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# Resources and Reading List

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## Overview

Over the years, one of the challenges we have faced in delivering technical classes for the Pacific Energy Center, the University of Wisconsin, SMUD, and other venues is to establish a common level of understanding of the fundamentals behind the topics to be discussed. Classes are often attended by people with a broad range of experience, including operators and facilities engineers who deal with technical issue and machinery on a day to day basis at one end of the technical spectrum and people new to the industry or who function more in management roles than technical roles at the other end. There can also be people with very deep knowledge in a focused area of expertise who have less depth in other areas.

Initially, we tried to address this by starting with the fundamentals and working our way up to the targeted content. But this tended to frustrate the more experienced attendees, reduced the time we had to spend on the intended topic, and could be overwhelming for the less experienced folks because we went at a pretty fast pace.

Over the past several years, we have successfully experimented with a different approach where-in we distribute a resource and reading list to attendees prior to class to allow them to self-educate where necessary. Typically, we supplement this list with a class specific cover memorandum to focus the pre-class preparation effort on topics we feel it is essential for you to understand to fully appreciate the class content that is associated with the class. This affords opportunity to everyone to come into the class at about the same level in terms of background knowledge. And the list serves as a resource for further reference and learning after the class.

Version 15 of the list (indicated by the "v15" in the file name) went through a major reorganization from the previous list. Specifically, the resources were categorized to follow the ten key retrocommissioning skills I discuss in the blog post titled [Key Retrocommissioning Skills](#). In the past, I have coded changes by using a colored italic font, usually red. But with the reorganization, everything would have been in red italic font. So, I reserved colored font convention to highlight items that have been added to the list since the last time it was updated no matter how they are organized. So, new items will be *highlighted in green italic font* (someone told me red meant that I was yelling at them, which I'm not, so sorry if I created that impression in the past; besides green is my favorite color).

Generally, all of the resources are publically available via the internet or by simply showing up in person someplace and asking for them. And many of them are free all-though some may require a modest

expenditure to obtain a full copy of the resource. If they are not free, I try to note that and indicate why I think they might be worth the investment.

Other than being categorized by the skill associated with them, items are in no particular order and simply reflect how I put the list together, which was generally as I thought of things or found things. I have tried to break software tools out in a separate heading under each category.

There are a number of resources that are good, all-around references so I have included a “General Reference” category for them. If they have something that is particularly useful to one of the 10 skills, I have also tried to highlight that feature under the appropriate skill.

The appendix section contains supplemental information that is either difficult to find directly on the internet or simply not available there.

To the best of my knowledge, all of the links in this document are active. But, occasionally, folks rearrange their web site and one will break. If that happens, usually you can find what you are looking for by searching for the document name directly via Google or a similar search engine.

In addition, if you hover over the links, you usually can see the actual path to the link. By going to the main web site associated with the link (the first part of the link, from “www.” thorough “.com”, you can often find the revised location for the reference. But, having said that, if you find a broken link, please let us know and we will research it and send you a new one in addition to updating our records.

Another common reason that links may not work is the firewall settings on the network you are using. A lot of corporate networks seem to really restrict how much you can search for and then download from the web. The only way I know of to get around this problem is to talk with your IT folks, or, to simply do your searching and downloading at home, outside of your corporate firewall.

I want to emphasize that this is far from a comprehensive list; there may be other great resources out there that I don’t know about and if you know of some and don’t mind me including them here, feel free to send me the information and I will add it. This list is also not intended to be any sort of endorsement for a particular product or approach. It’s simply an effort to provide information to those who might find it useful.

Finally, I want to extend a special “Thank You” to Dawn Kahalewai, one of the Administrative Assistants at FDE who spend a considerable amount of time reorganizing this and checking and repairing broken links. Without her help, this revision would likely not have happened for a very long time.

## Document Navigation

To minimize the effort required to find a particular piece of information or point in the document, headings and subheadings have been used in a way that create bookmarks in the electronic version of the document. You can use the bookmarks to jump to a topic of interest, as illustrated in Figure 1 (red arrows). “Previous View” arrows on the main toolbar (blue arrow in Figure 1) will take you back to the point you came from.

Also note that if you hover over a figure number or similar reference, the cursor will become a “pointing hand” that lets you link to the figure by clicking on the reference (green arrows in Figure 1). Note that in most cases, you can also click on a reference to a figure or a section title within the text of the document and jump to that location.

Note that the illustration and specifics are based on Acrobat/Adobe Reader X. Other versions have similar features all though the Acrobat folks seem to move things around and change where the various buttons are, which can be frustrating and annoying. But, at least in my experience, if all else fails, you can do things like open the bookmarks window by accessing it from the “View” drop down menu as illustrated in Figure 2 and Figure 3.

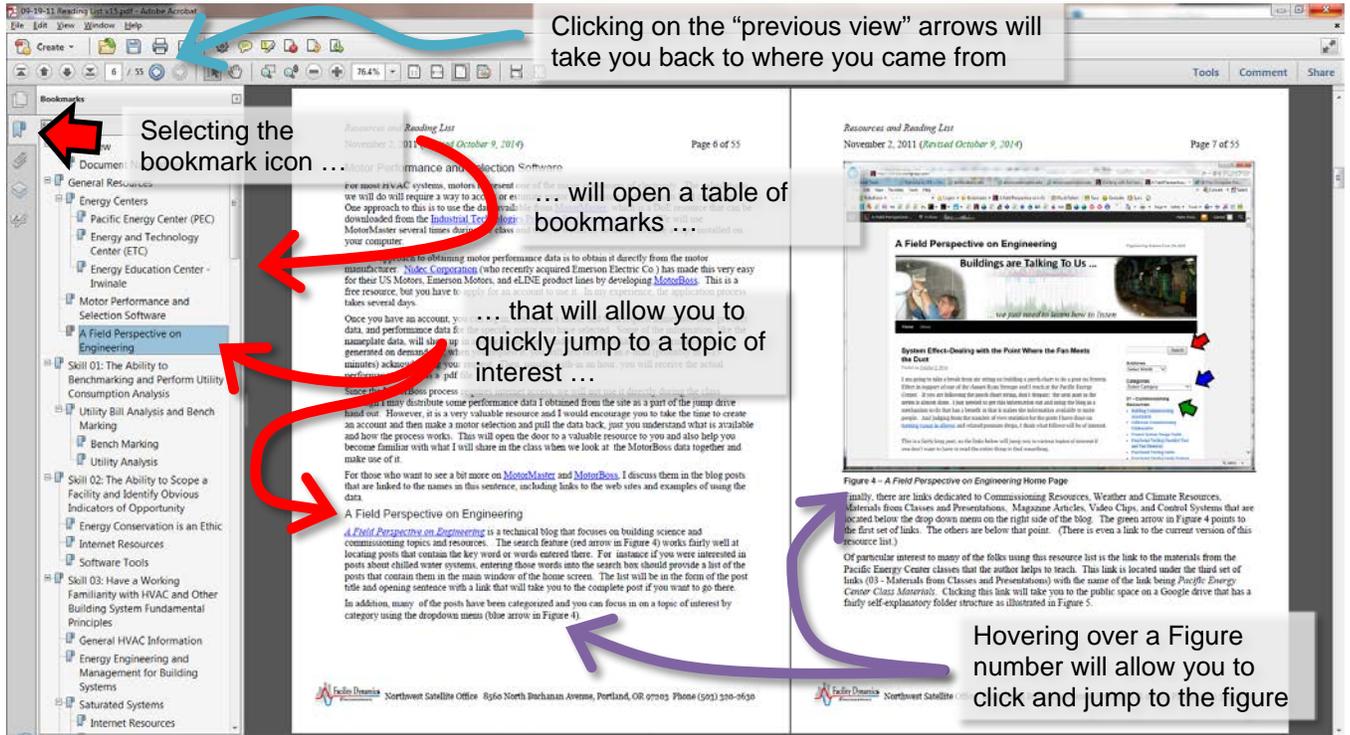


Figure 1 – Using the Navigation Panel to Jump to Content

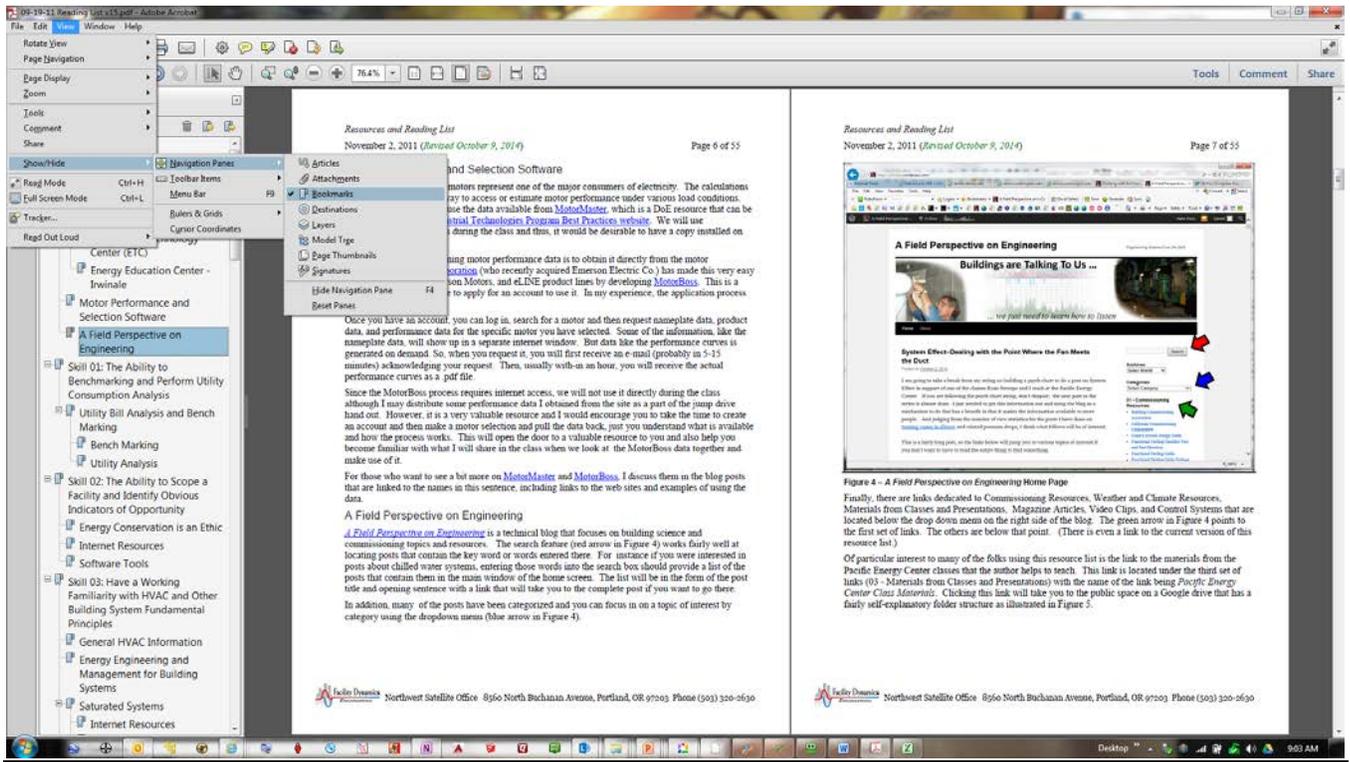


Figure 2 – Using the View Menu to Open the Bookmarks Window

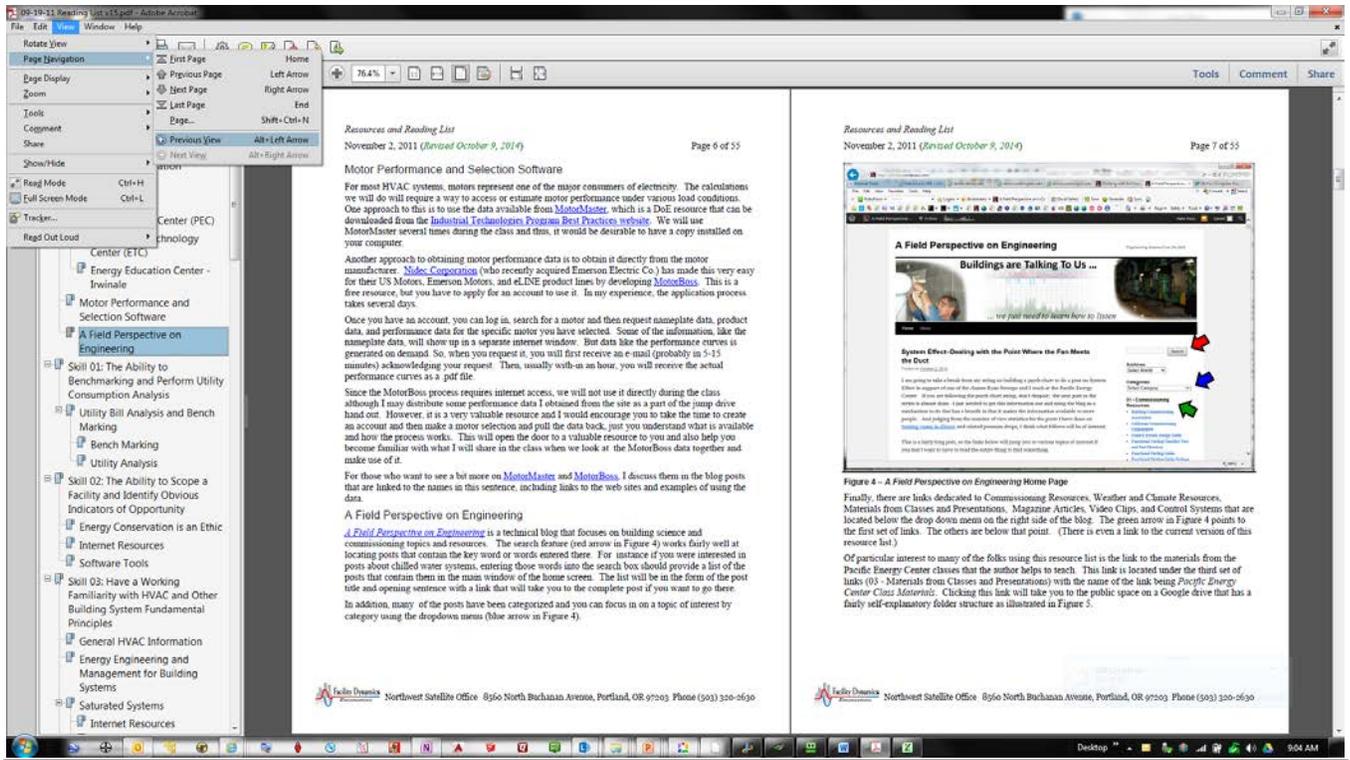


Figure 3 – Using the View Window to Access the Previous View Buttons

## General Resources

### Energy Centers

Many utility companies provide resource centers to help support their customers in terms of knowledge, improving efficiency and sustainability, and other outreach functions. Frequently, the classes they provide are given by industry leaders and are offered at no charge as a service to rate payers. In some instances, the classes are offered on the internet, making them available to the broader public.

