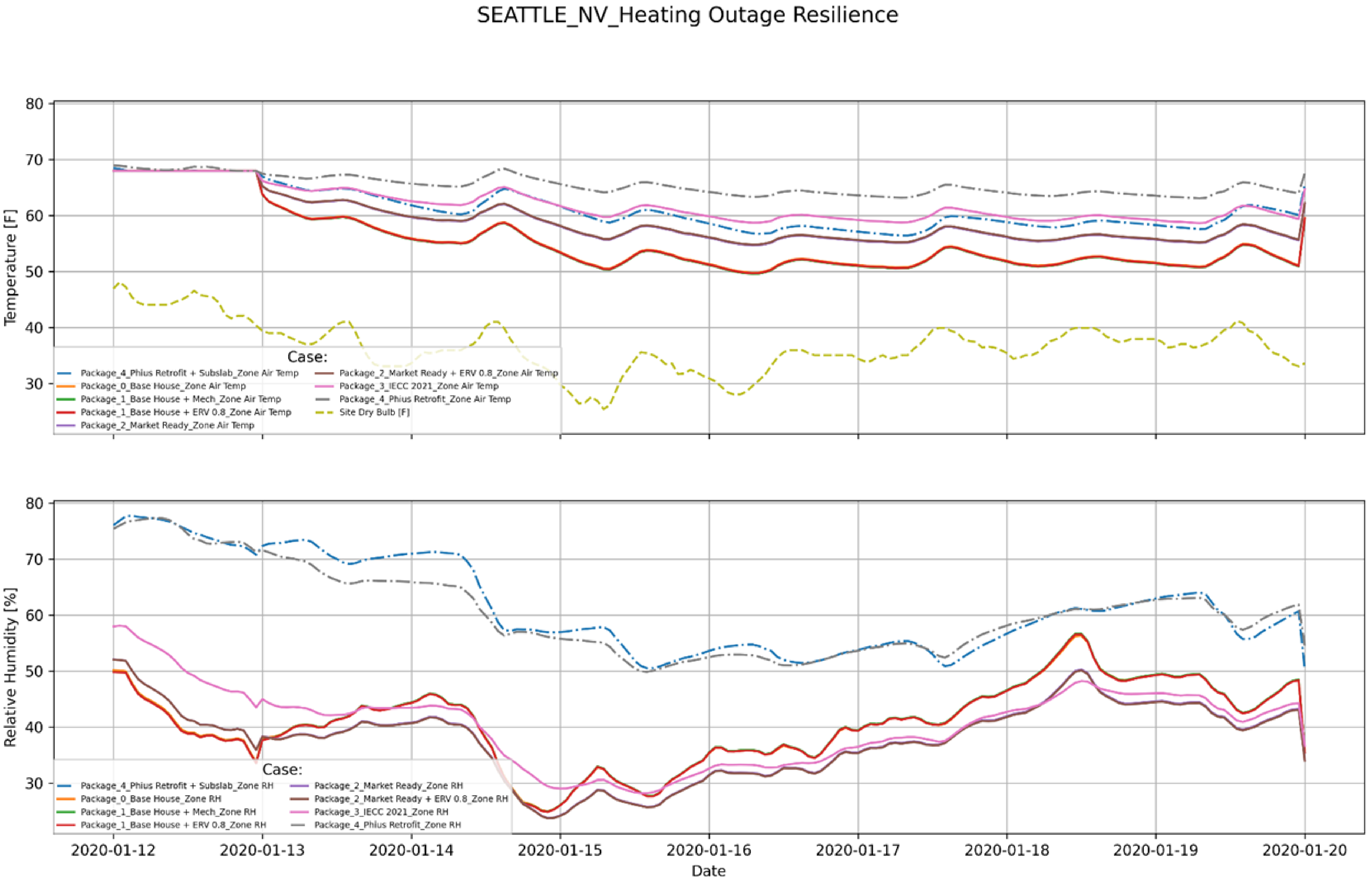

EL-PASO_HP+Shd_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Date

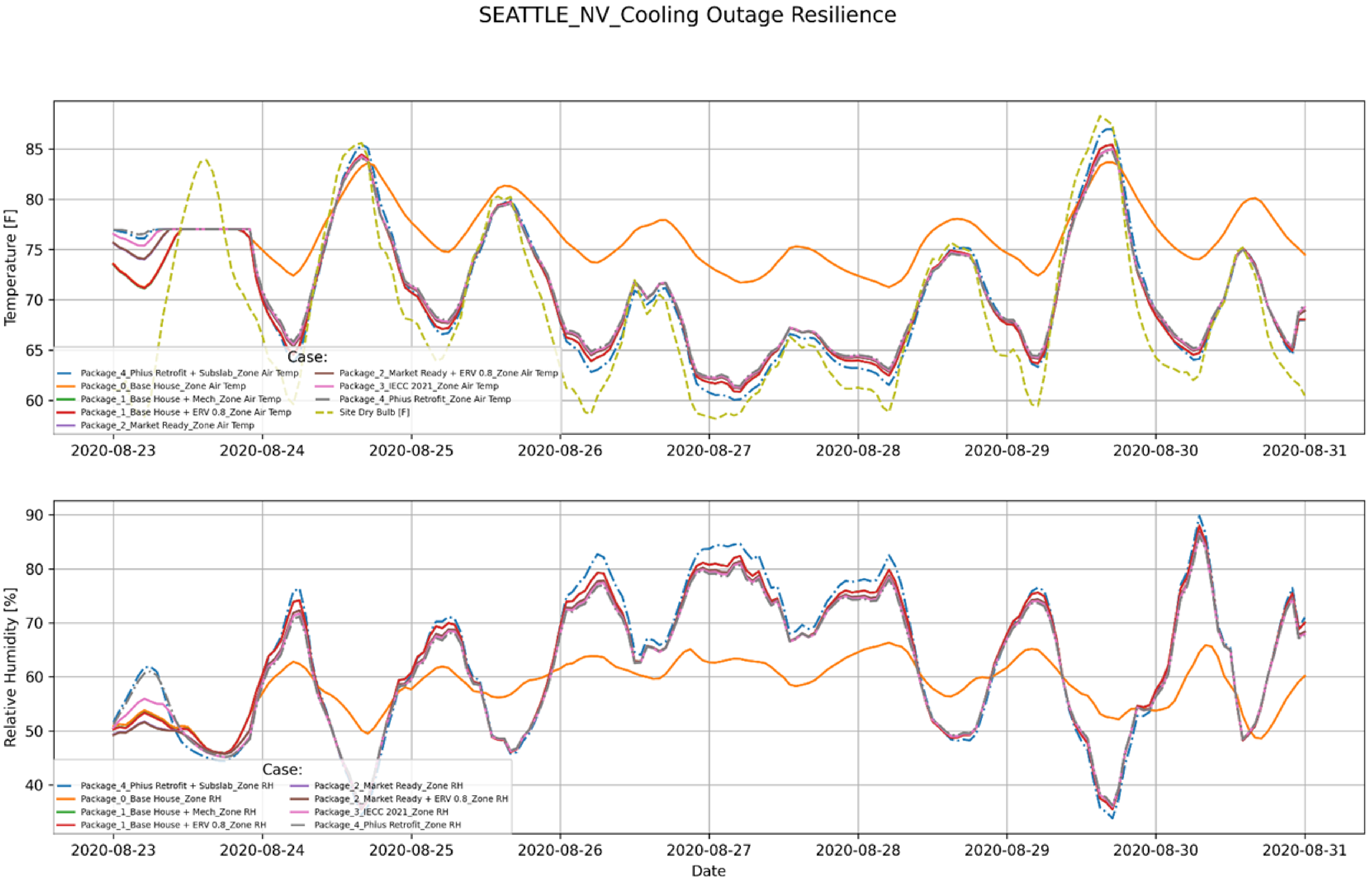


EL-PASO_EC_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

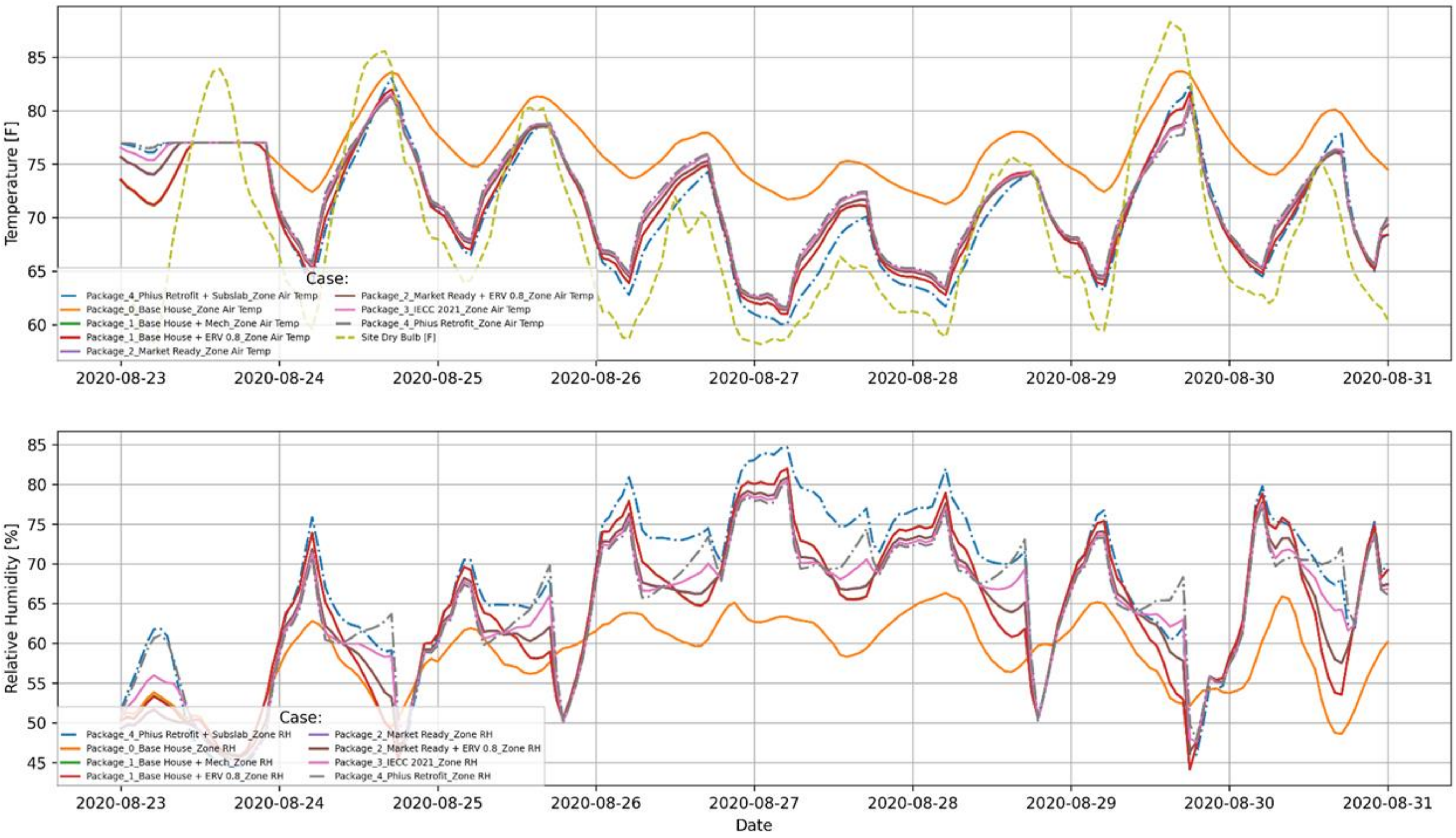

EL-PASO_EC+Shd_Cooling Outage Resilience
Temperature [F]
95
90
85
80
75
70
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Relative Humidity [%]
100
90
80
70
60
50
40
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
