Simulating PCM Energy Savings in Residential Buildings with EnergyPlus

Buildings XI Conference

Thermal Mass Workshop

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Cambridge, MA, USA

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Motivation: Create a Parametric Model for New Product Development

- Support Building America research plan
- Inform product design by optimizing performance
- Estimate energy savings potential of new PCM technologies

Talk Goals

- Show simulation setup steps
- Show what can be determined
  - wall temperature profiles
  - heat flow profiles
  - energy savings
  - load time shift
  - design load size
- Provide some tips

Input

Simulation Setup Steps

- Create base building construction
- Specify HVAC equipment, sizing options
- Select climate locations
- Define wall segments to study
- Specify basic and advanced material properties

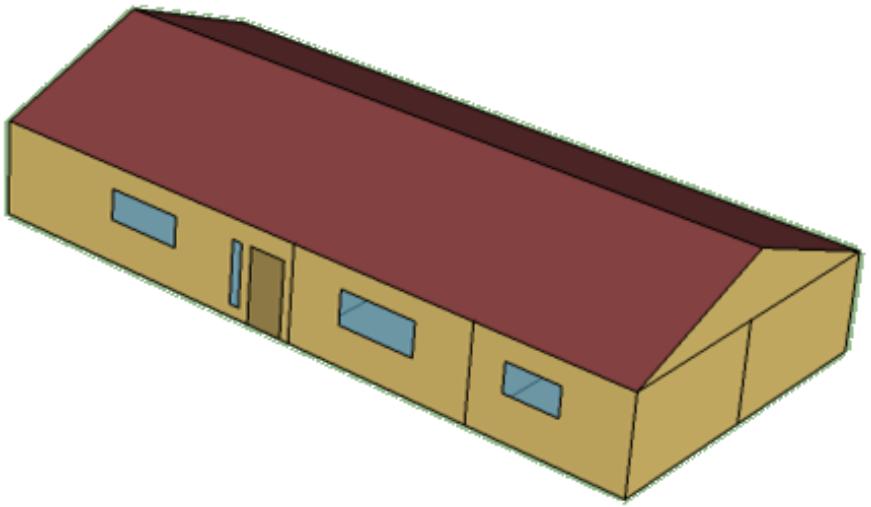
1. Define Simulation Run Parameters

- Consistent simulation run options
  - Conduction Finite Difference Method (even for non-PCM runs!)
  - 60 timesteps per hour (maximum allowable)

- Select run period
  - Whole year, month, week, day?
  - 2 minute run time (for one month simulation)
  - Detailed output creates BIG files

2. Create Base Building Construction

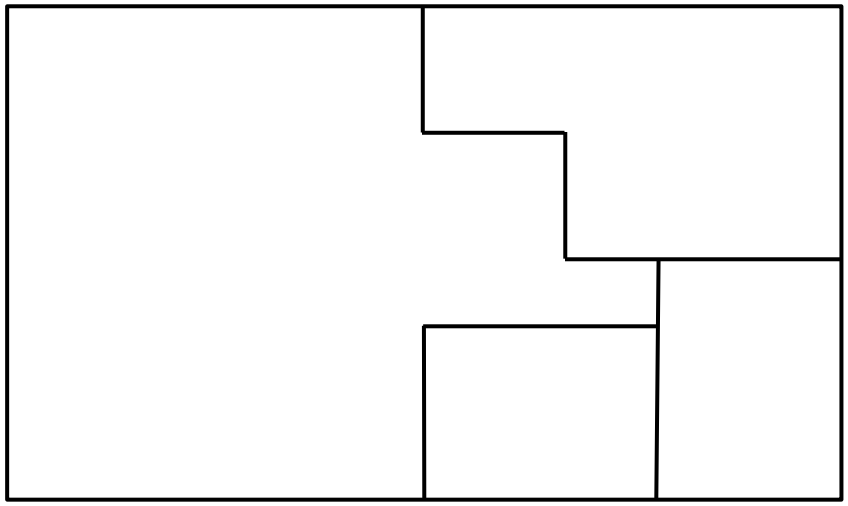
1,625 ft^2 single family, 1-story



- Layout based on prototypical Model Energy Code house

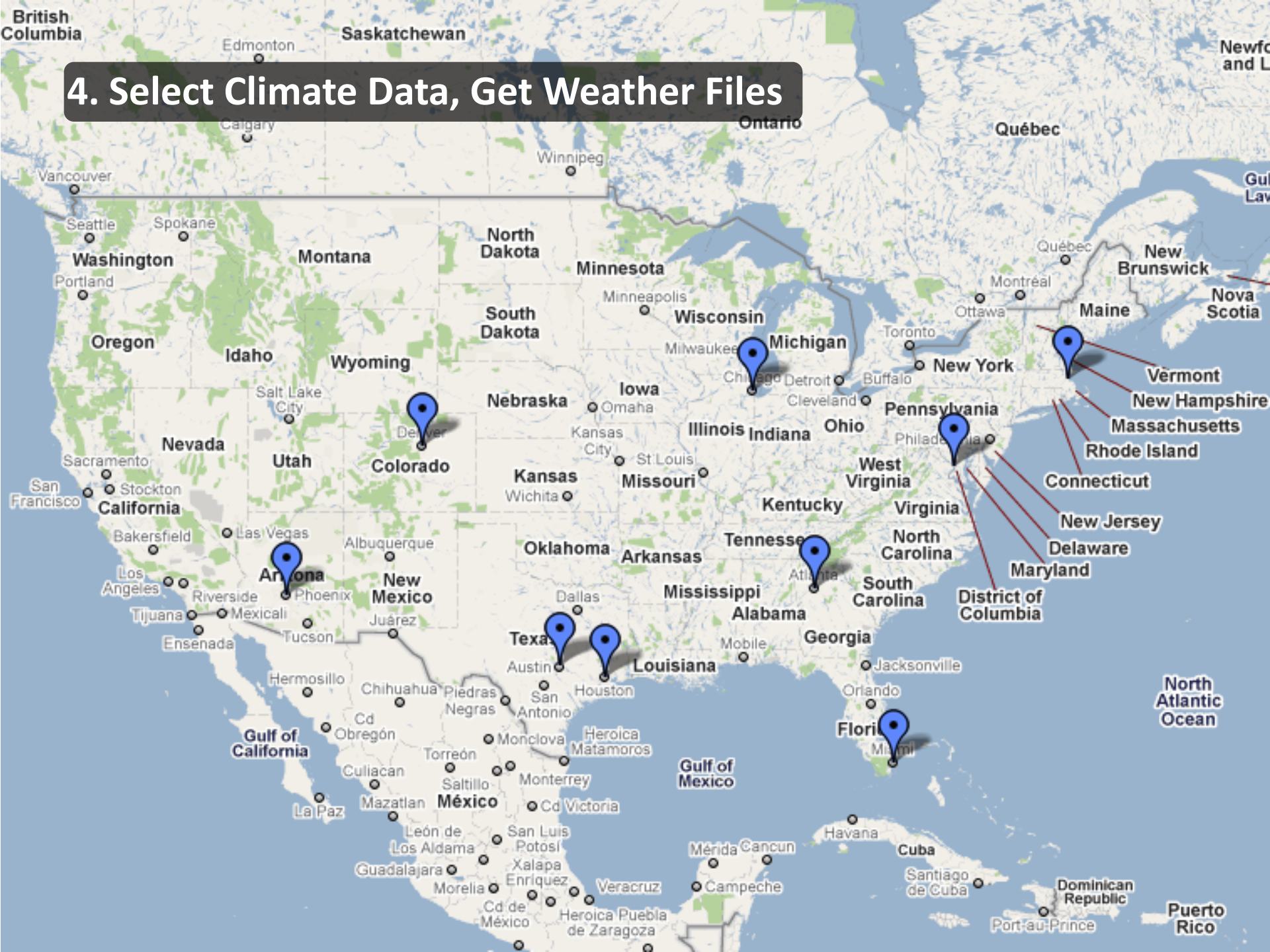
- Getting started
  - E+ comes with a bunch of example buildings
  - DOE commercial reference building models

