Standardizing Model Inputs Using Published BEM Resources

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Learning Objectives for this Session

- Use key BEM resources to inform early modeling assumptions
- Employ accepted methods for converting equipment efficiency values into model input values

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INTRODUCTION

- Goals
  - Credible, realistic energy models
  - Consistent results
- Challenges
  - So many inputs, so little time
  - Unknown inputs
- Some help…
  - Published resources
    - Research results
    - Established methods

TOPICS

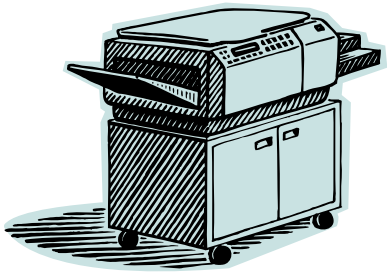
- Primary sources of information
- Internal load inputs
- Enclosure inputs
- HVAC inputs
- Other resources

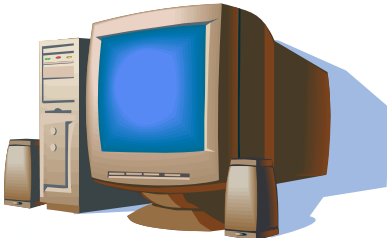
PRIMARY SOURCES

COMNET	Commercial Buildings Energy Modeling Guidelines and Procedures, August 2010, www.comnet.org
HOF 2009	ASHRAE Handbook 2009 Fundamentals
AEDG 50%	Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings, PNNL
VAV Design Guide	Advanced VAV System Design Guide www.energydesignresources.com
CoolTools	CoolTools Chiller Bid and Performance Tool www.energydesignresources.com

INTERNAL LOADS
Plug Load Power

Challenge
Typical plug loads for energy simulation





- COMNET
  - Whole building and space-by-space defaults
  - Custom equation
    - Individual equipment demand values
- HOF
  - Office: low, medium, high usage
  - Individual equipment: office, kitchen, lab
- AEDG
  - Office: standard and efficient
- 90.1 User's Manual
  - Whole building values

INTERNAL LOADS
Plug Load Power

Source
COMNET, Appendix B

	2 - Plug Loads				
	Default Receptacle Power Density (W/ft²)		Receptacle Power Coefficients		
	California 2005 ACM	COMNET	C	Pdmisc	D
Whole Building Categories					
Auto Repair	1.00	0.65	2.00	0.55	0.94
College/ University	1.00	N/A	2.00	N/A	0.77
Convention Center	0.96	1.09	2.00	0.55	0.78
Court House	1.00	1.09	2.00	0.55	0.92
Dining, Bar/Coctail Lounge	0.79	1.53	2.00	0.93	1.00
Dining, Cafeteria/Fast Food	0.79	1.53	2.00	0.93	1.00
Dining, Family	0.79				
Dormitory	0.50				
Exercise Center	1.00				
Gymnasium	1.00	1.86	2.00	0.55	0.78
Health Care Clinic	1.18	1.99	2.00	0.76	0.96
Hospital	1.18	1.99	2.00	0.76	0.68
Hotel	0.50	1.26	2.00	0.30	0.57
K-12 School	1.00	1.02	2.00	0.19	0.77

$$EPD = (C \times PD_{your\ count} + PD_{misc}) \times D$$

33 whole building categories + 95 space-by-space classifications

INTERNAL LOADS
Plug Load Power

Source
COMNET, Section 6.4.5

Table 38 – Nominal Mean Power for Surveyed Devices

Subscript	Mean Nominal Peak Power Levels of Surveyed Devices	CBECS Variable	Data Source	Nominal Mean Power (W)
PC	Personal computers	PCNUM8	Roth et al. 2002	55
CRT	CRT personal computer monitors	PCNUM8	Roth et al. 2002	90
LCD	Flat personal computer monitors	PCNUM8	Roth et al. 2002	25
Server	Servers	SRVNUM8	Roth et al. 2002	650
POS	Point of sale (cash registers)	RGSTRN8	Roth et al. 2002	50
Las	Laser Printers	PRNTRN8	Roth et al. 2002	263
	Ink Jet Printers	PRNTRN8	Roth et al. 2002	42.5
Copy	Copy machines	COPRN8	Roth et al. 2002	660
Refrig	Residential refrigerators	RFGRSN8	Assumption	350
Vend	Vending machines	RFGVNN8	Assumption; see ADL 1993)	450

INTERNAL LOADS
Plug Load Power

Source
HOF, Chapter 18

Table 11 Recommended Load Factors for Various Types of Offices

Load Density of Office	Load Factor, W/ft^2	Description
Light	0.5	Assumes 167 ft^2/workstation (6 workstations per 1000 ft^2) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.67, printer diversity 0.33.
Medium	1	Assumes 125 ft^2/workstation (8 workstations per 1000 ft^2) with computer and monitor at each plus printer and fax. Computer, monitor, and fax diversity 0.75, printer diversity 0.50.
Medium/ Heavy	1.5	Assumes 100 ft^2/workstation (10 workstations per 1000 ft^2) with computer and monitor at each plus printer and fax. Computer and monitor diversity 0.75, printer and fax diversity 0.50.
Heavy	2	Assumes 83 ft^2/workstation (12 workstations per 1000 ft^2) with computer and monitor at each plus printer and fax. Computer and monitor diversity 1.0, printer and fax diversity 0.50.

Source: Wilkins and Hosni (2000).