2020-07-27
Date

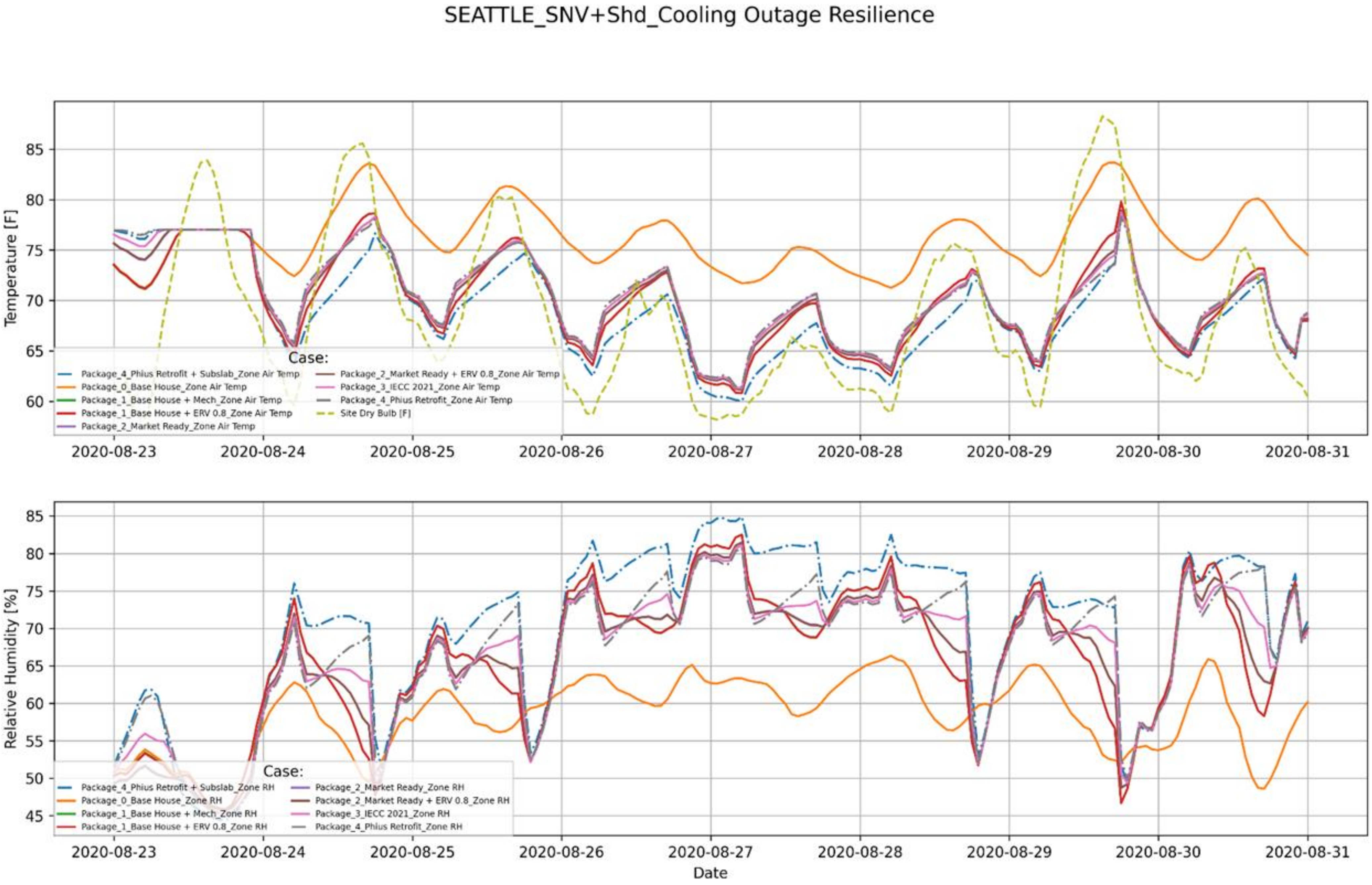
Seattle, WA


SEATTLE_NV_Heating Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-01-12
2020-01-13
2020-01-14
2020-01-15
2020-01-16
2020-01-17
2020-01-18
2020-01-19
2020-01-20
Date

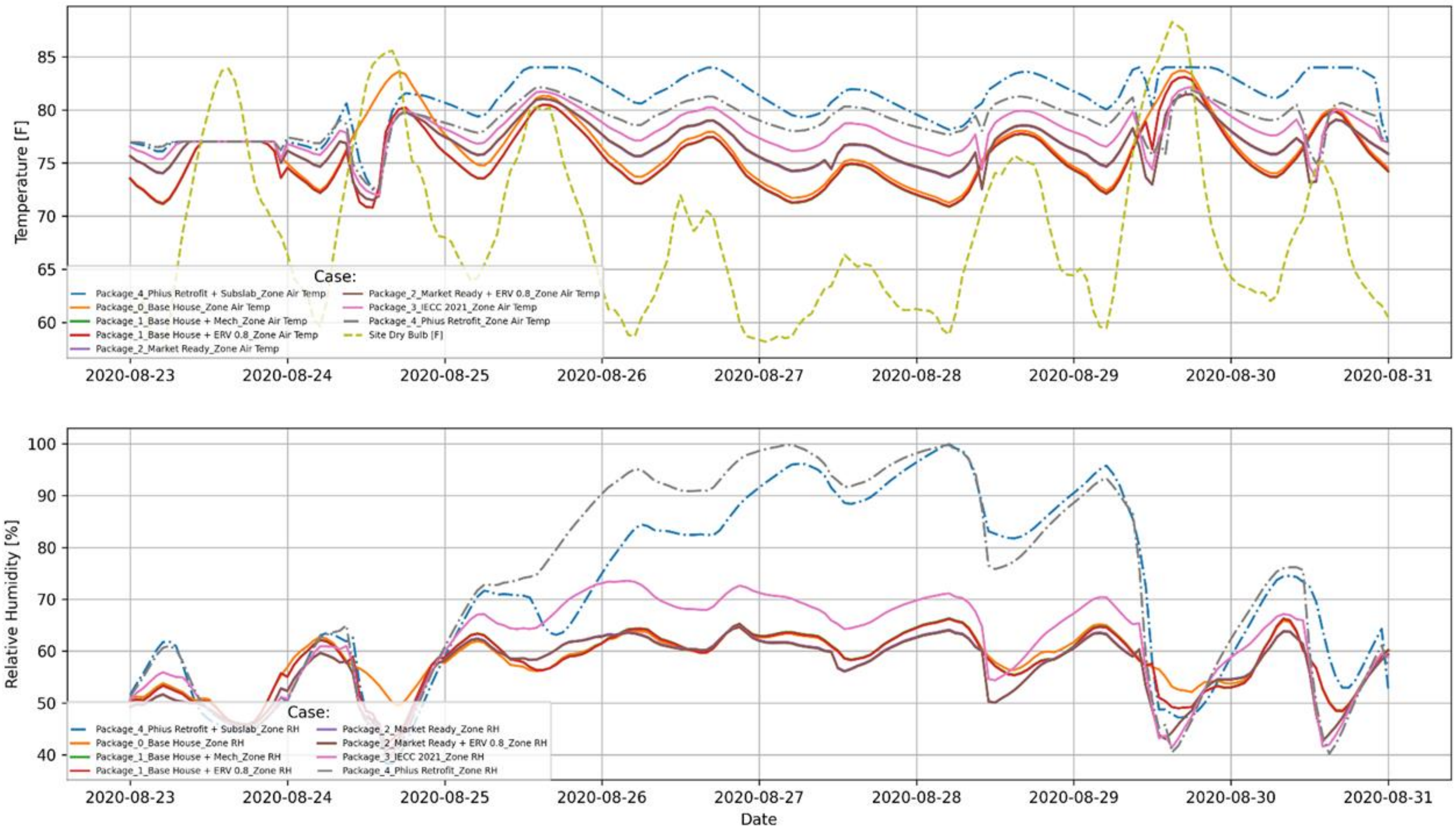

SEATTLE_NV_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-08-23
2020-08-24
2020-08-25
2020-08-26
2020-08-27
2020-08-28
2020-08-29
2020-08-30
2020-08-31
Date

