Assessing Passive Survivability in Multifamily Buildings

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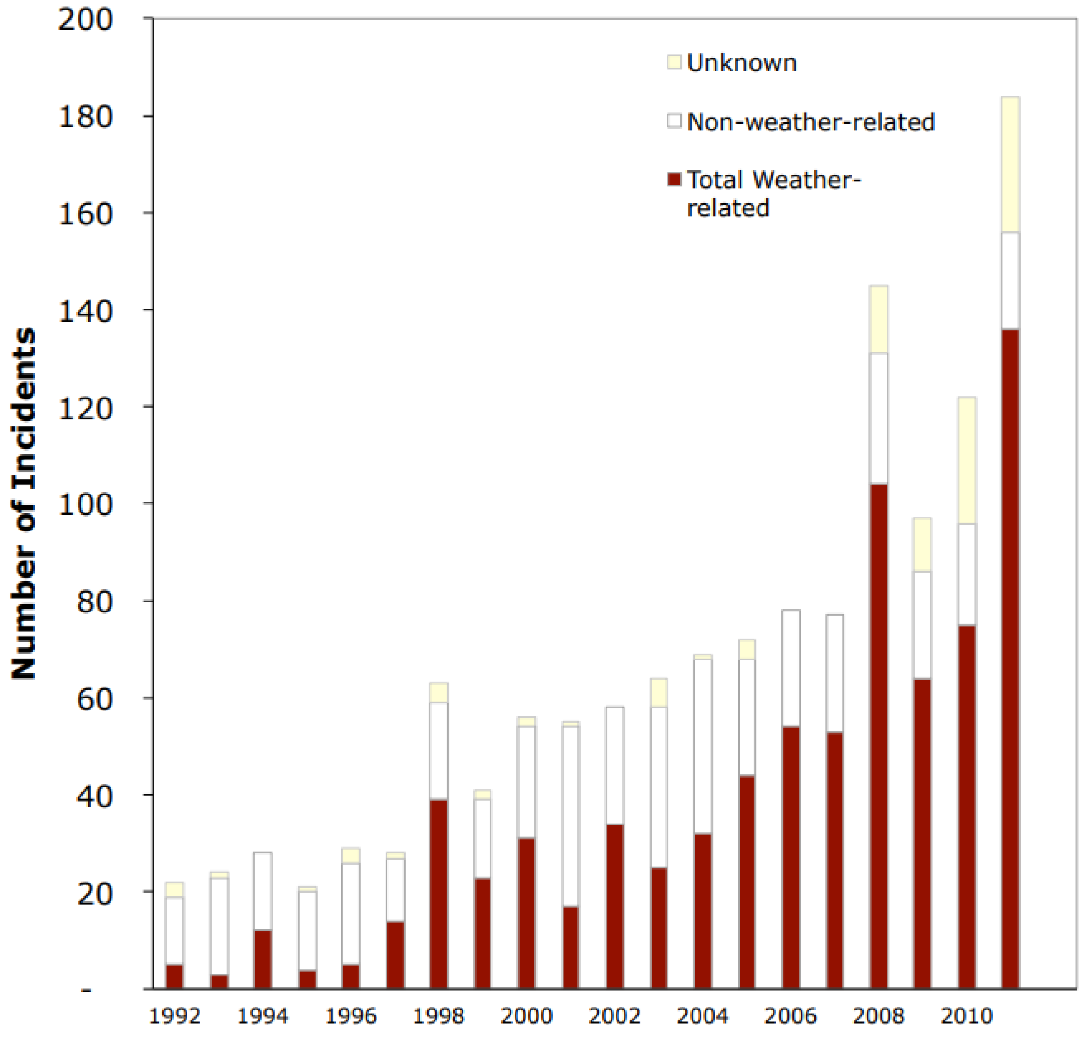
Outline

- Background
- Defining Passive Survivability
- Assessment Protocol & Simulation Setup
- Winter Resilience Results
- Summer Resilience Results
- Conclusions

WEATHER RELATED POWER DISRUPTIONS

<u>1992 to 2010:</u>

- 1,333 significant US electric grid disturbances occurred in the United States
- 78% of them being weather related
- Affected more than 178 million metered customers



Cause	% of events	Mean size in MW	Mean size in customers
Earthquake	0.8	1,408	375,900
Tornado	2.8	367	115,439
Hurricane/tropical storm	4.2	1,309	782,695
Ice storm	5.0	1,152	343,448
Lightning	11.3	270	70,944
Wind/rain	14.8	793	185,199
Other cold weather	5.5	542	150,255
Fire	5.2	431	111,244
Intentional attack	1.6	340	24,572
Supply shortage	5.3	341	138,957
Other external cause	4.8	710	246,071
Equipment failure	29.7	379	57,140
Operator error	10.1	489	105,322
Voltage reduction	7.7	153	212,900
Volunteer reduction	5.9	190	134,543

Type	Impact Region	Predictability	Span/area	Affecting time
Hurricane, tropical storm	Coastal regions	24-72 hours, moderate to good	Large (radius up to 1,000 miles)	Hours to days
Tornado	Inland plains	0-2 hours, bad to moderate	Small (radius up to 5 miles)	Minutes to hours
Blizzard, Ice Storm	High latitude regions	24-72 hours, moderate to good	large, up to 1,000 miles	Hours to days
Earthquake	Regions on fault lines	Seconds to minutes, bad	Small to large	Minutes to days (after-shock)
Tsunami	Coastal regions	Minutes to hours, moderate	Small to large	Minutes to hours
Drought, Wild Fire	Inland regions	Days, good	Medium to large	Days to months

NYC Manhattan Outages post Hurricane Sandy 2012

Many places left without power for > 5 days

Hurricane Florence
Sept 2018, North Carolina

PASSIVE SURVIVABILITY

A building's ability to maintain livable conditions when sources such as electricity, water, or heating fuel are cut off.

- Alex Wilson, 2005

METRICS FOR PASSIVE SURVIVABILITY

ASHRAE's *Thermal Environmental Conditions for Human Occupancy Standard* 55-2004

- Indoor Summer Comfort Range: 74^{o}F – 83^{o}F
- Indoor Winter Comfort Range: 67^{o}F – 79^{o}F
- **Acceptable for naturally ventilated spaces: 50^{o}F – 93^{o}F**

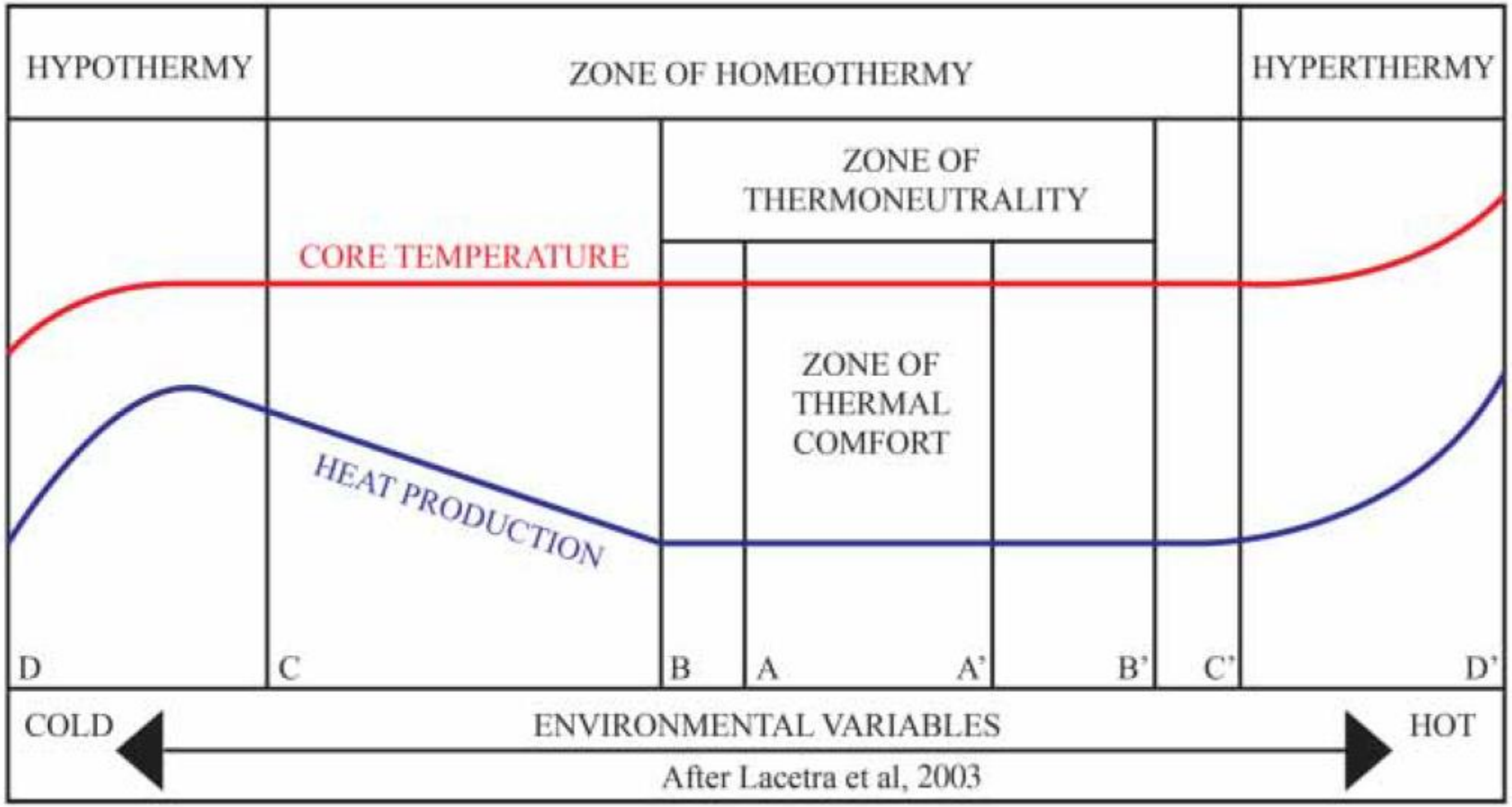
Homeothermy: form of temperature regulation used by humans, where the body maintains the same internal core temperature (98.6^{o}F), regardless of external influences.

PASSIVE SURVIVABILITY

A building's ability to maintain livable conditions when sources such as electricity, water, or heating fuel are cut off.