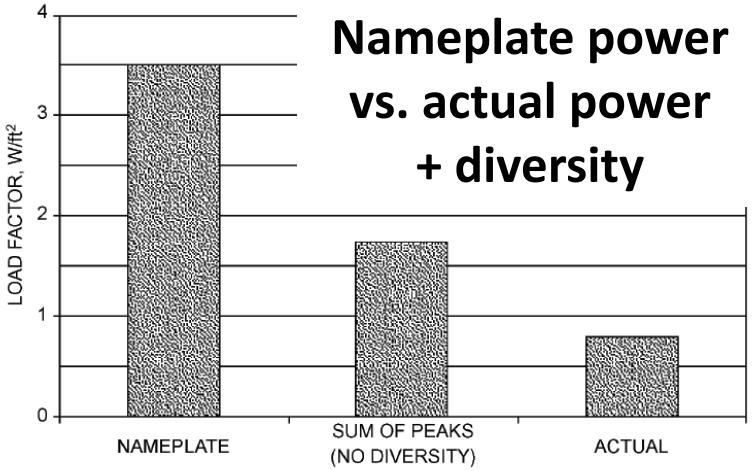
Table 12 Cooling Load Estimates for Various Office Load Densities

Load Density*	Number	Each, W	Total, W	Diversity	Load, W
Light					
Computers	6	55	330	0.67	220
Monitors	6	55	330	0.67	220
Laser printer—small desk top	1	130	130	0.33	43
Fax machine	1	15	15	0.67	10
Total Area Load					493
Recommended equipment load factor = 0.5 W/ft^2					
Medium					
Computers	8	65	520	0.75	390
Monitors	8	70	560	0.75	420
Laser printer—desk	1	215	215	0.5	108
Fax machine	1	15	15	0.75	11
Total Area Load					929
Recommended equipment load factor = 1.0 W/ft^2					
Medium/Heavy					
Computers	10	65	650	1	650
Monitors	10	70	700	1	700
Laser printer—small office	1	320	320	0.5	160
Fax machine	1	30	30	0.5	15
Total Area Load					1525
Recommended equipment load factor = 1.5 W/ft^2					
Heavy					
Computers	12	75	900	1	900
Monitors	12	80	960	1	960
Laser printer-small office	1	320	320	0.5	160
Fax machine	1	30	30	0.5	15
Total Area Load					2035
Recommended equipment load factor = 2.0 W/ft^2					

Source: Wilkins and Hosni (2000).
*See Table 11 for descriptions of load densities.

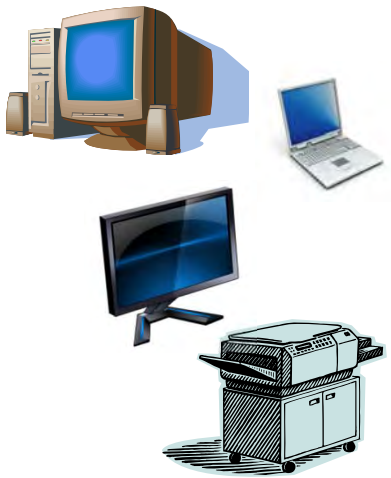
INTERNAL LOADS
Plug Load Power

Source
HOF, Chapter 18



Nameplate power vs. actual power + diversity

Fig. 4 Office Equipment Load Factor Comparison
(Wilkins and McGaffin 1994)



Typical Equipment Power & Radiant/convective splits

	Actual Power	Actual Power as Fraction of Nameplate (Typical)	Convective/ Radiant Split
Desktop computer	50 -100W (65 typical)	10-15%	90 / 10
Laptop computer	15 – 40W	25%	75 / 25
Flat panel monitor 15 in.	20W		60 / 40
Flat panel monitor 19-22 in.	30W		60 / 40
Flat panel monitor 30 in.	90W		60 / 40
Laser printer	75 – 140 W	10-25%	70 / 30
Large copier	550 – 1100W	40-60%	70 / 30

INTERNAL LOADS
Plug Load Power

Source
AEDG 50% Tech Doc

Table 4.7. Plug Load Calculation for the Advanced Case without Additional Controls

	Baseline			Advanced		
Plug Load Equipment Inventory	Quantity	Plug load, each (W)	Plug load (W)	Quantity	Plug load, each (W)	Plug load (W)
Office Equipment						
Computers – servers	8	65	520	8	54	432
Computers – desktop[(a)]	134	65	8,710	89	54	4,806
Computers – laptop[(a)]	134	19	2,546	179	17	3,043
Monitors – server – LCD	8	35	280	8	24	192
Monitors – desktop – LCD	268	35	9,380	268	24	6,432
Laser printer – network	8	215	1,720	8	180	1,440
Copy machine	4	1,100	4,400	4	500	2,000
Fax machine	8	35	280	8	17	136
Water cooler	8	350	2,800	8	193	1,544
Refrigerator	8	76	608	8	65	520
Vending machine	4	770	3,080	4	770	3,080
Coffee maker	4	1,050	4,200	4	1,050	4,200
Portable HVAC (heaters, fans)	30	30	900	30	30	900
Other small appliances, chargers	250	4	1,000	250	4	1,000
Total plug load (W)			40,424			29,725
Plug load density, W/ft^2 (W/m^2)			**0.75 (8.07)**			**0.55 (5.92)**