- Google Sketch Up
  - Open Studio Plugin



3. Specify HVAC Equipment

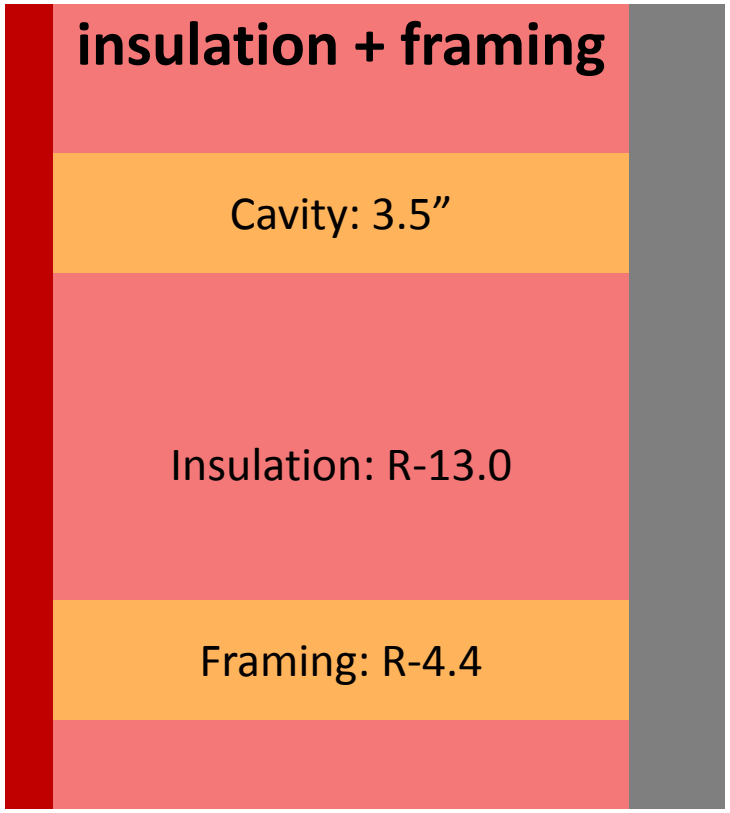
- Cooling: DX cooling coil COP = 3.0
- Heating: Heat pump COP = 2.75
- Fan Ventilation: 0.57 m3/s [1,200 CFM]
- Fan: 60% total efficiency 600 Pa


4. Select Climate Data, Get Weather Files
British Columbia
Saskatchewan
Edmonton
Calgary
Ontario
Québec
Winnipeg
Vancouver
Seattle
Spokane
Washington
Montana
North Dakota
Minnesota
Portland
Oregon
Idaho
Wyoming
South Dakota
Minneapolis
Wisconsin
Michigan
Milwaukee
Chicago
Detroit
Toronto
Ottawa
Montréal
Québec
New Brunswick
Nova Scotia
Maine
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
Virginia
North Carolina
South Carolina
Georgia
Florida
Jacksonville
Orlando
Miami
Mobile
Alabama
Mississippi
Louisiana
Texas
Houston
Austin
San Antonio
Dallas
Oklahoma
Arkansas
Tennessee
Kentucky
West Virginia
Pennsylvania
New York
Buffalo
Cleveland
Ohio
Indiana
Illinois
Missouri
St Louis
Kansas City
Omaha
Nebraska
Iowa
Colorado
Denver
Utah
Salt Lake City
Nevada
Arizona
Phoenix
Las Vegas
New Mexico
Albuquerque
Wichita
Kansas
California
San Francisco
Sacramento
Stockton
Bakersfield
Los Angeles
Riverside
San Diego
Tijuana
Mexicali
Ensenada
Tucson
Juárez
Chihuahua
Hermosillo
Piedras Negras
Monclova
Heroica Matamoros
Torreón
Saltillo
Monterrey
Culiacan
Mazatlan
México
Cd Victoria
La Paz
León de los Aldama
San Luis Potosí
Guadalajara
Morelia
Xalapa Enríquez
Veracruz
Cd de México
Heroica Puebla de Zaragoza
Campeche
Mérida
Cancun
Gulf of California
Gulf of Mexico
Cd Obregón
Havana
Cuba
Santiago de Cuba
Dominican Republic
Port-au-Prince
Puerto Rico
North Atlantic Ocean

5a. Define Exterior Wall Configurations

3 Interior-Facing Configurations:

2 sizes of gypsum board, 1 gypsum board with PCM



Assembly: R-11

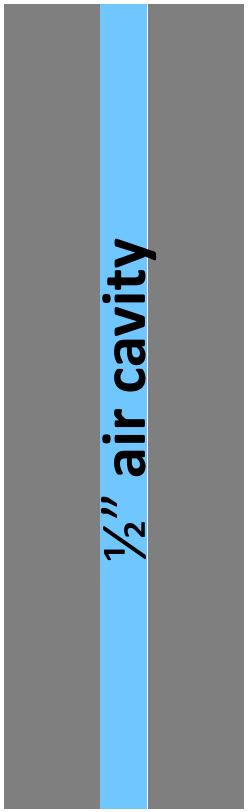
gypsum ½”

gypsum 1”

gypsum +PCM 1”

5b. Define Interior Partition Wall Configurations

3 matching gypsum board configurations



Assembly: R-1.8-2.7

½"gypsum

1" gypsum

1" gypsum-PCM

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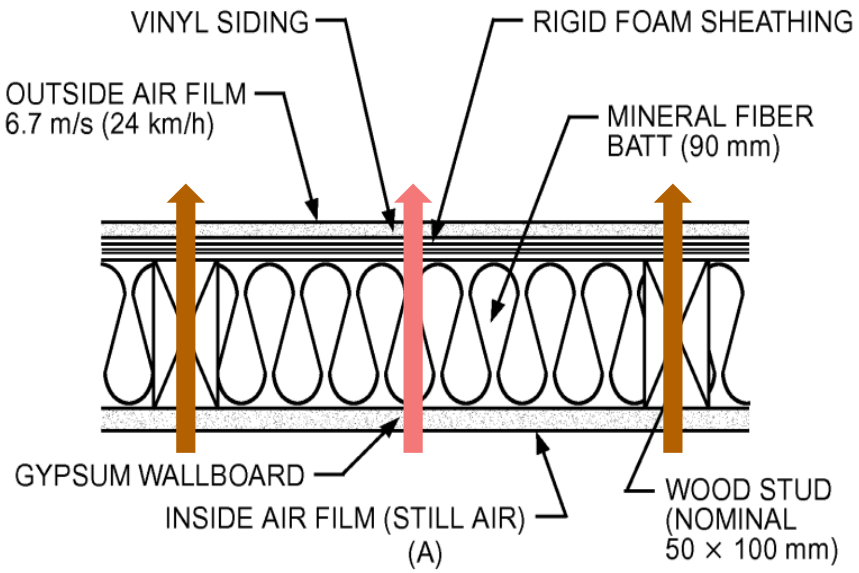
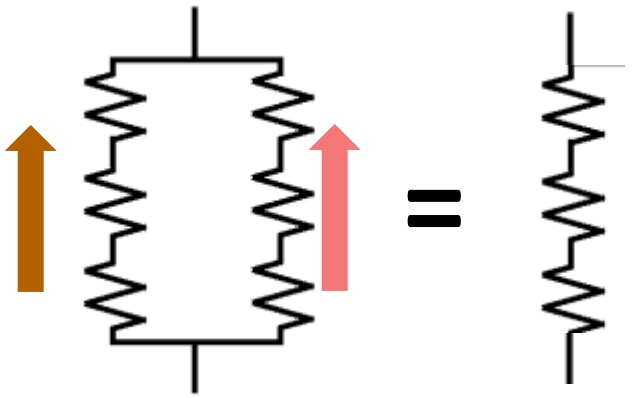
Limitations of Most Building Energy Simulation Tools: Clear Wall vs. Nominal R-Value

- Simulation requires continuous material layers
- Typical US homes have a 25% framing factor
- Single stud wall with R-13 batts can yield R-11 assembly
- Must adjust insulation layer properties to achieve desired nominal or assembly R-Value