Metrics for passive survivability

Core body temperatures shown below.

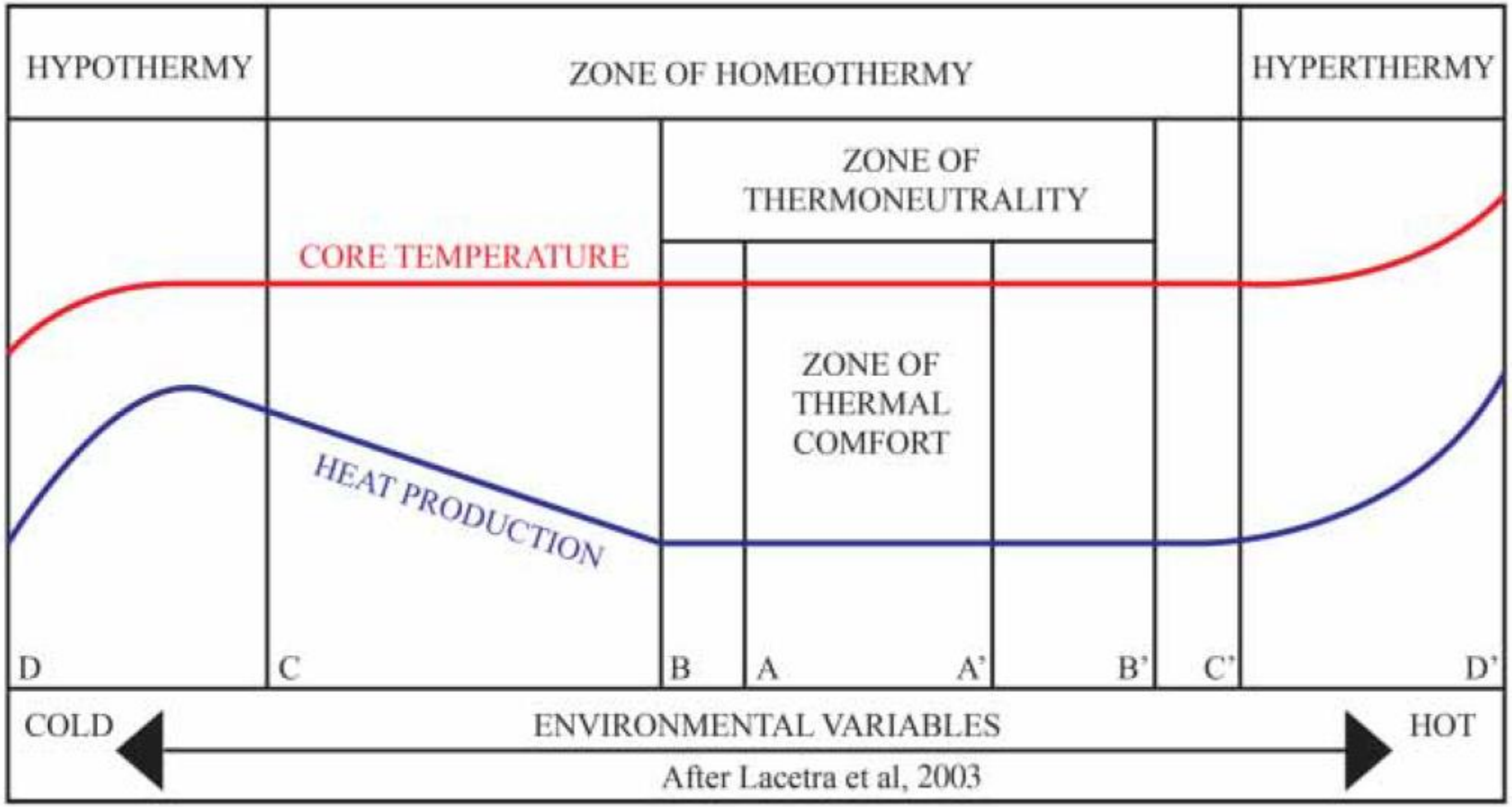


~80ºF ~95ºF ~98ºF ~100ºF ~108ºF

Picture Courtesy of Holmes, S, et al. Overheating and passive habitability: indoor health and heat indices.

Metrics for passive survivability

Interior/room temperatures shown below.



~??? 50^{o}F 67-83^{o}F 93^{o}F ~???

Picture Courtesy of Holmes, S, et al. Overheating and passive habitability: indoor health and heat indices.

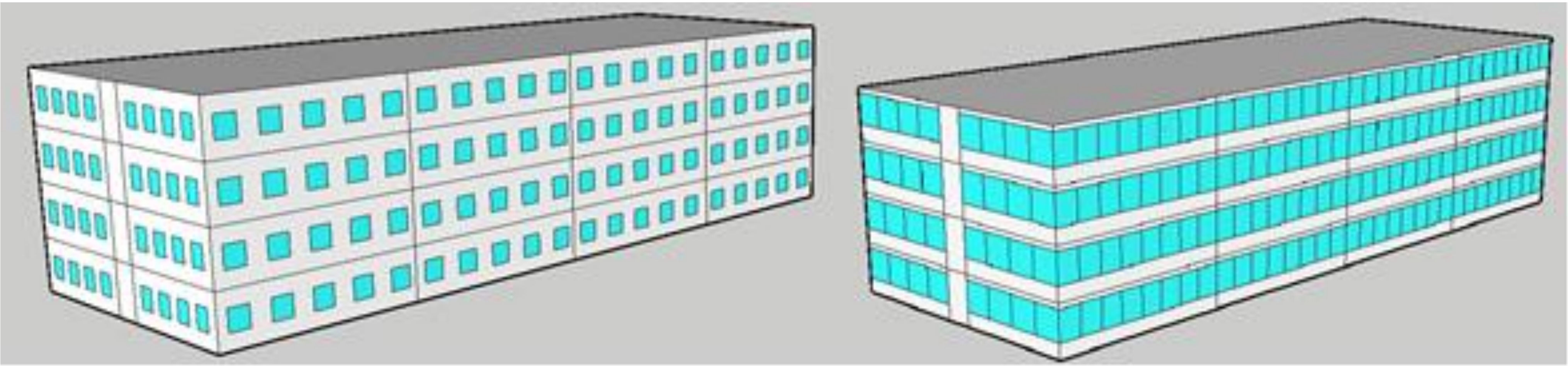
PASSIVE SURVIVABILITY

Assessment overview

- Determine resilience design week
- Model worst case unit of multifamily buildings in WUFIplus
- Simulate 5-day outages on worst case units
- Note interior conditions
- ‘Rate’ for passive survivability

ASSESSMENT OVERVIEW

Overview of 8 Unique Building Types			
1	20% WWR	WOOD FRAMED CONSTRUCTION	ASHRAE 90.1
2			PHIUS+ 2015
3		ICF/CONCRETE CONSTRUCTION	ASHRAE 90.1
4			PHIUS+ 2015
5	60% WWR	WOOD FRAMED CONSTRUCTION	ASHRAE 90.1
6			PHIUS+ 2015
7		ICF/CONCRETE CONSTRUCTION	ASHRAE 90.1
8			PHIUS+ 2015



ASSESSMENT OVERVIEW - VARIABLES

1) **Window to wall ratio**

   20%, 60%

2) **Building Performance Standards**

   ASHRAE 90.1, PHIUS+ 2015

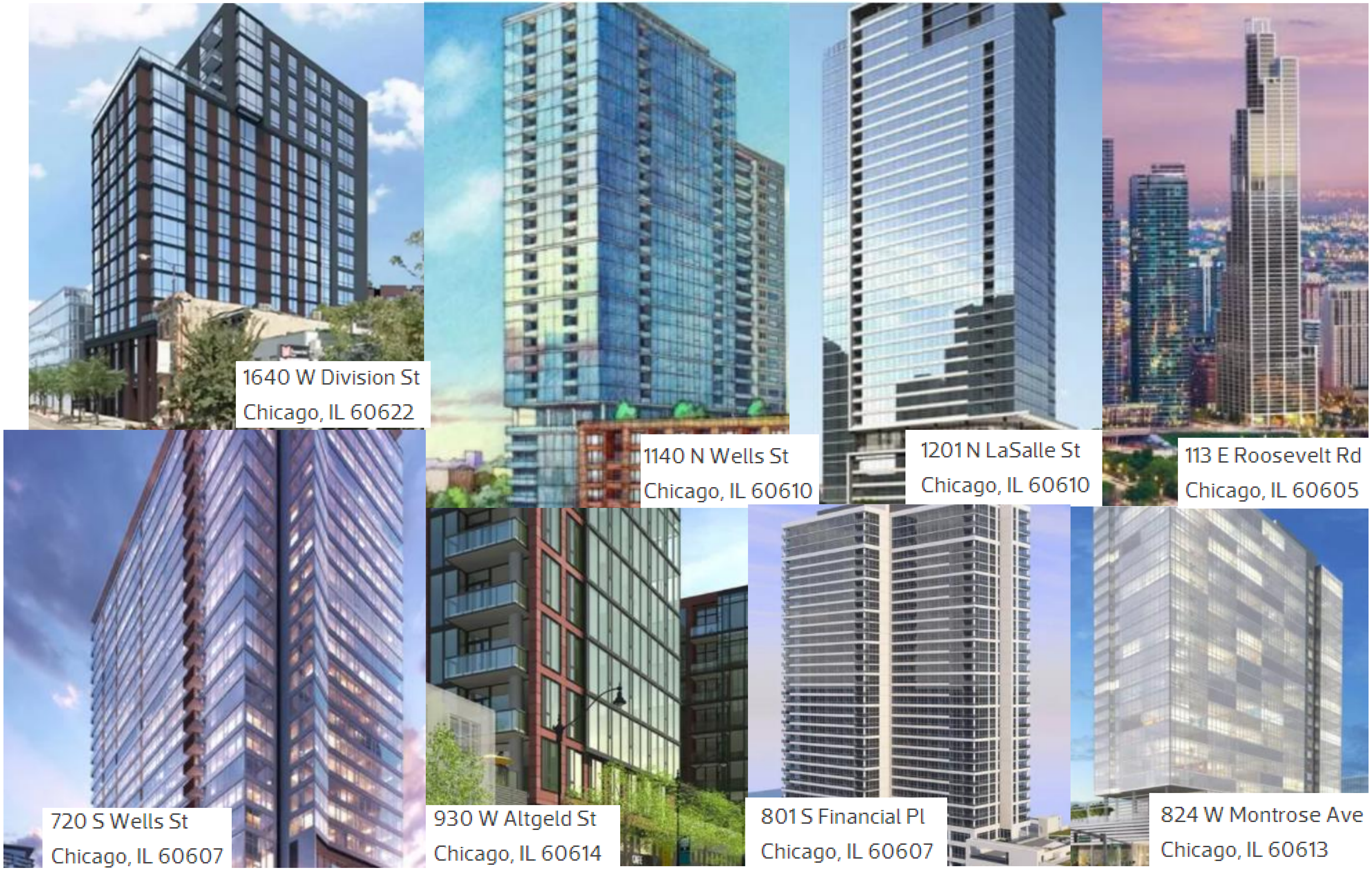
3) **Construction Types / Thermal Mass**