The following locations are ones that I am familiar with having taught in them. I'm sure there are others that can be added to the list as I become aware of them.

#### Pacific Energy Center (PEC)

Pacific Gas and Electric's [Pacific Energy Center](#) offers a broad range of training and support including:

- [Classes and webinars](#) on selected topics related to buildings, building systems, energy efficiency, sustainability, and conservation. Classes are offered at a number of venues through-out the PG&E service territory in addition to at the PEC. To find out which classes are offered on line, select "Internet" for the location. Classes function on a semester basis with the offerings changing in January and September of each year.
- A [tool lending library](#) that includes a huge array of instrumentation that you can borrow at no charge if you are working in their service territory.
- A [resource acenter](#) that includes an on-line catalogue system and some electronic content.
- [On demand learning modules](#) that you can down-load and review at your leisure. This is a new feature and is constantly growing.

#### Energy and Technology Center (ETC)

Sacramento Municipal Utility District's [Energy and Technology Center's](#) mission is to be a premier information source on energy technology applications for commercial and residential customers.

Towards that end the center offers:

- [Basic and advanced classes](#) on energy, efficiency, renewable energy and climate change.
- [Interactive exhibits](#) that demonstrate energy efficiency and renewable energy technologies.
- A self-service [reference room](#) featuring building science information.

#### Energy Education Center - Irwindale

Southern California Edison's Energy Education Center - Irwindale is a source of energy efficiency information anyone wanting to learn about technology for saving energy, money, and the planet.

Resources include:

- [Workshops and classes](#) on a broad range of energy efficiency topics.
- Displays and exhibits on energy efficiency including a Daylighting, Food Service, Lighting, Sustainability, and Innovation.
- An electromagnetic field lab and power quality center.

## Motor Performance and Selection Software

For most HVAC systems, motors represent one of the major consumers of electricity. The calculations we will do will require a way to access or estimate motor performance under various load conditions. One approach to this is to use the data available from [MotorMaster](#), which is a DoE resource that can be downloaded from the [Industrial Technologies Program Best Practices website](#). We will use MotorMaster several times during the class and thus, it would be desirable to have a copy installed on your computer.

Another approach to obtaining motor performance data is to obtain it directly from the motor manufacturer. [Nidec Corporation](#) (who recently acquired Emerson Electric Co.) has made this very easy for their US Motors, Emerson Motors, and eLINE product lines by developing [MotorBoss](#). This is a free resource, but you have to apply for an account to use it. In my experience, the application process takes several days.

Once you have an account, you can log in, search for a motor and then request nameplate data, product data, and performance data for the specific motor you have selected. Some of the information, like the nameplate data, will show up in a separate internet window. But data like the performance curves is generated on demand. So, when you request it, you will first receive an e-mail (probably in 5-15 minutes) acknowledging your request. Then, usually with-in an hour, you will receive the actual performance curves as a .pdf file.

Since the MotorBoss process requires internet access, we will not use it directly during the class although I may distribute some performance data I obtained from the site as a part of the jump drive hand out. However, it is a very valuable resource and I would encourage you to take the time to create an account and then make a motor selection and pull the data back, just you understand what is available and how the process works. This will open the door to a valuable resource to you and also help you become familiar with what I will share in the class when we look at the MotorBoss data together and make use of it.

For those who want to see a bit more on [MotorMaster](#) and [MotorBoss](#), I discuss them in the blog posts that are linked to the names in this sentence, including links to the web sites and examples of using the data.

## Induction Motors

Induction motors are typically the prime movers behind most commercial and industrial HVAC processes. Thus, having a grasp of how they work and what some of their characteristics are is important. Towards that end, have been working with the staff at the Pacific Energy Center in San Francisco to create “on demand” content that will be available for public access at no cost on the internet.

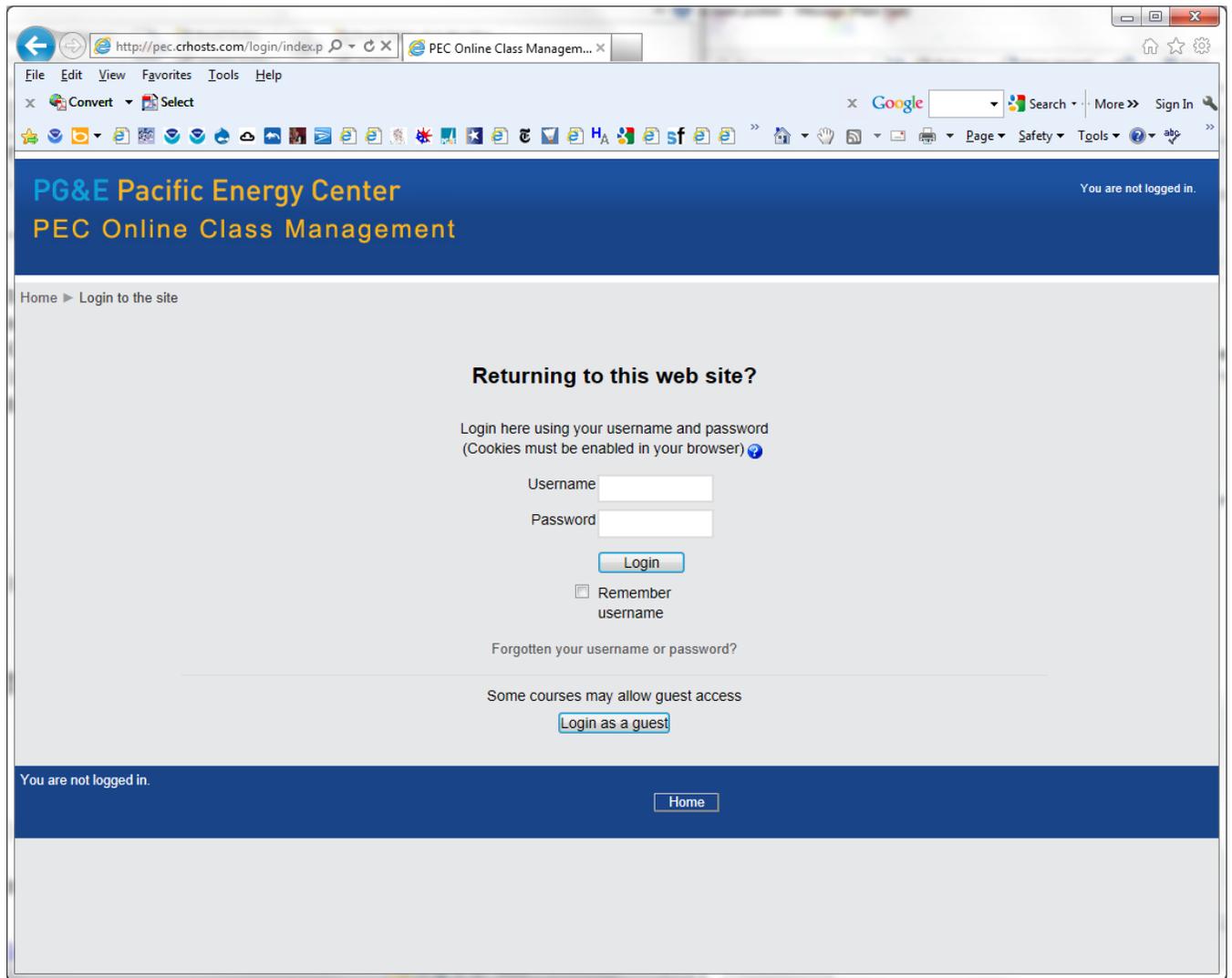
## PowerPoint Slide Sets

As of the time I am writing this we have completed everything but the final slide set that will show how the data collected during the pump test in one of the videos can be plotted on a pump curve. Hopefully, we can complete that soon.

Meanwhile, you can view the content by going to one of two locations. For training in the form of narrated PowerPoint slides that covers:

- Induction Motor Fundamentals,
- Induction Motor Applied Theory,
- Induction Motor Characteristics – Efficiency, Power factor, Speed, Amps and kW vs. Load,
- Induction Motor Characteristics – Speed vs. Torque,
- Induction Motors And Centrifugal Machines, and
- Induction Motor Resources,

you can go to the [Pacific Energy Center Online Class Management Center](#). That link should take you to a web page that looks something like Figure 4.



**Figure 4 – Log-in Page**

Select “Login as a guest” and you should be directed to a page that looks something like Figure 5.

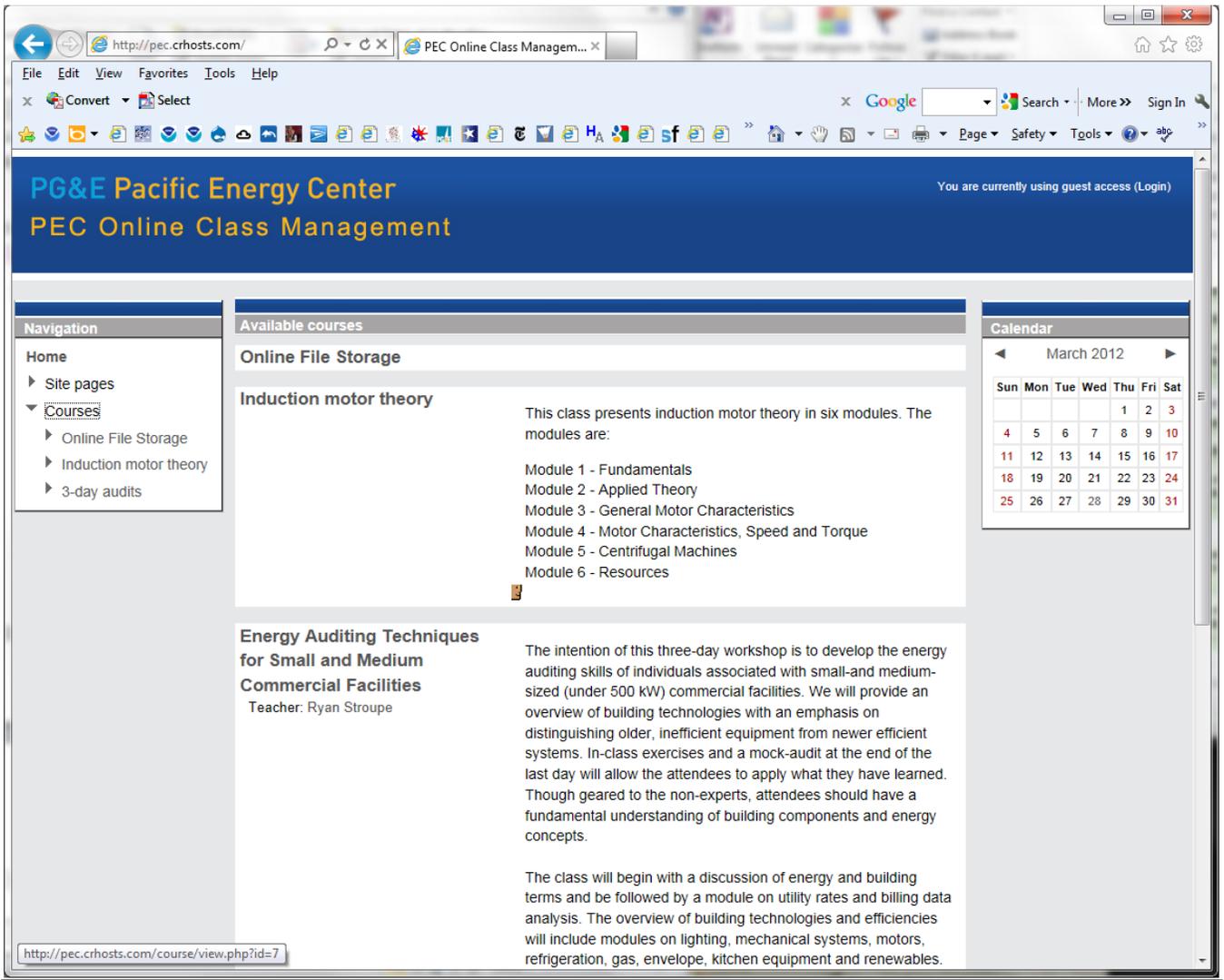


Figure 5 - PEC Online Class Management Web Site Home Page

From this point, select “Induction Motor Theory” from the drop-down “Courses” menu on the left. That will take you to a page that looks like Figure 4.