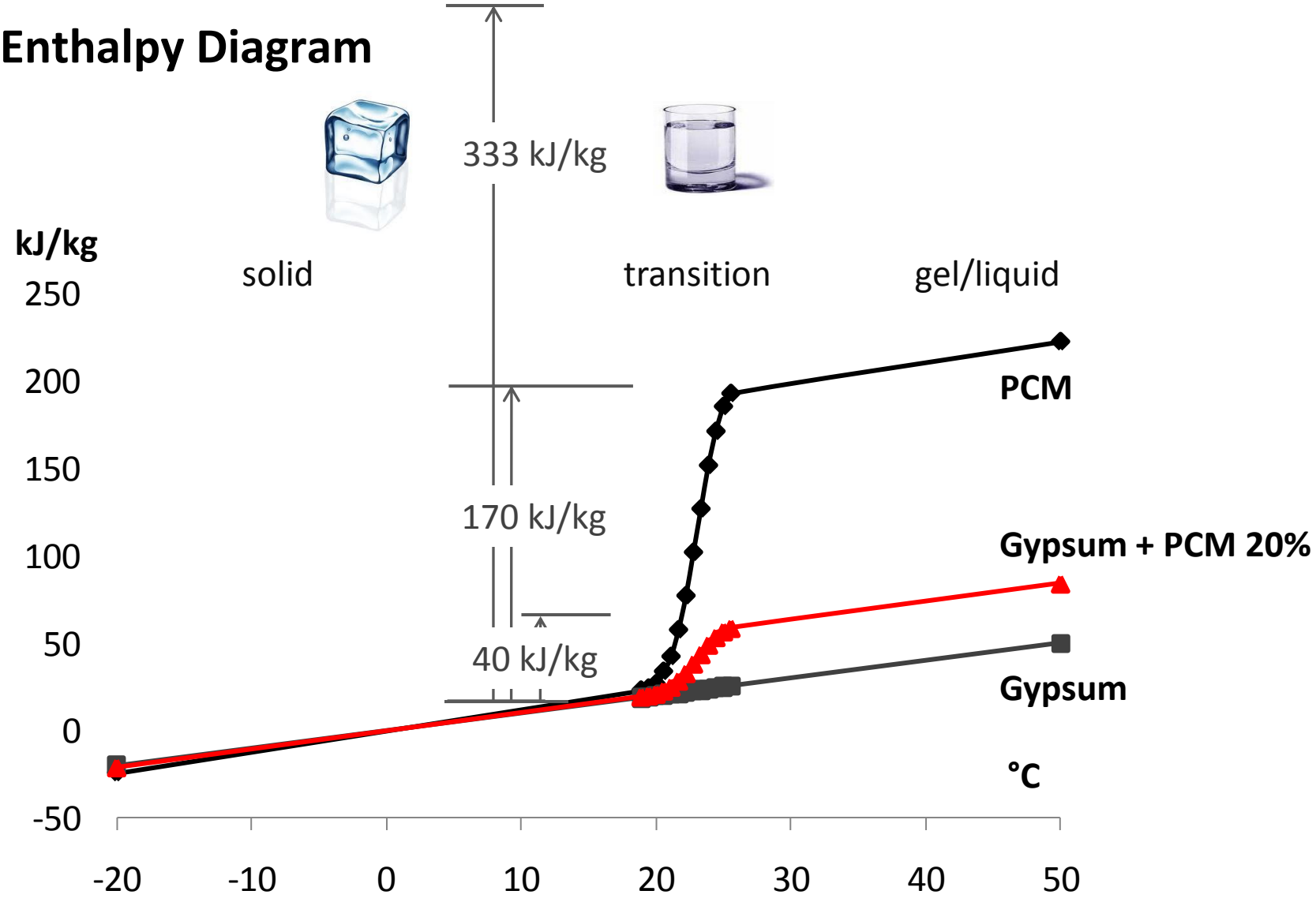
Parallel Paths Method to Find Equivalent R-value for Framing + Insulation Layer





6. Specify Advanced Material Properties

Enthalpy Diagram



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PCM Heat Capacity

c_p= 4.2 kJ/kg·K

c_p= 2.1 kJ/kg·K

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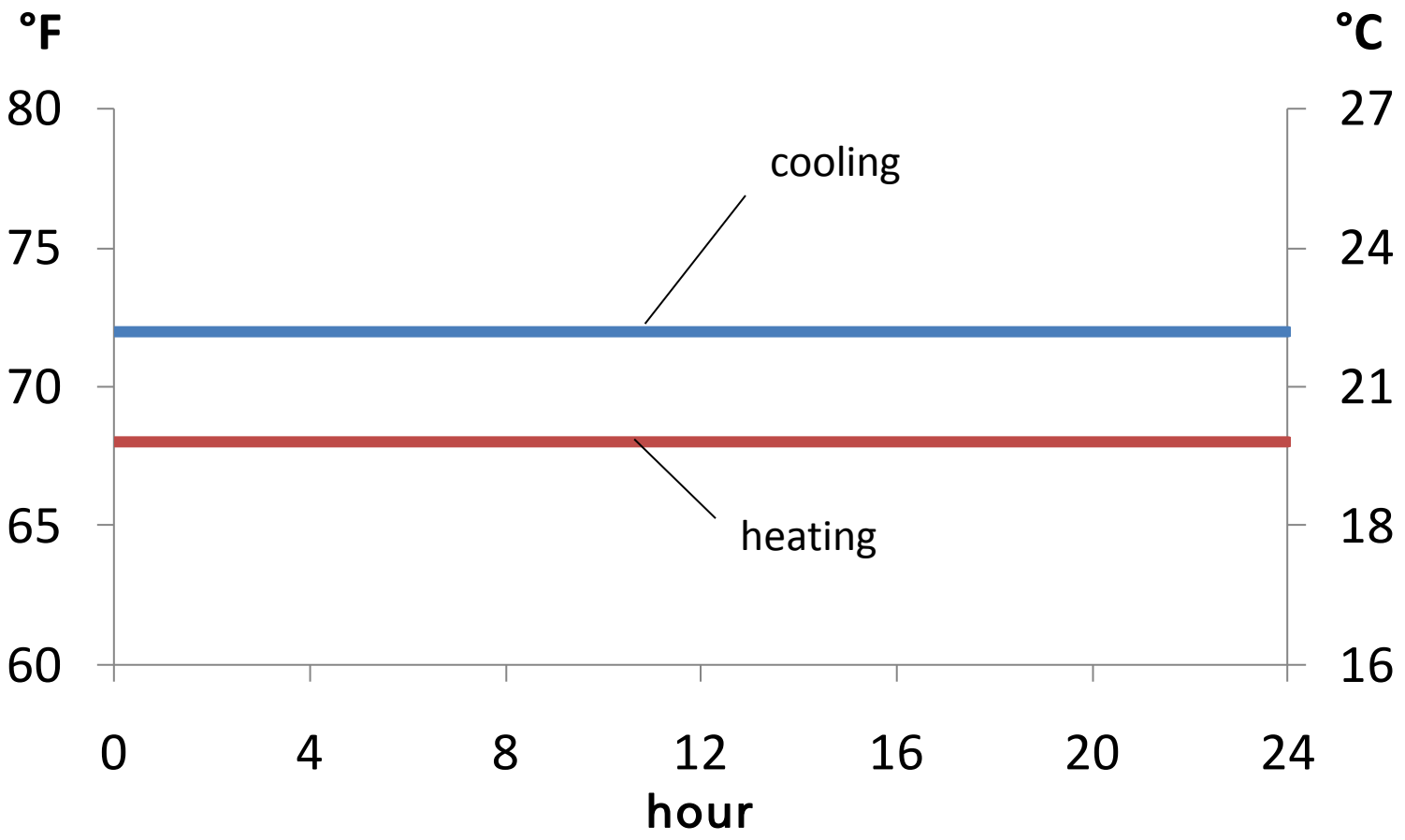
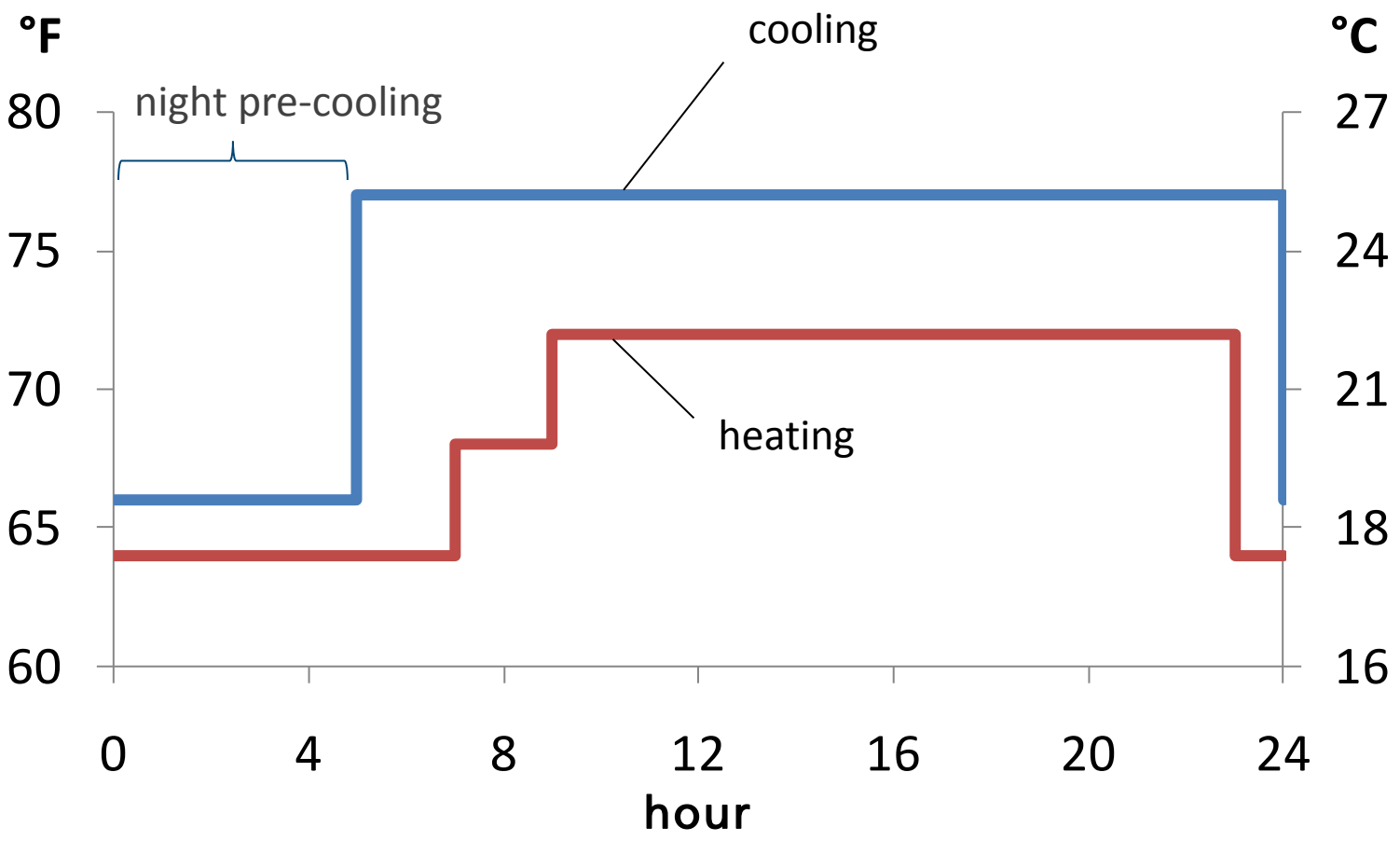
7. Define Building Operation Schedules
#1: Simple Setpoint Schedule