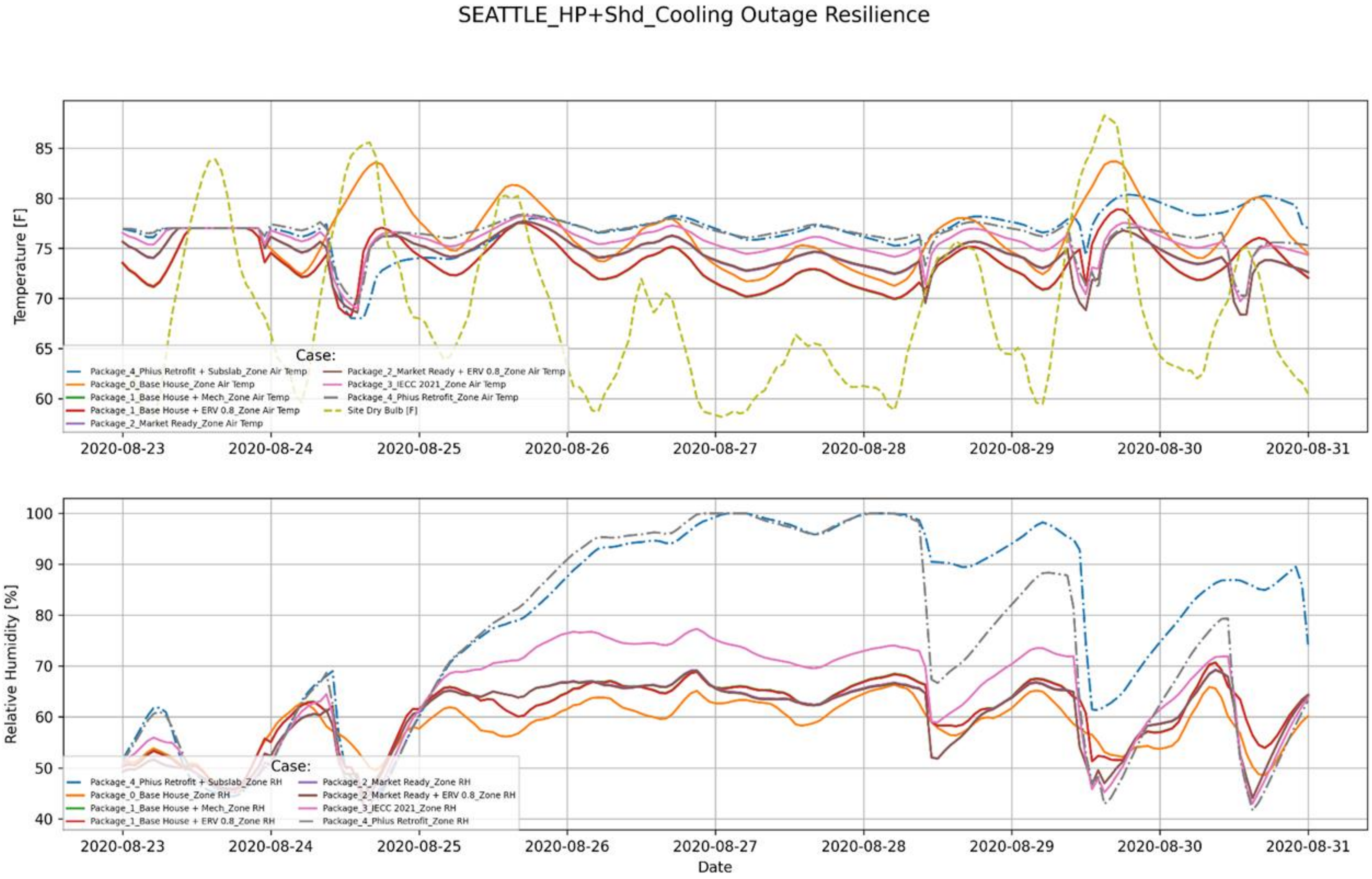
SEATTLE_SNV_Cooling Outage Resilience




SEATTLE_SNV+Shd_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

SEATTLE_HP_Cooling Outage Resilience

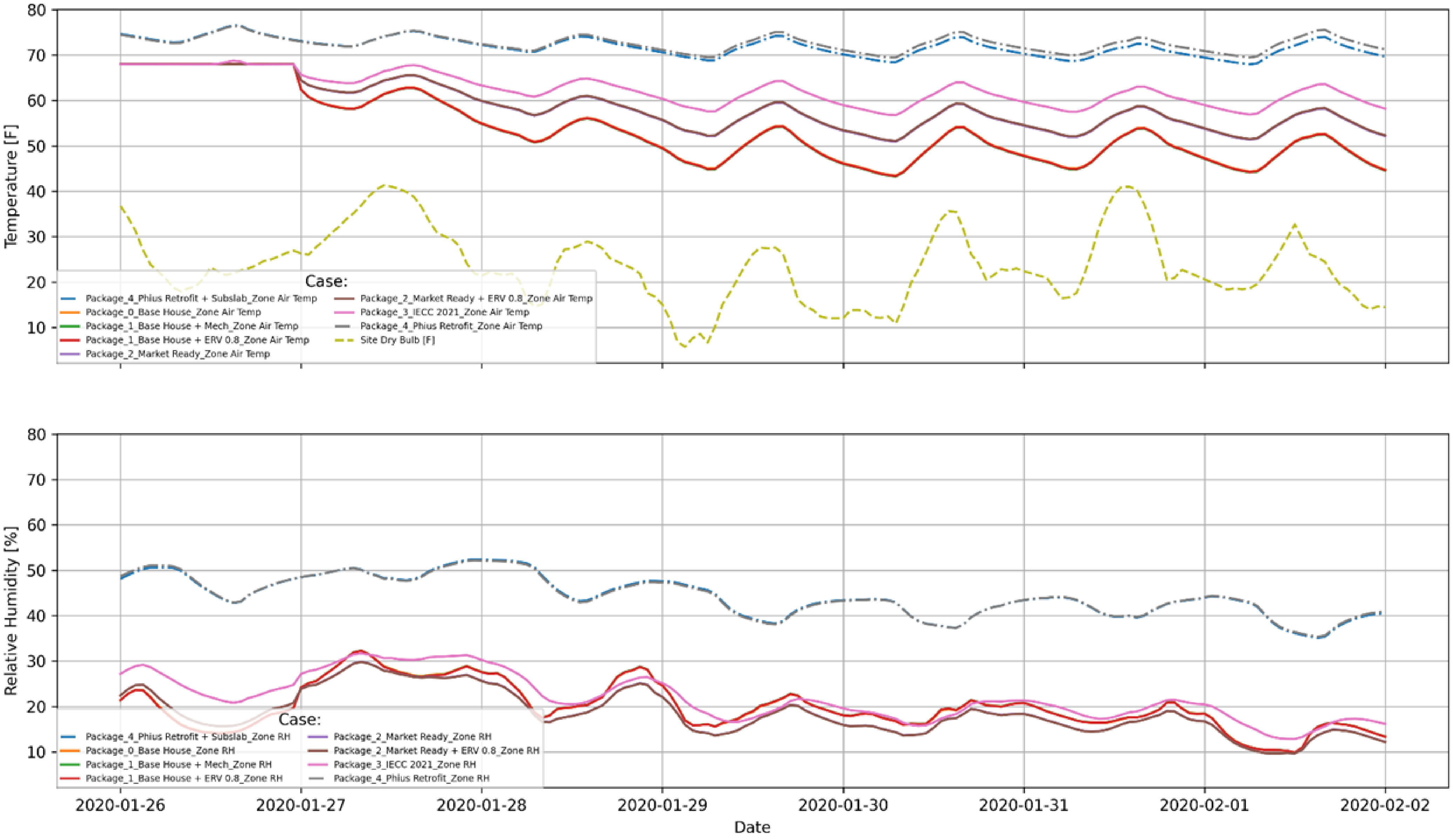




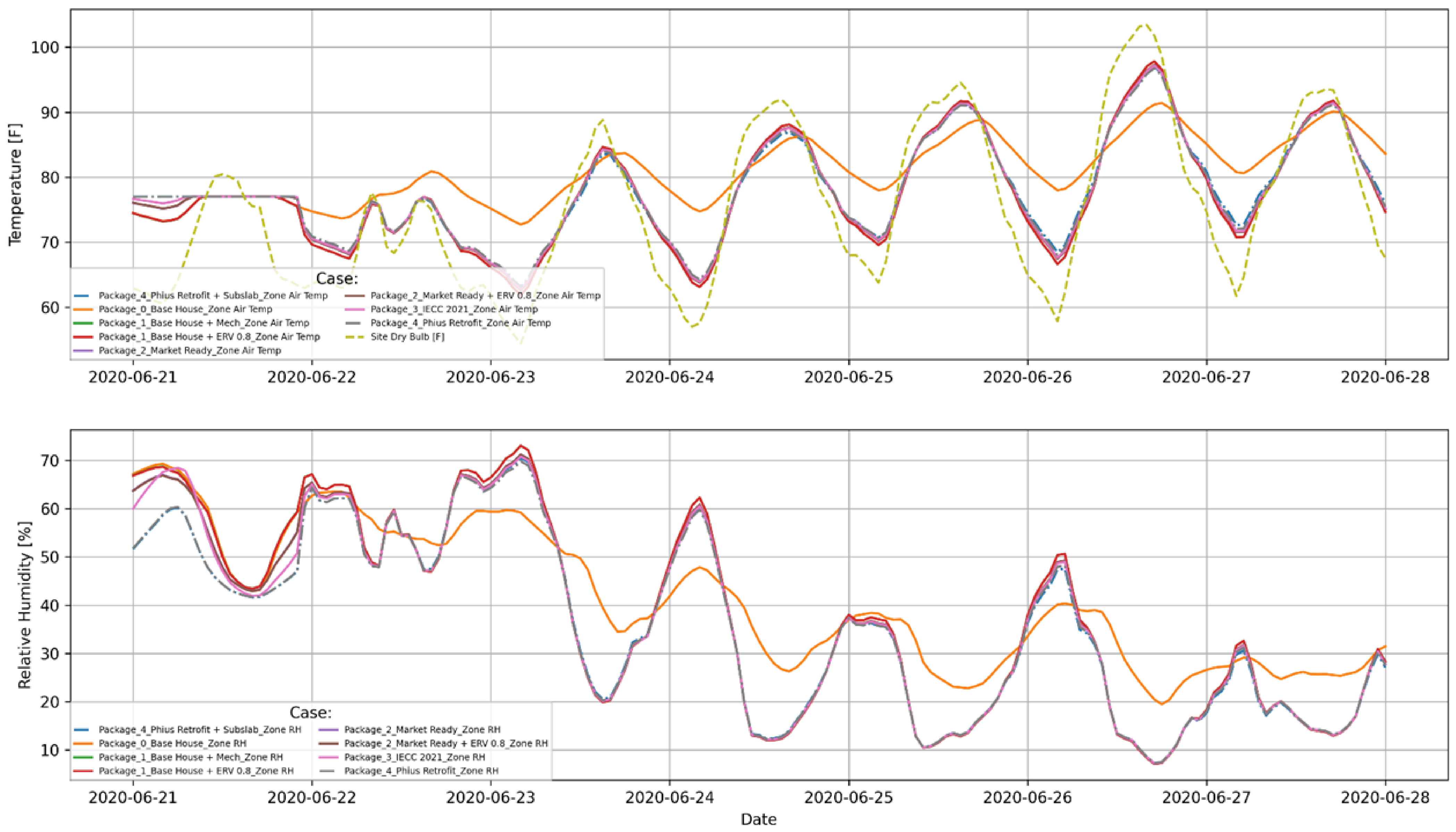
SEATTLE_HP+Shd_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