INTERNAL LOADS
Plug Load Power

Source
90.1 User's Manual

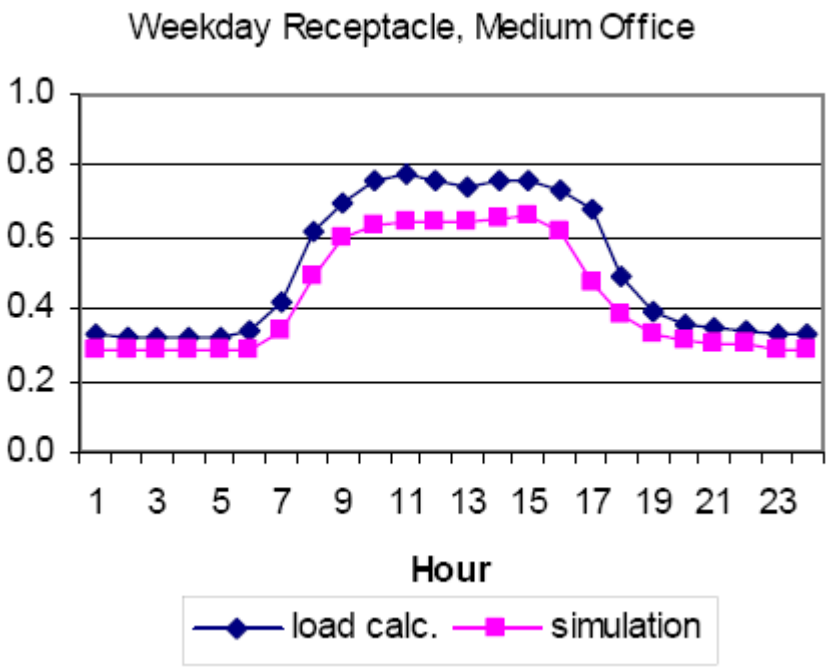
EPD = equipment power density

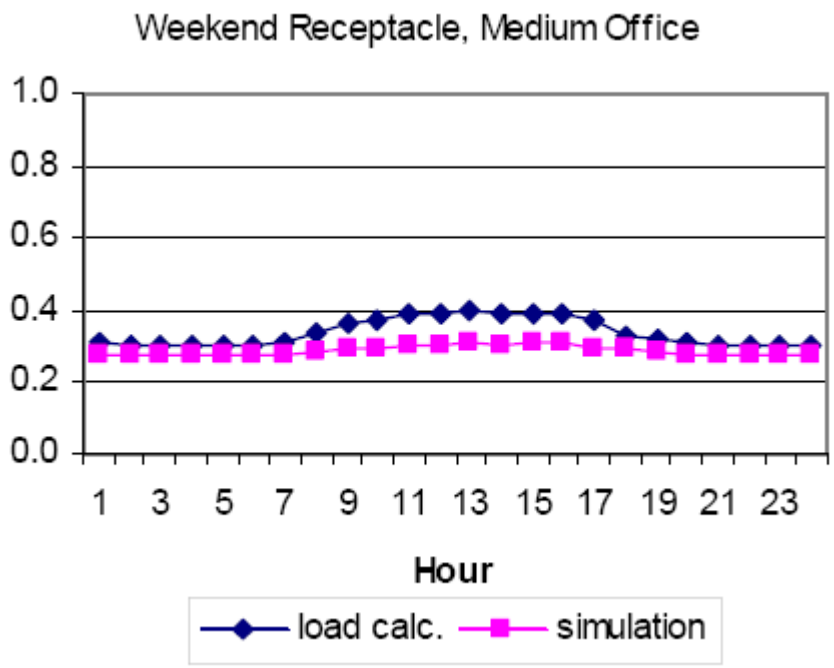
Building Type	EPD (W/ft^2)
Assembly	0.25
Office	0.75
Retail	0.25
Warehouse	0.10
School	0.50
Hotel or Motel	0.25
Restaurant	0.10
Health	1.00
Multi-family	0.75