   Wood-framed, concrete/insulated concrete forms

4) **Orientation of units**

   Southwest, Northeast

BUT IN REALITY…



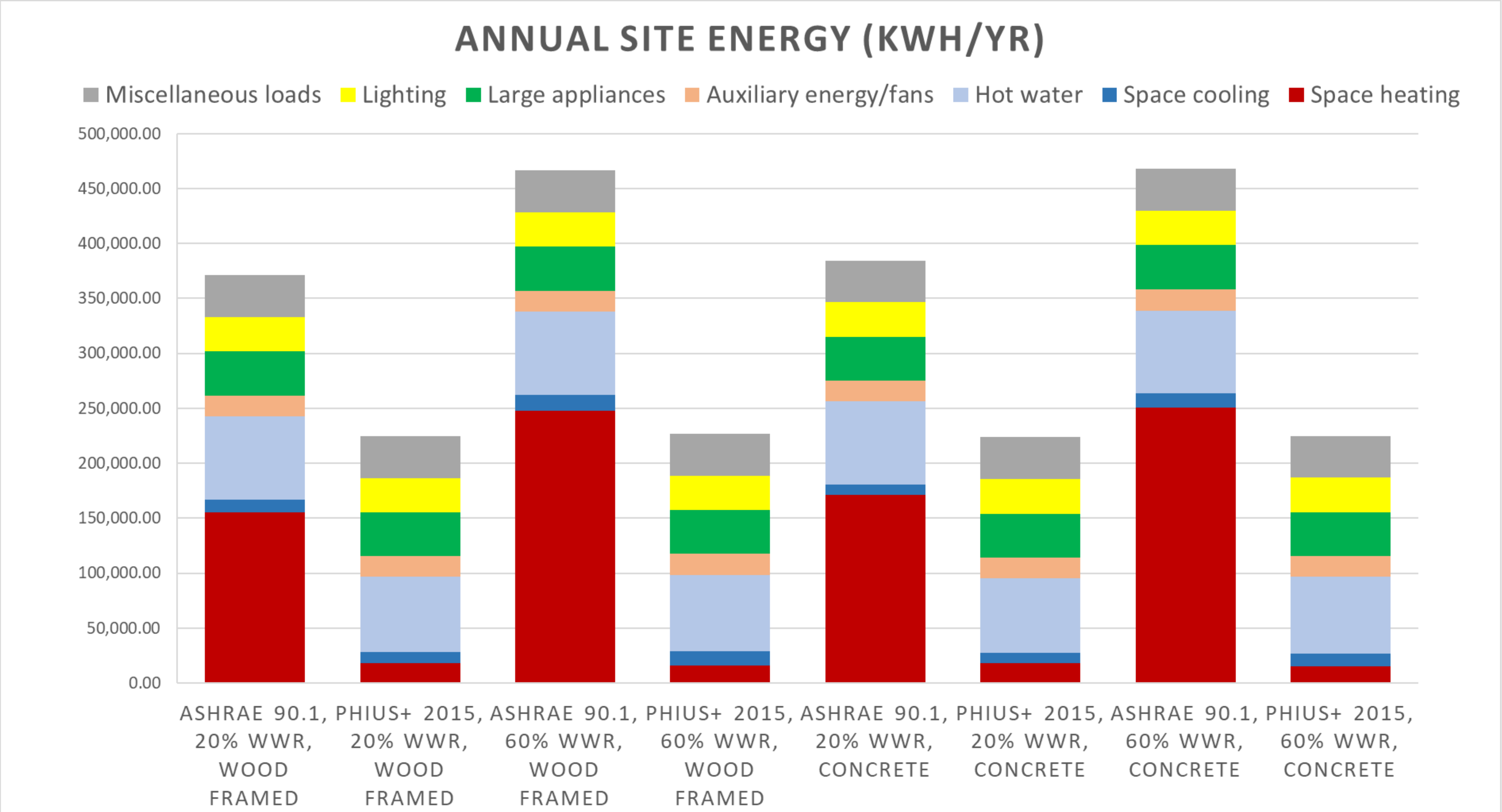
Picture Courtesy of Curbed Chicago

8 Unique Building Types

Main Characteristics

Window to Wall Ratio		20% WWR				60% WWR			
Construction Type		WOOD FRAMED CONST.		ICF/CONCRETE CONST.		WOOD FRAMED CONST.		ICF/CONCRETE CONST.	
Performance Standard		ASHRAE 90.1	PHIUS+ 2015	ASHRAE 90.1	PHIUS+ 2015	ASHRAE 90.1	PHIUS+ 2015	ASHRAE 90.1	PHIUS+ 2015
Opaque Building Envelope	Wall	R13+7.5ci	R22 + 8ci	R13.3 ci	R24 ci	R13+7.5ci	R22 + 8ci	R13.3 ci	R32 ci
	Roof	R49 Attic	R49 Attic	R30 ci	R36 ci	R49 Attic	R49 Attic	R30 ci	R36 ci
	Floor Slab	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated	R4 Slab	Uninsulated	R4 Slab
	Perimeter Insulation	R20 for 24"	N/A	R20 for 24"	N/A	R20 for 24"	N/A	R20 for 24"	N/A
	Specific Heat Capacity [BTU/ft2.F]	11 (Lightweight)		23 (Mixed)		11 (Lightweight)		23 (Mixed)	
Windows	Operability	All operable							
	SHGC (glass only)	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.2
	U-Value, Whole Window [BTU/hr.ft2.F]	0.46	0.25	0.46	0.25	0.46	0.28	0.46	0.28
Shading	Interior Blinds	80% (20% shaded)							
	Site Shading	80% (20% shaded)							
Infiltration	CFM75/ft2	0.4	0.08	0.4	0.08	0.4	0.08	0.4	0.08
	CFM50/ft2	0.31	0.05	0.31	0.05	0.31	0.05	0.31	0.05
	ACH50	1.95	0.32	1.95	0.32	1.95	0.32	1.95	0.32

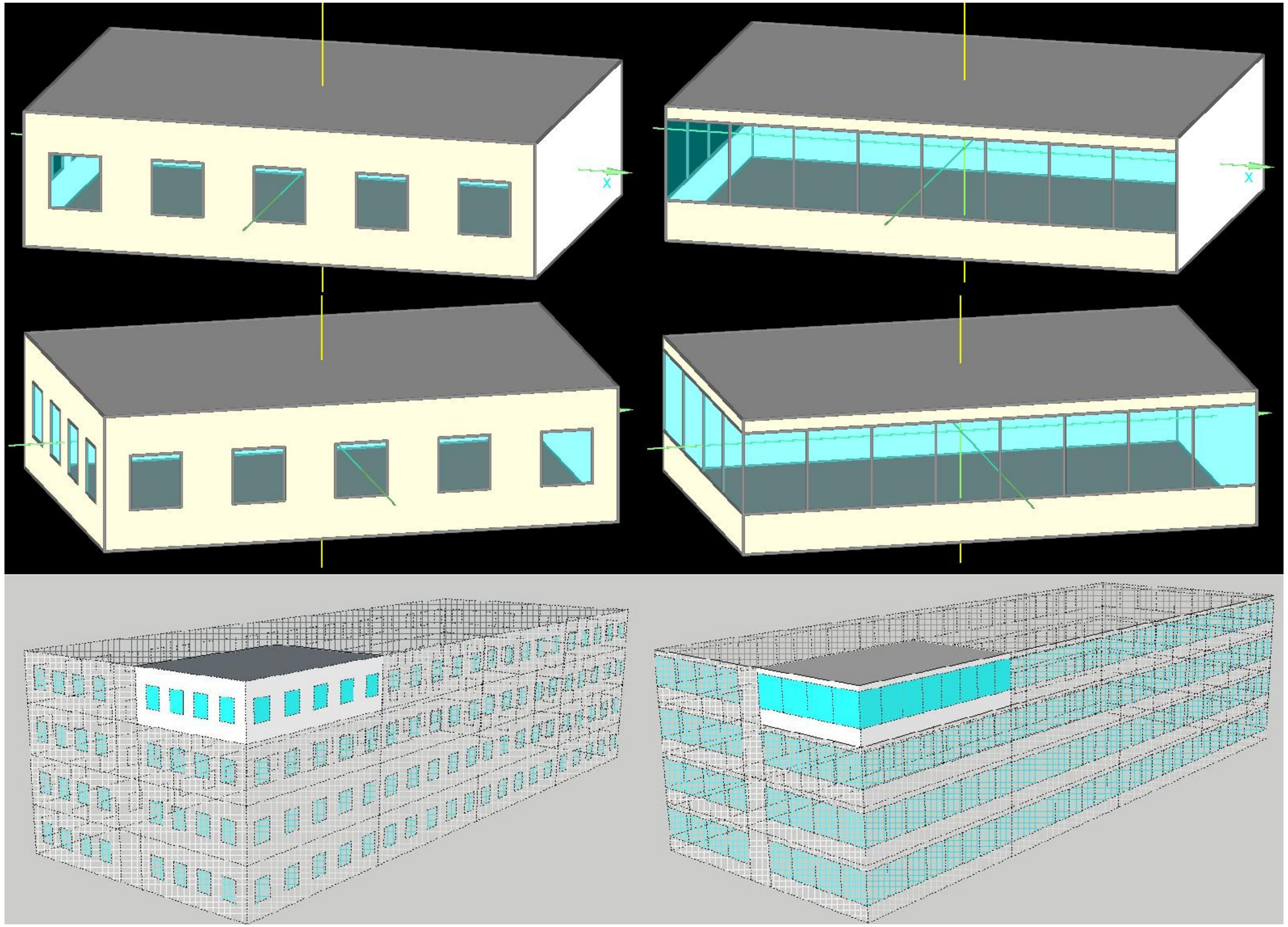
SITE ENERGY



ANNUAL SITE ENERGY (KWH/YR)
Miscellaneous loads
Lighting
Large appliances
Auxiliary energy/fans
Hot water
Space cooling
Space heating
500,000.00
450,000.00
400,000.00
350,000.00
300,000.00
250,000.00
200,000.00
150,000.00
100,000.00
50,000.00
0.00
ASHRAE 90.1, 20% WWR, WOOD FRAMED
PHIUS+ 2015, 20% WWR, WOOD FRAMED
ASHRAE 90.1, 60% WWR, WOOD FRAMED
PHIUS+ 2015, 60% WWR, WOOD FRAMED
ASHRAE 90.1, 20% WWR, CONCRETE
PHIUS+ 2015, 20% WWR, CONCRETE
ASHRAE 90.1, 60% WWR, CONCRETE
PHIUS+ 2015, 60% WWR, CONCRETE