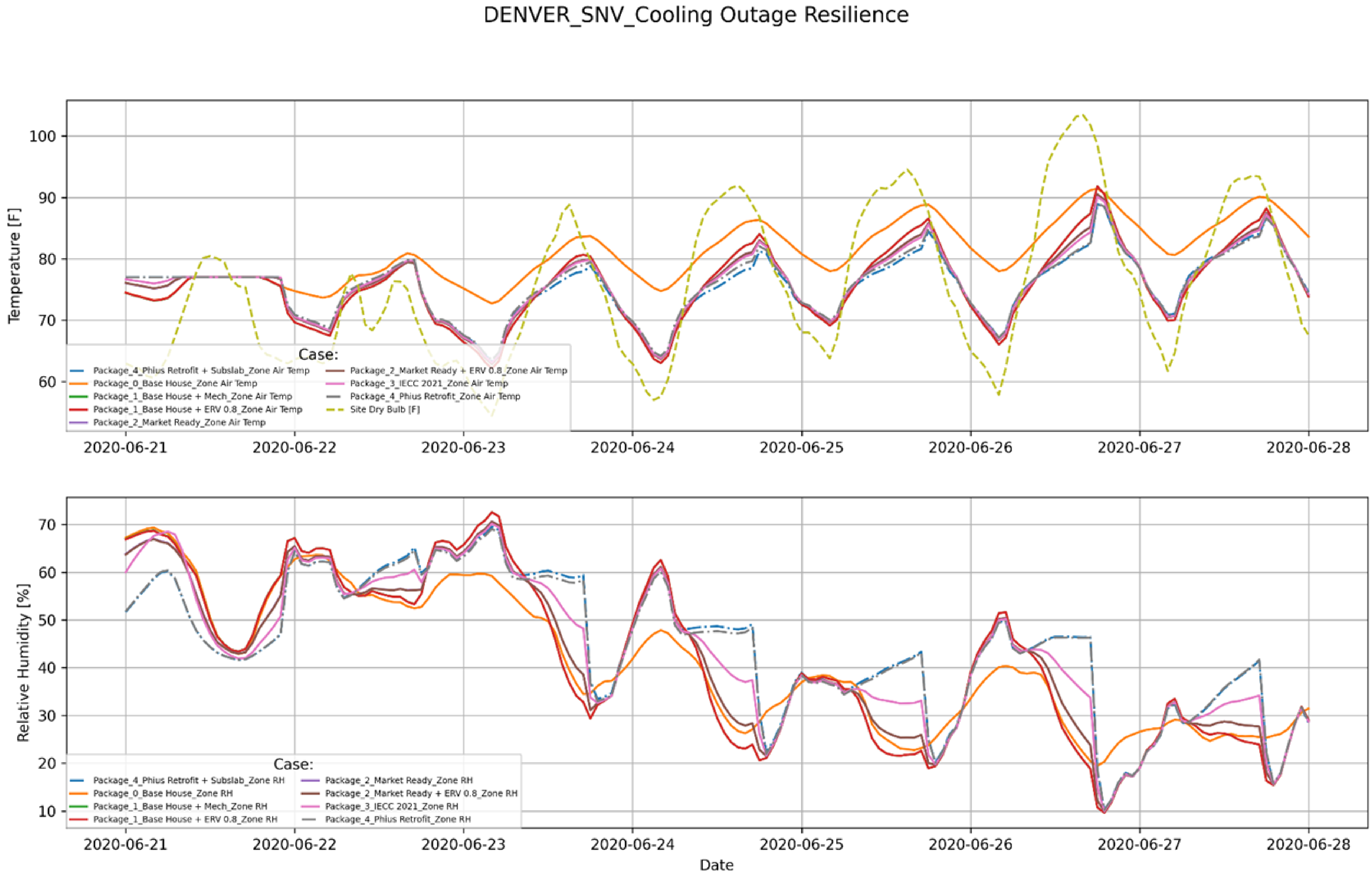
Denver, CO

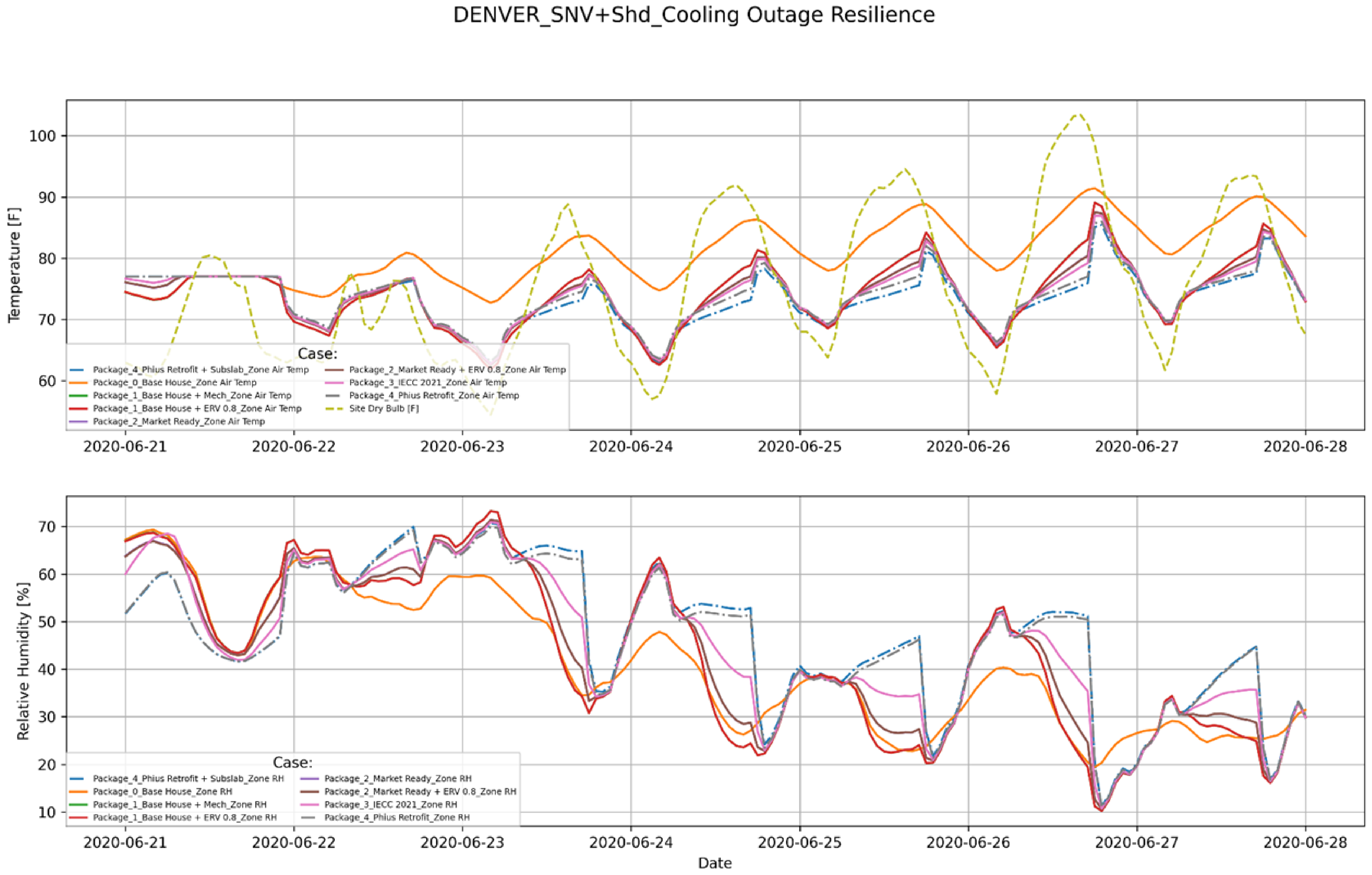
DENVER_NV_Heating Outage Resilience



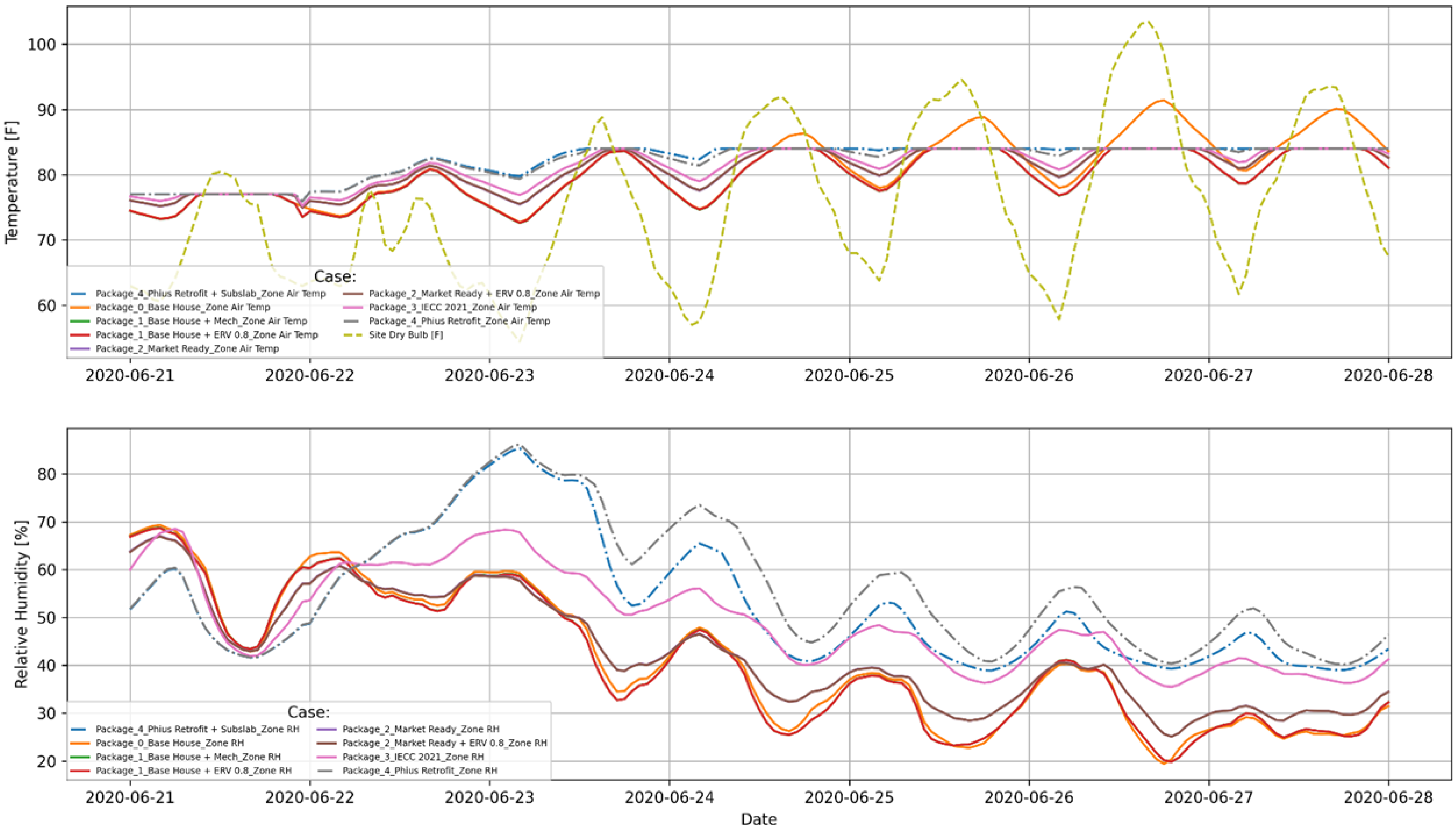
DENVER_NV_Cooling Outage Resilience

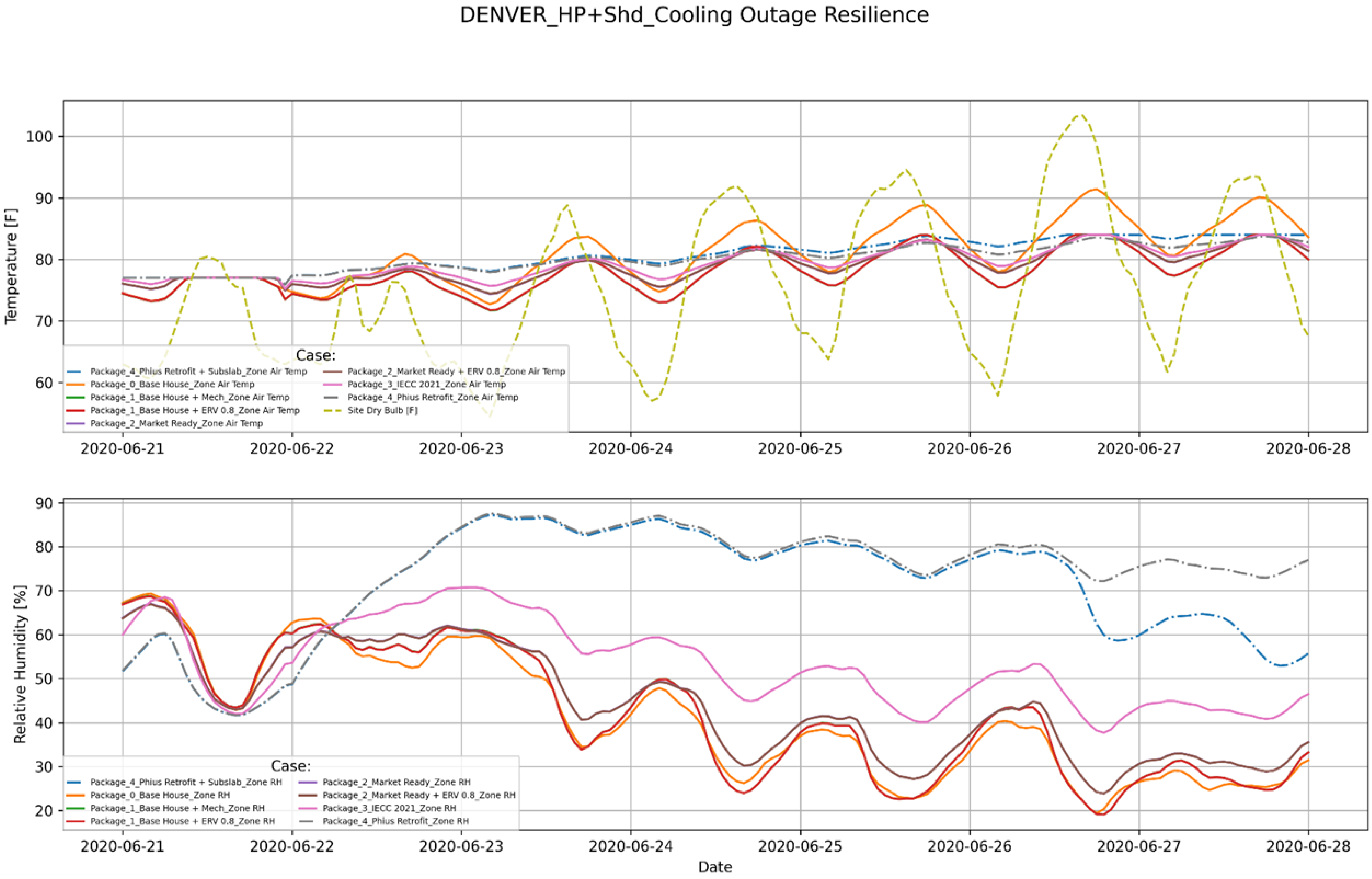


