HVACPowDen.xls
An Easy-to-Use Tool for Recognizing Energy Efficient Buildings and HVAC Systems

Fundamental Principles of Environmentally Responsible, Energy Efficient Buildings

1. Energy efficiency is a critical component for buildings with low environmental impact.
2. Energy efficient buildings should require very small cooling and heating equipment compared to conventional buildings.
3. Small and efficient cooling and heating equipment serving energy efficient buildings substantially reduces power, energy, and environmental impact compared to conventional equipment serving conventional buildings.

Purpose of HVACPowDen.xls

1. To provide architects, engineers, and building owners an easy-to-use tool that compares the specified size of the cooling and heating equipment to the required equipment size for high quality, energy efficient buildings.
2. To provide architects, engineers, and building owners an easy-to-use tool that compares the required power and fuel consumption rate of specified equipment to the required power and fuel consumption rate of energy efficient equipment in high quality buildings.
3. The tool has three tiers (base efficiency, high efficiency, and premier efficiency) and is corrected for building type (over 30 options) and climate (10 climate zones).

Example 1: A design team provides specifications for a 100,000 ft^2 school in St. Louis, MO that requires a 500-ton cooling unit and a 10,000,000 Btu/h heating unit. **As shown in the example instructions following this paper,** the HVACPowDen.xls user enters the St. Louis climate zone (Zone 4-Moist), building type (school), and size (100,000 ft^2). The program output indicates a base efficiency building (~ASHRAE 90.1-2004) requires a 400-ton cooling unit and a 3,500,000 Btu/h heating unit. A high efficiency building requires a 270-ton cooling unit and 1,600,000 Btu/h heating unit and a premier efficiency school building requires a 240-ton cooling unit and a 1,300,000 Btu/h heating unit. ***Clearly the building energy efficiency quality can be improved.***

Development of Guidelines for Base, High and Premier Efficiency

Power density allowances encompass the entire system which includes the quality of the building envelope, the efficiency HVAC equipment, and the attention to load minimization (ventilation efficiency, internal equipment, and lighting). The initial step in the procedure was to conduct cooling and heating load calculations for over 30 building types located in 10 primary climate zones listed in ASHRAE Standard 90.1. The calculations were based on three levels of building energy efficiency quality (base, high, and premier). Climate corrected envelope specifications and lighting power densities comply with ASHRAE 90.1. Building occupancies and ventilation rates use ASHRAE Standard 62.1-2004 as the primary reference for default values. Base level loads were conducted with 90% ventilation efficiency without the assistance of heat recovery units (HRUs) on the ventilation air. High and premier levels assume HRUs are applied, which results in a large reduction in heating requirements in most climates. Base level internal loads represent typical values for the building type and are lowered for high and premier efficiency buildings. Duct losses for the base efficiency represent values that comply with ASHRAE 90.1-2004 while premier efficiency assumes all ducts are in the conditioned space. Table 1 list these assumed values in more detail.

Table 1 – Characteristics of Buildings Used to Determine Cooling and Heating Requirements

Component	Base Efficiency	High Efficiency	Premier Efficiency
Envelope (walls, roof, windows, floors)	ASHRAE Standard 90.1-2004 compliant	U-factors/SHGC/C-factors 25% lower than Std. 90.1-2004	U-factors/SHGC/C-factors 50% lower than Std. 90.1-2004
Lighting	LPDs comply with ASHRAE Standard 90.1-2001	LPDs comply with ASHRAE Standard 90.1-2004	LPDs 20% lower than ASHRAE Standard 90.1-2004
Internal Loads	Medium for building type [i.e. 1.0 W_e/ft^2 (11 W_e/m^2) for office]	Low for building type [i.e. 0.75 W_e/ft^2 (8 W_e/m^2) for office]	Very low for type [i.e. 0.5 W_e/ft^2 (5.4 W_e/m^2) for office]
Ventilation Air	ASHRAE Standard 62.1-2004 compliant 90% vent. efficiency ($E_V = 0.9$)	ASHRAE Standard 62.1-2004 compliant with 70% HRU, 90% vent. efficiency	ASHRAE Standard 62.1-2004 compliant 70% HRU and 100% vent. efficiency
Ductwork	ASHRAE Standard 90.1-2004 compliant	50% thicker insulation than ASHRAE Standard 90.1-2004	No losses - All duct in conditioned space
Building Mass	Medium mass for building type [i.e. office: heavy weight walls (HW block, rigid insulation, brick veneer) and lightweight (metal) roof]		

HVAC System Efficiency

The computation of HVAC system efficiency diverges from ASHRAE 90.1 because the standard only requires compliance on a component-by-component basis. Designers are not required to compute the impact of auxiliary equipment upon system efficiency at design for non-unitary equipment. Since there are no reasonable limits on the number of components, systems with low efficiency are possible.