OUTAGE SIMULATION SETUP

- 32 dynamic simulations
- Simulate outage during 5-day resilience design week



Cover all combinations of:

- 8 buildings
- 2 unit locations
- 2 seasons

RESILIENCE DESIGN WEEK

- Similar to ASHRAE 99.6% and 0.4% design temperatures used to calculate heating and cooling loads
- 16 years of climate data (1998-2015)
- Look at 5-day moving average temp.
- Create histogram
  - Determine 99.6% temperature, choose hour with lowest global radiation
  - Determine 0.4% temperature, choose hour with highest global radiation
- Winter and summer resilience design weeks start at midnight on day that hour occurs

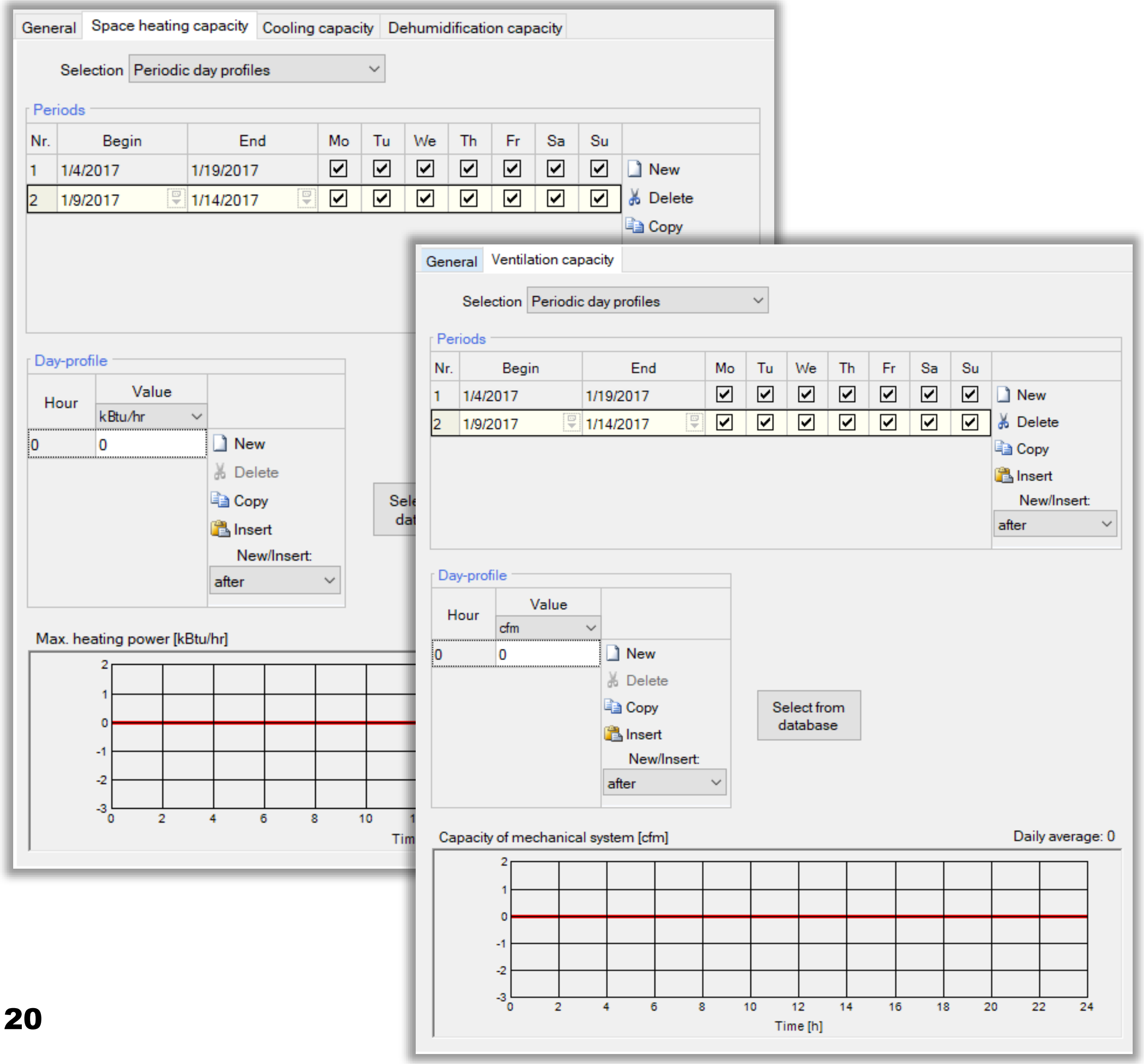
Chicago:

Winter – January 9-14, 1999

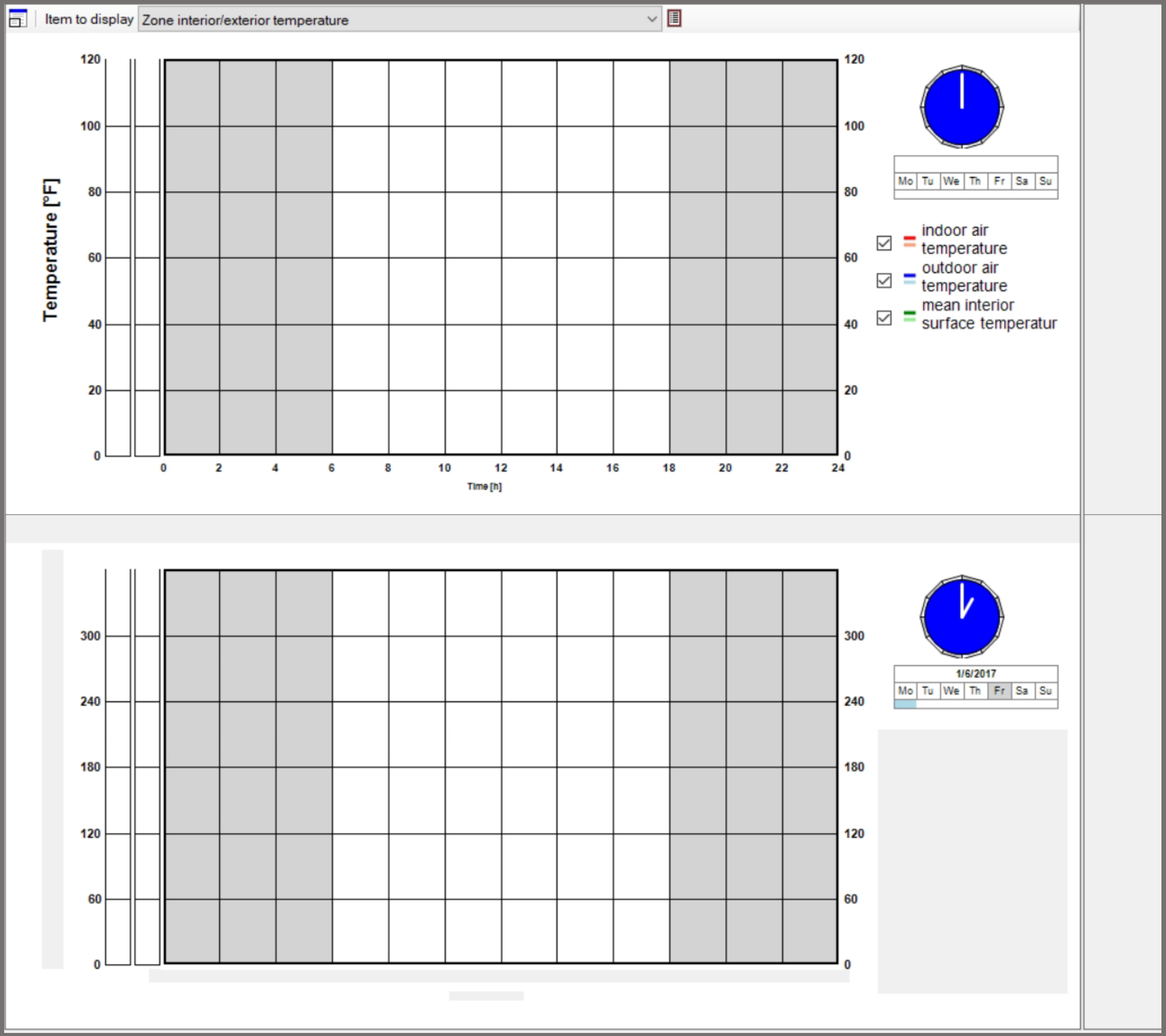
Summer – August 3-8, 2007

OUTAGE SIMULATION SETUP

- Hourly modeling tool (WUFIplus)
- Remove heating and cooling capacity
- Remove ventilation capacity
  - Some natural ventilation in both summer and winter
- Internal gains/loads in the space reduced to occupant only, no lighting, appliances, or miscellaneous loads
  - Should use mostly flat load profile rather than typical day