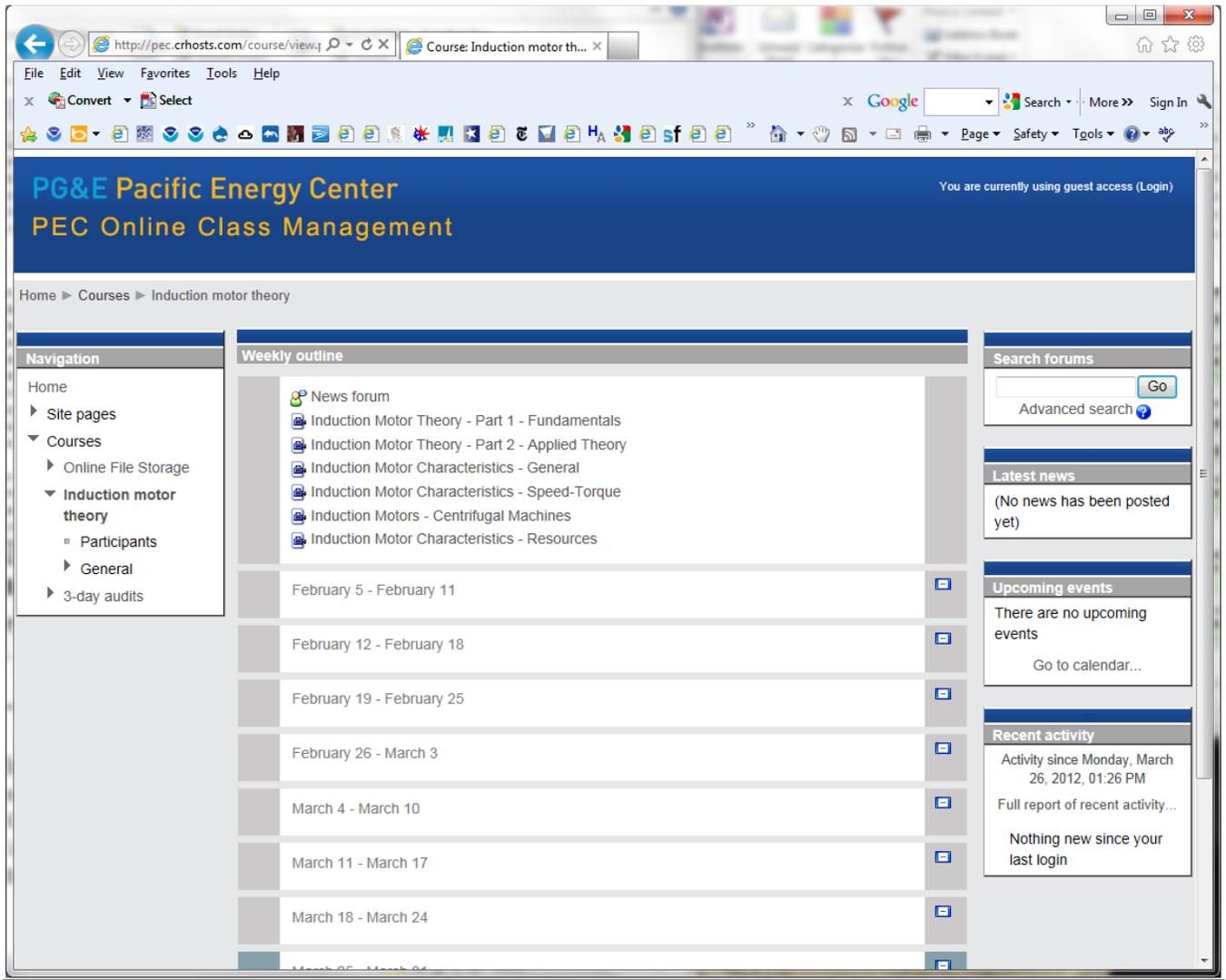


Figure 6 – Induction Motor Content Files

From this point, you should be able to select a file and when you do, it should open up in a separate window and play as a video presentation.

Note that the final slide set in the series is dedicated to induction motor resources, so rather than reproducing that information here, I will simply let you access it from the slide set.

### Videos Showing Induction Principles in Action

To complement the training presentations discussed in the preceding section, the PEC has created three video presentations showing induction principles in action which are available by following the [On Demand Classes](#) link from the [PG&E Energy Efficiency Classes](#) page on the [Pacific Energy Center web site](#).

- [Pump Motor Interaction](#) shows how the speed of an induction motor changes as the load that is applied to it changes. It also illustrates how to perform a pump test, including dead-heading the pump.

- [Induction Part 1](#) shows a very simple experiment you can perform to demonstrate the basic principle of induction.
- [Induction Part 2](#) ; if you thought *Induction Part 1* was spell-binding, then you will *love Induction Part 2*. It picks up where *Induction Part 1* leaves off, showing a second experiment that expands the basic induction principle to a motor.

### Alternative Locations for Accessing the Induction Motor Content

The sites referenced above are fairly new and there may be some issues with them. If you have trouble accessing the content, please let Ryan Stroupe (R2S2@pge.com) at the Pacific Energy Center know so he can have someone look into the issue.

Meanwhile, you can find copies of the narrated slides sets as well as the videos on induction motor principles in a temporary home on my Google drive. You can access the content by going to <http://tinyurl.com/InductionMotorSlides>.

You can view the slides on the Google Documents web site, but you can also download the presentation and view it on your laptop. The advantage to the latter is that you can run it as a PowerPoint show, which will allow the animations that are built in the slides to work. This may make some of the points easier to understand vs. viewing the unanimated slides. If you don't have PowerPoint, you can download a [free PowerPoint viewer from the Microsoft web site](#).

### Electric Motors and Their Applications

This book by Thomas Cox Lloyd taught me a lot about electric motors. I was given my copy by Tom McCarthy, an electrical engineer who mentored me and finally got tired of having to come to my office to retrieve his copy when he needed it. While it is dated in some areas, the basic principles it contains still apply and to me at least, it was written in a very understandable manner.

You can still find used copies around in used book stores and online, at places like [Powells.com](#) and [Amazon.com](#). As of this date, prices range from \$.01 to \$14.99. If you want a used copy, Amazon says it will run you \$2,420.43; not sure if shipping is included. So, unless the new copy was autographed by Nikola Tesla or something, I would probably just go for one of the used copies.

### A Field Perspective on Engineering

[A Field Perspective on Engineering](#) is a technical blog that focuses on building science and commissioning topics and resources. The search feature (red arrow in Figure 7) works fairly well at locating posts that contain the key word or words entered there. For instance if you were interested in posts about chilled water systems, entering those words into the search box should provide a list of the posts that contain them in the main window of the home screen. The list will be in the form of the post title and opening sentence with a link that will take you to the complete post if you want to go there.

In addition, many of the posts have been categorized and you can focus in on a topic of interest by category using the dropdown menu (blue arrow in Figure 7).

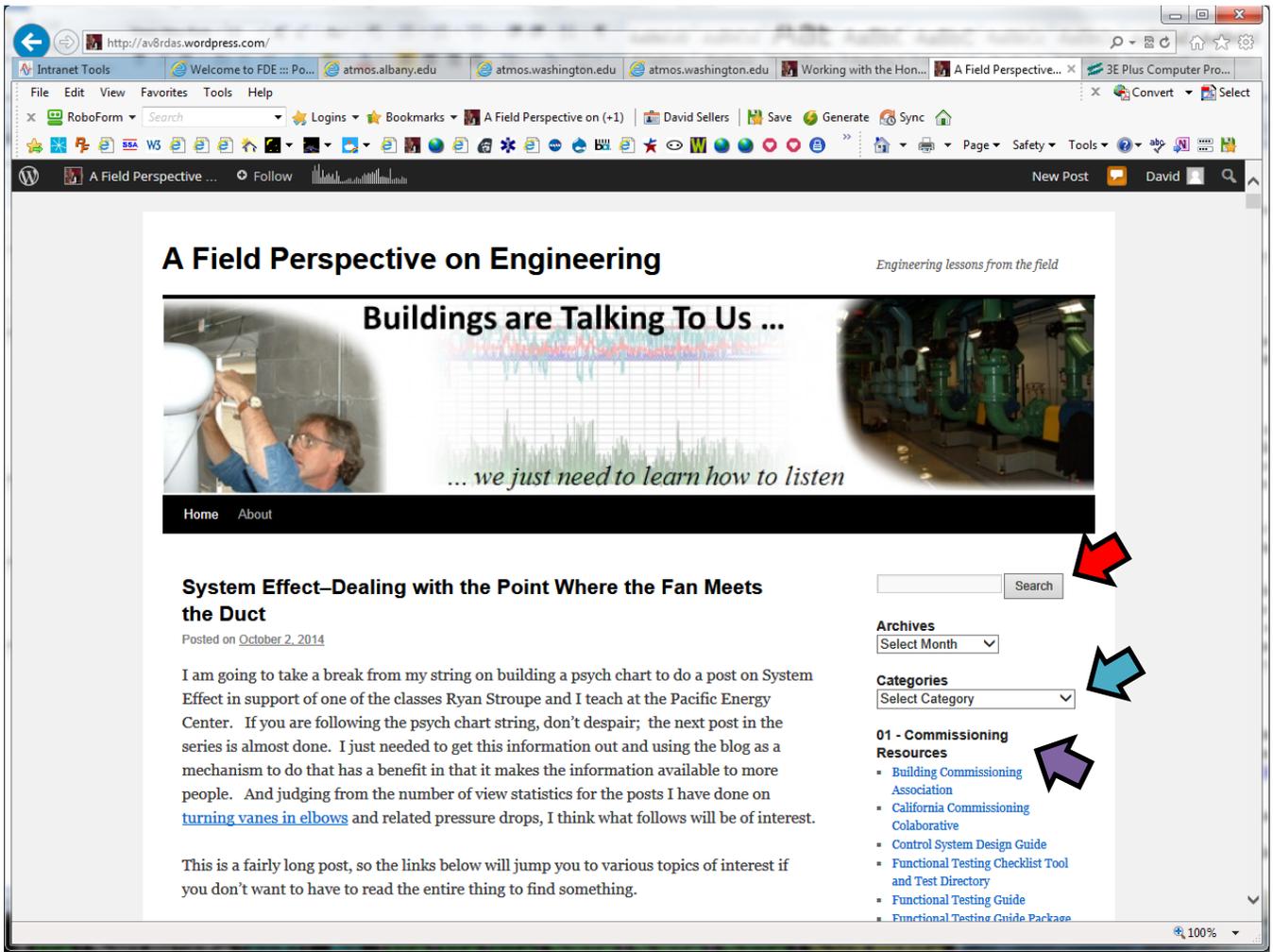


Figure 7 – A Field Perspective on Engineering Home Page

Finally, there are links dedicated to Commissioning Resources, Weather and Climate Resources, Materials from Classes and Presentations, Magazine Articles, Video Clips, and Control Systems that are located below the drop down menu on the right side of the blog. The green arrow in Figure 7 points to the first set of links. The others are below that point. (There is even a link to the current version of this resource list.)

Of particular interest to many of the folks using this resource list is the link to the materials from the Pacific Energy Center classes that the author helps to teach. This link is located under the third set of links (03 - Materials from Classes and Presentations) with the name of the link being Pacific Energy Center Class Materials. Clicking this link will take you to the public space on a Google drive that has a fairly self-explanatory folder structure as illustrated in Figure 8.