7. Define Building Operation Schedules
#2: Night Setpoint Schedule



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8. RUN the Simulations

- Sanity check first
- Debug
- Simulate batches
  - Careful with your naming conventions
  - Careful with file sizing
  - Careful about simulation runtime
- Process data

FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ	FR	FS	FT	FU	FV	FW
25.08494	25.60779	26.05926	26.43697854	26.7399	26.9682	27.12316	27.20701	27.22283	27.17439	27.06598	26.90234	26.68851	26.42967	26.13086	25.79645	25.42906
25.06327	25.58494	26.03564	26.41301889	26.71599	26.94469	27.10035	27.18517	27.20219	27.15512	27.04823	26.88619	26.674	26.41672	26.11922	25.78559	25.41822
25.04171	25.56222	26.01216	26.38918359	26.69218	26.92127	27.07762	27.16341	27.18161	27.1359	27.0305	26.87004	26.65945	26.40368	26.10743	25.77454	25.40736
25.02024	25.53962	25.98881	26.36547094	26.66849	26.89795	27.05498	27.14172	27.16109	27.11672	27.0128	26.8539	26.64487	26.39055	26.09549	25.76337	25.39655
24.99887	25.51714	25.96558	26.34187905	26.64492	26.87473	27.03243	27.1201	27.14062	27.09758	26.99512	26.83775	26.63025	26.37735	26.08344	25.75211	25.38581
24.97759	25.49477	25.94247	26.31840588	26.62145	26.85161	27.00996	27.09855	27.12021	27.07849	26.97746	26.8216	26.61559	26.36406	26.07129	25.74079	25.37517
24.95638	25.4725	25.91948	26.29504921	26.59809	26.82858	26.98758	27.07707	27.09985	27.05943	26.95982	26.80544	26.60089	26.35071	26.05906	25.72945	25.36464
24.93525	25.45034	25.8966	26.27180669	26.57484	26.80566	26.96528	27.05566	27.07955	27.04041	26.9422	26.78928	26.58616	26.33729	26.04678	25.71811	25.35421
24.91417	25.42827	25.87383	26.24867586	26.55169	26.78283	26.94307	27.03432	27.05931	27.02143	26.9246	26.77311	26.57139	26.32383	26.03444	25.70677	25.3439
24.89316	25.40629	25.85116	26.22565418	26.52865	26.[illegible]09	26.92093	27.01305	27.03912	27.00248	26.90701	26.75693	26.5566	26.31031	26.02208	25.69546	25.3337
24.87221	25.3844	25.8286	26.20273905	26.50571	26.[illegible]3745	26.[illegible]98	26.[illegible]81	27.01[illegible]	[illegible]983	26.[illegible]94	[illegible].74074	26.54177	26.29677	26.0097	25.68417	25.3236
24.8513	25.36259	25.80614	26.17992781	26.48288	26.[illegible]1491	26.[illegible]76	26.[illegible]07	26.99[illegible]9	[illegible]96	26.[illegible]188	26.72454	26.52692	26.28319	25.9973	25.67292	25.31361
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24.78884	25.2976	25.7393	26.11209078	26.41496	26.64782	26.8115	26.90773	26.93895	26.90827	26.8193	26.67594	26.48227	26.24235	25.96012	25.63943	25.28421
24.7681	25.27607	25.7172	26.08966847	26.39251	26.62563	26.78986	26.88686	26.91907	26.88953	26.8018	26.65974	26.46737	26.22872	25.94774	25.62835	25.27459
24.74739	25.25461	25.69517	26.06733681	26.37015	26.60353	26.76829	26.86606	26.89923	26.87083	26.78432	26.64354	26.45246	26.21509	25.93539	25.61733	25.26505
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24.70606	25.21186	25.65136	26.02293525	26.3257	26.55959	26.72538	26.82465	26.85972	26.83351	26.74942	26.61116	26.42264	26.18784	25.91075	25.59543	25.2462
24.68544	25.19056	25.62956	26.00086038	26.30361	26.53774	26.70403	26.80404	26.84004	26.81491	26.732	26.59499	26.40774	26.17423	25.89846	25.58456	25.23689
24.66484	25.16932	25.60783	25.97886622	26.2816	26.51598	26.68276	26.78349	26.8204	26.79633	26.7146	26.57882	26.39285	26.16064	25.88621	25.57374	25.22765
24.64427	25.14813	25.58617	25.95695046	26.25967	26.49429	26.66156	26.763	26.80081	26.7778	26.69722	26.56267	26.37797	26.14706	25.87399	25.56296	25.21848
24.62371	25.12698	25.56458	25.93511082	26.23782	26.47268	26.64043	26.74257	26.78127	26.7593	26.67986	26.54653	26.3631	26.1335	25.86179	25.55223	25.20936
24.60318	25.10588	25.54305	25.91334511	26.21605	26.45115	26.61937	26.7222	26.76178	26.74083	26.66253	26.53042	26.34825	26.11996	25.84963	25.54155	25.20031
24.58267	25.08482	25.52158	25.8916512	26.19436	26.42969	26.59838	26.70189	26.74234	26.7224	26.64523	26.51432	26.33341	26.10644	25.83751	25.53092	25.19132
24.56218	25.0638	25.50016	25.87002704	26.17274	26.4083	26.57746	26.68164	26.72294	26.704	26.62795	26.49824	26.3186	26.09295	25.82542	25.52034	25.18239
24.5417	25.04283	25.47881	25.84847063	26.15119	26.38699	26.5566	26.66145	26.70359	26.68565	26.6107	26.48218	26.3038	26.07949	25.81336	25.5098	25.17351
24.52124	25.02189	25.45751	25.82698008	26.12971	26.36575	26.53581	26.64132	26.68429	26.66733	26.59348	26.46615	26.28903	26.06605	25.80134	25.4993	25.16468
24.5008	25.00099	25.43626	25.80555352	26.1083	26.34457	26.51509	26.62124	26.66504	26.64905	26.57629	26.45014	26.27428	26.05264	25.78935	25.48885	25.15591
24.48037	24.98012	25.41507	25.78418918	26.08696	26.32347	26.49443	26.60122	26.64583	26.6308	26.55913	26.43416	26.25956	26.03926	25.7774	25.47845	25.14718
24.45996	24.95929	25.39392	25.76288535	26.06569	26.30243	26.47383	26.58125	26.62667	26.6126	26.542	26.4182	26.24487	26.02591	25.76549	25.46809	25.13851
24.43956	24.93849	25.37282	25.74164037	26.04448	26.28145	26.45329	26.56134	26.60756	26.59444	26.5249	26.40228	26.2302	26.01259	25.75361	25.45777	25.12988
24.41917	24.91772	25.35177	25.72045267	26.02333	26.26054	26.43281	26.54148	26.5885	26.57631	26.50784	26.38638	26.21557	25.9993	25.74177	25.44749	25.12129
24.3988	24.89698	25.33077	25.69932071	26.00225	26.23969	26.41239	26.52168	26.56948	26.55823	26.49081	26.37052	26.20096	25.98604	25.72997	25.43725	25.11275
24.37843	24.87628	25.30981	25.67824303	25.98122	26.2189	26.39203	26.50193	26.55051	26.54018	26.47382	26.35468	26.18638	25.97282	25.71821	25.42706	25.10426
24.35808	24.8556	25.28889	25.65721821	25.96025	26.19818	26.37173	26.48224	26.53159	26.52218	26.45686	26.33888	26.17184	25.95963	25.70648	25.4169	25.0958
24.33774	24.83494	25.26801	25.63624491	25.93934	26.17751	26.35149	26.4626	26.51272	26.50422	26.43994	26.32311	26.15733	25.94648	25.69479	25.40679	25.08739
24.31741	24.81432	25.24718	25.61532181	25.91849	26.1569	26.3313	26.44301	26.49389	26.4863	26.42305	26.30738	26.14285	25.93336	25.68313	25.39671	25.07901
24.29709	24.79372	25.22638	25.59444766	25.89769	26.13634	26.31117	26.42347	26.47511	26.46842	26.40621	26.29168	26.1284	25.92027	25.67151	25.38668	25.07068
24.27679	24.77315	25.20562	25.57362127	25.87695	26.11585	26.29109	26.40399	26.45637	26.45058	26.3894	26.27602	26.11399	25.90722	25.65993	25.37668	25.06238