INTERNAL LOADS
Plug Load Schedule

Source
ASHRAE Research Project 1093-RP

Challenge
Realistic plug load schedules for energy simulation

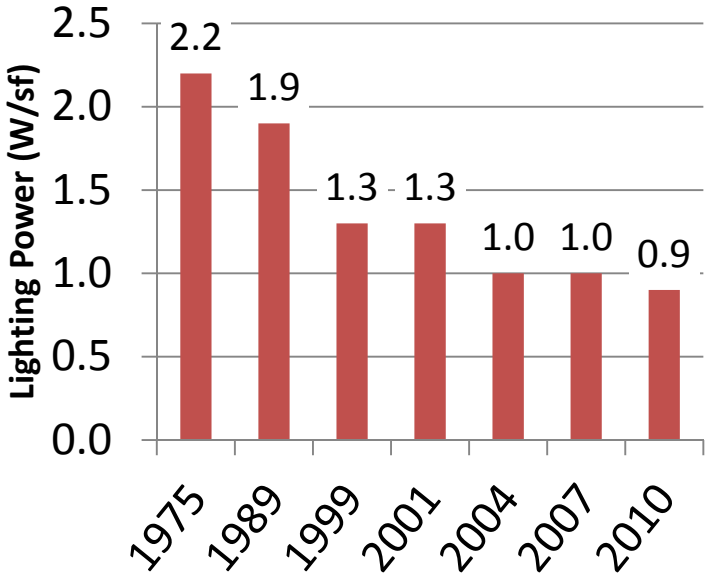




INTERNAL LOADS
Lighting Power

Office Building Maximum Allowed Lighting Power

ASHRAE Standard 90.1



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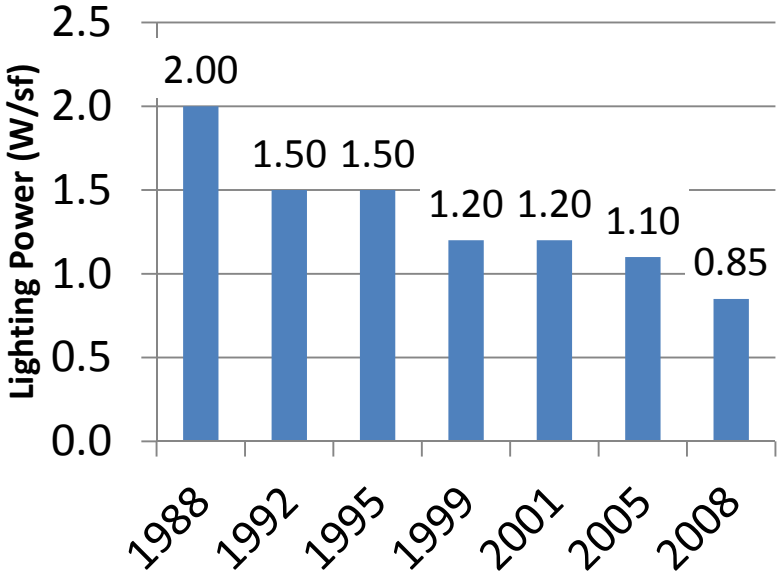
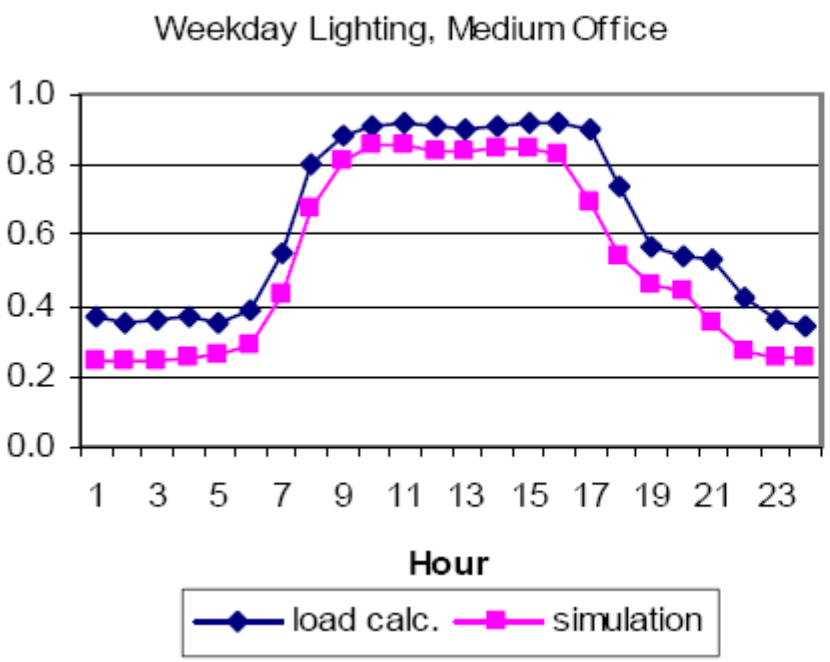
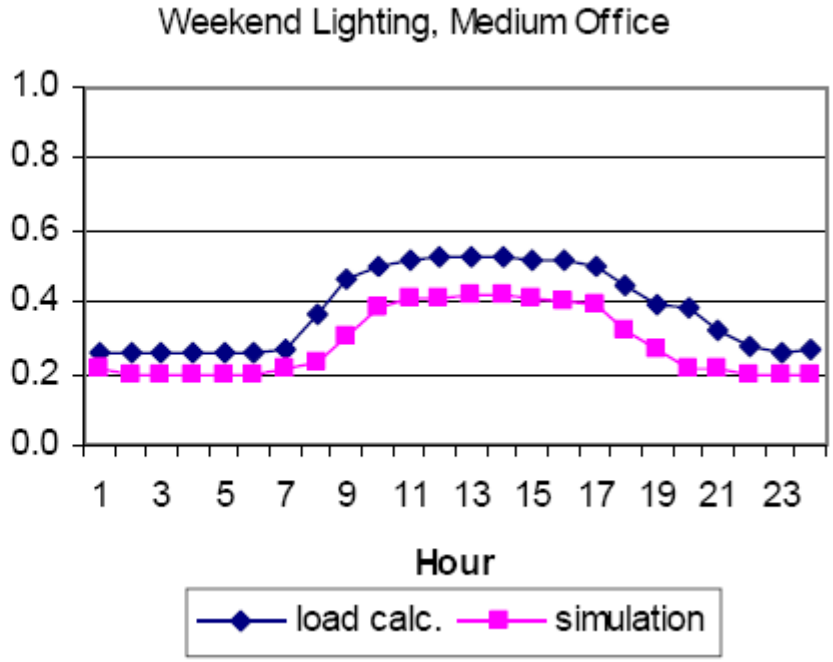