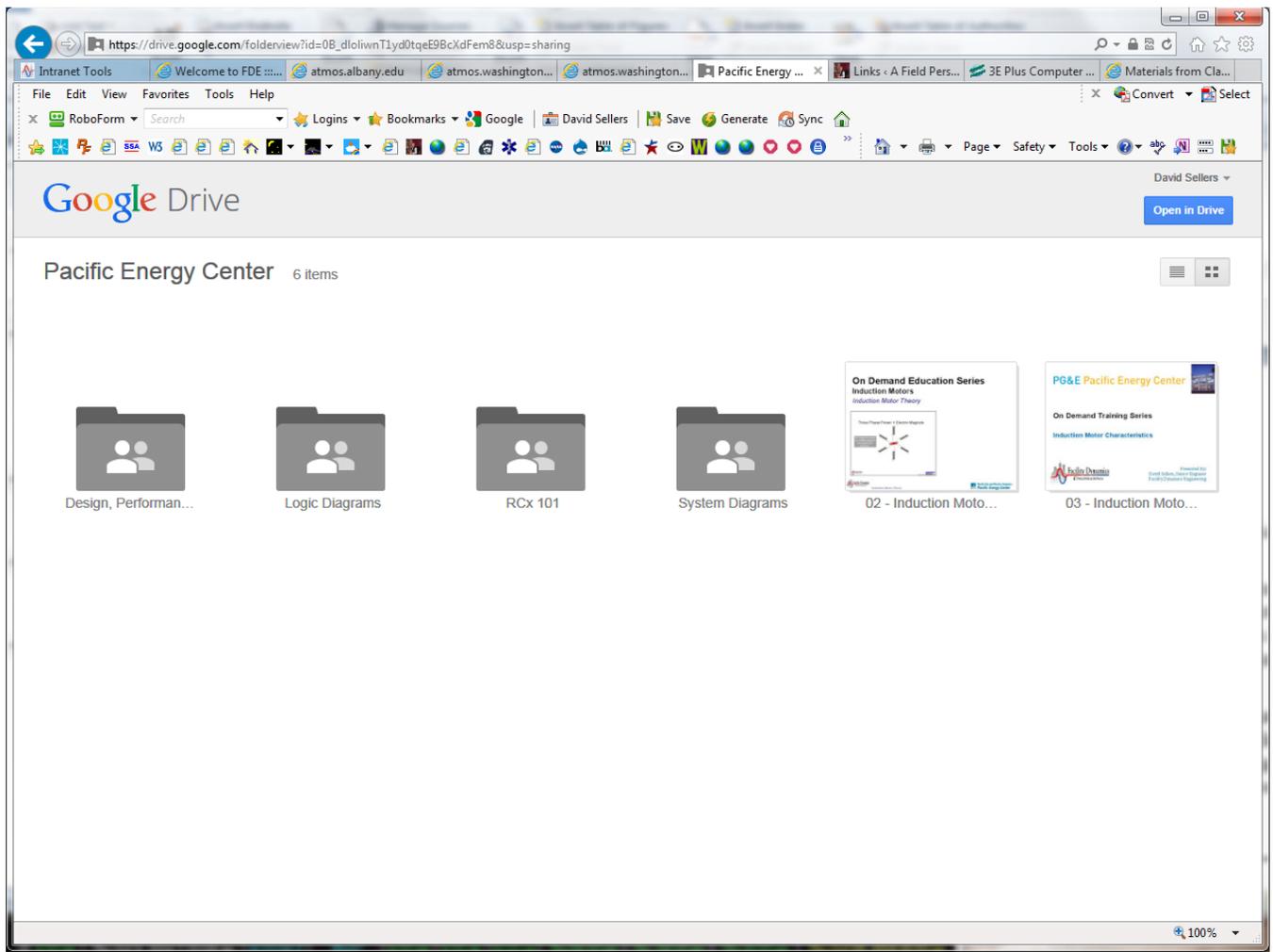
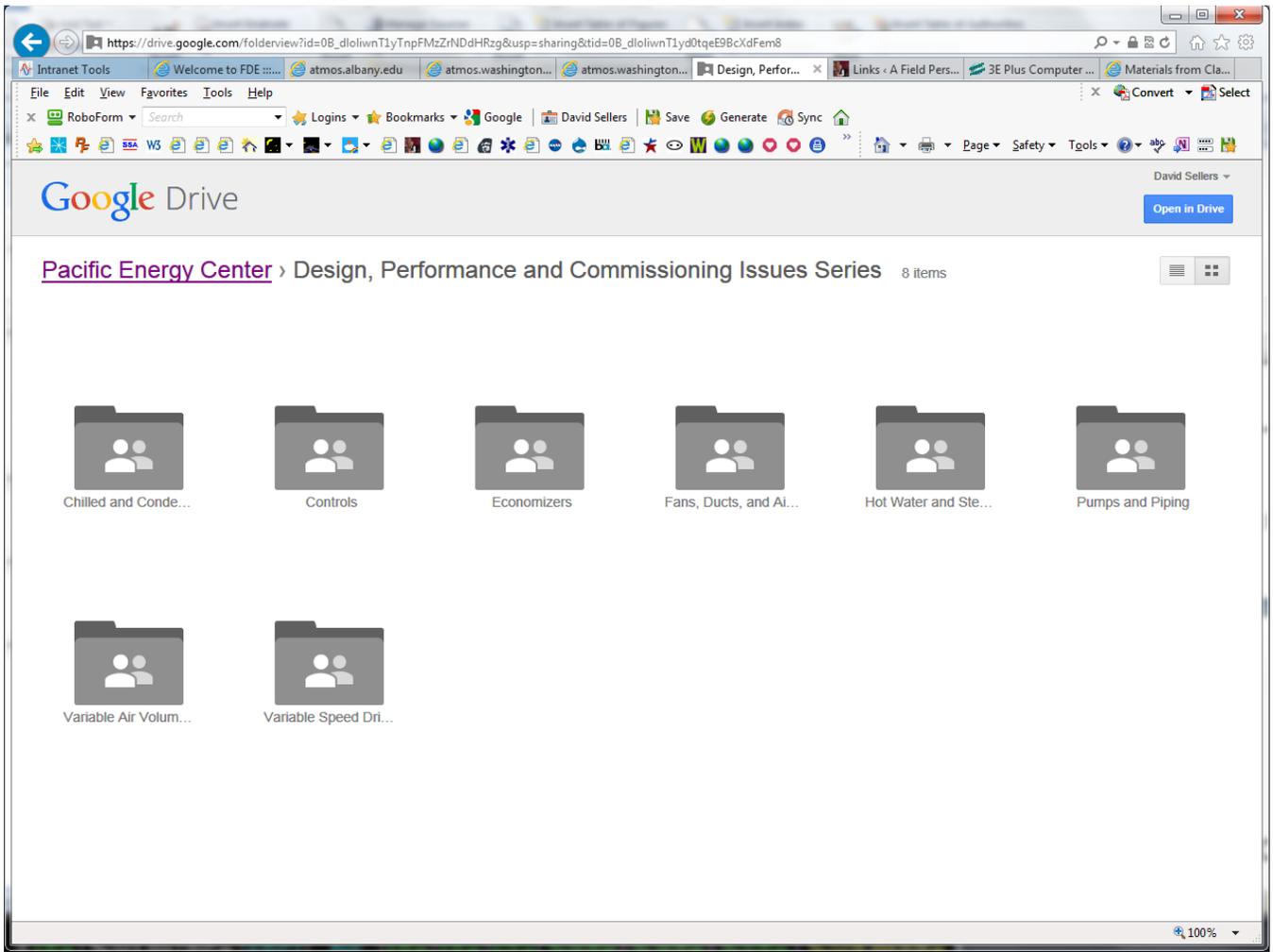


Figure 8 – Google Drive Folder Structure



**Figure 9 – Design, Performance and Commissioning Issues Class Series Folders**

If you click on a folder, for example the one titled Design, Performan..., you will be taken to a page that has a folder for each class, as illustrated in Figure 9. The folders contain the presentations from the most recent version of the class.

### A Free Digitizing Tool

One of the challenges that can come up in the electronic age is the need to work electronically with things like pump curves, fan curves, friction charts, etc. Normally, if you wanted a chart in Excel, you either needed to “do the math” to create it, something that I illustrate in a [blog post about creating thermodynamic diagrams](#) and in [a string of blog posts about creating your own psych chart](#). Or, if you were using empirical data like a pump curve, you had to laboriously read points off the various lines on the actual curve and create tables in Excel that you then would use to plot the chart.

Thankfully, there is now a great little shareware package that lets you quickly digitize any curve you can get in the form of an image of some sort (.jpg files, .pdf files, etc.). It is called Plot Digitizer and you can download it at <http://plotdigitizer.sourceforge.net/>. It works very well and can accommodate standard and logarithmic axis.

From what I can tell, the program basically correlates pixels on your screen with the image you are trying to digitize by first having you click on the origin and end points of the two axis and tell it the scale associated with each. Then, you simply tell it you want to digitize a line and pick points on that line. The result is a little Comma Separated Value (CSV) file that you save. Once you have done that process for all of the lines you need, you can open up Excel, load the csv files into it, and recreate the curve.

Figure 10 and Figure 11 illustrate how I used Plot Digitizer to create in Exel version of a pump curve. In addition to allowing me to recreate the original curve in Excel, which is handy in and of itself for reports and presentations, once I have the data in Excel, I can do all sorts of handy things with it.

For instance, the spreadsheet behind the illustrations lets me enter field data from my pump test and on that basis, plots the operating point (the red circle with blue shading in the right illustration in Figure 10) and the system curve (the red line). It also lets me enter a non-standard impeller size, based on nameplate data or a shut off test and draws the impeller line for me (the blue line) based on the affinity laws.

There is also a tab in the spreadsheet that lets me enter the output frequency of a variable speed drive controlling the pump or a tach reading along with the impeller size and uses that data to draw the pump curve for the current operating speed. So pretty handy, and many thanks to Louis Langlois of [Carbon Lighthouse](#) for letting us know the tool existed.

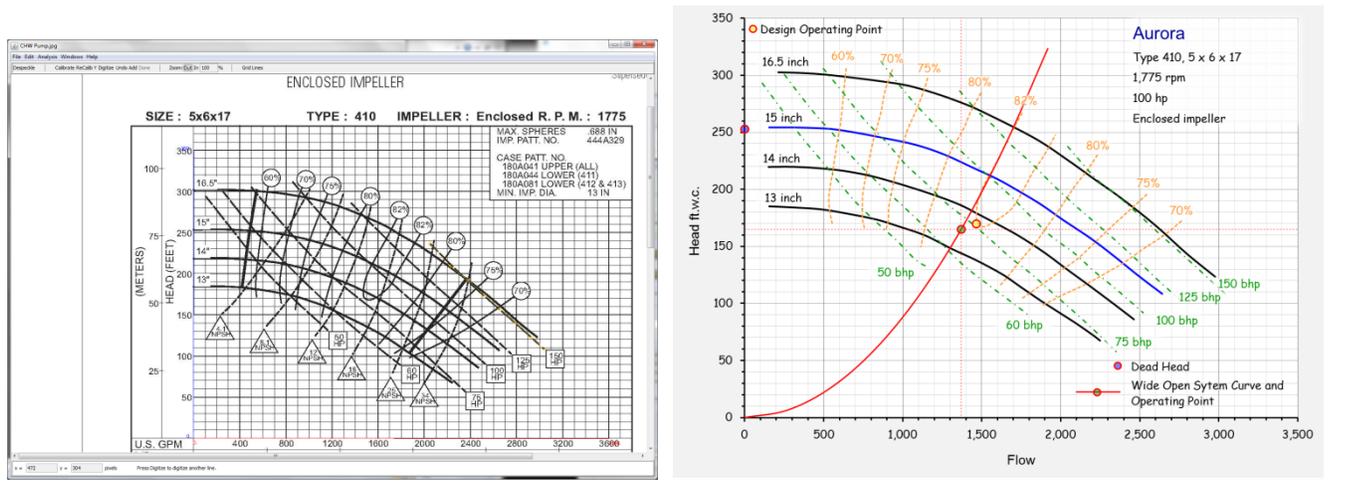


Figure 10 – An Original Pump Curve Image in Plot Digitizer (right) and the Resulting Curve Created in Exel (left)



- [Interpreting IEEE Std 519 and Meeting it's Harmonic Limits in VFD Applications](#) is an IEEE paper that discusses the standard in the context of VFD applications.

### Advanced Lighting Design Guide

[The Advanced Lighting Guidelines](#), an interactive web tool that has its roots in development by the [New Buildings Institute](#) provides a comprehensive look at a number of lighting topics including:

- Lighting and Human Performance
- Lighting's Energy and Environmental Impacts
- Codes and Standards Associated with Lighting
- Lighting Design
- Lighting Applications
- Light Sources
- Luminaries and Lighting Distribution
- Lighting Controls and Day-lighting

You can use the interactive content on the website for no cost. Or, for a modest annual fee, you can subscribe to the full version, a monthly newsletters, complete access to ALG's eight regularly updated chapters, two continuously expanding design directories (Application and Luminaire) and the latest case studies.

### Cooper Bussmann

The Cooper Bussmann [Selecting Protective Devices Handbook](#) is a great way to learn about this topic and its relationship to the National Electric code. It also contains useful information on how properly selected dual element fuses can be used to protect motors from "single phasing", an extreme case of phase to phase voltage imbalance that can happen when one phase of a multiphase supply system is lost. In this situation, three phase motors will continue to operate, but the current on some of their phases will be excessive, leading to excessive heating and failure of the motor windings.

### Variable Speed Drives

A while back, I completed a string of three blog posts that look at variable frequency drives and their application to HVAC systems and equipment. At the time I wrote the posts, one of the reasons for developing them was to supplement and support this class. They can be viewed on the Field Perspective on Engineering blog at <http://av8rdas.wordpress.com/>. Specifically:

- [Variable Frequency Drive System Efficiency - Part 1](#) looks at the information that I found on line regarding drive and motor efficiency and how they can vary with load.
- [Variable Frequency Drive System Efficiency - Part 2](#) looks at why we find it attractive to be able to vary the speed of HVAC equipment in the first place.
- [Variable Frequency Drive System Efficiency – Part 3](#) looks at the over-all efficiency of a fan-motor-variable frequency drive system as they interact when the system loads and unloads

In the retrofit and retrocommissioning arena, we often are faced with the need to apply a variable speed drive to an existing motor. This may or may not be as straight-forward as it sounds. The following article from the EC&M web site is dated, but full of good information; [Mating new variable frequency drives to existing motors](#). You will need to register with EC&M to get the article, but registration is free. EC&M has a lot of real world articles and information on their website.

The National electrical Manufacturer Association (NEMA) [Application Guide for AC Adjustable Speed Drive Systems](#) is available at no cost from their web site. When you go follow this link you will need to accept the conditions and then you can download the electronic document for free or you can purchase a hard copy. This is not a document to be read cover to cover, but is a great source for basic information and a beginning point for more in depth research.

There is also a class Ryan Stroupe, Kim Parson and I offer at the Pacific Energy Center about once a year called *Variable Speed Drives; Design, Performance and Commissioning Issues*. It is a free class and usually offered as a webinar. You can find out more about that under the *General Resources - Energy Centers - Pacific Energy Center (PEC)* heading. And, typically, you can find the most recent slide set for the class via the link under *03 - Materials from Classes and Presentations* on the right hand side of [my blog's opening page](#).

## Belts and Drive Systems

On a lower technology note, many HVAC systems – fans in particular - often include belts between the motor and the equipment served. Even a well adjusted set of belts can result in a loss of 2-3%. Losses for poorly adjusted belts can be as high as 10% or even more. For years, [TB Woods](#) has published [Installation and Maintenance of V-Belt Drives](#), a very practical guide on belt installation, adjustment and maintenance which now be downloaded from the web at no cost.

If you want a “second opinion” on the topic, [Twin City Fan and Blower's](#) Engineering Data Sheet EB-1400 provides their perspective on [V-Belt Drive Selection for Fans](#) and can be downloaded at no cost. And [Carlisle Belts](#) provides a number of useful resources on their web site, including a [drive design program](#) and [a paper with test data regarding the efficiency of different belt types](#), including how the losses show up as an increased temperature in the drive system.

## Design Review

Design review is an important tool and can be applied at a number of points in a typical commissioning process including:

- Reviewing schematic design, design development and construction documents.
- Reviewing shop drawings and submittals for new equipment
- Reviewing the actual installation of the systems and equipment during construction
- Reviewing proposals for replacement equipment in existing buildings.

The design brief titled [Improving Mechanical System Energy Efficiency Through Architect and Engineer Coordination](#), available from the [Energy Design Resources](#) (EDR) web site will provide insight into the general desirability of the process and ways to accomplish it. The EDR design briefs [Design Details](#), [Design Review](#), and [Field Review](#) will also provide insights into techniques and the value of the design review process.

The [EDR Charrette tool](#), also available on the Energy Design Resources web site, will to experiment with different design features in a hypothetical project and view their impacts on building performance.

While a little more difficult to find, the Energy Design Resources Design Review Tool is a valuable resource providing checklists developed by experienced commissioning professionals that can be used to guide your design review process. To find it, go to the [California Commissioning Collaborative](#) web site ([www.cacx.org](http://www.cacx.org)), then select “Library” then search for “Design Review”. It should come up in the list of no cost downloads, along with other resources that may be of interest.