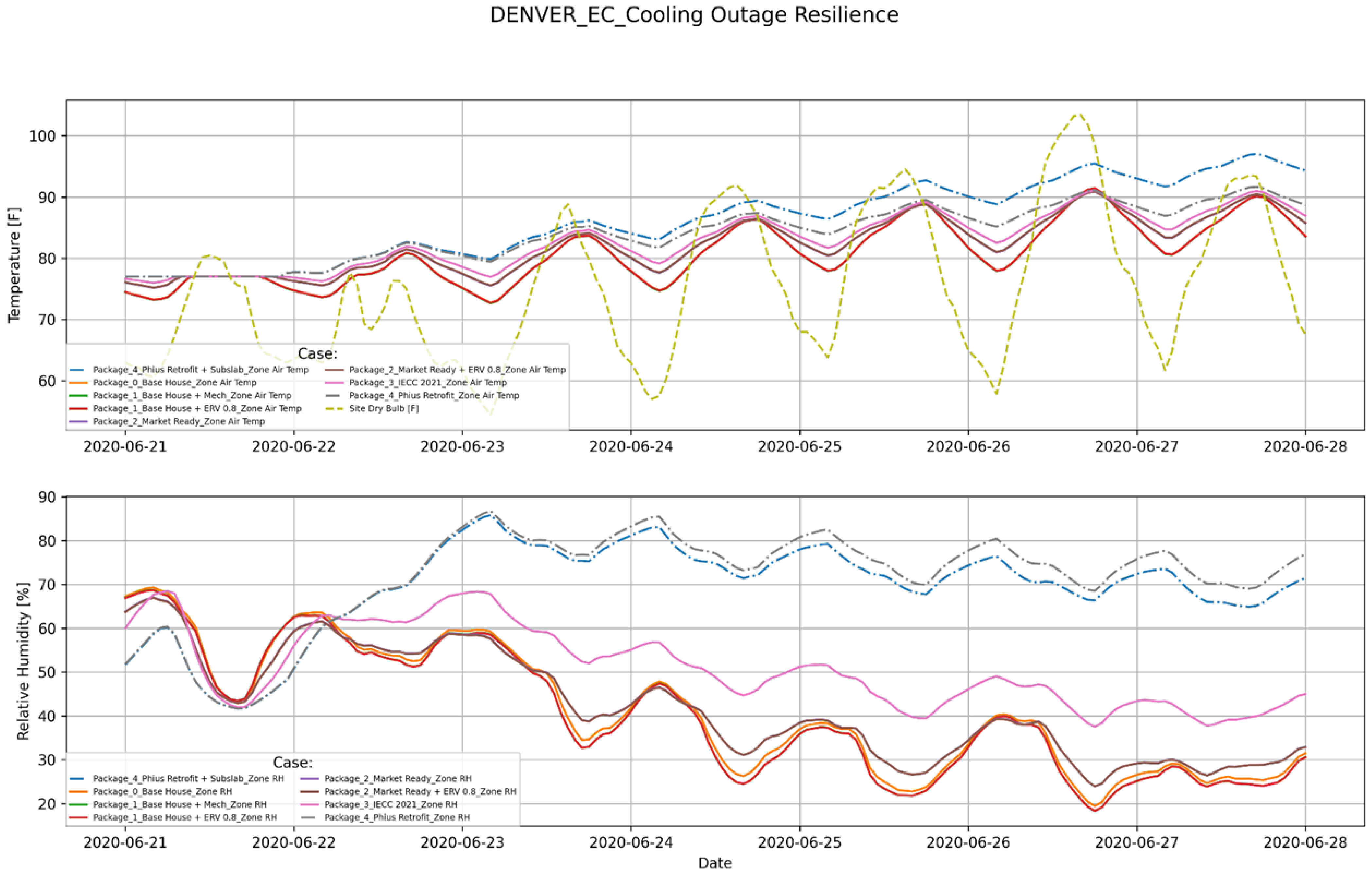

DENVER_SNV_Cooling Outage Resilience
Temperature [F]
100
90
80
70
60
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Relative Humidity [%]
70
60
50
40
30
20
10
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Date