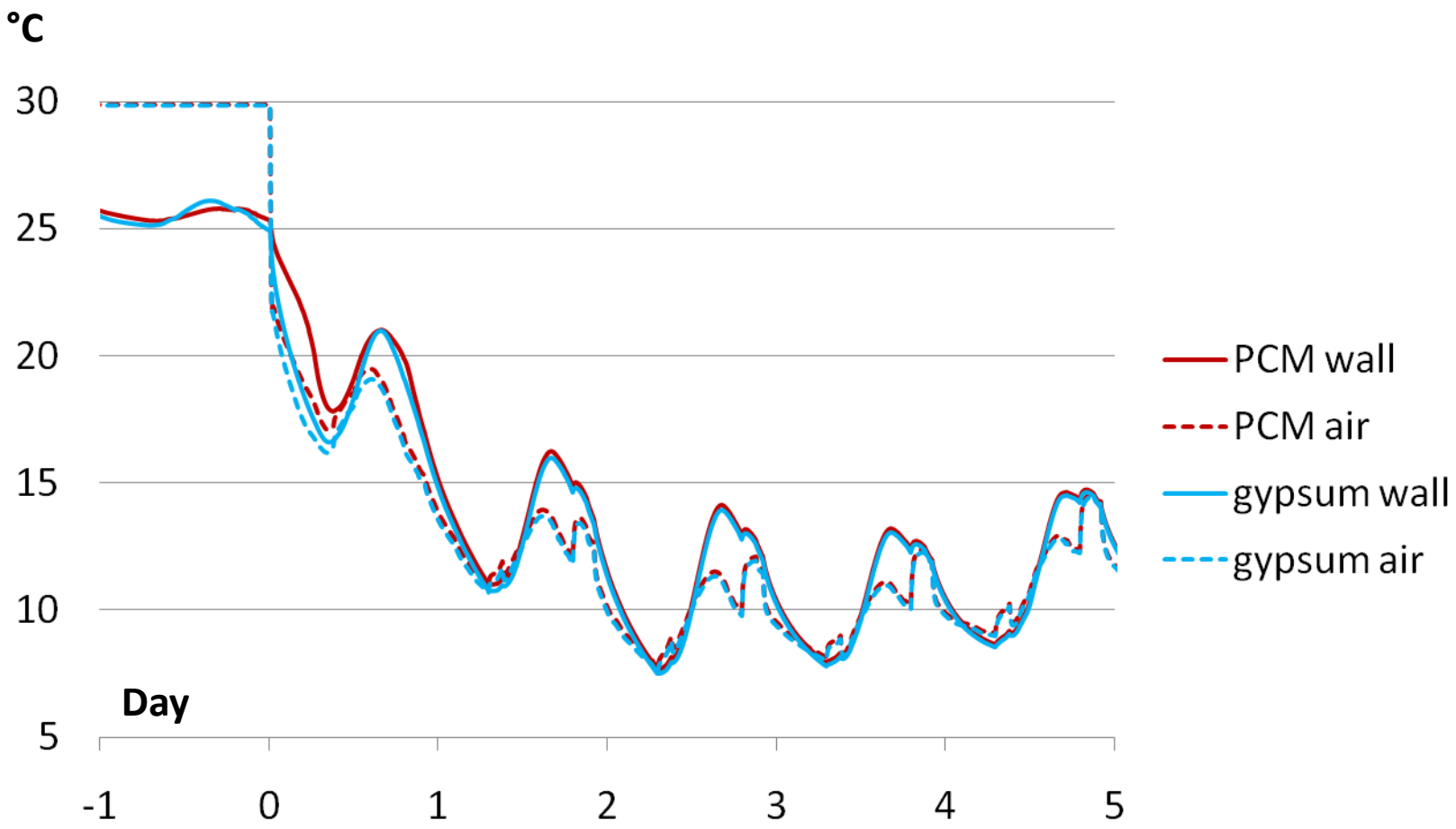
Results

Results Summary:

- Wall response
  - temperature profiles
  - heat flow histories
  - PCM decay / recharge time
- Energy for
  - heating
  - cooling
  - ventilation
- Design loads
  - heating
  - cooling

PCM Discharge

Chicago February



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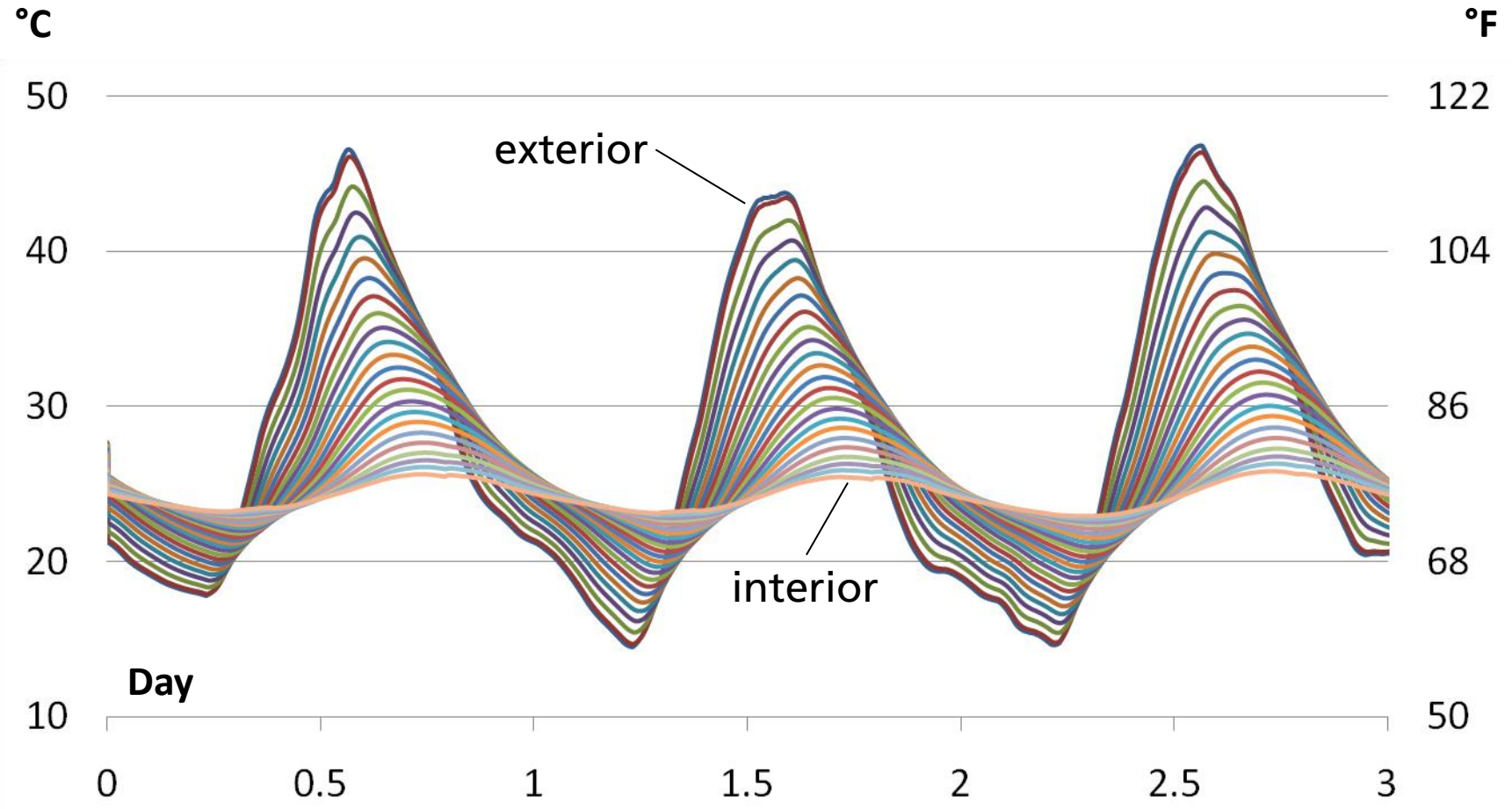
Temperature Profiles 1” Gypsum Schedule 1 Atlanta June 1-7