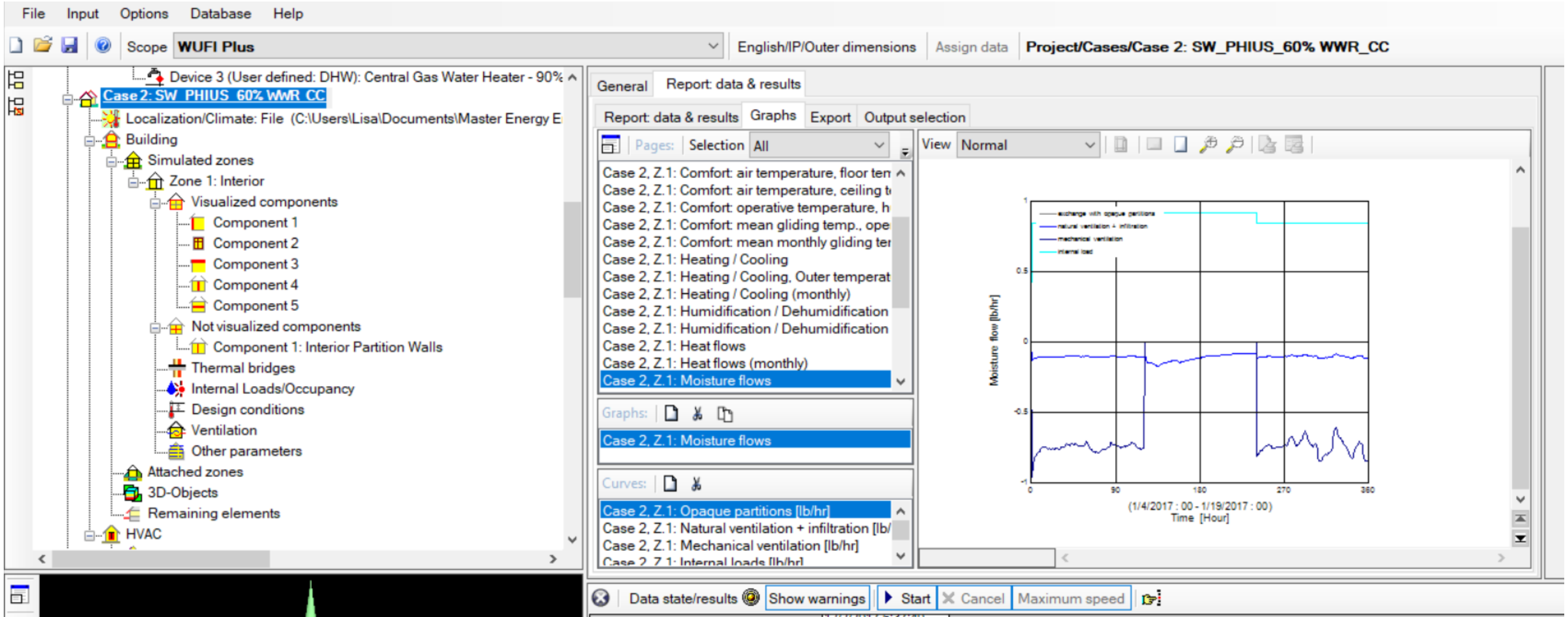
WUFIplus Simulation



Interior Temperature

Solar Radiation

Modeling Software - WUFIplus



Last calculation	[date/time]	12/2/2017 6:37:40 PM	Date & time of last calculation
Calculation period	[hr]	360	1/4/2017 : 00 - 1/19/2017 : 00
Heating	[kBtu]	1411	Calculated sum of heating energy
Cooling	[kBtu]	0	Calculated sum of cooling energy
Humidification	[lb]	0	Calculated sum of humidification
Dehumidification	[lb]	0	Calculated sum of dehumidification
Min. Ti	[°F]	46.6	Minimal interior temperature
Max. Ti	[°F]	72.6	Maximal interior temperature
Min. RHi	[%]	41.9	Minimal interior rel. humidity
Max. RHi	[%]	100	Maximal interior rel. humidity
Max. iterations	[-]	16	Maximal count of iterations
Calculation time	[d,h,min,sec]	4sec	Total calc. time
Convergence errors	[-]	0	Count of covergence errors

WINTER RESILIENCE RESULTS

								% of Hours in Simulation Above Threshold Temperature											
Case	Season	Const. Type	Orientation	Standard	WWR %	Avg. Temp.	Min. Temp.	>65°F	>60°F	>55°F	>50°F	>45°F	< 40°F	< 35°F	< 30°F	>25°F	>20°F	>15°F	>10°F
1	Winter	Wood framed	SW	PHIUS	20	43.8	29.2	3%	14%	21%	32%	42%	53%	68%	97%	100%	100%	100%	100%
2					60	50.9	33.5	13%	27%	41%	47%	61%	78%	97%	100%	100%	100%	100%	100%
3				ASHRAE	20	32.0	18.1	0%	3%	7%	15%	19%	23%	36%	42%	54%	91%	100%	100%
4					60	28.5	14.4	0%	1%	6%	12%	17%	20%	27%	38%	41%	61%	98%	100%
5			NE	PHIUS	20	40.4	27.1	3%	8%	16%	22%	33%	42%	55%	81%	100%	100%	100%	100%
6					60	35.5	22.9	3%	5%	13%	18%	22%	33%	39%	47%	83%	100%	100%	100%
7				ASHRAE	20	30.3	17.7	2%	5%	8%	13%	18%	22%	28%	38%	45%	79%	100%	100%
8					60	21.8	10.3	2%	3%	4%	6%	8%	13%	16%	18%	22%	36%	60%	100%
9		Concrete/ICF	SW	PHIUS	20	57.6	49.2	12%	37%	62%	95%	100%	100%	100%	100%	100%	100%	100%	100%
10					60	57.3	46.8	11%	39%	59%	83%	100%	100%	100%	100%	100%	100%	100%	100%
11				ASHRAE	20	49.2	36.8	3%	16%	27%	42%	61%	84%	100%	100%	100%	100%	100%	100%
12					60	42.9	27.5	2%	10%	18%	29%	39%	48%	68%	93%	100%	100%	100%	100%
13			NE	PHIUS	20	56.3	47.9	7%	28%	53%	85%	100%	100%	100%	100%	100%	100%	100%	100%
14					60	53.2	43.1	3%	19%	38%	60%	93%	100%	100%	100%	100%	100%	100%	100%
15				ASHRAE	20	48.1	35.7	3%	13%	23%	38%	55%	79%	100%	100%	100%	100%	100%	100%
16					60	39.7	25.4	2%	6%	14%	20%	33%	40%	56%	78%	100%	100%	100%	100%

Percentage of hours ***above*** threshold temperature shown across the top

<50% = red

50-90% = yellow

>90% = green

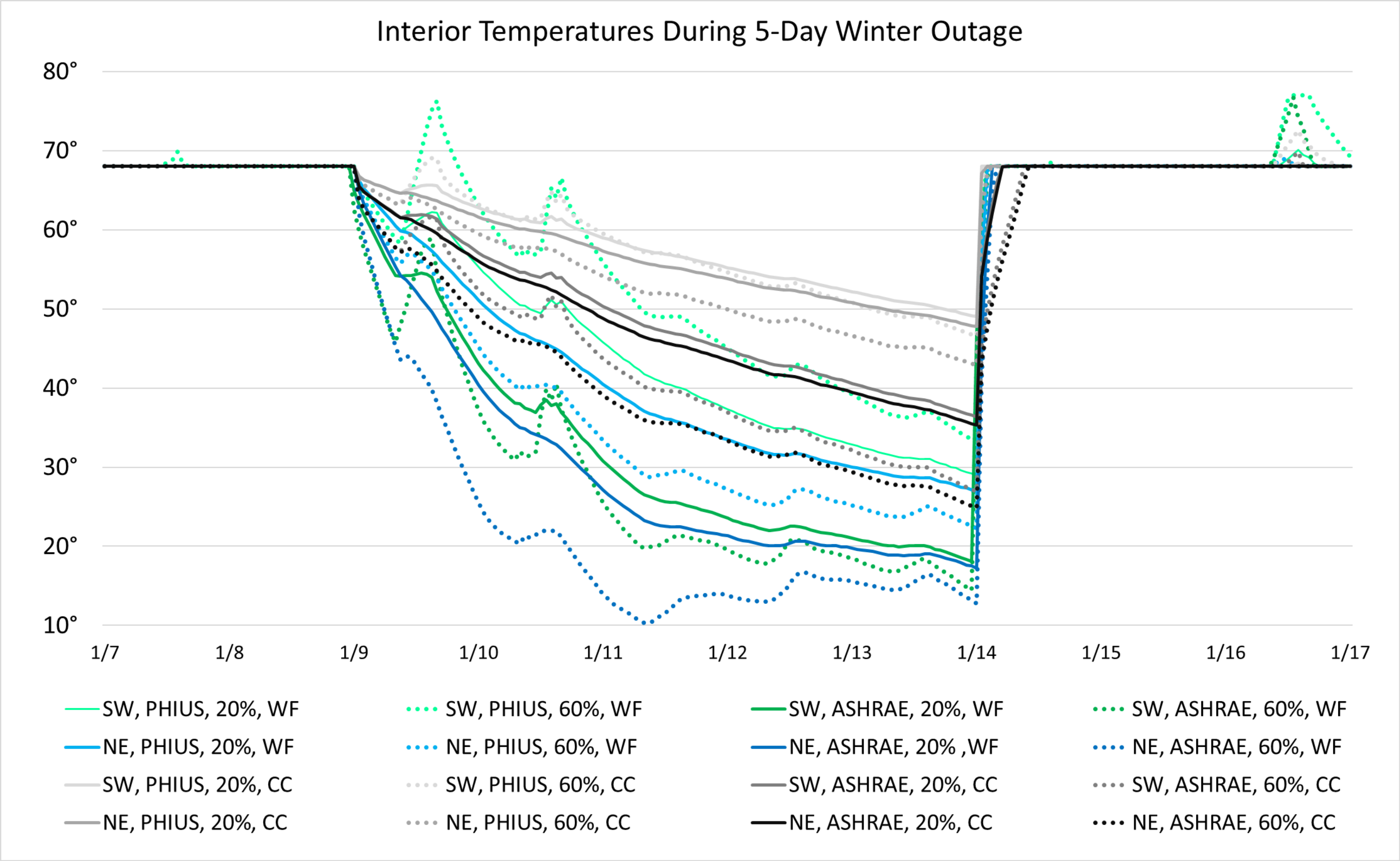
WINTER RESILIENCE RESULTS

Case #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Season	Winter															
Construction Type	Wood framed								Concrete/ICF							
Orientation	SW				NE				SW				NE			
Standard	PHIUS		ASHRAE		PHIUS		ASHRAE		PHIUS		ASHRAE		PHIUS		ASHRAE	
WWR (%)	20	60	20	60	20	60	20	60	20	60	20	60	20	60	20	60
°F dropped in 1 hour	1.8	2.3	1.7	2.7	1.8	2.8	3.1	6.0	1.3	1.8	2.5	4.2	1.3	1.8	2.5	4.2
°F dropped in 4 hours	4.4	5.3	5.7	9.1	4.4	6.8	7.5	13.9	2.3	3.2	4.2	7.1	2.3	3.2	4.2	7.1
°F dropped in 12 hours	6.9	1.0	10.5	7.6	9.1	11.3	15.9	25.0	2.7	1.1	6.2	7.7	3.6	4.2	7.1	10.9
Temp (°F) at 1 AM Day 1	66.2	65.8	63.2	59.8	66.2	65.2	64.9	62.0	66.7	66.2	65.5	63.8	66.7	66.2	65.5	63.8
Temp (°F) at 4 AM Day 1	63.6	62.7	59.2	53.4	63.6	61.2	60.5	54.1	65.8	64.8	63.8	60.9	65.8	64.8	63.8	60.9
Temp (°F) at Noon Day 1	61.1	67.0	54.4	54.9	58.9	56.7	52.1	43.0	65.3	66.9	61.8	60.3	64.4	63.8	60.9	57.1