DENVER_SNV+Shd_Cooling Outage Resilience
Temperature [F]
100
90
80
70
60
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Relative Humidity [%]
70
60
50
40
30
20
10
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Date

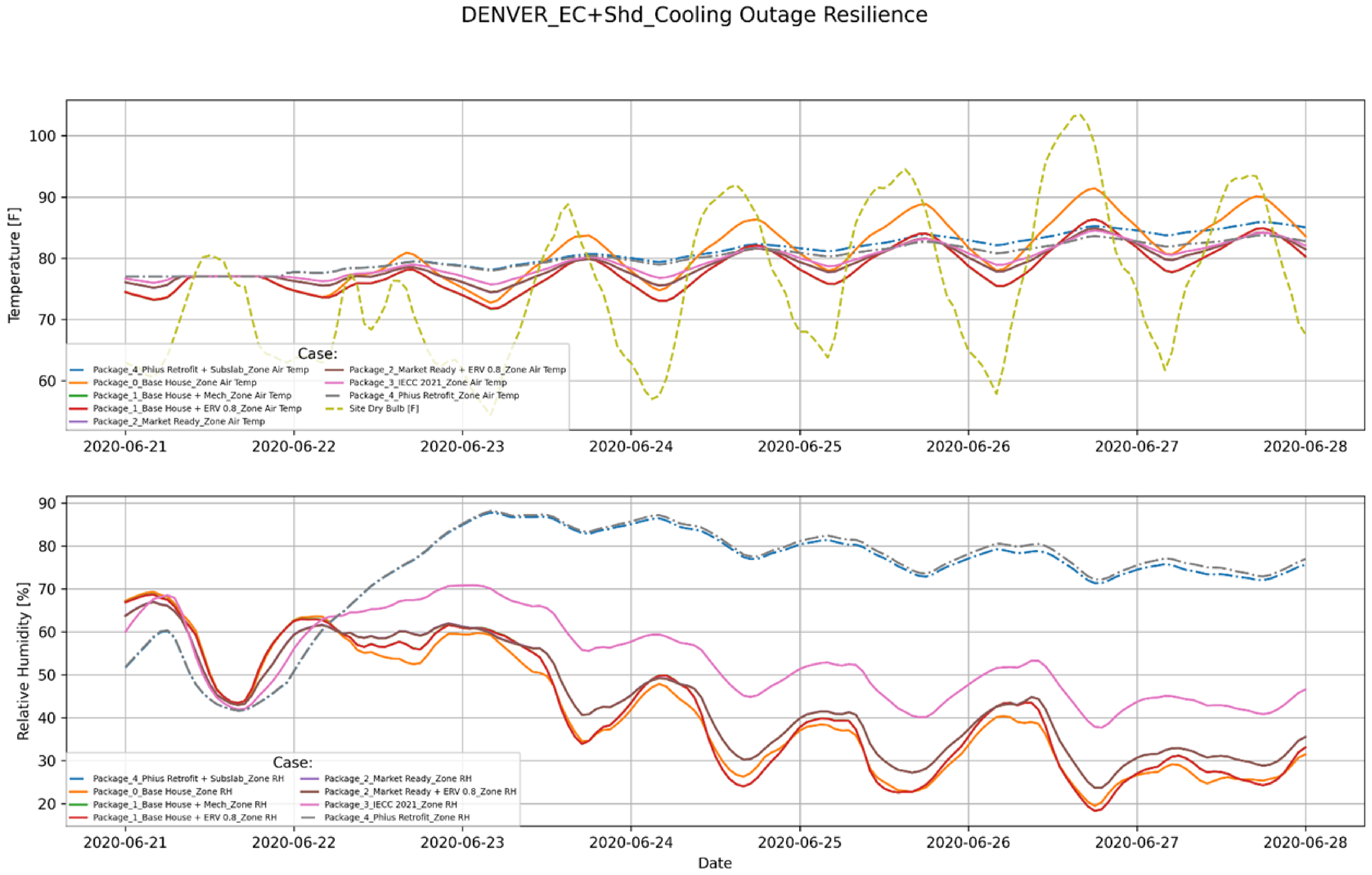
DENVER_HP_Cooling Outage Resilience




DENVER_HP+Shd_Cooling Outage Resilience
Temperature [F]
100
90
80
70
60
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Relative Humidity [%]
90
80
70
60
50
40
30
20
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Date

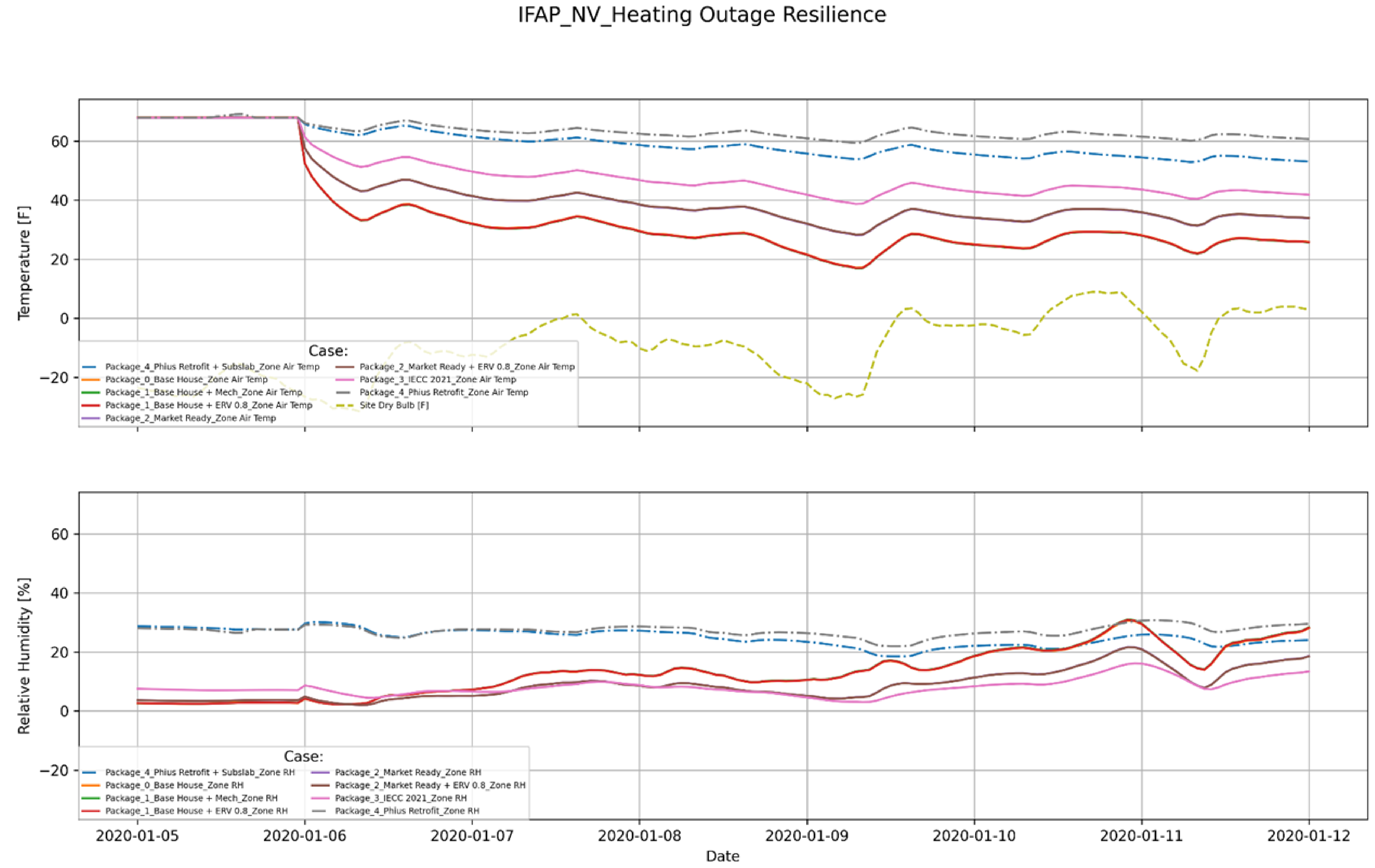


DENVER_EC_Cooling Outage Resilience
Temperature [F]
100
90
80
70
60
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Relative Humidity [%]
90
80
70
60
50
40
30
20
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Date