INTERNAL LOADS
Lighting Schedules

Source
ASHRAE Research Project 1093-RP

Challenge
Realistic lighting schedules for energy simulation





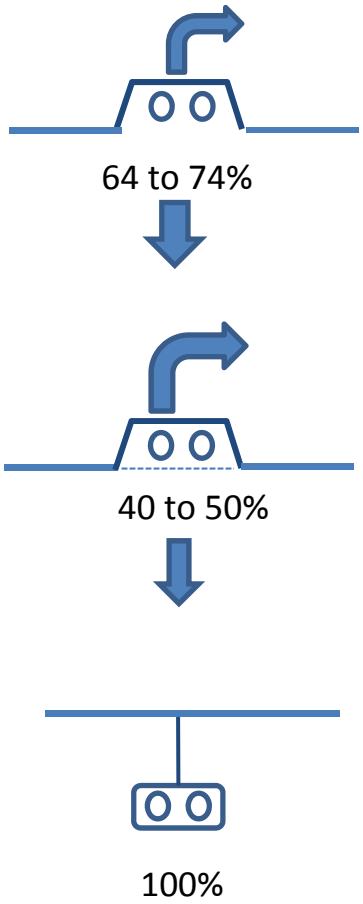
INTERNAL LOADS
Lighting Heat Distribution

Source
HOF, Chapter 18

Challenge
"LIGHT-TO-SPACE" input

Luminaire Category	Space Fraction	Radiative Fraction
Recessed fluorescent luminaire without lens	0.64 to 0.74	0.48 to 0.68
Recessed fluorescent luminaire with lens	0.40 to 0.50	0.61 to 0.73
Downlight compact fluorescent luminaire	0.12 to 0.24	0.95 to 1.0
Downlight incandescent luminaire	0.70 to 0.80	0.95 to 1.0
Non-in-ceiling fluorescent luminaire	1.0	0.5 to 0.57

Source: Fisher and Chantrasrisalai (2006).



INTERNAL LOADS
Elevators

Source
COMNET, Section 6.4.7

Challenge
Elevator energy consumption

Table 43 – Unit Energy Consumption Data for Elevators, Escalators and Moving Walkways[18]

	Elevators		Escalators and Moving Walkways	
Mode	Power (W)	Annual Hours	Power (W)	Annual Hours
Active	10,000	300	4,671	4,380
Ready	500	7,365	n.a.	0
Standby	250	1,095	n.a.	0
Off	0	0	0	4,380
Typical Annual Energy Use	7,000 kWh/y		20,500 kWh/y	

ENCLOSURE
Fenestration U-factor

Source
HOF, Chapter 15, Table 4

Challenge
Overall U-factor, including frame

Table 4 U-Factors for Various Fenestration Products in Btu/h· ft²·°F

Product Type		Glass Only		Vertical Installation: Operable (including sliding and swinging glass doors)					Vertical Installation: Fixed				
Frame Type		Center of Glass	Edge of Glass	Aluminum Without Thermal Break	Aluminum With Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl	Aluminum Without Thermal Break	Aluminum With Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl
ID	Glazing Type												
	Single Glazing												
1	1/8 in. glass	*1.04*	*1.04*	1.23	1.07	0.93	0.91	0.85	1.12	1.07	0.98	0.98	1.04
2	1/4 in. acrylic/polycarbonate	*0.88*	*0.88*	1.10	0.94	0.81	0.80	0.74	0.98	0.92	0.84	0.84	0.88
3	1/8 in. acrylic/polycarbonate	*0.96*	*0.96*	1.17	1.01	0.87	0.86	0.79	1.05	0.99	0.91	0.91	0.96
	Double Glazing												
4	1/4 in. air space	*0.55*	*0.64*	0.81	0.64	0.57	0.55	0.50	0.68	0.62	0.56	0.56	0.55
5	1/2 in. air space	*0.48*	*0.59*	0.76	0.58	0.52	0.50	0.45	0.62	0.56	0.50	0.50	0.48
6	1/4 in. argon space	*0.51*	*0.61*	0.78	0.61	0.54	0.52	0.47	0.65	0.59	0.53	0.52	0.51
7	1/2 in. argon space	*0.45*	*0.57*	0.73	0.56	0.50	0.48	0.43	0.60	0.53	0.48	0.47	0.45
	Double Glazing, $e = 0.60$ on surface 2 or 3												
8	1/4 in. air space	*0.52*	*0.62*	0.79	0.61	0.55	0.53	0.48	0.66	0.59	0.54	0.53	0.52
9	1/2 in. air space	*0.44*	*0.56*	0.72	0.55	0.49	0.48	0.43	0.59	0.53	0.47	0.47	0.44
10	1/4 in. argon space	*0.47*	*0.58*	0.75	0.57	0.51	0.50	0.45	0.61	0.55	0.49	0.49	0.47
11	1/2 in. argon space	*0.41*	*0.54*	0.70	0.53	0.47	0.45	0.41	0.56	0.50	0.44	0.44	0.41
	Double Glazing, $e = 0.40$ on surface 2 or 3												
12	1/4 in. air space	*0.49*	*0.60*	0.76	0.59	0.53	0.51	0.46	0.63	0.57	0.51	0.51	0.49
13	1/2 in. air space	*0.40*	*0.54*	0.69	0.52	0.47	0.45	0.40	0.55	0.49	0.44	0.43	0.40
14	1/4 in. argon space	*0.43*	*0.56*	0.72	0.54	0.49	0.47	0.42	0.58	0.52	0.46	0.46	0.43
15	1/2 in. argon space	*0.36*	*0.51*	0.66	0.49	0.44	0.42	0.37	0.52	0.46	0.40	0.40	0.36
	Double Glazing, $e = 0.20$ on surface 2 or 3												
16	1/4 in. air space	*0.45*	*0.57*	0.73	0.56	0.50	0.48	0.43	0.60	0.53	0.48	0.47	0.45
17	1/2 in. air space	*0.35*	*0.50*	0.65	0.48	0.43	0.41	0.37	0.51	0.45	0.39	0.39	0.35
18	1/4 in. argon space	*0.38*	*0.52*	0.68	0.51	0.45	0.43	0.39	0.54	0.47	0.42	0.42	0.38
19	1/2 in. argon space	*0.30*	*0.46*	0.61	0.45	0.39	0.38	0.33	0.47	0.41	0.35	0.35	0.30
	Double Glazing, $e = 0.10$ on surface 2 or 3												
20	1/4 in. air space	*0.42*	*0.55*	0.71	0.54	0.48	0.46	0.41	0.57	0.51	0.45	0.45	0.42
21	1/2 in. air space	*0.32*	*0.48*	0.63	0.46	0.41	0.39	0.34	0.49	0.42	0.37	0.37	0.32
22	1/4 in. argon space	*0.35*	*0.50*	0.65	0.48	0.43	0.41	0.37	0.51	0.45	0.39	0.39	0.35
23	1/2 in. argon space	*0.27*	*0.44*	0.59	0.42	0.37	0.36	0.31	0.44	0.38	0.33	0.32	0.27
	Double Glazing, $e = 0.05$ on surface 2 or 3												
24	1/4 in. air space	*0.41*	*0.54*	0.70	0.53	0.47	0.45	0.41	0.56	0.50	0.44	0.44	0.41
25	1/2 in. air space	*0.30*	*0.46*	0.61	0.45	0.39	0.38	0.33	0.47	0.41	0.35	0.35	0.30
26	1/4 in. argon space	*0.33*	*0.48*	0.64	0.47	0.42	0.40	0.35	0.49	0.43	0.38	0.37	0.33
27	1/2 in. argon space	*0.25*	*0.42*	0.57	0.41	0.36	0.34	0.30	0.43	0.36	0.31	0.31	0.25