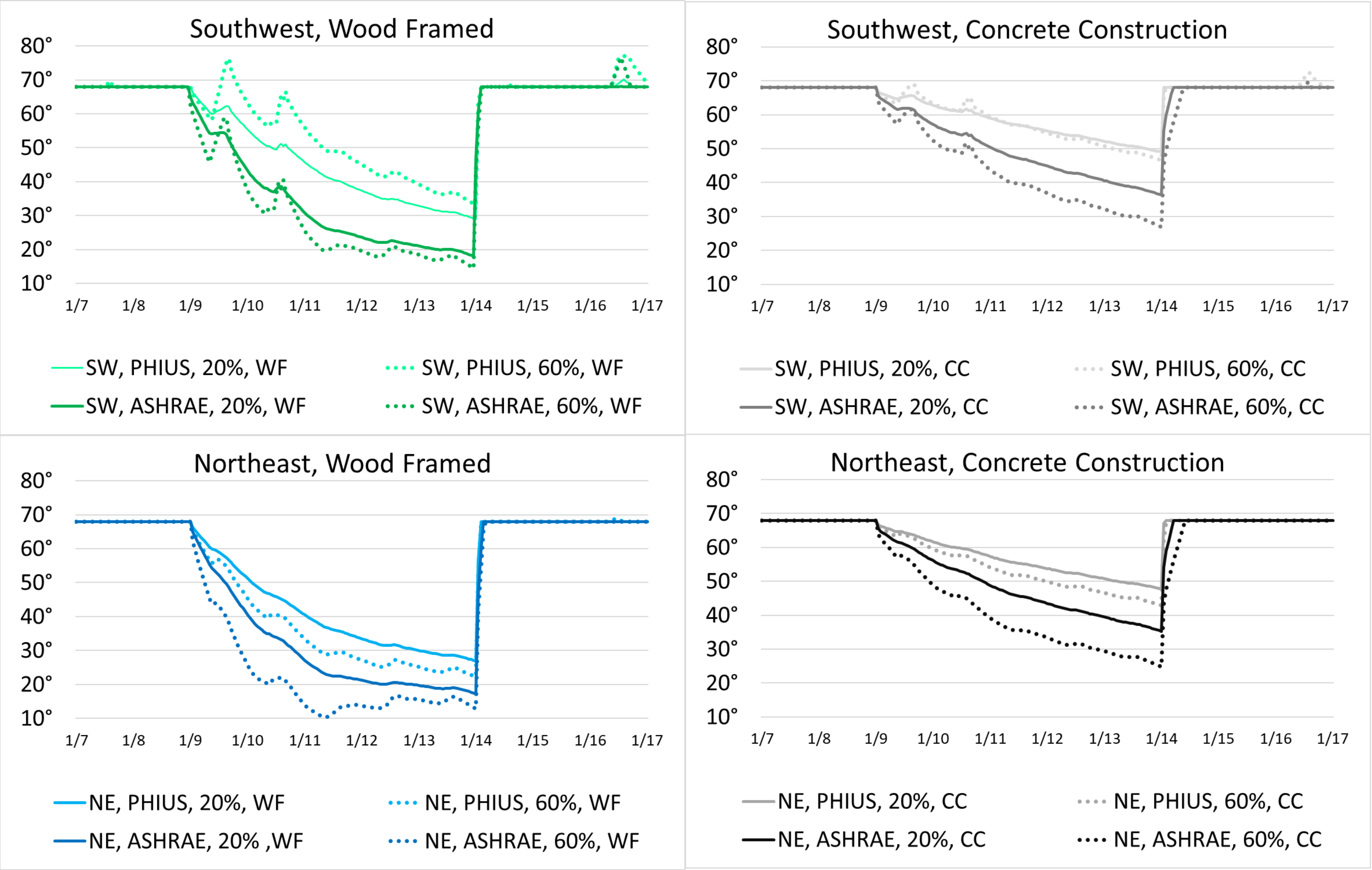
Decrease in interior temperature after 1 hour, 4 hours, and 12 hours