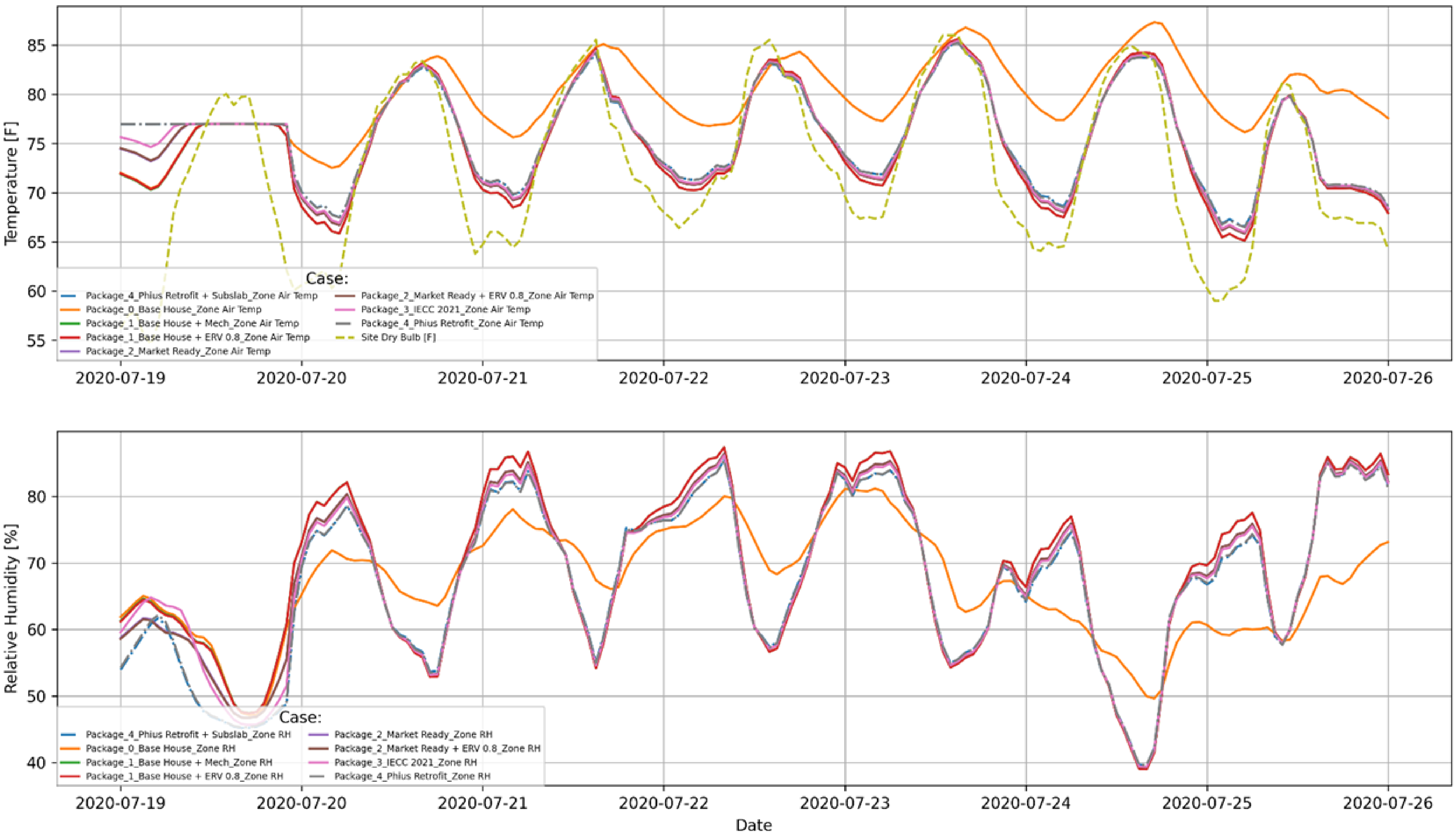


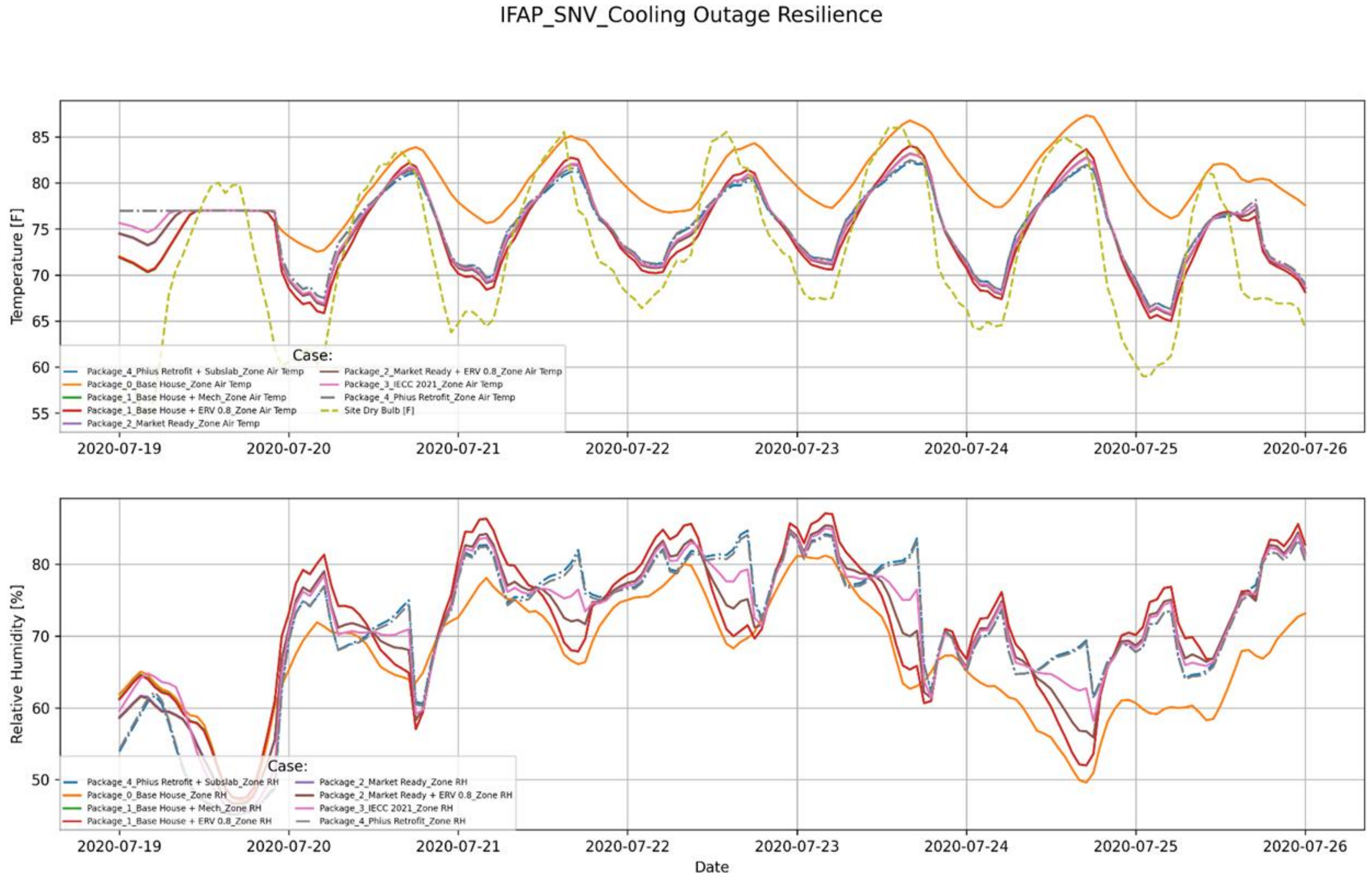
DENVER_EC+Shd_Cooling Outage Resilience
Temperature [F]
100
90
80
70
60
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Relative Humidity [%]
90
80
70
60
50
40
30
20
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-06-21
2020-06-22
2020-06-23
2020-06-24
2020-06-25
2020-06-26
2020-06-27
2020-06-28
Date

International Falls, MN


IFAP_NV_Heating Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-01-05
2020-01-06
2020-01-07
2020-01-08
2020-01-09
2020-01-10
2020-01-11
2020-01-12
Date