Finally, the [Functional Testing Guide](#) includes a design review checklist tool that not only provides guidance for design review, but also links you up for the reasons that specific items matter as describe in the content of the FT Guide. The entire suite can be used interactively on the web or downloaded to your personal computer for off-line use.

I also recently put up [a blog post about system effect in fan systems](#). One of the points of the post is that field lessons from existing building experiences like retrocommissioning and day to day operations provide valuable insights into how to prevent a problem in the first place. Design review offers the opportunity for field experience to be brought back to the drawing board, often saving first cost in addition to avoiding energy waste and operational problems down the road.

## Commissioning

### California Commissioning Collaborative

The [California Commissioning Collaborative](#) offers a broad array of commissioning resources for both new construction and existing building commissioning. The ones I use the most include:

- [A resource library](#) that is searchable by author, title, key word etc.
- Tools and templates for both [new construction](#) and [existing building](#) commissioning including:
  - [Sample documents](#) and templates for typical commissioning documents like a commissioning plan, a commissioning RFP, etc.
  - A [Building Optimization Analysis Tool](#) designed to standardize and streamline energy savings calculations and engineering processes particularly for those working in California utility system commissioning programs.
  - A [pumping system Excel workbook](#) that projects energy savings for a number of pump optimization strategies. One issue to be aware of is that this tool was developed in Excel 2003 and the changes that occurred in Excel 2007 introduced problems if you try to use it in that version of Excel.
  - A [fan system Excel workbook](#) that projects energy savings for a number of fan optimization strategies. Similarly to the pump tool, this tool was developed with Excel 2003 and the current version has issues if you run it in Excel 2007.
  - An [Energy Charting and Metrics tool \(ECAM\)](#) designed to facilitate the analysis of energy data from buildings. As I write this (September 2011), there is a new version of the tool about to be upload, which will have many more features and be more robust than the original version.

- A [utility consumption analysis tool](#) designed to make it very simple to do average daily energy consumption analysis. All you need is a stack of utility bills (amount and date of reading) and after entering that basic data, the tool produces a normalized average daily consumption table and graph for the year or years that you entered data for. You can also add data like heating or cooling degree days, occupancy, production, etc. for comparison to the utility consumption patterns.
- A [findings workbook](#) designed to organize and track retrocommissioning findings from investigation through implementation.

### Building Commissioning Association

The [Building Commissioning Association](#) is an industry group whose goal is to promote professional standards while allowing for variable approaches to the commissioning process. Their website provides links to a number of features including:

- [Process templates](#) that include an RFQ template and checklists for a variety of equipment. You need to create an account to access them; members can access more information than non-members.
- A [member directory](#), which can be a handy way to look up a commissioning provider in your area.
- A [quarterly newsletter](#) that can be obtained free of charge by simply subscribing to it.
- An [employment opportunity listing](#), which is handy if you are looking for a job in the industry?

### Commissioning Assistant

The Commissioning Assistant is a web based tool designed to provide support for design professionals interested in incorporating commissioning into their projects. It includes tools and resources to:

- Project costs.
- Identify scope.
- Develop design intent.
- Develop basis of design information.
- Review sample commissioning specifications.
- Review sample sequences of operation.
- Develop a commissioning plan.
- Develop a training plan.
- Develop a systems manual.

### Process Guidelines

There are a number of free commissioning process guidelines available.

- The California Commissioning Collaborative publishes both a [New Construction](#) and an [Existing Building](#) commissioning guideline.
- Oakridge National Laboratories publishes [A Practical Guide for Commissioning Existing Buildings](#) on their web site.

- The [Whole Building Design Guide](#), associated with the National Institute of Building Sciences includes a [guideline targeted at GSA facilities](#) on their web site.
- Portland Energy Conservation Incorporated (PECI) has a number guidelines on their web site in the [Searchable Resource Library they maintain](#).

### National Conference on Building Commissioning

Since 1982, PECI has organized the [National Conference on Building Commissioning](#) (NCBC) every year. Since 2005, the [proceedings](#) have been made available on line on the PECI web site. Selected papers from the proceedings from past conferences can also be found on the [California Commissioning Collaborative](#) web site.

### Engineering Software International HVAC Software

Laclede Gas in St. Louis offers [no charge access to an HVAC load calculation tool](#) developed by ESI Software International. They also offer access [to the other software packages in the ESI suite](#), which are now also offered free of charge.

[ESI software](#) originally started out as a pay per use service providing on-line computer resources to designers. Now, use of the programs is offered at no charge via the Laclede Gas program. If you find yourself in need of support, it is available for a modest charge.

The programs are designed to be intuitive to use so I imagine you can go a long way on your own. I say that because the programs have their roots in the in-house software that Al Black developed when I worked at McClure Engineering, so I am fairly familiar with using them. In fact, the hour by hour loads that I use to illustrate things in classes are calculated with this software.

The data files you generate when using the programs can be stored at no charge for up to 90 days on the ESI servers or transferred to your own computer system. After 90 days, maintaining your data on the ESI server will incur a modest monthly charge.

The current program offering includes:

- Psychrometric Properties
- Psychrometric Processes
  - Mixing
  - Cooling and Dehumidifying
  - Sensible Heating or Cooling
  - Isothermal Humidification
  - Evaporative Cooling
  - Difference Between Two State Points
- Heating and Cooling Load Calculations
- Heating and Cooling Coil Selection
- Heating and Cooling Coil Diagnostics

- Expansion Tank Sizing
- Hydronic Pipe Sizing
- Steam Properties
- Steam Processes
  - Expansion (Power) Process
  - Fuel Heat Required to Generate Steam
  - Steam Control Valve Sizing
  - Steam Orifice Size or Capacity
  - Difference Between 2 State Points

## HVAC Equations, Data and Rules of Thumb

This is one resource that is not offered free of charge, but it is one I reference frequently and also mention frequently in class. I list it here because I recently (September 2011) discovered that it is available as a Kindle book for about \$35 (09-2011 price) which is about half of what a new, paperbound edition costs. And, it's much more portable.

And, it turns out you don't have to have a Kindle to have a Kindle book. Amazon now offers a Kindle for PC application that you can download at no charge which appears to run under Windows XP (I think service Pac to or higher is required) or later versions of Windows. I think they have one for Macs too.

I recently tried it out and obtained a Kindle copy of the HVAC Equations ... book and it seems to work very well. It did take the program a while to download and index the book when I first purchased it, but once that process was complete, it all seems to work just fine.

## HVAC Design

### How to Design Heating-Cooling Comfort Systems

This book, by Joseph B. Olivieri, is no longer in print, but you can find used copies of it around at reasonable prices (\$5-\$10) at used book sellers, both physical and on line. I should also mention that a quick internet search right now revealed that you could also buy it for somewhat crazy prices, like \$140 - \$150, so heads up on that.

I bring the book up because it is a very well written practical guide to HVAC design. It was written back in the days when there were not computers and things like the ASHRAE duct fitting data base, but the fundamentals it contains are still sound and I still reference it occasionally. The psychrometrics chapter is particularly helpful for someone new to the field since it is written in layman's terms and includes problems with answers worked out on the chart. The load calculation chapter will give you some insight into the basics behind the computer load calculations we run now since it shows you how to do it by hand.

An indication of the book's practical approach to things comes from my days as a Facilities Engineer at Komatsu. At one point, I had answered a question one of the operators had by referencing my copy of the book and he asked if he could borrow it, which I gladly allowed. However, the book was used so

frequently by the operating team that I finally bought them their own copy so that I could keep mine in my bookshelf so I could find it when I needed it.

## The Carrier Design Manual

The copy I have of this design guide is dated 1960 and was given to me by Bud Weiczorek, one of my mentors. But despite its age, the fundamentals in it still apply. And, as a person working in existing buildings, I frequently find the information on legacy design approaches from the 1960's to be helpful when I run into a system from that era.

A current technology version of this guide is [still available from Carrier](#) for around \$125 currently. But I suspect you can find used copies for less than that and like I said, the basics are still the same.

## Skill 01: The Ability to Benchmarking and Perform Utility Consumption Analysis

### Utility Bill Analysis and Bench Marking

Typically, in many of the commissioning and retrocommissioning classes, we spend some time discussing how utility data can be used to gain insight into where opportunities for improvement lie in your facility as well as to monitor the persistence of those improvements.

#### Bench Marking

Benchmarking is a quick way to compare your facility's efficiency to similar facilities. This can be a useful technique for a number of reasons. For one thing, if you are looking at a number of buildings and trying to decide where to start, benchmarking them can provide a quick picture of which is the most efficient and which is the least, which can help you focus your effort on the facility or facilities where you are most likely to achieve the "biggest bang for the buck".

And, once you have worked on a facility, benchmarking it every once-in-a-while can help you track its performance and catch problems that are causing it to degrade. In addition, many benchmarking tools, like the Energy Star Portfolio Manager, have a constantly growing data base.

This means that people are constantly adding buildings and/or updating the data on their facilities as they make improvements. As a result, the "target" is constantly moving, meaning that as other Owners improve the efficiency of their facilities, you will need to do the same if you want to maintain or improve your score. In other words, if you score a 75% this year but don't do anything to improve upon that, it is likely that your building will no longer achieve that score after several years because your peers have made improvements and "raised the bar".

There are a number of free resources out there that can help you with this process.

- [Energy Star Portfolio Manager](#) is probably the most sophisticated benchmarking tool in terms of what it takes to create the benchmark. It allows you to track energy and water consumption for a broad array of facility types and also gain EPA recognition. Many programs like [LEED O&M](#) include achieving an Energy Star rating as a part of the process.
- *The [Building Performance Database](#) is a relatively new tool that provides a really fast way to do a benchmark once you know your EUI. Frequently, as a starting point, I will benchmark on their site*

*and do a screen shot of the result for use in a report or presentation because the graphics are clean and fairly intuitive to understand.*

- [EnergyIQ](#) is a new tool that grew out of the [CALARCH](#) benchmarking tool. It includes a number of databases for comparison including the California End Use Survey (CEUS), the USDOE Commercial Buildings Energy Consumption Survey (CBECS) and the Labs21 Benchmarking Database. You can focus the comparison on only California buildings (the California Energy Commission's Public Interest Energy Research (PIER) program was a significant contributor to the tool's development) or on buildings from across the country.
- [Labs21](#) ([Labs for the 21<sup>st</sup> Century](#)) sponsors a benchmarking tool that is focused on high tech laboratory type facilities.
- [Oak Ridge National Laboratory](#) developed one of the earliest benchmarking tools around. The database behind this tool is less robust and fixed in time compared to the newer tools described above. But, if you are trying to understand what benchmarking is and how it works, this tool will walk you through the steps quickly and as a result, you will likely gain some insights.

If you are looking for a [tutorial on benchmarking](#), you will find just that in the form of a one hour presentation by Mark Jewell (of the Energy Efficiency Funding Group or [EEFG](#)). The presentation can be found on the [On Demand Classes](#) link from the [PG&E Energy Efficiency Classes](#) page on the [Pacific Energy Center web site](#). In it, Mark walks you through using the Energy Star tool. While the presentation is focused on using the tool to support PG&E programs and processes, I think anyone wanting to learn about or use the Portfolio Manager software will find the information to be useful.

### Utility Analysis

If you are not familiar with normalizing utility to present it as average daily energy consumption (vs. consumption per billing period), then you will benefit from reading [Using Utility Bills and Average Daily Energy Consumption to Target Commissioning Efforts and Track Building Performance](#) which can be downloaded from the [California Commissioning Collaborative](#) on line library among other places. The [CCC](#) also has a number of free tools on their website that will help you apply the principles discussed in the paper.

- The [Utility Consumption Analysis Tool](#) literally automates the techniques described in the paper listed above. All you need is a pile of utility bills with the total consumption and the date of the meter reading. Once you have entered the data, the tool normalizes it to calendar months and plots average daily consumption for you. The tool also allows you to enter data for comparison, like cooling or heating degree days, production, or occupancy to name a few.
  - *The [Energy Charting and Metrics \(ECAM\) Tool](#) allows you to quickly work with interval meter data and other trend data to analyze a buildings load profile, create square foot metrics of building energy use and developing scatter plots comparing consumption to other parameters like occupancy or time of day. The link above takes you to the download from the California Commissioning Collaborative website. [This link](#) was provided by Bill Koran, the program's author and takes you to a download page on the Association for Facilities Engineers website. This particular download includes a cool little Excel tool that goes out and pulls back a year's worth of hourly weather data from a Weather Underground weather station. That means you can find a station close to your project location and get a year's worth of hourly weather data*

pretty quickly. Figure 12 illustrates the input form for Bill's tool to give you an idea of what it does.