Picture Courtesy of Lisa White

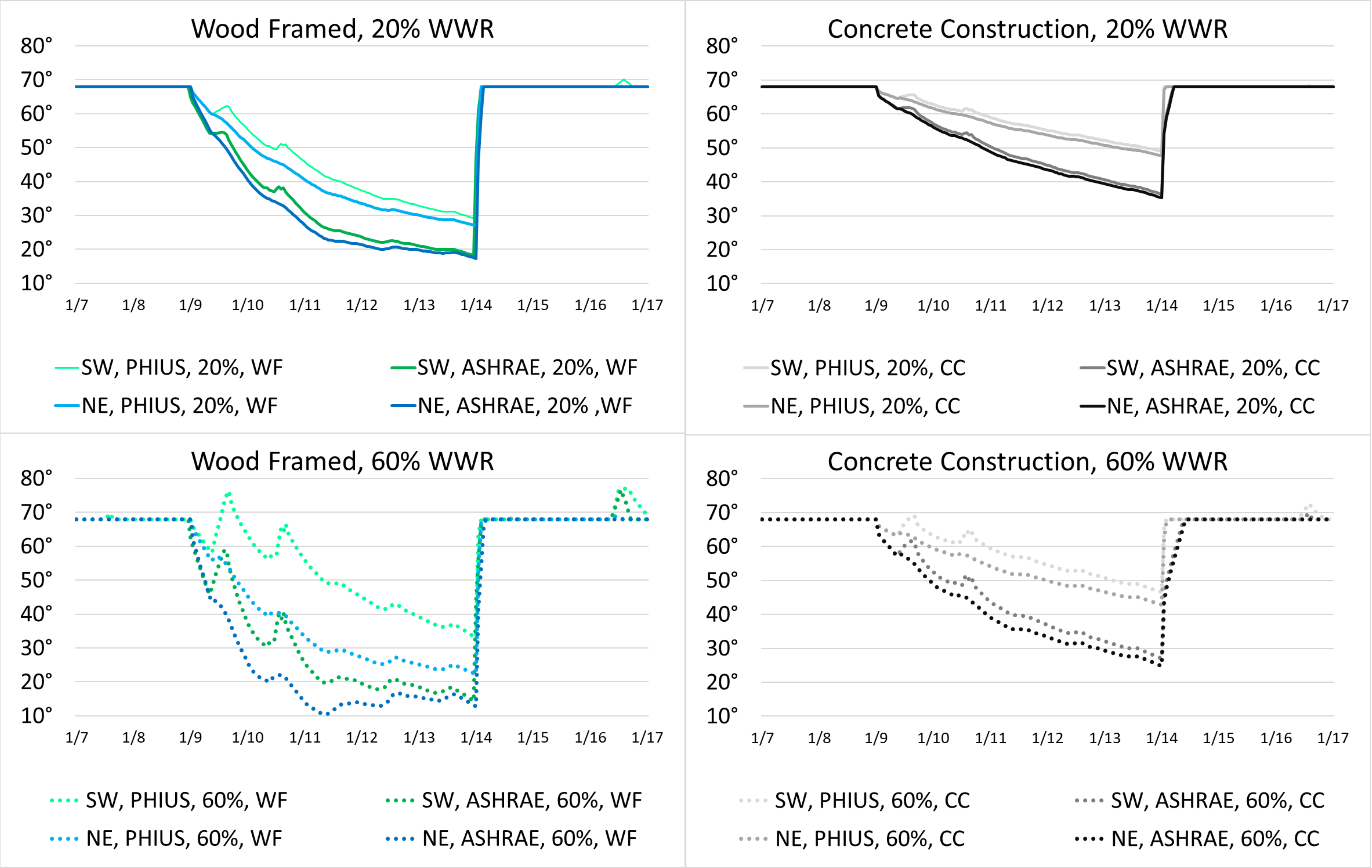
WINTER RESILIENCE RESULTS



WINTER RESILIENCE RESULTS

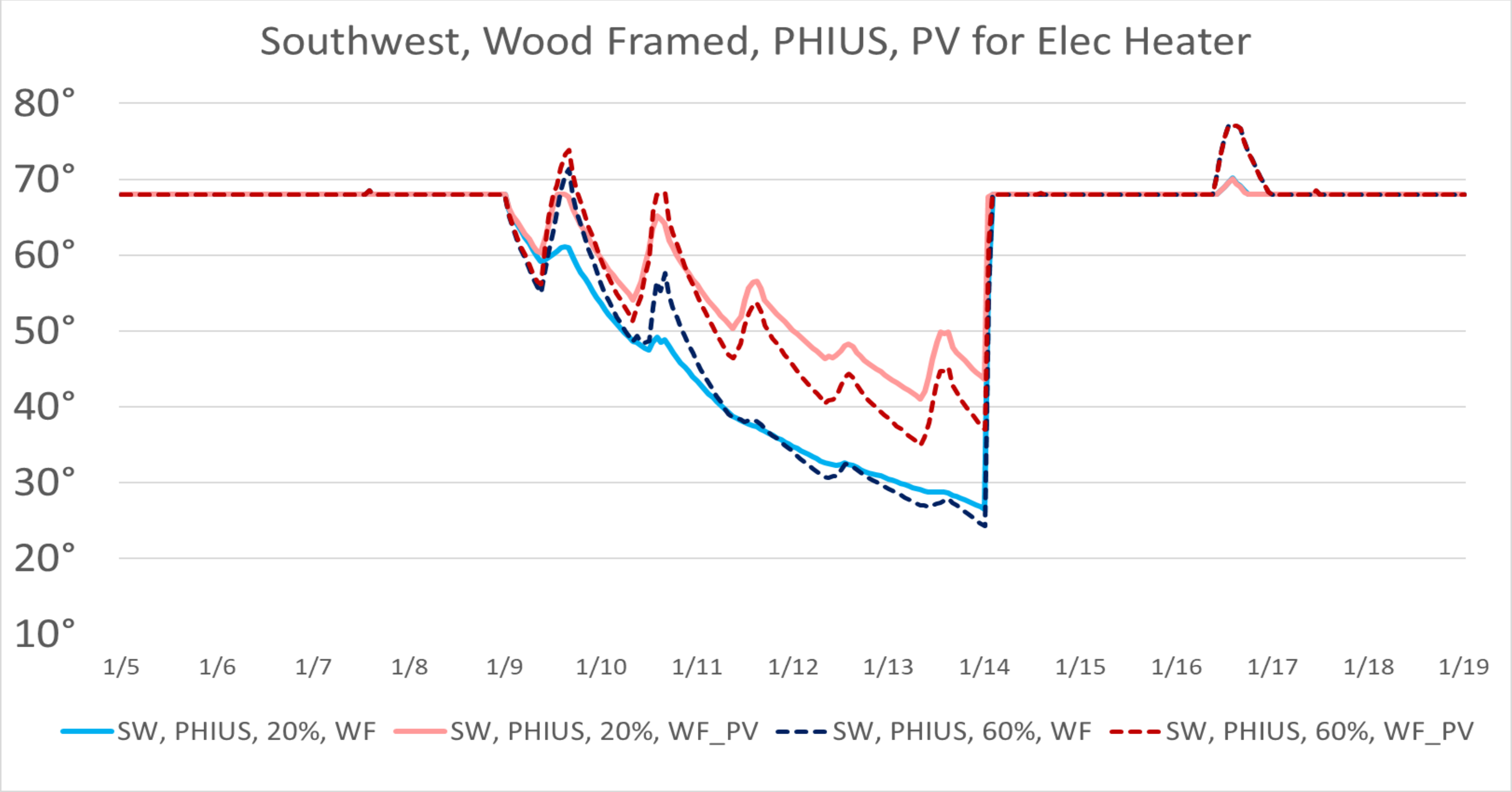


WINTER RESILIENCE RESULTS



WINTER RESILIENCE RESULTS

195 kW array, instantaneous PV output used for ventilation & electric resistance space heating during outage



Picture Courtesy of Lisa White

SUMMER RESILIENCE RESULTS

Summer Resilience Results

								% of Hours in Simulation Below Threshold Temperature							
Case	Season	Const. Type	Orientation	Standard	WWR %	Avg. Temp.	Max. Temp.	< 80°F	< 85°F	< 90°F	< 95°F	< 100°F	< 105°F	< 110°F	< 115°F
17	Summer	Wood framed	SW	PHIUS	20	81.6	94.5	59%	59%	70%	100%	100%	100%	100%	100%
18					60	86.0	110.6	59%	59%	59%	59%	76%	88%	98%	100%
19				ASHRAE	20	80.8	92.7	60%	60%	83%	100%	100%	100%	100%	100%
20					60	83.2	103.8	60%	60%	66%	80%	92%	100%	100%	100%
21			NE	PHIUS	20	81.1	91.9	59%	59%	81%	100%	100%	100%	100%	100%
22					60	84.3	101.9	59%	59%	59%	69%	87%	100%	100%	100%
23				ASHRAE	20	80.5	90.4	59%	59%	93%	100%	100%	100%	100%	100%
24					60	82.1	96.7	59%	59%	72%	88%	100%	100%	100%	100%
25		Concrete/ICF	SW	PHIUS	20	78.3	84.9	59%	100%	100%	100%	100%	100%	100%	100%
26					60	81.3	94.7	59%	59%	80%	100%	100%	100%	100%	100%
27				ASHRAE	20	78.5	85.5	59%	92%	100%	100%	100%	100%	100%	100%
28					60	80.9	93.6	59%	59%	83%	100%	100%	100%	100%	100%
29			NE	PHIUS	20	78.0	83.8	59%	100%	100%	100%	100%	100%	100%	100%
30					60	80.4	90.8	59%	60%	90%	100%	100%	100%	100%	100%
31				ASHRAE	20	78.2	84.4	59%	100%	100%	100%	100%	100%	100%	100%
32					60	80.1	90.0	59%	65%	100%	100%	100%	100%	100%	100%