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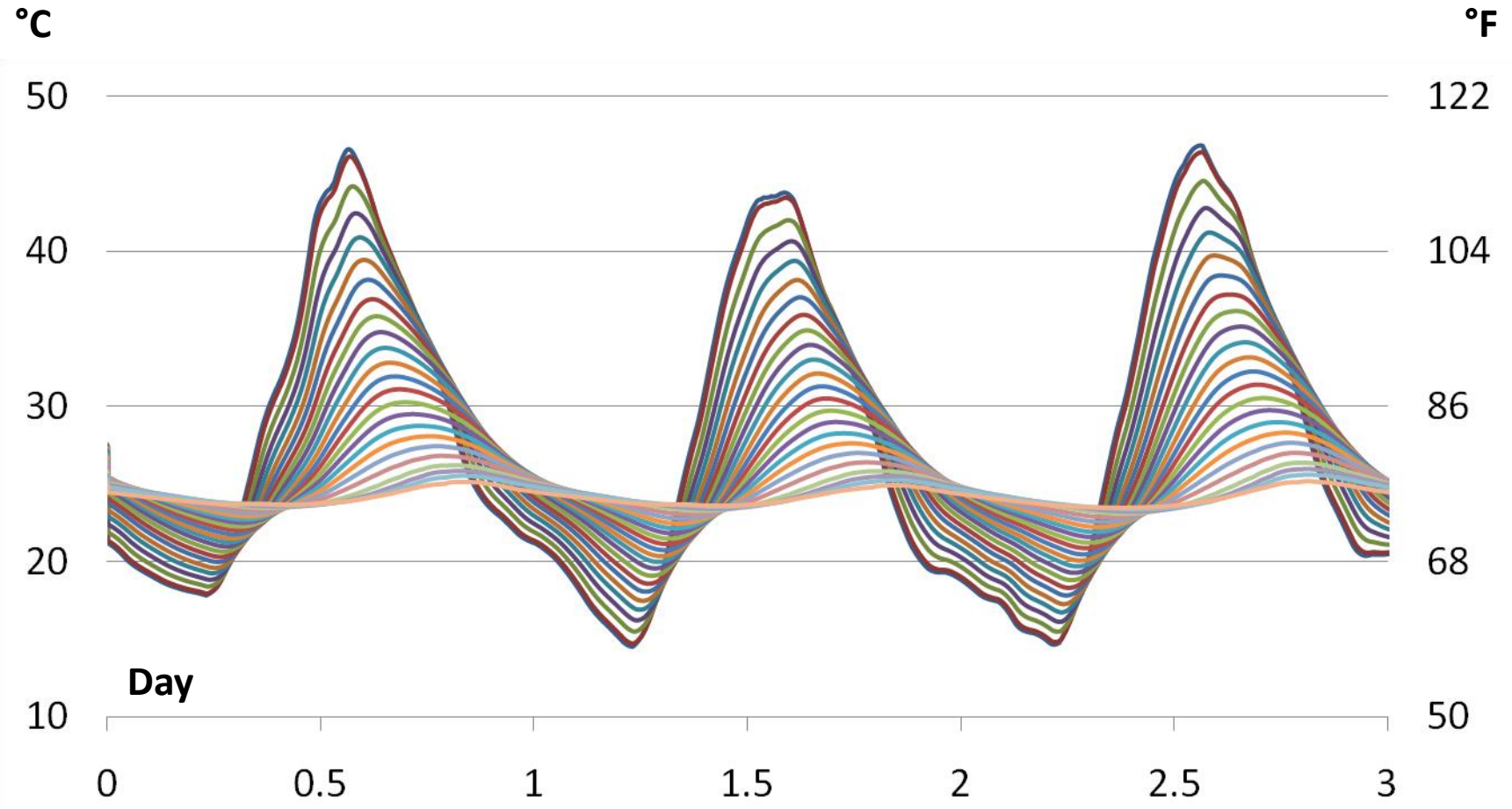
Temperature Profiles 1” Gypsum+PCM Schedule 1 Atlanta June 1-7



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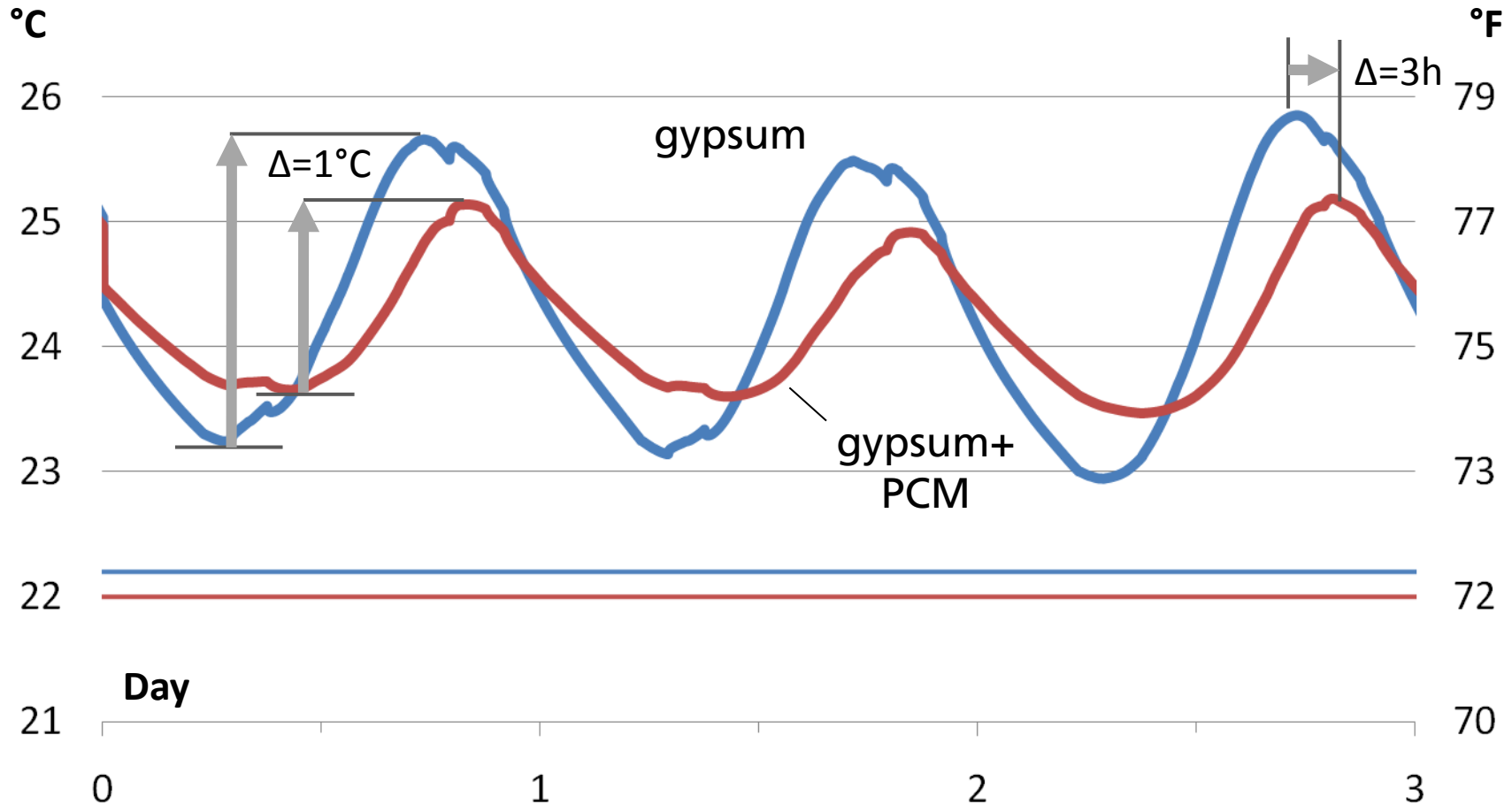
Indoor Wall Surface Temperature