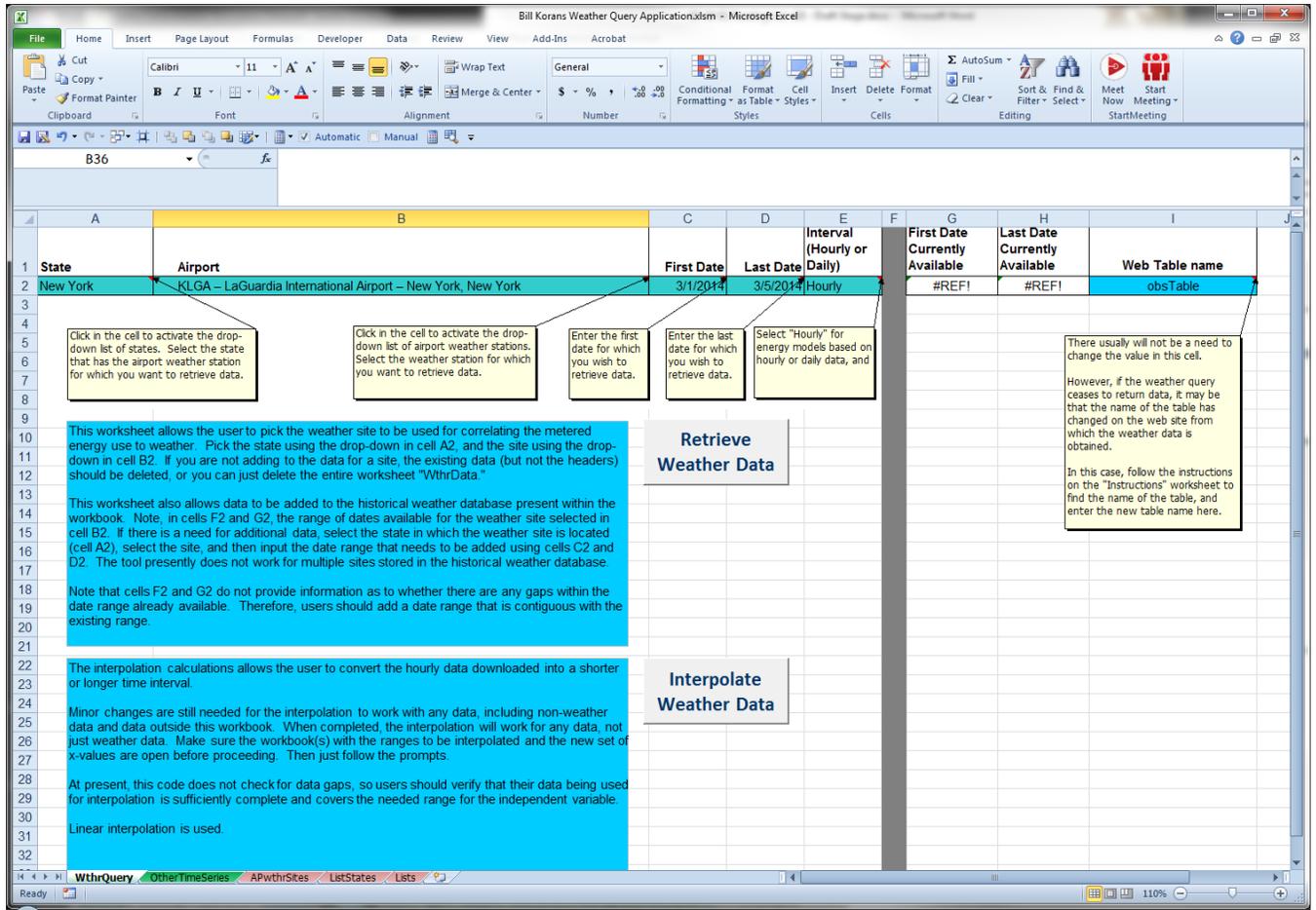


Figure 12 – Bill Koran’s Weather Data Retrieval Tool

## Skill 02: The Ability to Scope a Facility and Identify Obvious Indicators of Opportunity

### Energy Conservation is an Ethic

Frequently in class, I mention a paper Bill Coad wrote titled *Energy Conservation is an Ethic*. If you are an ASHRAE member, you can read the original article by [accessing your free copy of the ASHRAE Journal back-issue for July 2000](#). Non-members can [purchase a copy for a nominal fee](#) from the ASHRAE bookstore.

You can also read the fundamental philosophy behind the article by visiting the [Coad Engineering Enterprises](#) web site and [reading the discussion topic for March of 2006](#). If you have never thought about this before and are working in the energy efficiency/energy conservation field, I strongly recommend that you read this article.

## A Field Perspective on Engineering

The [A Field Perspective on Engineering](#) blog includes a number of posts on the topic of scoping, including a string of posts that show how the clues add up to [identify targets in a makeup air handling system](#).

## Skill 03: Have a Working Familiarity with HVAC and Other Building System Fundamental Principles

### General Heating, Ventilating and Air Conditioning (HVAC) Information

#### Energy Design Resources Design Briefs

There are several design brief on the Energy Design Resources website that you may find useful in the context of developing a general understanding of HVAC:

- [Air Conditioning & Ventilation](#) looks at energy efficient approaches to the design of HVAC systems and will reinforce and expand what you might read in the Honeywell manual.
- [Design for your Climate](#) looks at how climate can influence design decisions and how you can leverage an understanding of the climate associated with your project to optimize efficiency and comfort.
- [Integrated Building Design](#) looks at how taking a whole building, life cycle cost based approach to design can save energy and resources.
- [Improving Mechanical System Energy Efficiency](#) looks at how the “fuzzy” information available during schematic design can be used to make sound integrated design decisions, capturing opportunities that would be lost later in the process.
- [Design Details](#) looks at how seemingly minor issues like the configuration of a duct fitting or the arrangement of a piping connection can yield big savings in energy and first costs.

#### ASHRAE Handbooks

The ASHRAE Handbooks are also good resources for general information on various types of systems, and their components. For instance, the *2008 ASHRAE Handbook of Applications* includes chapters on the following relevant topics.

- |                                                              |                                                   |
|--------------------------------------------------------------|---------------------------------------------------|
| ■ Comfort Control in Various Occupancies                     | ■ Operation and Maintenance Management            |
| ■ Industrial Applications like Clean Rooms, and Laboratories | ■ Building Energy Monitoring                      |
| ■ Geothermal Energy                                          | ■ Supervisory Control and Optimization Strategies |
| ■ Solar Energy Use                                           | ■ Commissioning                                   |
| ■ Thermal Storage                                            | ■ Building Envelopes                              |
| ■ Energy Use and Management                                  | ■ Design and Application of Controls              |
| ■ Owning and Operating Costs                                 | ■ Water Treatment                                 |
| ■ Testing Adjusting and Balancing                            |                                                   |

*Resources and Reading List*

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- Service Water Heating
- Snow Melting and Freeze Protection
- Radiant Heating and Cooling
- Electrical Considerations
- Integrated Building Design

The *2008 ASHRAE Handbook of HVAC Systems and Equipment* includes chapters on the following relevant topics.

- Panel heating and cooling
- Heat Pump and Heat Recovery Systems
- Steam Systems
- District Heating and Cooling Systems
- Hydronic Heating and Cooling
- Medium and High Temperature Water Heating
- Automatic Fuel-Burning Systems
- Boilers
- Hydronic Heat-Distributing Units and Radiators
- Solar Energy Equipment
- Centrifugal Pumps
- Motors, Motor Controls and Variable Speed Drives
- Pipes, Tubes and Fittings
- Valves
- Heat Exchangers
- Thermal Storage
- Codes and Standards

The *2009 ASHRAE Handbook of Fundamentals* includes chapters on the following relevant topics.

- Psychrometrics
- Thermodynamics
- Fluid Flow
- Heat Transfer
- Two-Phase Flow
- Mass Transfer
- Fundamentals of Control
- Thermal Comfort
- Climate Design Information
- Heating and Cooling Load Calculations
- Energy Estimating and Modeling
- Pipe sizing
- Insulation
- Building Envelope
- Combustion and Fuels
- Physical Properties of Materials
- Energy Resources
- Sustainability
- Measurement and Instruments

The ASHRAE Handbooks are updated on a 4 year cycle , and if you [join ASHRAE](#), one of the benefits of membership is a copy of the current year's handbook, which now includes an electronic version in .pdf format as well as the printed version. Students receive a discount in the annual membership fee.

### Jargon and Definitions

The Honeywell manual also contains a definitions section at the very beginning of the Control Fundamentals chapter that you may find useful if you are new to the jargon of the HVAC industry. I have also attached the current draft of a glossary for a guideline we are working on as an appendix to this memo to supplement the Honeywell definitions.

### Fundamentals to Frontiers

From 1973 to 1990, Bill Coad wrote a monthly column for Heating Piping and Air Conditioning Magazine called *Fundamentals to Frontiers*. These columns were one of my primary sources of knowledge and learning and I always read them first when my magazine came. Occasionally, I was lucky enough to get the lesson in person from Bill.

I have a file with paper copies of many of them, but had lost some and never had others (for instance, the ones from before I started in the industry – pre 1976). Fortunately, Bill has put .pdf copies of all of them on the [Engineering Software International](#) web site. They can be accessed from the William J. Coad Publications button on the left side of the screen and then selecting the *Monthly Columns In Heating/Piping/Air Conditioning* link. Here is an alphabetical list of the titles.

- A Dissertation on Loads, September 1985.pdf
- Air Distribution Techniques, A new Challenge, July 1982.pdf
- Air in Hydronic Systems, July 1980.pdf
- Air Transport Factor, Opportunities and Limitations, July 1986.pdf
- An Overlooked Objective of System Testing, November 1987.pdf
- An Overlooked Objective of System Testing, Part II, December 1987.pdf
- A Perspective on Operation and Maintenance, January 1981.pdf
- Applying the Dry Bulb Economizer, October 1982.pdf
- A Primer on Electric Rates, March 1980.pdf
- A Reexamination of Engineering Education, January 1978.pdf
- A Renewed Interest in District Heat, April 1981.pdf
- A Single Equation for Cogeneration Analyses, December 1979.pdf
- Basics of Combustion - II, February 1982.pdf
- Basics of Combustion - I, June 1982.pdf
- Building Automation Systems, September 1977.pdf
- Causal Analysis of Machinery Failures, December 1985.pdf

- Causes of and Cures for Building System Defects, February 1985.pdf
- Central Plants - I, August 1984.pdf
- Central Plants - II, September 1984.pdf
- Centrifugal Pumps, Construction and Application, September 1981.pdf
- Chilled Water Hydronic Systems, December 1980.pdf
- Complementary Technologies, May 1987.pdf
- Cost control through Design, September 1982.pdf
- Curiosity, Hallmark of an Engineer, April 1987.pdf
- Dalton and Vapor Migration, May 1985.pdf
- Demand Control, April 1982.pdf
- Design Parameters, February 1975.pdf
- Domestic Hot Water Systems, New Way to Size Components, Febr 1983.pdf
- DX Control Problems with VAV, January 1984.pdf
- Education, The Key to the Energy Dilemma, October 1976.pdf
- 198308 EMCS and Digital Controllers, August 1983.pdf
- Energy Analyses for Existing Buildings, September 1980.pdf
- Energy and Your Home, Part I, February 1986.pdf
- Energy and your Home, Part II, March 1986.pdf
- Energy Audits II, Components of Energy Use, August 1979.pdf
- Energy Audits III, Components of Energy Use, October 1979.pdf
- Energy Audits I, The Energy Profile, July 1979.pdf
- Energy Audits IV, The Uses of Audits, November 1979.pdf
- Energy, A Unique Commodity, December 1977.pdf
- Energy Concepts of Air Handling Systems, August 1980.pdf
- Energy Economics, A Design Parameter, June 1973.pdf
- Energy Economics, A Needed Science, January 1975.pdf
- Energy Economics of Domestic Hot Water Systems, July 1984.pdf
- Energy Management, January 1977.pdf
- Energy Management Systems, A Spontaneous Technology, November 1982.pdf
- Energy Profile - The Base, November 1980.pdf
- Energy Profile - The Electrical Variable, November 1981.pdf

- Energy Profile - The Thermal Variable, October 1981.pdf
- Energy Transportation, April 1976.pdf
- Engineering, Can We Afford it!, April 1975.pdf
- Evaluation Functions, December 1978.pdf
- Expansion Tanks, May 1980.pdf
- Extending the Cogeneration Equation, February 1980.pdf
- FADS, Their Influence on Design, October 1978.pdf
- False Loads, March 1983.pdf
- Fan Curves, Development and Use - Part II, August 1988.pdf
- Fan Curves, Development and Use - Part III, September 1988.pdf
- Fan Curves, Development and Use - Part I, July 1988.pdf
- Feeding the Mechanical Slave, April 1980.pdf
- Freeze Prevention of Steam Heating Coils, I, February 1984.pdf
- Freeze Protection of Steam Heating Coils, II, March 1984.pdf
- From the Laboratory to the User, The Widening Gap, September 1986.pdf
- Fundamentals of Thermodynamics, February 1981.pdf
- Hydronic Systems Overview, Part III, August 1977.pdf
- Hydronic Systems Overview, Part II, July 1977.pdf
- Hydronic Systems Overview, Part I, May 1977.pdf
- Ideal Terminal Control and Distribution Systems, II, Nov 1984.pdf
- Ideal Terminal Control and Distribution Systems, I, Oct 1984.pdf
- Improved Control for Steam Systems, April 1986.pdf
- Improved Thermal Envelopes, A New Challenge, December 1981.pdf
- Infinite Sink!, January 1979.pdf
- Infinite Source, February 1977.pdf
- Inspect Existing Buildings, March 1987.pdf
- Integrated Loop System for Campus Cooling, May 1973.pdf
- It's Time to Re-Evaluate Computer Use, January 1980.pdf
- Keep it Simple, May 1976.pdf
- Legislative Regulation and Engineering, May 1981.pdf
- Life-Cycle Costing, December 1975.pdf

- Local Building Codes, December 1976.pdf
- Look to the Obvious, July 1976.pdf
- Minor Details!, September 1978.pdf
- More on Simplicity, November 1983.pdf
- More on the Energy Hypothesis, September 1975.pdf
- New Energy Technology, Closer Than We Think!, May 1979.pdf
- On Evolution and Innovation in Engineering Design, April 1985.pdf
- Phase Change, August 1982.pdf
- Phase II, Energy Analysis for Existing Buildings, October 1980.pdf
- Picking an Energy Source and Conversion System, November 1975.pdf
- Planned Versus Breakdown Maintenance, March 1975.pdf
- Planning future opportunities, August 1981.pdf
- Psychrometric Principles, October 1985.pdf
- Pure Versus Applied Science, March 1977.pdf
- Refrigeration Piping for DX, Part I, February 1990.pdf
- Refrigeration Piping for DX, Part II - Discharge Line Design.pdf
- Refrigeration Piping for DX, Part IV - Suction Line Design, .pdf
- Reliability by Design, April 1978.pdf
- Retrofit Design Requires Painstaking Engineering, January 1983.pdf
- Retrofit Opportunities for Building Systems, July 1987.pdf
- Return to Regionalism in Building Design, January 1976.pdf
- Safety Factors in HVAC Design, January 1985.pdf
- Second Law Concepts, I, February 1979.pdf
- Section 12, An Overview, October 1977.pdf
- Seven Years in Retrospect, March 1981.pdf
- Simplified Sizing of Pipes and Ducts, July, 1985.pdf
- Specialty Devices (or gadgets!), February 1978.pdf
- Standards 1, The Cornerstone of Commerce, July 1978.pdf
- Standards 2, The Role of Consensus Standards, August 1978.pdf
- Steam, A State of the Art Update II, August 1975.pdf
- Steam, A State of the Art Update I, June 1975.pdf