HVACPowDen.xls computes system efficiency using default values for component specifications and operating conditions. These default values can be replaced with values specific to the application and climate. The three system efficiency levels are shown in Table 2 using three common figures of merit for cooling and three levels of thermal efficiency for fossil fuel heating equipment.

Table 2 HVAC **SYSTEM** Cooling and Heating Efficiencies

HVAC System Efficiency Level	EER (Btu/Wh)	COP	Specific Demand (W_e/**Net** Ton)	Heating AFUE (%)
Base	10	2.9	1.2	80%
High Efficiency	11.5	3.4	1.04	90%
Premier Efficiency	13	3.9	0.9	95%

The desired result of this HVAC system efficiency computation is the generation of a set of power density allowances or total demand for the building. The building cooling and heating load values in Table 1 are divided by the HVAC system efficiencies from Table 2 to generate a building electrical demand (kW_e) in cooling and building heating input requirement (Btu/h). These values can be compared to cooling demand and heat rate for the HVAC system actually chosen by the design team.

Example 2: The design team for the 100,000 ft^2 school in Example 1 specifies a central chilled water system (CWS) with variable air volume (VAV) distribution using air handling units (AHUs), return fans and fan powered terminal boxes. **As shown in the example instructions following this paper, t**he resulting system EER is 6.0 Btu/W-h. The program output indicates a base efficiency building **796 kW_e** with this system. The high and premier efficiency buildings require **534 kW_e** and **476 kW_e** with this HVAC system. Had the designers specified an 10 EER HVAC system the base building demand would be **478 kW_e**. An 11.5 EER system with the high efficiency building would require **279 kW_e** while a 13 EER system in the premier building would only require **220 kW_e**. ***Clearly the HVAC system design can be improved.***

Summary

The identification of the impact of energy efficiency building envelopes, internal equipment, lighting and HVAC systems is difficult given the complexity of modern installations. The use of HVAC System Power Density guidelines is an alternative that does not require much beyond the level of effort required for conventional design. It also directly identifies the impact of all system components upon the net efficiency of the building HVAC system. HVAC Power Densities are intended to provide a set of indicators to identify “good, better, best” building efficiency levels for a variety of building types and climates.

Acknowledgements

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References

ASHRAE. 2004a. ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta.

ASHRAE. 2004c. ANSI/ASHRAE ASHRAE Standard 62.1, *Ventilation Air for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta.

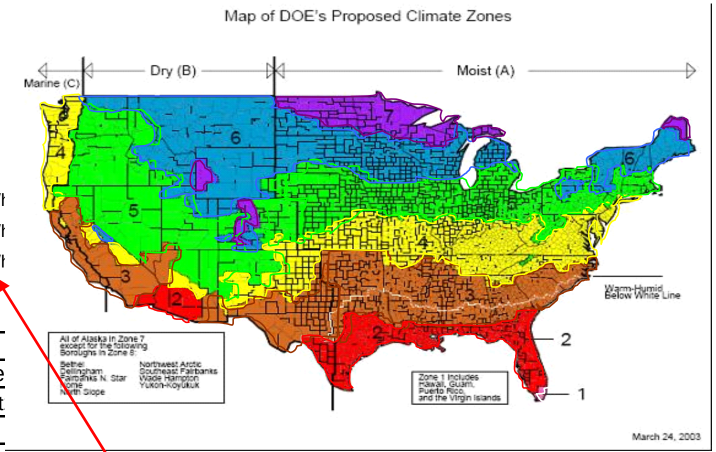
Kavanaugh, S. P. 2003. “Estimating Demand and Efficiency”. *ASHRAE Journal.* Vol. 45. No. 7.

Kavanaugh, S. P., S. E. Lambert, N. Devin. 2006. “HVAC Power Density:An Alternate Path to Efficiency”. *ASHRAE Journal.* Vol. 48. No. 12.

This is the Main worksheet that provides guidelines for the required size of cooling and heating equipment for 32 building types in 10 climate zones. Values are based on calculations for buildings that have energy efficient envelopes, lighting practices, optimum ventilation air handling strategies and typical internal equipment loads. Three levels of efficiency are provided: base, high and premier. The portion of the program beginning with Table 2 combines HVAC system efficiency with equipment size to provide the resulting power and fuel requirements for the energy efficient buildings. The HVAC system efficiencies are computed with an embedded program using default values or user defined inputs. Access to this program is accomplished by clicking on the most appropriate HVAC system worksheet at the bottom of the main program. The results are compared to values obtained for base energy efficient HVAC systems (EER=10), high efficiency (EER=11.5) and premier (EER=13).

