# 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**

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

Map of DOE's Proposed Climate Zones
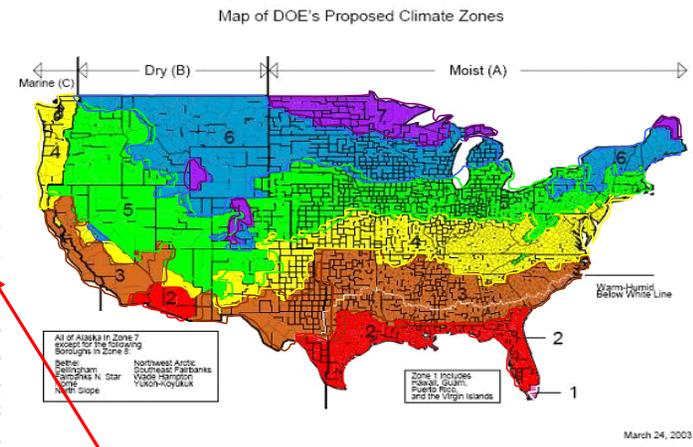


Table 1. Building Heating and Cooling Load Requirements

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

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 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-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 | Base | 478.3 kW$_e$ | Heating Thermal Input For AFUE=80%, 90% and 95% | 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

Enter chiller or compressor kW/ton

Std 90.1
Fan HP

| | | Input | | kW | Ton | hp/ton | 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 | |

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.

| | |
|---|---|
| kW/Ton = | 2 |
| EER = | 6.0 |
| COP = | 1.76 |

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

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 |

Upper Tray (~95°F)
Fan
Condenser Water
Impeller
Discharge Port
Condenser
Motor
Compressor
Chiller (Evaporator)
Centrifugal Chiller
Return ~55°F
Chilled Water
Chiller Pump
Water Basin (~85°F)
Cooling Tower
Supply ~45°F
Return Air Fan
Return Air
Exhaust Air
Re-Circulated Air
Supply Fan
Chilled Water Coil
Supply Air
VS Fan Motor
Mixed Air
Filter
Ventilation Air
VAV Terminal
Inverter Drive
Chilled Water Return
Chilled Water Supply
Series Fan Powered VAV Terminal
Primary Air
Air Valve
Re-Circulated Room Air
Hot Water or Electric Coil
Central AHU with Variable-Speed Drive Fan Motor
Loop Pump(s)
Other AHUs