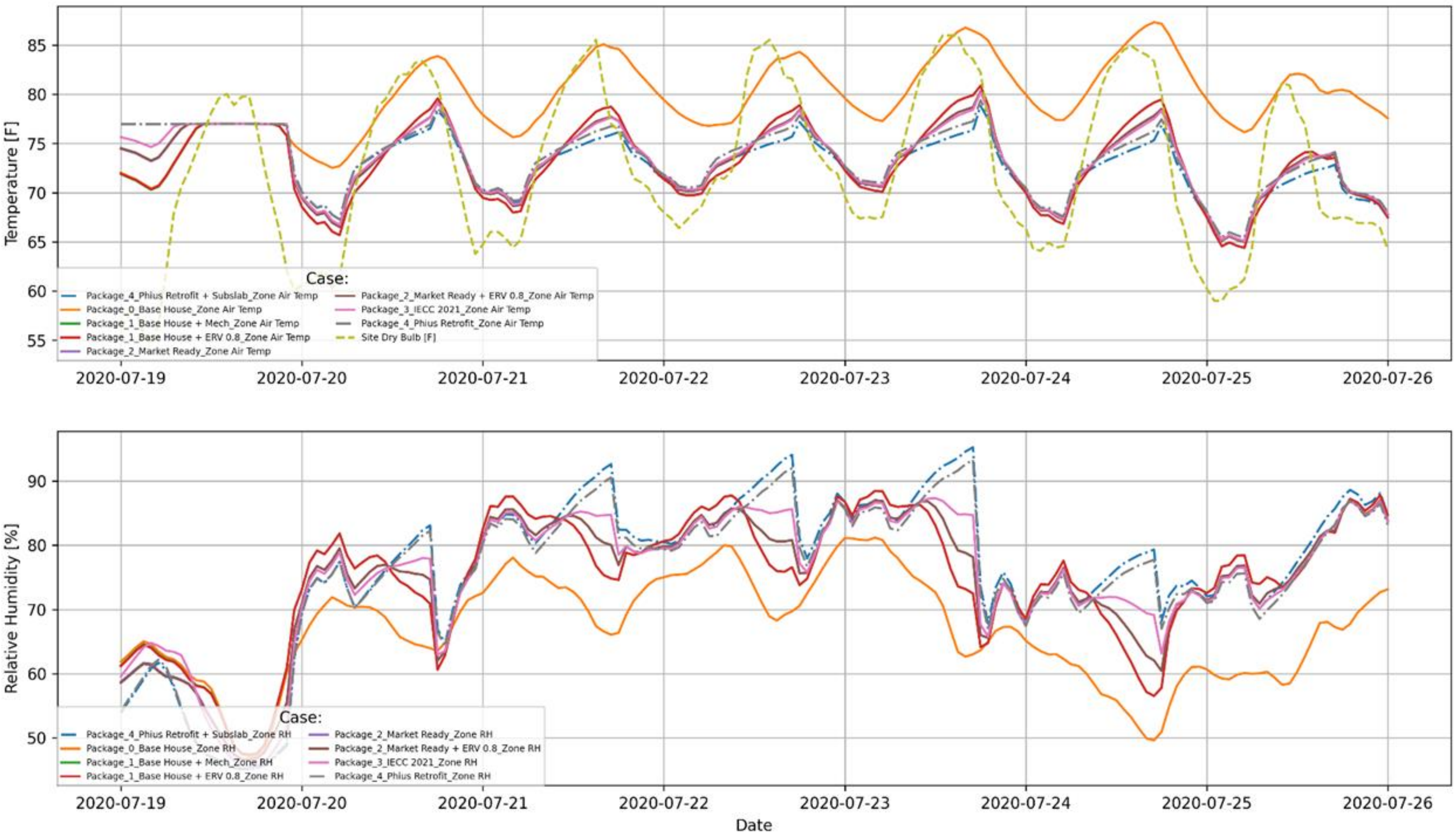
IFAP_NV_Cooling Outage Resilience

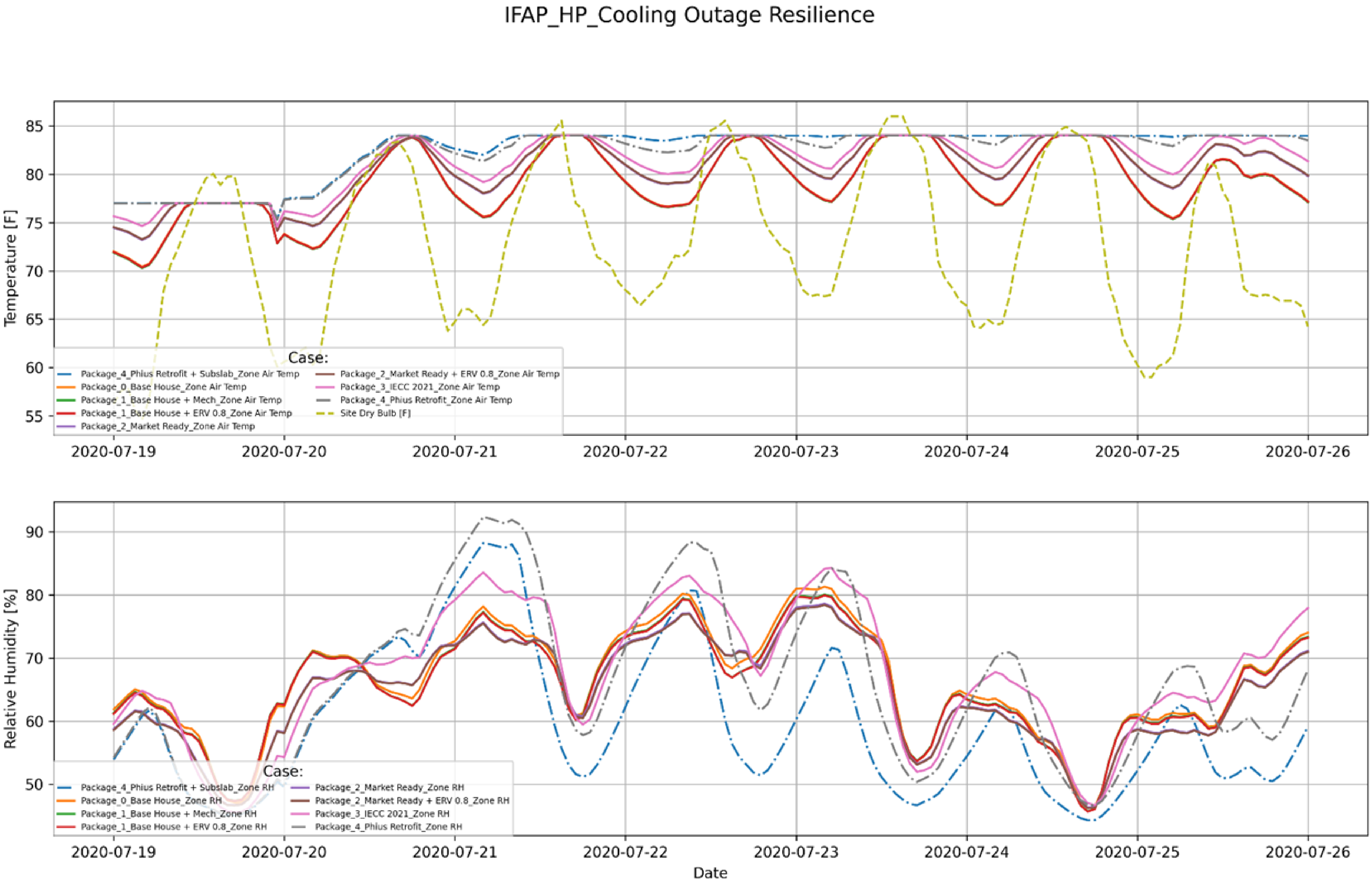


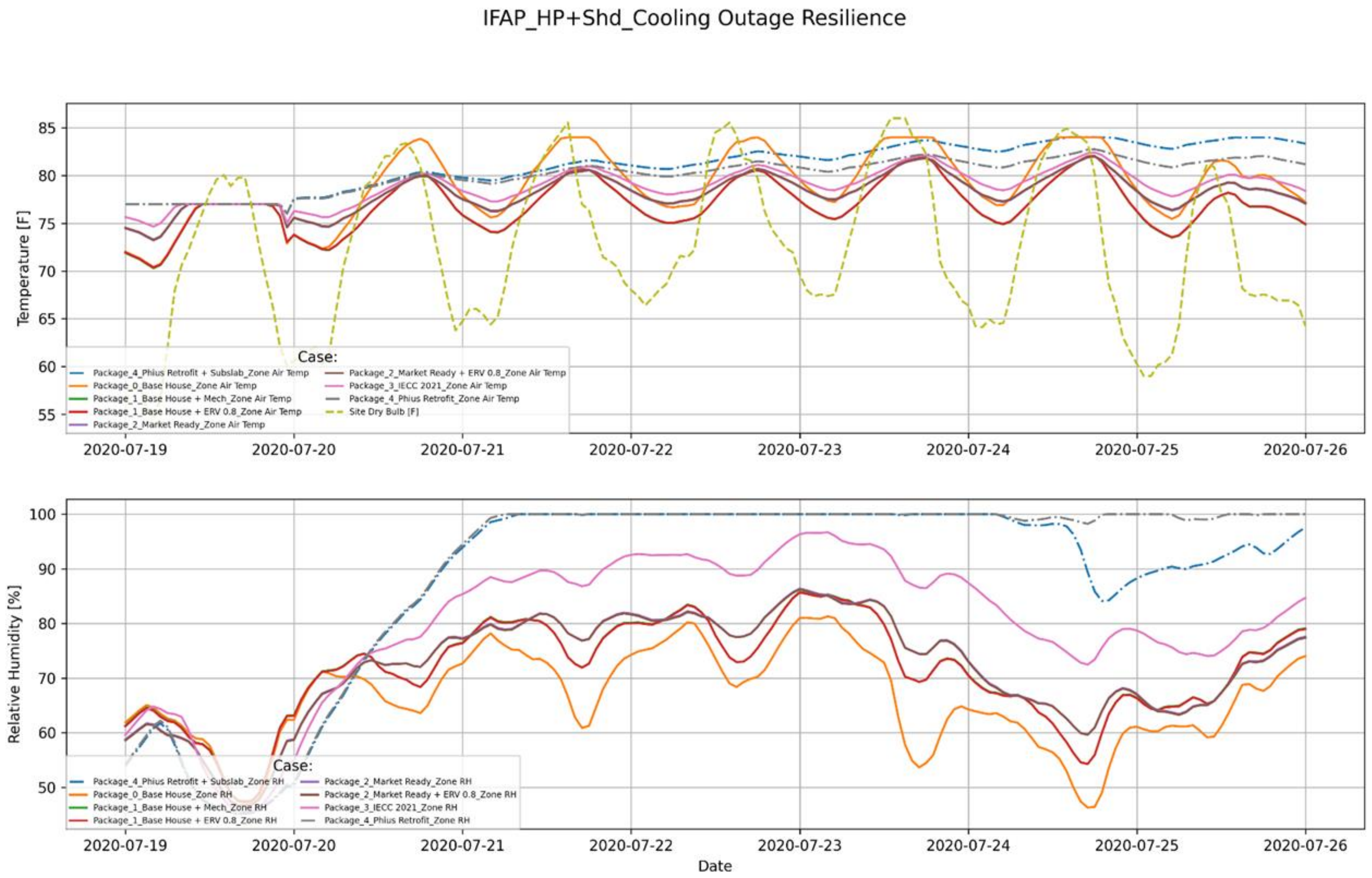


IFAP_SNV_Cooling Outage Resilience
Temperature [F]
85
80
75
70
65
60
55
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
Relative Humidity [%]
80
70
60
50
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date

IFAP_SNV+Shd_Cooling Outage Resilience




IFAP_HP_Cooling Outage Resilience
Temperature [F]
85
80
75
70
65
60
55
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
Relative Humidity [%]
90
80
70
60
50
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26
Date


IFAP_HP+Shd_Cooling Outage Resilience
Temperature [F]
Case:
Package_4_Phius Retrofit + Subslab_Zone Air Temp
Package_0_Base House_Zone Air Temp
Package_1_Base House + Mech_Zone Air Temp
Package_1_Base House + ERV 0.8_Zone Air Temp
Package_2_Market Ready_Zone Air Temp
Package_2_Market Ready + ERV 0.8_Zone Air Temp
Package_3_IECC 2021_Zone Air Temp
Package_4_Phius Retrofit_Zone Air Temp
Site Dry Bulb [F]
Relative Humidity [%]
Case:
Package_4_Phius Retrofit + Subslab_Zone RH
Package_0_Base House_Zone RH
Package_1_Base House + Mech_Zone RH
Package_1_Base House + ERV 0.8_Zone RH
Package_2_Market Ready_Zone RH
Package_2_Market Ready + ERV 0.8_Zone RH
Package_3_IECC 2021_Zone RH
Package_4_Phius Retrofit_Zone RH
Date
2020-07-19
2020-07-20
2020-07-21
2020-07-22
2020-07-23
2020-07-24
2020-07-25
2020-07-26