- Steam Hammer, Causes and Cures, November 1986.pdf
- System Commissioning, A Concept Whose Time Has Come, May 198.pdf
- System Commissioning, A Concept Whose Time Has Come - Part I.pdf
- System Energy Losses, May 1983.pdf
- System Tuning, Part I, August 1976.pdf
- System Tuning, Part II, September 1976.pdf
- The 10 Years Since the Oil Embargo, April 1984.pdf
- The Air System in Perspective, October 1989.pdf
- The Computer and HVAC System Design, October 1975.pdf
- The Design Process, March 1978.pdf
- The Energy Budget, An Invaluable Device, July 1983.pdf
- The Fan Curve, A Useful Tool!, April 1977.pdf
- The Fan Inlet Box, January 1989.pdf
- The Heat Pump, December 1983.pdf
- The Key to Vapor Lock, March 1976.pdf
- The Laundry List, April 1979.pdf
- The Myth of Free Steam, November 1977.pdf
- Thermal Effectiveness of a Vapor Compression Cycle, February 1976.pdf
- Thermodynamic vs. System Efficiency, March 1979.pdf
- The Sprayed Coil Option, November 1988.pdf
- The Status of Total Energy, May 1978.pdf
- The Unoccupied Cycle, A Design Requirement, September 1983.pdf
- Unavailable Energy, March 1982.pdf
- Vibration Isolation for Fans, March 1988.pdf
- What is Energy!, May 1975.pdf
- What's the Load!, November 1976.pdf

### Trade Publications

Trade publications can be a great way to keep current regarding what is going on in the industry. And, if you work in the industry, you typically can get a free subscription to many of them which in many instances, can be delivered electronically. Most also offer archives of past issues and articles and access to the current digital edition on their web site. Many also offer free webinars, some of which include professional development credits.

Some of the ones I reference frequently include:

- *ASHRAE Journal*: This is the journal for the American Society of Heating, Refrigeration and Air Conditioning Engineers and is one that you have to pay for. But if you join ASHRAE, it is a benefit of membership, including free access to the back-issue archives and a copy of the current handbook both bound and on CD.
- *Consulting Specifying Engineer*: This is targeted at the design community and may be one you can obtain for free.
- *High Performance Buildings*: This is targeted at the sustainable design community and, I believe, is published under the ASHRAE umbrella.
- *Electrical Apparatus and Testing*: This is actually one of my favorites because while it is small, it always includes good content on some aspect of motor or electrical equipment design, operation, fabrication, or repair. It is one of the few that I think you can only get in a paper format, but I really look forward to my copy.
- *Heating, Piping and Air Conditioning*: This publication, I believe, spun off of the ASHRAE journal to address the contracting and field side of the business.
- *Engineered Systems*: One of the nice things about this journal is that it always includes a section on commissioning, including a checklist or test plan for a particular system type. For a modest cost, you can also obtain and download what has become a very extensive library of tests and checklist that were published in previous issues.
- *NETA World*: This publication is focused on the electrical commissioning side of the industry and is one you would probably need to purchase unless you joined the international Electrical Testing Association. But, if you want to learn about that side of the business, the subscription price is probably worth it. And, they generously share the main technical articles from each issue at no cost on their web site.
- *Sport Aviation*: Just seeing if you were still paying attention. But that aside, if you like airplanes, this is a pretty cool magazine. You get it as a benefit of membership if you join the Experimental Aircraft Association (typically under \$50 a year), which is a grass roots aviation organization dedicated to all things that fly.

## Energy Engineering and Management for Building Systems

Bill Coad, the author of the Fundamentals to Frontiers articles mentioned above also wrote a text book titled *Energy Engineering and Management for Building Systems*, originally published by Van Nostrand Reinhold Company in 1982. Some of you may already have a copy, but for those who do not, or for those who would like to have it electronically, Bill now [as a .pdf of the entire book available on the Coad Engineering Enterprises web site](#).

The following is a list of the major sections in the book from the table of contents.

- Engineering Philosophy
- Concepts Of Energy
- Energy Economics

- Energy Management
- Codes And Standards
- Uses Of The Computer
- Financial Considerations
- Energy Source Systems
- Liquid And Two-Phase Thermal Fluid Systems (Hydronics, Steam, And Refrigerants)
- Air Systems, Adjusting, And Balancing
- Maintenance Management And Reliability
- Evaluating The Effectiveness Of Energy Utilization

## Saturated Systems and Psychrometrics

There are a string of blog posts on the [Field Perspective on Engineering](#) web site that are targeted at discussing saturated systems and should provide the basic understanding necessary. They start with a post titled [Saturated, Multi-Phase Systems and Proof that a Watched Pot Does Actually Boil – Part 1](#) and continue on for 5 installments.

A lot of my knowledge of psychrometrics goes back to one-on-one mentoring sessions graciously provided to me by several of my mentors, including Bill Coad, Al Black, Jerry Williams, and Phil Sutherlin. Thanks to modern technology, you too can learn about the science of psychrometrics in nearly the same way as I did. Bill Coad has written up the talks he used to give “on demand” in his office and they can be found on [Coad Engineering Enterprises](#) web site in the form of 3 discussions:

- [Psychrometrics Review - \(Part 1\)](#) explores Dalton’s Law, properties of air, ideal gas behavior, and basic psychrometrics.
- [Psychrometrics Review - \(Part 2\)](#) walks you through the process of constructing your own psychrometric chart using the basic understandings developed in Part 1. This is a great way to get a real gut feel for the science, and is a pretty cool trick to be able to pull off in this age of computers and software.
- [Psychrometrics Review - \(Part 3\)](#) explores psychrometric processes like cooling, heating, humidification, dehumidification, mixing, etc.

Sadly, Bill passed on recently, and in his honor, I started a string of blog posts where [I walk you through the process of drawing your own psych chart using the principles Bill taught me and Excel](#) as the tool for developing the chart. So if you want some exposure to the principles behind the chart and maybe to pick up a few Excel tricks as well, follow along as I work my way through the process on the blog.

If you get really interested in psychrometrics (and who wouldn’t?), one of the best ways to learn more is to start plotting HVAC processes and climate data on a psych chart. Back in the “olden days” when I was learning this stuff, that meant finding a way to make a copy of the one, clean, paper chart you had that had been given to you by a mentor (or draw your own each time as mentioned above). Now, there are electronic psych charts available that let you plot points on your computer screen, print the results or cut and paste the result into other electronic documents.

Downloading the [free Greenheck electronic psych chart](#) will give you a tool for understanding and practicing basic psychrometric analysis. Upgrading the free version to the pro version will provide you with significant analysis capability, including bin climate data, design data, typical meteorological year data and other tools for a fraction of the cost of similar products that are currently on the market

The *Psychrometric Chart Fundamentals* chapter in the [Honeywell Gray Manual](#) will provide a basic understanding of the saturated system we live in and work with every day (the atmosphere).

## Loads

The chapter titled *Understand and Estimate the Loads* in the [Energy Design Resources](#) design brief titled [Improving Mechanical System Energy Efficiency through Architect and Engineer Coordination](#) provides guidance and resources for performing load estimates and analysis.

The chapter titled *Review Load Calculations* in the Energy Design Resources design brief titled [Design Review](#) discusses loads and provides a case study regarding what can happen if they are over-estimated.

The blog post on the [Field Perspective on Engineering](#) web site titled [Working with the Honeywell W7212 Economizer Controller; Nuances of the Economizer Control Process, Part 2 –Economizer Basics](#) includes a sections titled *The Modern Building; A Year Round Need for Cooling* and *A Source of Cold Air* that illustrates how the hour by hour loads vary for a modern office building.

Lighting systems are major loads on the electrical distribution system. And the heat they generate becomes a major load on the HVAC systems that are the focus of the technical side of the AEP training. Thus, understanding them and managing them can save energy on a number of fronts. There are a number of design briefs on the [Energy Design Resources](#) web site that will provide insight into this topic including:

- [Efficient Lighting Systems](#)
- [Lighting Controls](#)
- [High Intensity Fluorescent Lighting](#)
- [Outdoor Lighting and Title 24](#)
- [Daylighting](#)
- [Understanding Daylight Metrics](#)

The building envelope also can impact the loads seen by the HVAC systems we are focused on in the AEP training, in particular the glazing. The [Energy Design Resources](#) website includes a design brief titled [Glazing](#), which will provide insight into this topic.

Note that the HVAC Equations, Data and Rules of Thumb resource mentioned previously includes basic load data in the form of square feet per ton, cfm per square foot, etc. for many building types. While not the way to do your final design, these figures certainly are a way to establish an order of magnitude for a system or facility, which is often all you are looking for when dealing with a problem out in the field

## Cooling Load Temperature Differential Method

The Cooling Load Temperature Differential method (CLTD) is a manual load calculation technique that was in use when I first entered the field in the mid 1970's. It used a series of tables to allow the designer

to account for the thermal lags introduced by the mass of a building's structure, a significant improvement from previous techniques that had no direct, scientific way to account for this. In addition to identifying the peak load, the technique allowed you to assess daily and seasonal load profiles. If you work in the field with buildings, you probably realize that understanding the load profile and how the systems manage it is probably more important than understanding the peak since most of the time, the building is operating at less than peak design conditions most of the time.

Now-days, we use computer programs to run the algorithms in real time that were used to generate the tables that the CLTD technique used. And, once a model is built, we can develop seasonal and daily load profiles in a matter of minutes, often with only a few clicks of the mouse. But back when the CLTD technique first evolved, there were no personal computers and developing the tables used by the technique represented significant work and computing time in and of itself.

I still use the technique to estimate loads when I want a better number than I can get from square foot data and other rule of thumb or if I want to see what the seasonal or daily load profiles might look like but don't have the time or resources to develop a model. The trick there is to find a copy of the tables. Sadly, they disappeared from the ASHRAE Fundamentals Handbook after the 1989 edition (one good reason to hang on to your old copies of the handbooks since useful stuff tends to come and go as time and technology advances). Interestingly enough, the tables can still be found in the ASHRAE Pocket Handbook, at least in the copies I have.

So bottom line, you may want to try your hand at the technique. If you do, you will probably learn a bit about loads and how they are estimated. To facilitate that, I have included scans of the section from the 1989 Handbook of Fundamentals that illustrates the technique, including the tables, as an appendix to this resource list.

## Climate

The climate plays a big part in the loads our building systems see and how they perform. If you go to my blog you will find that there are a number of posts discussing climate and how it interacts with building and building systems and links to a lot of resources. You can find the posts of interest by using the drop-down menu and picking either the *Weather and Climate Resources* or the *Weather and Climate Interactions with Building Systems* categories from the Category dropdown menu. Further down the right side of the blog, you will find some direct links to weather and climate resources that I frequently reference.

## Load Analysis Software

One of the things we will explore in some classes is how to estimate loads that the systems will see. Typically, in the types of processes we discuss in the classes I teach (field work, commissioning, design review, etc. ), you would estimate loads with rules of thumb or building data if it was available. If you happen to have access to a computer based load calculation program, you might even use it to run a quick load. But you would likely not take the time to develop a full blown model. And, most load programs had to be purchased and had a steep learning curve to get up to speed. So the "rule of thumb" and building data approaches were usually the mechanism of choice for folks out in the field operating buildings.

Fairly recently, [Taco](#) released a [free load calculator software package](#). The "free" part eliminated the need to purchase software hurdle. And while, there still is a learning curve, the structure of the interface

tends to minimize that. In addition, one of the best ways to learn about things like this is to just try them out.

Note also that the

mentioned below includes a load calculation module. I am not as familiar with the Taco software as I am with the ESI software, but from what I can tell, the ESI software will give you more flexibility in setting up the characteristics of the building envelope, but may have a bit steeper learning curve.

## Centrifugal Machines

Centrifugal machines are very common in HVAC being the technology of choice for most HVAC pumps and fans and a major technology used for the compressors in refrigeration machines. Fortunately, if you understand the principles behind any one of the specific applications (pumps for instance, which is how I came to understand centrifugal machinery), then you can easily transfer that knowledge to the others.

### Pumps

If you are not familiar with pump fundamentals and pump theory, then you can probably learn what you need to know from two design briefs that are available from [Energy Design Resources](#).

- [Design Brief: Centrifugal Pump Application and Optimization](#) provides an overview of pump theory, construction and application from a field perspective, including what can go wrong, commissioning, and making proper operation persist.
- [Design Brief: Pumping System Troubleshooting](#) picks up where *Centrifugal Pump Application and Optimization* leaves off by exploring pump/system interactions, particularly the parallel pump applications so common in the HVAC industry.

The two briefs listed previously, aside from providing a foundation for understanding pumps, will also provide a foundation for understanding centrifugal machinery and thus a foundation for understanding fans, and even centrifugal chillers to some extent.

There is also a class Ryan Stroupe and I offer at the Pacific Energy Center about once a year called Pumps; Design, Performance and Commissioning Issues. It is a free class and usually offered as a webinar. You can find out more about that under the General Resources- Energy Centers - Pacific Energy Center (PEC) heading. And, typically, you can find the most recent slide set for the class via the link under 03 - Materials from Classes and Presentations on the right hand side of [my blog's opening page](#).

### Pump and Hydronic System Component Selection Software

Bell and Gossett offers their ESP pump selection software at no charge, which allows anyone with an internet connection to select pumps and view performance curves for anything in their current product line. In addition to allowing you to enter your flow and head requirements and compare the various options, the software allows you to look at curves for multiple identical pumps in parallel and also look at performance for a given pump with a given impeller size at different speeds, which you can specify.