Schedule 1
Atlanta
June 1-7



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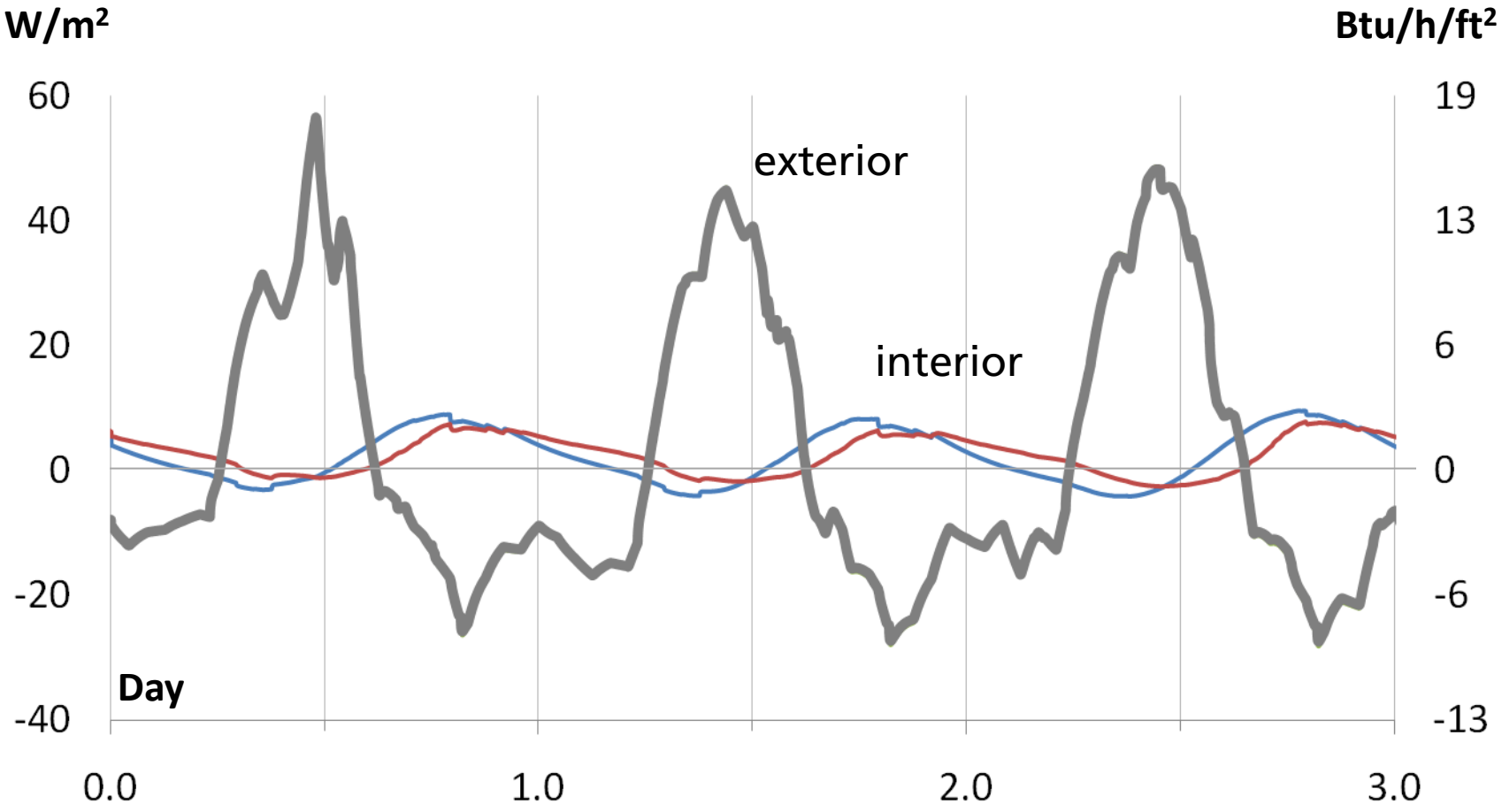
Heat Flux Profiles

Schedule 1
Atlanta
June 1-7



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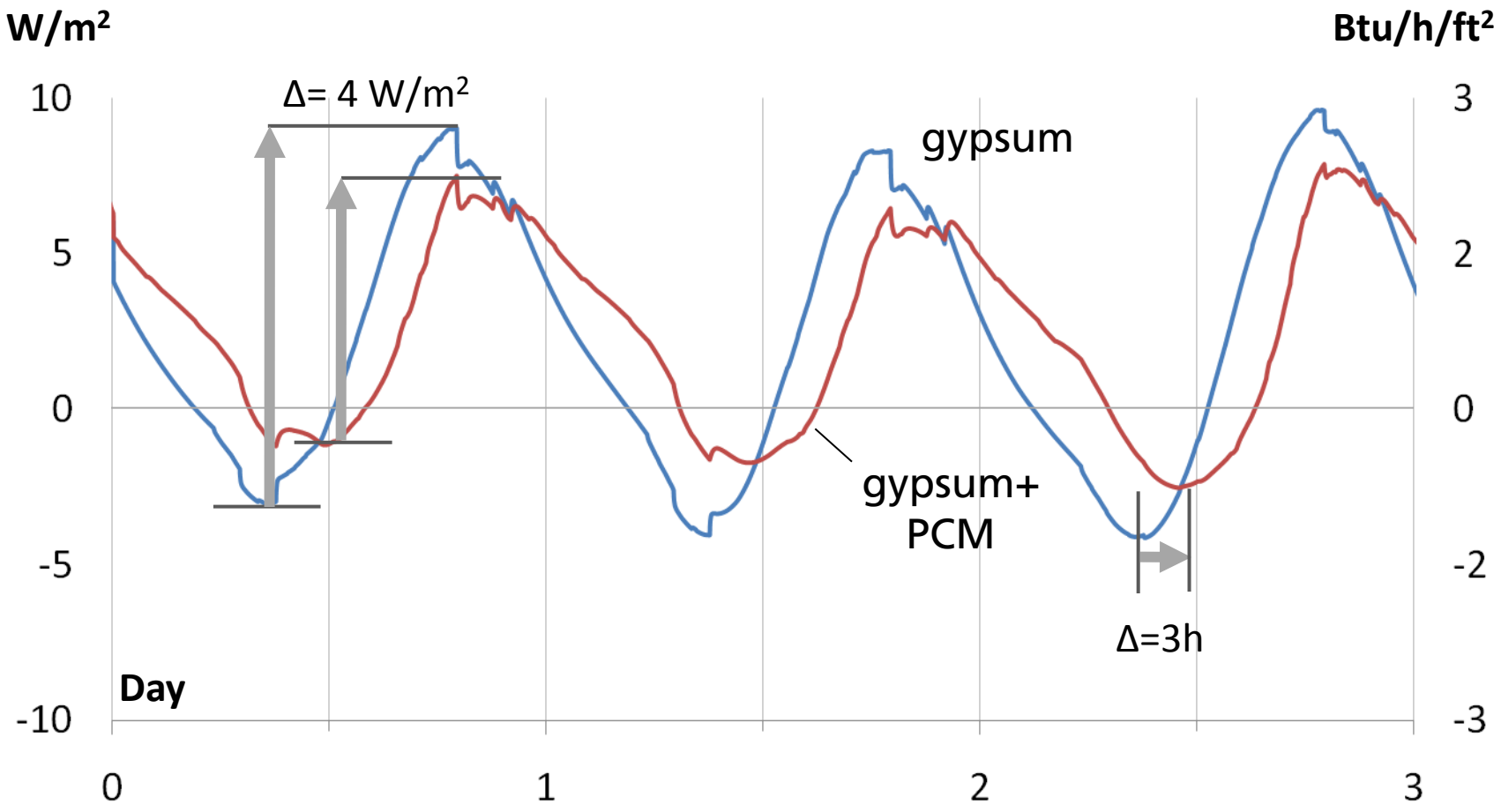
Heat Flux: Surface to Interior

Schedule 1
Atlanta
June 1-7



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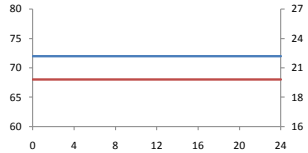
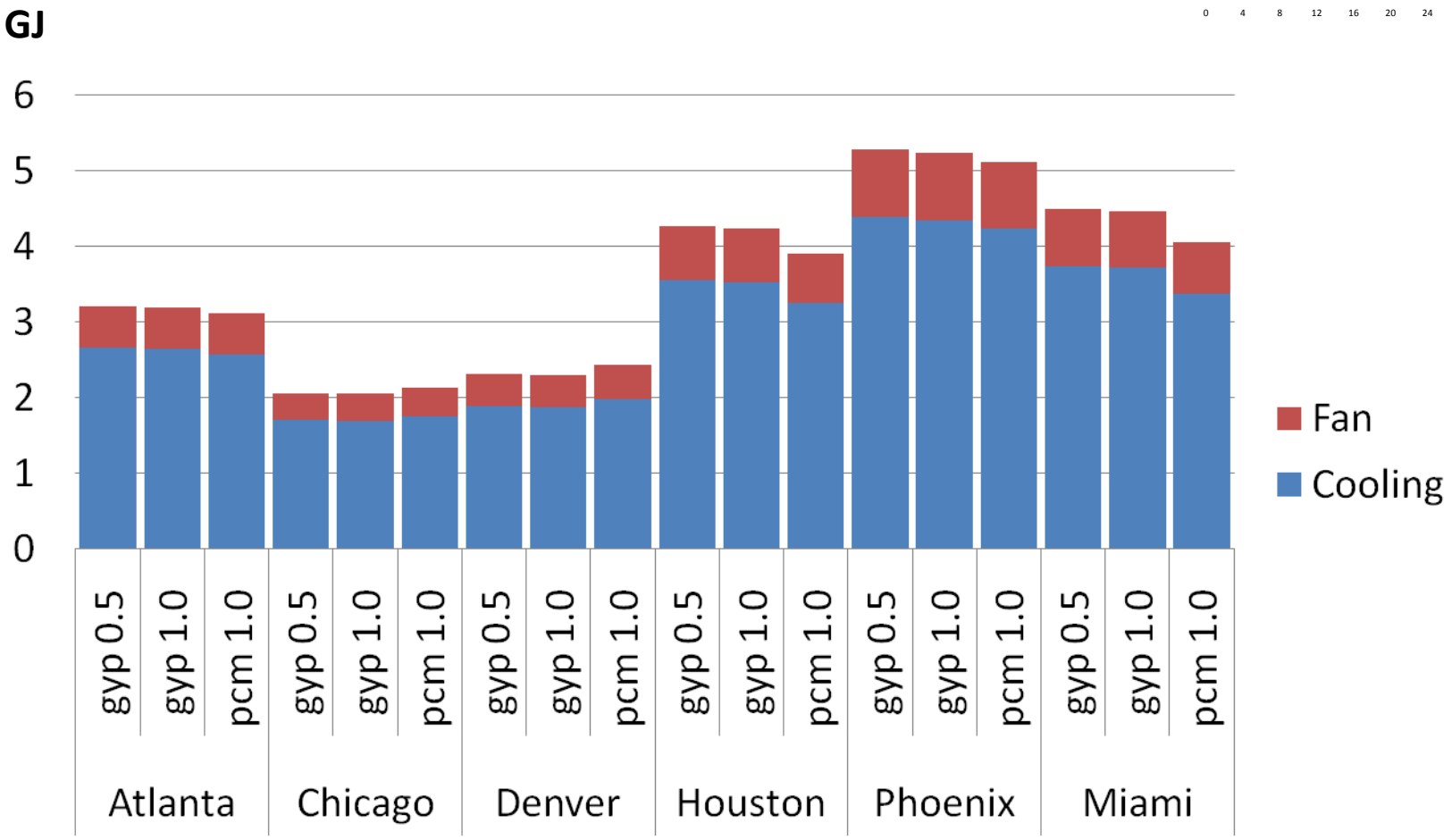
Cooling Energy (June)