Table includes:
Aluminum without thermal break
Aluminum with thermal break
Wood/vinyl
Curtain wall, with & without break
Manufactured skylight
Site-assembled skylight

ENCLOSURE
Wall & Roof U-factor

Source
COMNET, Sections 6.5.3 & 6.5.4

Challenge
Opaque constructions to match code minimum requirements

Table 47 – Baseline Building Wall Construction Assemblies

Construction	Layer	Thickness (inch)	Conductivity (Btu/h ft F)	Density (lb/ft²)	Specific Heat (Btu/lb F)	R-value (ft²·°F·h/Btu)	U-factor (Btu/ft²·°F·h)
Wall R-13 + R-18.8	Air film	-	-	-	-	0.17	-
	Stucco	0.400	0.4167	116	0.2	0.08	-
	R-18.8 continuous insulation	1.800	0.0200	1.8	0.29	18.8	-
	Gypsum board	0.625	0.0930	50	0.2	0.56	-
	R-13 insulation/steel framing	-	-	-	-	6.00	-
	Gypsum board	0.625	0.0930	50	0.2	0.56	-
	Interior air film	-	-	-	-	0.68	-
	Total for assembly	-	-	-	-	26.85	0.037

HVAC
DX Cooling Efficiency

Challenge
Translate mfr/code values to model inputs

You get
SEER or EER
(at specific conditions, including fan power and fan heat)

You need
EIR
(excluding supply fan and fan heat) at ARI rating conditions

HVAC
DX Cooling Efficiency

Source
COMNET, Section 6.7.3

Step 1. Estimate fan power

$$Fan_{kw} = 0.365 \times \frac{Q_{rated}}{30{,}000}$$

Step 2. Adjust the EER

$$EER_{adj} = \frac{Q_{t,rated} + BHP_{supply} \times 2.545}{\frac{Q_{t,rated}}{EER} - BHP_{supply} \times 0.7457}$$