- This program requires the MS Macro Security level to be set at Medium or Low (see ResetMacroSec.pdf).
- When prompted for links, enter "Continue"

Select Climate Zone or click on Climate Map---->	Zone4_Moist	
Choose building type from pull down menu-------->	School	
Enter floor area (ft^2 or m^2) of conditioned space-->	100000 ft^2	9293.7 m^2
Select Output to be English or Metric Units------->	English	Metric



Building Heat Gain				Building Heat Loss		
Base	398.5	Tons		Base	3573	1000xBtu/h
High	267.5	Tons		High	1529	1000xBtu/h
Premier	238.5	Tons		Premier	1279	1000xBtu/h

The classical prefix for 1000 Btu's is MBtu. However this creates confusion with kBtu and MBtu (1 million Btu's) used by Energy Star and CBECS.

Table 1. Building Heating and Cooling Load Requirements

Climate Zone 4 - St. Louis, MO			Cooling			Heating		
			Base	High	Premier	Base	High	Premie
Bldg. Type	Sub-type	Occ/1000ft^2	Btu/hr-ft2	Btu/hr-ft2	Btu/hr-ft2	Btu/hr-ft2	Btu/hr-ft2	Btu/hr-ft
School	Total		48	32	29	36	15	13

Table 2. HVAC SYSTEM Power Density Guidleines

Climate Zone 4 - St. Louis, MO			Cooling			Heating		
			Base	High	Premier	Base	High	Premier
Bldg. Type	Sub-type	Occ/1000ft^2	W/ft2	W/ft2	W/ft2	Btu/hr-ft2	Btu/hr-ft2	Btu/hr-ft2
School	Total		4.8	2.8	2.2	45	17	13
WaterCooledChilledWater_VAV			8.0	5.3	4.8			

W/ft^2 & $Btu/h\text{-}ft^2$ values for base, high & premier systems.

W/ft^2 values for system select in cell A22.

Electrical Cooling Demand For EER=10, 11.5 and 13				Heating Thermal Input For AFUE=80%, 90% and 95%		
Base	478.3	kW_e		Base	4466	1000xBtu/h
High	279.1	kW_e		High	1698	1000xBtu/h
Premier	220.2	kW_e		Premier	1346	1000xBtu/h

Electrical Cooling Demand For System Chosen in Cell A22		
Base	795.6	kW_e
High	534.0	kW_e
Premier	476.1	kW_e

This example worksheet is for water cooled chilled water variable air volume systems (WC-CWS-VAV). Several additional worksheets for other HVAC types are also available. **Caution this program is currently unlocked. Entries must be made in the yellow input cells only. The blue cells contain statements that output the default value (d). Default values can be overridden by typing in the yellow cell to the left of each blue cell.**

Water Cooled Chilled Water System
Variable Air Volume
Fan Powered Terminal

Override Default Values (d) in Input Column

		Input		kW	Ton	hp/ton	Std 90.1 Fan HP 1000 cfm
1	KWperTonWCC	d	0.6	0.60	1.00	0.72	
2	TSPSupply	5	5	0.40	-0.11	0.48	1.21
	MotorEffSup	d	90				
	FanEffSup	d	65				
	CFMperTonSup	d	400				
3	TSPReturn	d	2	0.16	-0.04	0.19	0.48
	MotorEffRet	d	90				
	FanEffRet	d	65				
	Exhaust%	d	20				
4	ChillWtrHead	d	100	0.08	-0.02	0.09	
	MotorEffChW	d	90				
	PumpEffChW	d	65				
	GPMperTonChW	d	2.4				
5	CondWtrHead	d	70	0.07			
	MotorEffCW	d	90				
	PumpEffCW	d	65				
	GPMperTonCW	d	3				
6	KWperTonCTower	d	0.065	0.07		0.08	
7	KWperTonTermFan	d	0.18	0.18	-0.05	0.16	0.39
			□□	1.55	0.78		

kW/Ton =	2
EER =	6.0
COP =	1.76

Chiller kW/ton based on 44 F Chilled Water & 85 F, 3.0 gpm/ton Condenser Water

Override Temperature Default Values (d) below (Condenser flow adjusted above)

	Input		CorFac
LWTempCHW	d	44	1.00
EWTempCW	d	85	1.00

Enter chiller or compressor kW/ton

Enter supply fan operating conditions and efficiencies.

Enter return fan data.

Enter chilled water & condenser pump data.

Enter cooling tower fan data.

Enter terminal fan data.

Resulting SYSTEM cooling efficiency indicators using default values corrected for impact of auxiliary equipment.