Schedule 1





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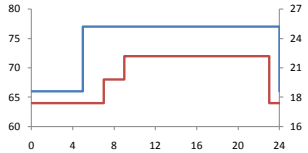
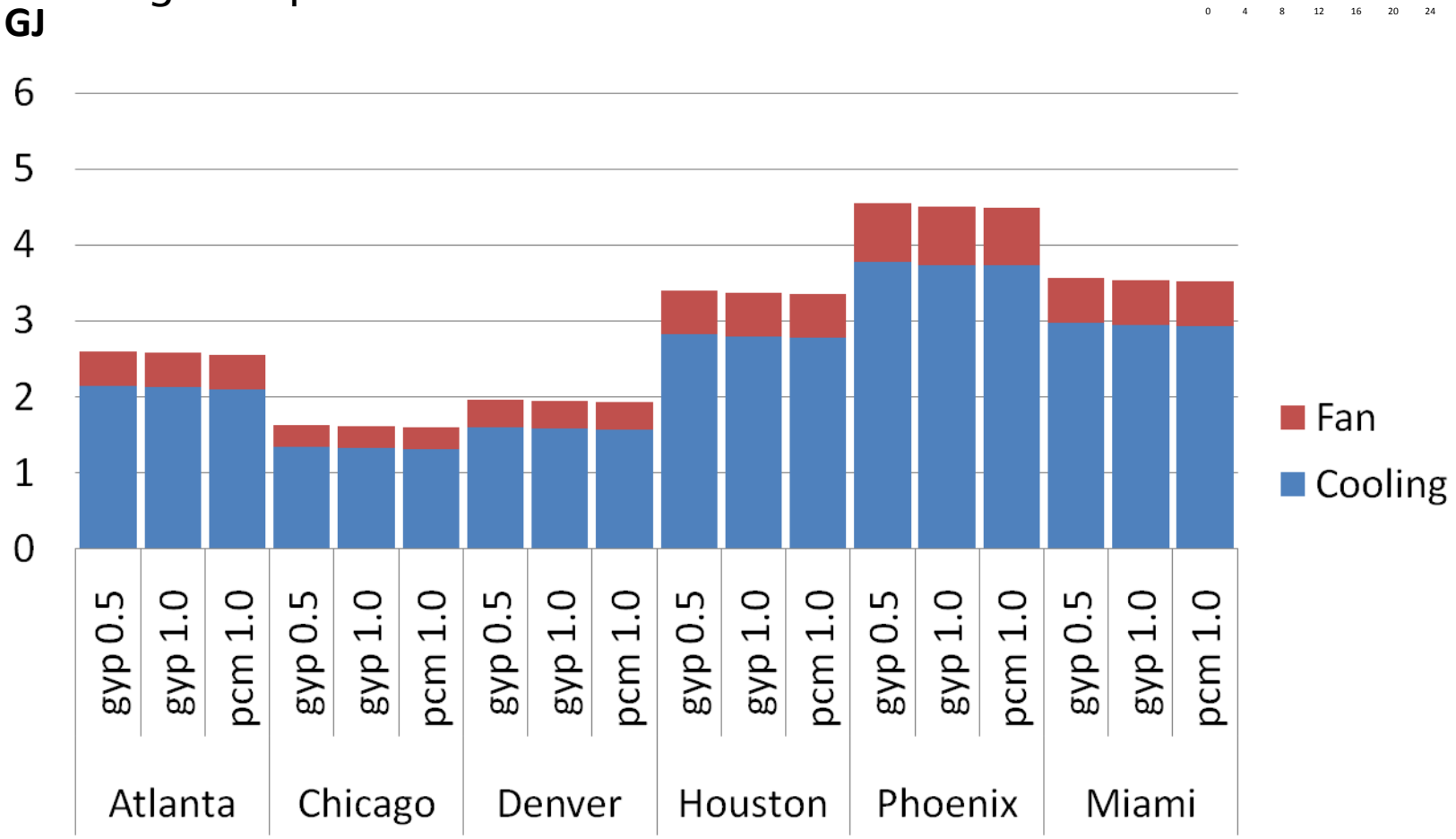
Cooling Energy (June)

Schedule 2



PCM is ineffective – a different phase change temperature must be selected



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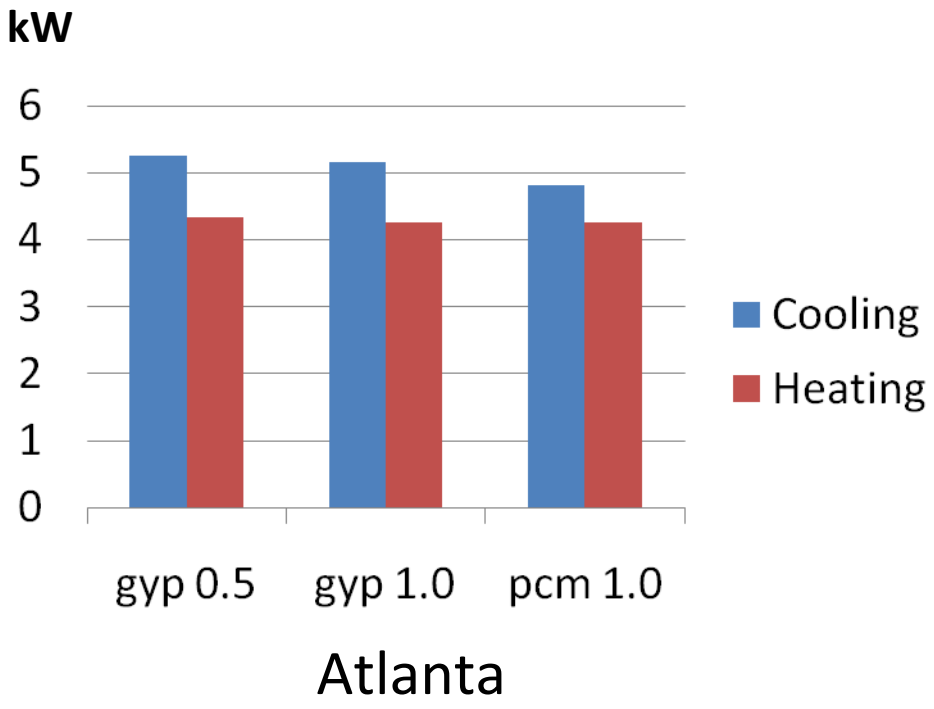
Peak Design Loads



- 7% peak cooling reduction
- <1% peak heating reduction
- Applicable for HVAC equipment sizing reductions

Summary

- Findings:
  - To improve energy savings, PCM transition temperature for Night Setpoint Schedule must be changed and re-evaluated
  - Detailed transient modeling is necessary
- Energy+ is useful for evaluating:
  - temperature, heat flow histories, energy savings
  - load time shift & design load size
  - optimal transition temperature, weight
- Tips:
  - Simulation files can become LARGE and SLOW – split them up
  - **Be careful with material properties!** small changes can mask the effect you are trying to measure!

Thank You! Any Questions?

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