Step 3. Calculate EIR

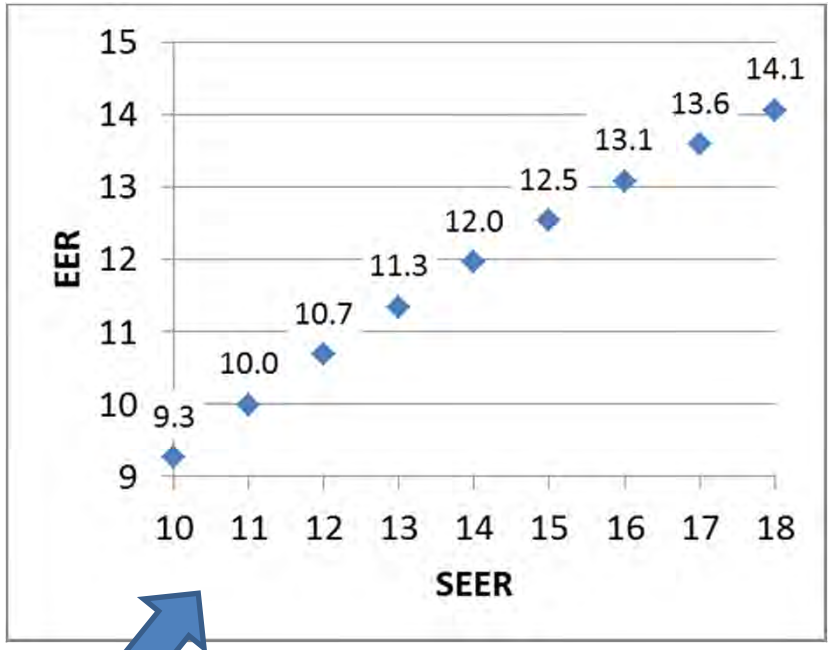
$$EIR = \frac{3.413}{EER_{adj}}$$

HVAC
DX Cooling Efficiency

Challenge
Translate SEER to EER

COMNET Section 6.7.5

EER = 10.0 if SEER ≥ 11.5



ASHRAE Research Project 1197-RP

$EER = -0.0182*SEER^2 + 1.1088*SEER$

HVAC
Static Pressure Reset Control

Source
COMNET, Section 6.7.3

Challenge
Fan part-load curve inputs

$$Fan\ Power\ Fraction = a + b \cdot FanRatio + c \cdot FanRatio^2 + d \cdot FanRatio^3$$

Table 66 – Fan Curve Default Values

Fan Type - Control Type	A	B	c	d	%Power$_{Min}$
AF or BI riding the curve[a]	0.1631	1.5901	-0.8817	0.1281	70%
AF or BI with inlet vanes[a]	0.9977	-0.659	0.9547	-0.2936	50%
FC riding the curve[a]	0.1224	0.612	0.5983	-0.3334	30%
FC with inlet vanes[a]	0.3038	-0.7608	2.2729	-0.8169	30%
Vane-axial with variable pitch blades[a]	0.1639	-0.4016	1.9909	-0.7541	20%
Any fan with VSD (use for baseline building)[b]	**0.0013**	**0.1470**	**0.9506**	**-0.0998**	**20%**
VSD with static pressure reset[c]	-0.0031	0.0991	1.0268	-0.1128	20%

Data Sources:

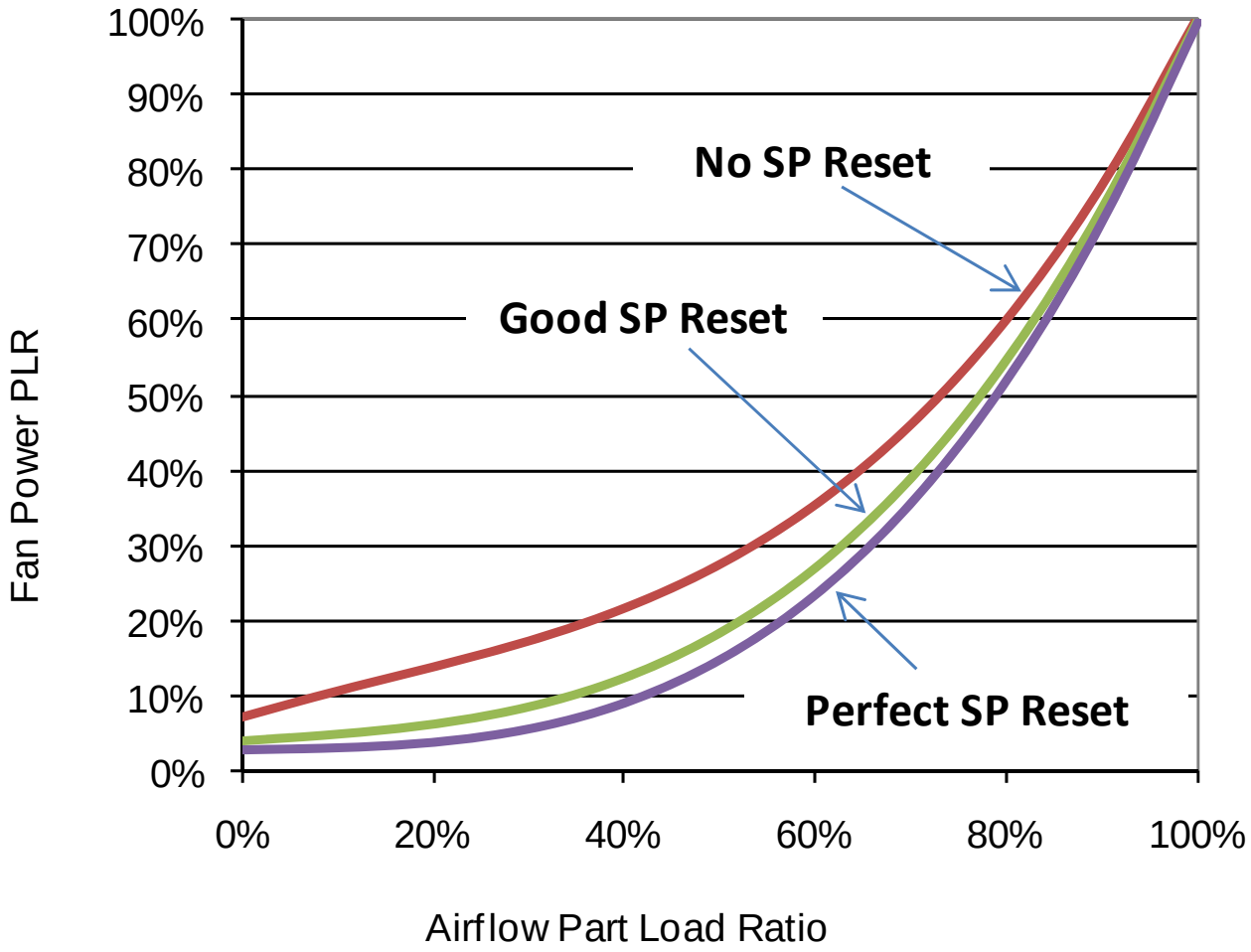
a. ECB Compliance Supplement, public review draft, Version 1.2, March 1996, but adjusted to be relatively consistent with the curve specified in the PRM.