Percentage of hours ***below*** threshold temperature shown across the top

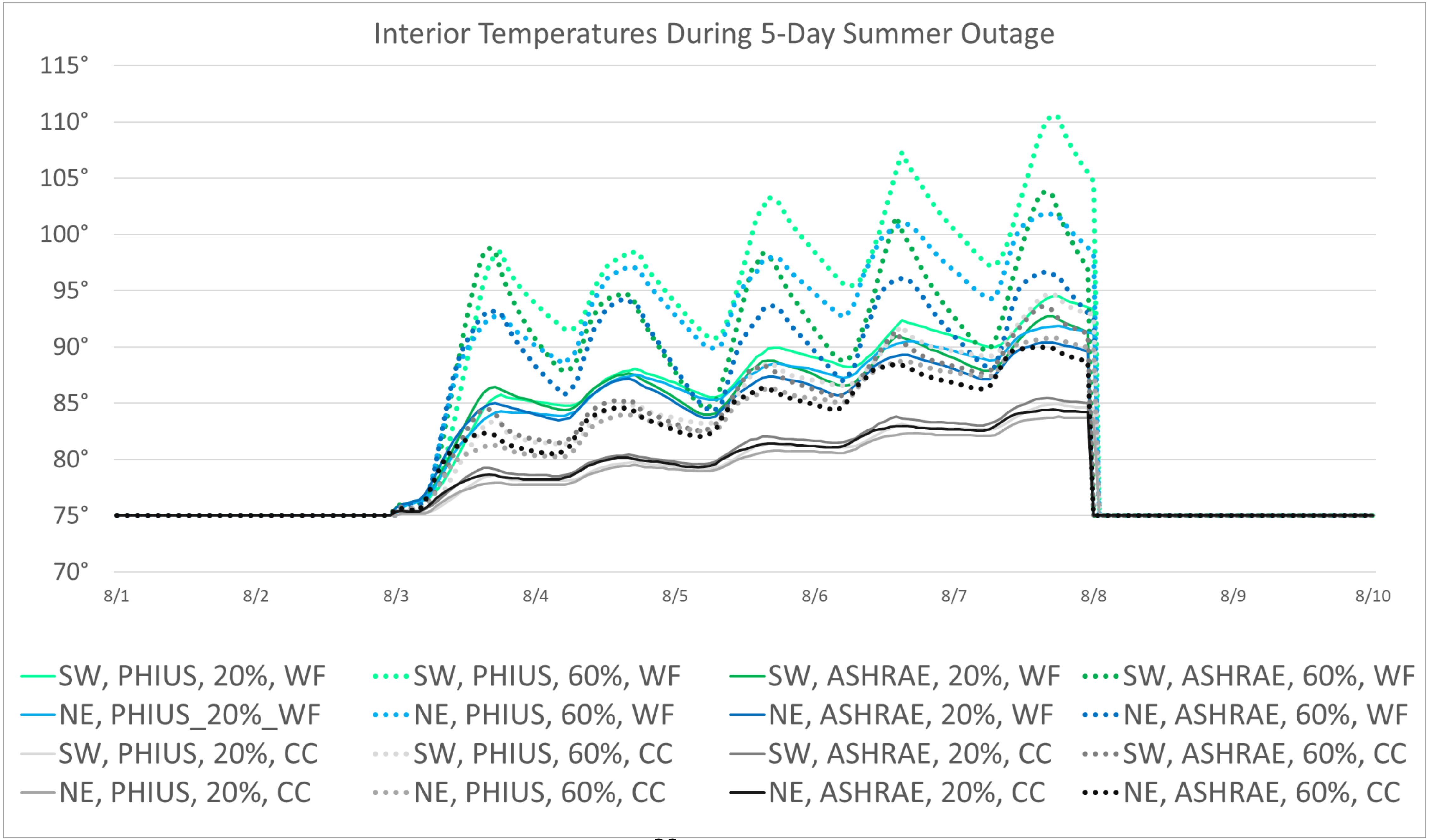
<50% = red

50-90% = yellow

>90% = green

Picture Courtesy of Lisa White

SUMMER RESILIENCE RESULTS



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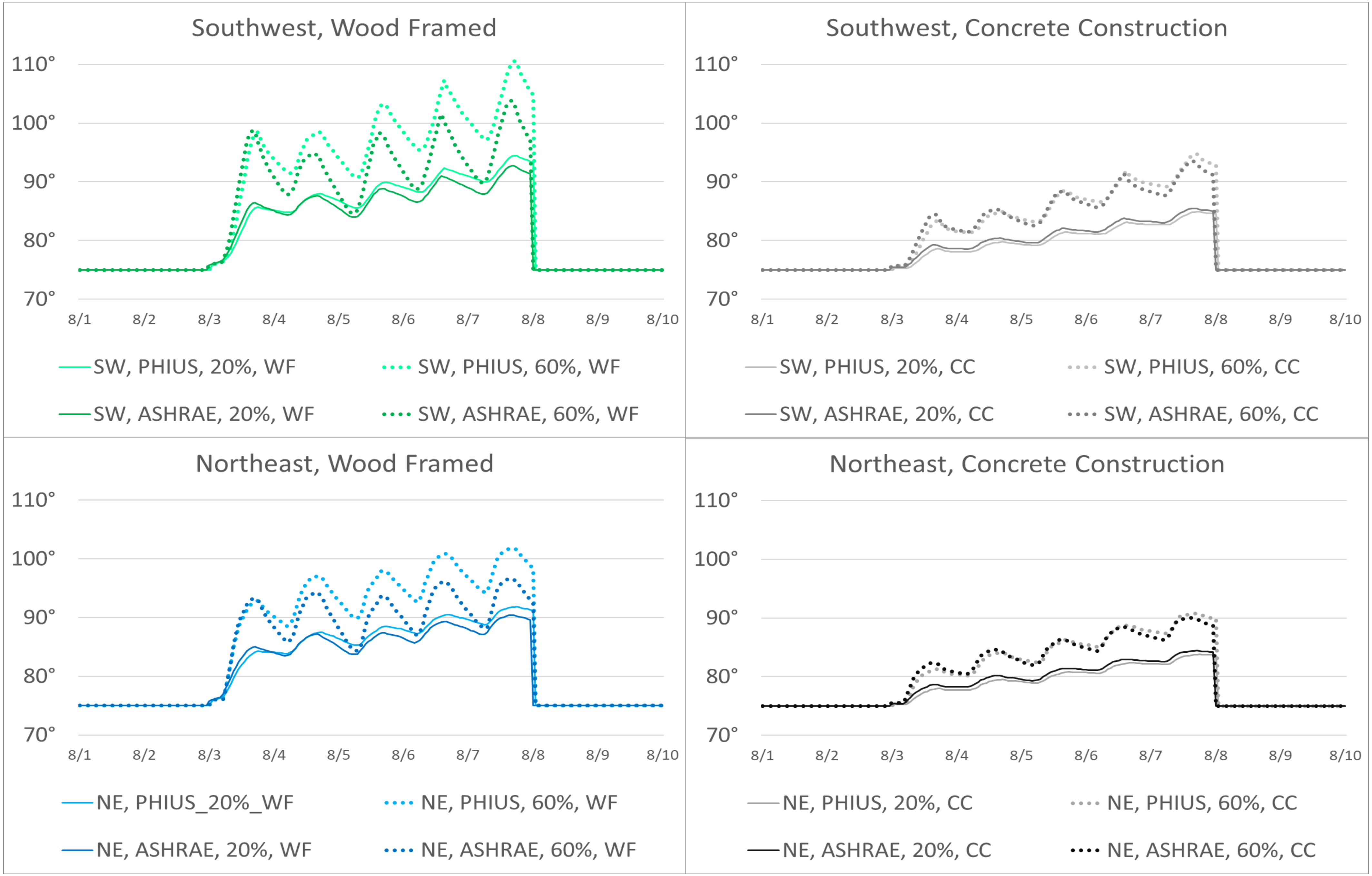

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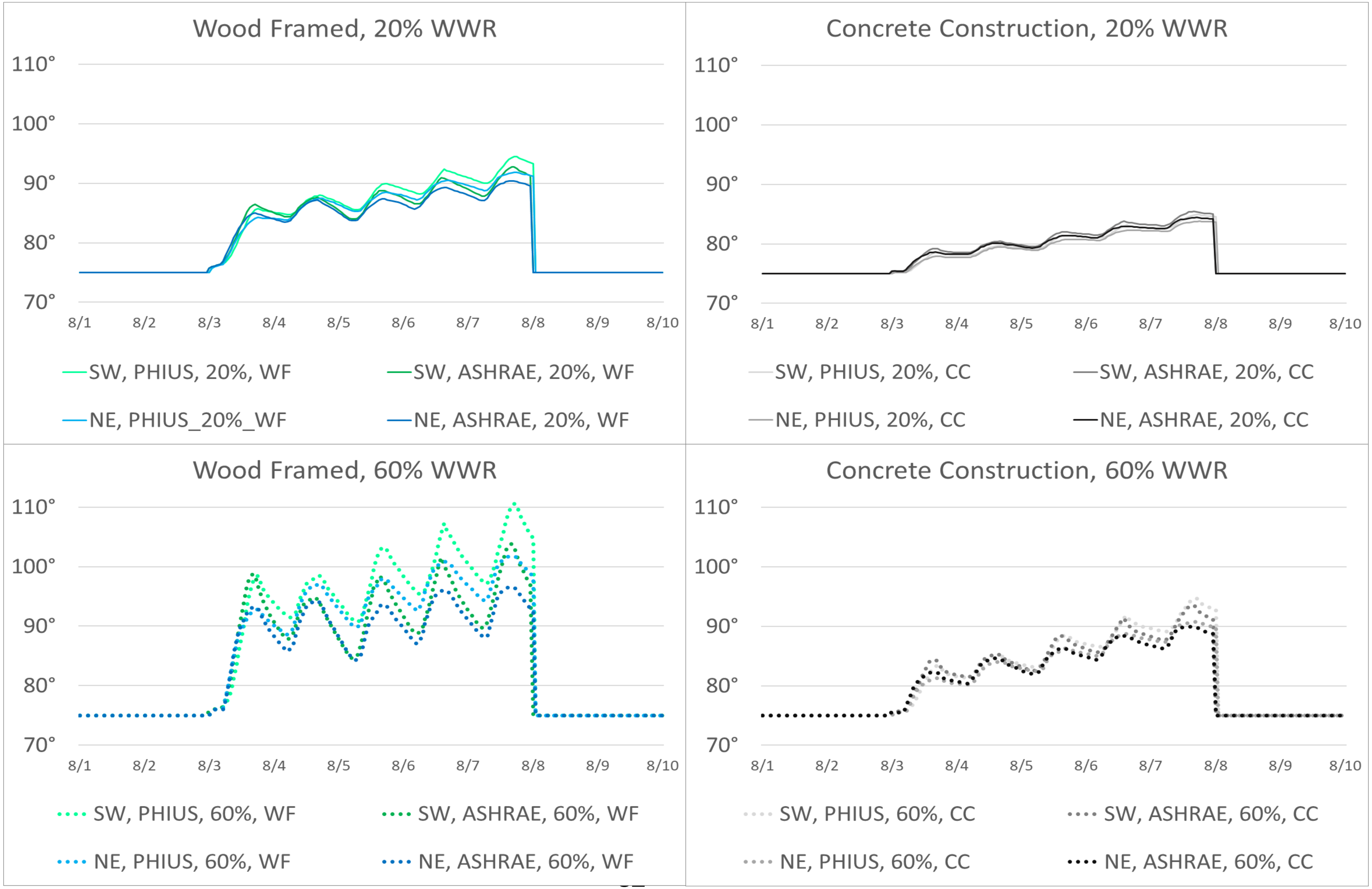
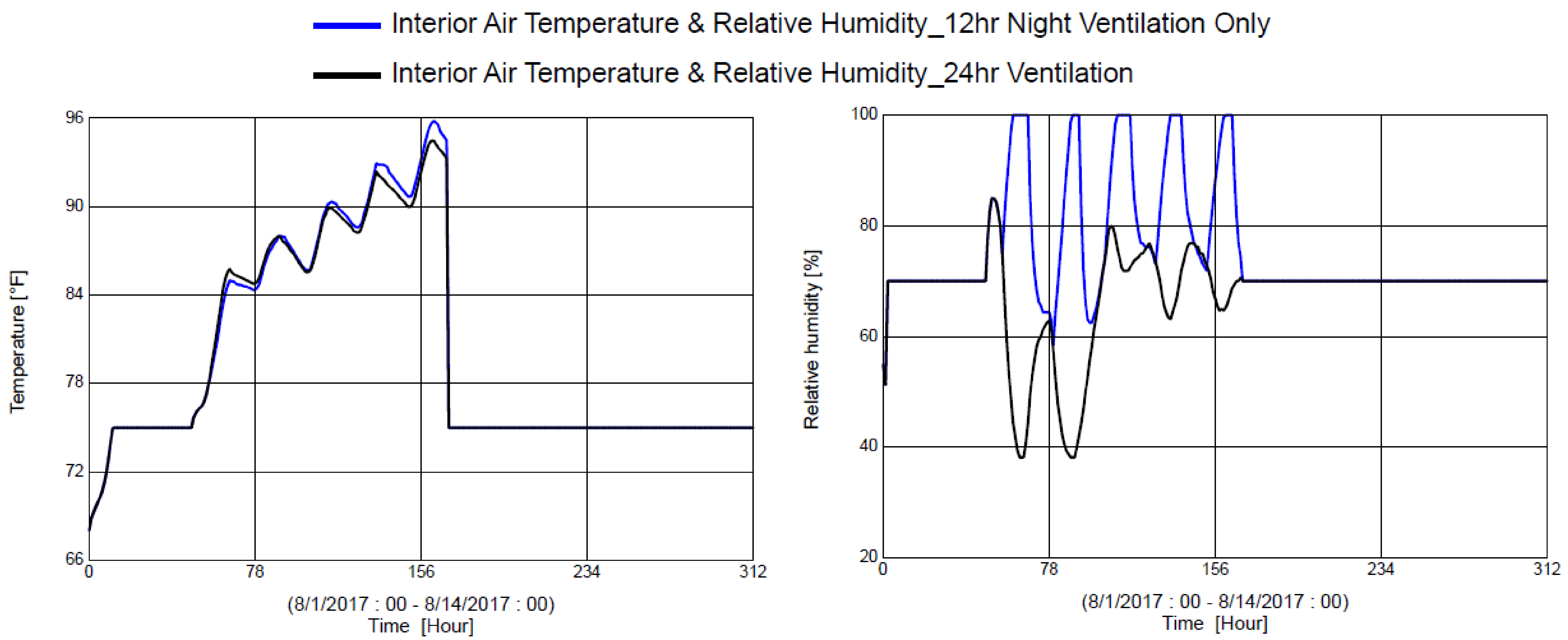
SUMMER RESILIENCE RESULTS



FUTURE OUTLOOK

- Study additional climates
- Study additional designs
- Re-run with future climate data sets
- Study with varying levels of internal gain/occupancy – stress cases
- Study with varying levels of natural ventilation
- Investigate shading strategies
- Detailed airflow model for ventilation
- Small backup power for designated undisturbed loads

Natural vent – summer test



CONCLUSIONS

- Concrete construction has a higher passive survivability rating than wood or steel framed
- Lower window-to-wall ratio and natural ventilation strategies are critical for maintaining favorable conditions during summer outages
- Insulation and air-tightness substantially increase interior temperature during winter outages
- Resilient design strategies need a higher priority and should be quantified and given a higher priority