b. The fan curve for VSD is specified in Table G3.1.3.15

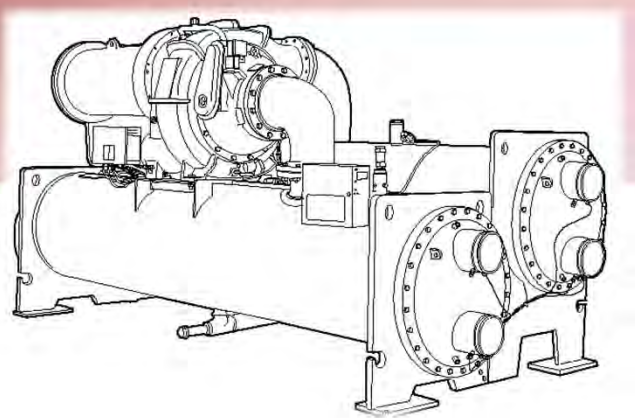
c. Advanced VAV System Design Guide, California Energy Commission, CEC Publication 500,-03-082 A-11, April 2005, but adjusted to be relatively consistent with the curve specified in the PRM..

HVAC
Static Pressure Reset Control

Source
VAV Design Guide, Appendix 5



HVAC
Chiller Performance



Challenge
Chiller performance curve coefficients

$$\begin{aligned} Elec_{in} &= Cap_{FullLoad} \\ &\times EIR_{FullLoad} \\ &\times CAPf(T) \\ &\times EIRf(T) \\ &\times EIRf(PLR, dT) \end{aligned}$$

1.0 at full load and rated temp.

HVAC
Chiller Performance

Source
COMNET, Section 6.8.2

Table 88 – Default Capacity Coefficients – Electric Water-Cooled Chillers

Coefficient	Scroll	Recip	Screw	Centrifugal
a	0.36131454	0.58531422	0.33269598	-0.29861976
b	0.01855477	0.01539593	0.00729116	0.02996076
c	0.00003011	0.00007296	-0.00049938	-0.00080125
d	0.00093592	-0.00212462	0.01598983	0.01736268
e	-0.00001518	-0.00000715	-0.00028254	-0.00032606
f	-0.00005481	-0.00004597	0.00052346	0.00063139

HVAC
Chiller Performance

Source
CoolTools spreadsheet

WATER-COOLED CHILLER PERFORMANCE FORM

Instructions:

1. Complete this worksheet before completing the worksheets, Full Load Data and Part Load Data;
2. Fill in yellow cells; Cells next to red font labels must be filled out;
3. Blue cells are calculated bu should be overwirtten for open drive chillers where noted;
4. White cells are locked;
5. **Please do not include ARI tolerances in performance data!**

GENERAL			
Option Name or Comments:			
Manufacturer:			
Model:			
Price for one chiller (including tax and freight)			
Alternate 1: Factory performance tests, non-witnessed			
Alternate 2: Factory performance tests, witnessed			
Alternate 3: Hot gas bypass			
Compressor type:			
Refrigerant type:		Refrigerant weight (lbs):	
Variable speed drive (Y/N)		Delivery lead time (weeks):	
ARI rated COP		ARI rated IPLV:	
Operating Weight (lbs.)		Voltage/phase:	480/3
OPERATING CONSTRAINTS			
Maximum CHW flow rate (GPM):		Maximum CW flow rate (GPM):	
Minimum CHW flow rate (GPM):		Minimum CW flow rate (GPM):	
Capacity (% of design capacity) below which hot-gas bypass operates (if HGBP is provided)		*Minimum "Lift" (CWRT-CHWST) at minimum load °F * :*	
Capacity (% of design capacity) below which chiller cycles		*CHWST reset range °F * :*	
DESIGN CONDITIONS			
EVAPORATOR		**CONDENSER**	
CHW fouling factor:		CW fouling factor:	
*Design CHW flow (GPM) * :*		*Design CW flow (GPM) * :*	
*Leaving CHWST °F * :*		*Entering CWST °F * :*	
*Entering CHWRT °F * :*		*Leaving CWRT °F * :*	-
CHW pressure drop (ft):		CW pressure drop (ft):	
Evaporator passes:		Condenser passes:	
Evap. Refrigerant Temperature (F)		Cond. Refrigerant Temperature (F)	
OTHER			
*Design kW (w/o ARI Tolerance) * :*		Full load amps:	
Design capacity (tons):	-	Design kW/ton:	-

OTHER RESOURCES
Energy Modeling Input Translator (EMIT)

- Rocky Mountain Institute spreadsheet tool
  - Lighting, Receptacle, Occupant Density
  - Domestic Hot Water Calculator
  - Cooling Tower Fan Efficiency Calculator
  - Proposed System Fan Power & EER
  - Baseline System Fan Power & EER
  - Schedule Exporter

www.rmi.org/ModelingTools

OTHER RESOURCES
HVAC Simulation Guide

- Energy Design Resources
  - UFAD and Displacement Ventilation
  - Chillers & custom curves
  - Advanced control sequences
    - Variable flow CHW and CW
    - Cooling tower
    - CHW and HW reset

www.energydesignresources.com/media/2654/EDR_DesignGuidelines_%20HVAC_Simulation.pdf

Questions?

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