To use the software, you simply go to the Bell and Gossett web site and create an account. But, if you would like to be able to use the software off line, you can also contact your local Bell and Gossett representative and ask for the ESP Plus CD. The CD is also offered at no cost, but you do need to sign a

licensing agreement. In addition to allowing you to perform pump selections off line, the CD allows you to select other products from the B&G product line like heat transfer equipment, condensate handling equipment, etc.

Bell and Gossett also offers an electronic version of their System Syzer that can be downloaded from the internet at no cost. Those of you who have been around the industry for a while probably have the real world, plastic, circular slide rule somewhere on your desk. The software mimics the hardware version but has the advantage of doing much larger line sizes and also can do different fluids besides water.

*One of my most valuable resources as a baby engineer was the Bell and Gossett Engineering Handbook, a large blue binder full of information about pumps and how to apply them as well as hydronic system design and operation. Now you can [download all of those bulletins from the internet at no charge from the resource portion of their web site.](#)*

Taco also offers pump selection software, but their package can be downloaded from the internet at no cost (vs. running on the internet or requiring a CD). The features and capabilities are very similar to the B&G package, but one thing that is different and handy is that it can model up to three parallel pumps that are different pumps instead of modeling identical pumps in parallel.

The program also includes a head loss calculator that allows you to project the pump head based on losses for the various elements in the system. Pipe losses are assessed using drop down menus to select line sizes, materials, etc. Other components can be entered manually.

### Pump System Improvement Modeling Software

The [Pump Systems Matter Initiative](#) offers a no-cost pump network node analysis software package for download from their web site. It is limited to 25 nodes, but you can still do quite a bit with it. The software is a subset of a much more sophisticated network analysis program costing thousands of dollars and retains many of the features.

In fact, it can be a bit overwhelming at first. But if you start with something simple and work through the process, you can learn quite a bit about pump and piping system interactions in the general case, and reach some conclusions about your specific projects. The [Design Brief: Centrifugal Pump Application and Optimization](#) mentioned under the *Pumps* heading includes an example contrasting the pump head estimated for a water feature using this tool with the result based on a manual calculation and a field estimate.

### Fans

To build on the fundamental knowledge regarding centrifugal machines that you might pick up from pump design briefs, you may want to refer to [Improving Fan System Performance; A Sourcebook for Industry](#), which was developed by US DOE and AMCA.

Speaking of AMCA (the Air Movement and Control Association International), they offer a number of very useful publications, all of which can be downloaded from their website. In the context of our industry, the [Fan and Air Systems Applications Handbook](#) would be the one I would pick up first. The AMCA publications are not free, but if you are active in the industry you may find that a number of them they are worthwhile additions to your corporate library if not your personal one.

The [Trane Fan Application Manual](#) is another good resource that not only looks at fans but at their application in an air handling unit, discussing clearances to coils and casing walls among other topics.

This was probably the first resource I encountered on the topic of fans as a young engineer and I learned a lot from it. I was given mine by the Trane representative who handled our account back in 1976, but it would definitely be worth the nominal \$10 that Trane sells it for on the internet.

Another great fan resource with a cost somewhere between the price for the Trane or AMCA manuals is the [Howden North America's Fan Engineering Handbook](#). They offer it in both a paper copy, which looks like a little bible (and it kind of is the fan bible) or an electronic version, which is really slick because of the search features and the built in spreadsheet tools and other linked resources. And, if you are a student, you can purchase either version at a discount.

There is also a class Ryan Stroupe and I offer at the Pacific Energy Center about once a year called Fans, Ducts, and Air Handling Systems; Design, Performance and Commissioning Issues. It is a free class and usually offered as a webinar. You can find out more about that under the General Resources-Energy Centers - Pacific Energy Center (PEC) heading. And, typically, you can find the most recent slide set for the class via the link under 03 - Materials from Classes and Presentations on the right hand side of [my blog's opening page](#).

### Fan Selection Software

Frequently, the examples I use in class involve calculating the energy savings or other parameters associated with fan systems. The calculations generally use the fundamental fan parameters to for the assessment rather than nameplate data, using the fan selection software as a way to estimate fan performance and efficiency for the calculation and leveraging the concept of geometric similarity to approximate the performance of Manufacturer A's equipment via Manufacturer B's software tool.

There are a number of programs available for free from the various manufacturers and I link you up with them in two different blog posts on my *Field Perspective on Engineering* blog. Most of them show up in the post titled [Design Review: Leveraging Opportunities before Ideas Become Realities](#), dated May 10, 2008. An additional one shows up in the post titled *Twin City Fan and Blower Company Fan Selection Software*, dated January 27, 2010 which also includes a link to the other post.

You may find it desirable to obtain and install copies of several of the packages, especially CAPS since it allows you to do other things beyond fan selections. But, to get several of the packages, including CAPS, you need to contact the manufacturer and request the CD. So time will be critical if you want to obtain the software between now and when the class happens. Since you can download and install the Twin City Software directly from the web site, I will work with that package for the class when I can, but I still may use CAPS for some functions or to simply illustrate its features.

### Centrifugal Chillers

Reading through the O&M manual for a centrifugal chiller from [Trane](#), [Carrier](#), [York](#), [McQuay](#), or any of the other manufacturers will provide product specific insights into centrifugal chiller theory and operation that can be applied in the general sense to other similar pieces of equipment. You will find varying degrees of detail between the four manuals that are linked above, but all have useful information in them. The Carrier manual probably goes into the most depth and if you had to pick one manual to review, that would be the one to pick.

*In addition, McQuay publishes a document titled [Centrifugal Chiller Fundamentals](#) that while specific to their product line in terms of the illustrations, contains content that is generally applicable if you are trying to understand that type of machinery.*

There is also a chapter on Centrifugal Chillers in Roy Dossatt's *Principles of Refrigeration*, a resource I mention and link to under the *Refrigeration and Cooling Equipment* heading.

You will also find some slides in the *Chiller* module of the *Chilled Water and Condenser Water Systems; Design, Performance and Commissioning Issues* class that I do with Ryan Stroupe at the Pacific Energy Center. As is the case with the other PEC classes, it is offered at no charge to California Public Utility rate payers and usually offered as a webinar. So far the PEC has been very generous with regard to webinar attendees outside of the California area, allowing them to attend also. You can find out more about that under *the General Resources- Energy Centers - Pacific Energy Center (PEC)* heading. And, typically, you can find the most recent slide set for the class via the link under *03 - Materials from Classes and Presentations* on the right hand side of [my blog's opening page](#).

### CACx.org Software Tools

For those who want to do some calculations based on their new found knowledge, there are two tools on the [California Commissioning Collaborative](#) web site that you may find to be helpful. Clicking the links will initiate a download. If you want to read more about the tools before using them, you will find [a description of all of the CCC tools](#) on their web page under *Resources – Tools and Templates – Existing Building Commissioning*.

- The [Pumping System Workbook](#) allows you to calculate energy savings from a number of different measures including flow reductions, reducing the differential pressure control set point in a system or resetting the set point. The spreadsheet has a very rich set of features including the ability to create pump curves, enter load profiles, and enter field data defining the pressure drop characteristics of the system. It may even seem a bit intimidating to use at first. But the tool comes with instructions and comments embedded in the spreadsheet, a PowerPoint training slide set, and a reference guide, all of which will help you to understand how to use the tool.
- The [Fan System Workbook](#) is similar to the Pumping System Workbook described above, but it is focused on air handling systems.

One caveat with regard to these two tools; they were written and tested using Excel 2003. They will not work with Excel 2007. So far, I have been able to use them with Excel 2010, [which opens them in compatibility mode](#). But I have not used all of the functions as of this time so I cannot say for sure that they will be fully functional in Excel 2010.

### Refrigeration and Cooling Equipment

Roy Dossat's [Principles of Refrigeration](#) is a very comprehensive resource for learning about refrigeration equipment written in easy to understand terms. You would have to purchase the current edition, which is the most comprehensive and detailed. But, the [original edition is available at no cost from internet archive](#) and is more than adequate in terms of providing a basic level of understanding.

Copeland offers their refrigeration engineering application guidelines at no cost. These are another very good, comprehensive resource for understanding vapor compression refrigeration systems. The guidelines can be found the [HVACRInfo.com website](#). However, by taking the time to create an account on the [Emerson Climate Technologies website](#), you can access these guidelines and also gain access to other useful engineering information on refrigeration and the Copeland product line. No

matter which way you go, for general reference, you should consider downloading the following guidelines:

- AE101 Fundamentals of Refrigeration
- AE102 Refrigeration System Components
- AE103 The Refrigeration Load
- AE104 System Design
- AE105 Installation and Service

If you are working with Variable Flow Refrigeration (VRF) systems, Mitsubishi has a number of very helpful resources on their [mylinkdrive.com website](http://mylinkdrive.com). By selecting your country and then navigating around the site, you can pull back product information, engineering manuals, service manuals and other very handy technical resources. While they are specific to their equipment, if you study them, it will give you some insight into generally how these systems work.

*On a related topic, at one point, in an effort to develop a class and support a client, I did a bunch of research on the details of VRF and ended up writing a really long memo with a lot of attachments that document the details I explored. You can find this on FDE's commissioning resources web site under the [General Resources page](#).*

Pressure Enthalpy (p-h) diagrams are a great way to understand and visualize how a refrigeration cycle works and identify opportunities for improvement. But until you understand them a bit, they can be intimidating charts to work with. Parker offers [a really nice engineering guideline](#) on their website that not only introduces the chart, but also:

- Plots an ideal cycle on it;
- Shows how a real cycle compares to the ideal cycle;
- Shows how information from the chart can be used to determine things like refrigeration effect, heat of compression, power required, volumetric flow required, etc.
- Shows how common problems like high head pressure or excessive superheat start to stick out like a sore thumb if you plot the cycle on the chart
- Shows how the data from the chart can be used to assess the impact of common problems and put useful metrics on them.

The guideline is written in the context of grocery store refrigeration, but the concepts are universally applicable to any refrigeration process using a vapor compression cycle.

*Cooling towers go hand in hand with refrigeration systems so learning how they work is an important skill to acquire. One of the most useful resources for me, one that was given to me early on by a local cooling tower sales representative is the [Marley Cooling Tower Fundamentals](#) handbook. In fact Marley offers [a library of white papers](#) that are a very comprehensive resource regarding cooling tower theory, cooling tower operation, and cooling tower maintenance.*

### Software Tools

One of the neatest software tools out there if you are trying to understand how VRF systems work are the [refrigerant flow diagram flash player applications](#) that Mitsubishi has on mylinkdrive.com website. There are three versions of the application (the links are to the ones on the USA site).

One version uses a simpler flow diagram but includes an audio track describing what is happening as the video plays. There are both [PC](#) and [MAC](#) versions of this application.

A [second version](#) (which I believe is PC only) has a much more detailed schematic.

In both versions, you are provided with a flow diagram of the system where animated highlights trace out the refrigerant flow path on the flow diagram while a dot traces the process out on a PH diagram and a picture of the component where the refrigerant flow is occurring is shown (Figure 12)

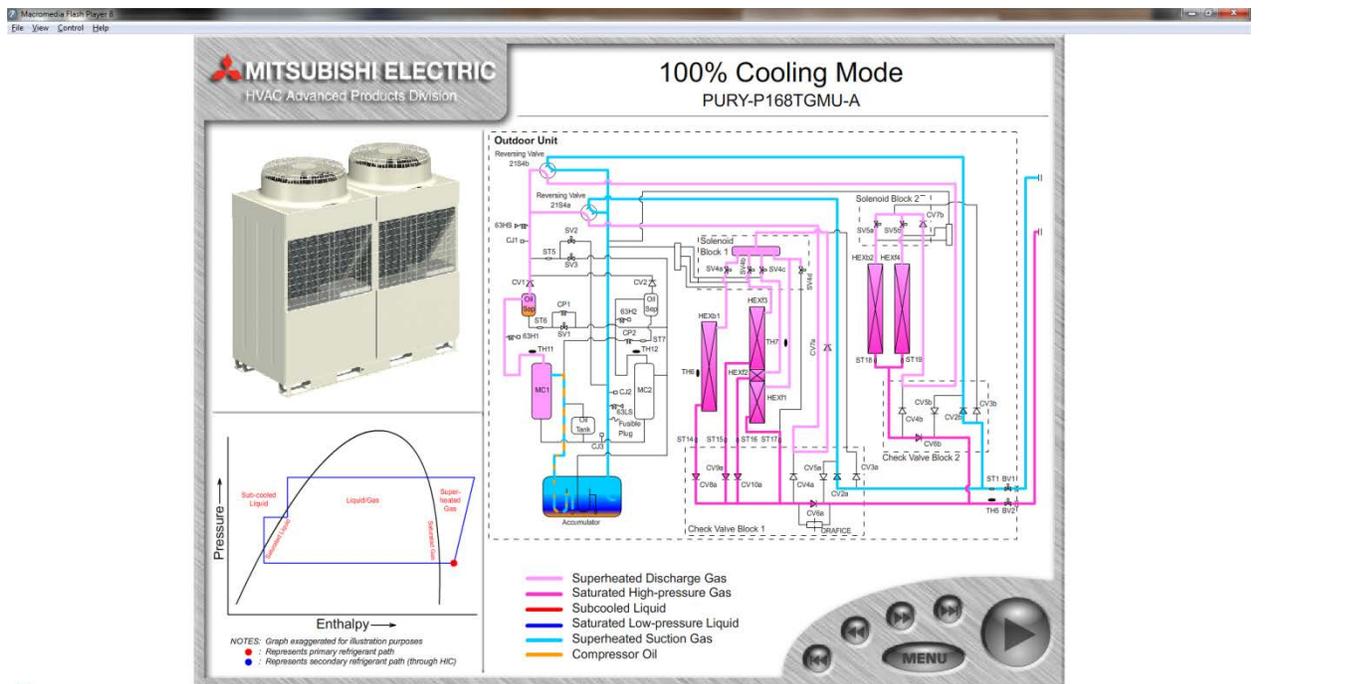


Figure 13

If you mouse over a component on the flow diagram, a cut-away of the equipment appears with the component outlined in red and a picture of the component with a description of what it does shows up in place of the P-h diagram (Figure 13). Pretty cool.

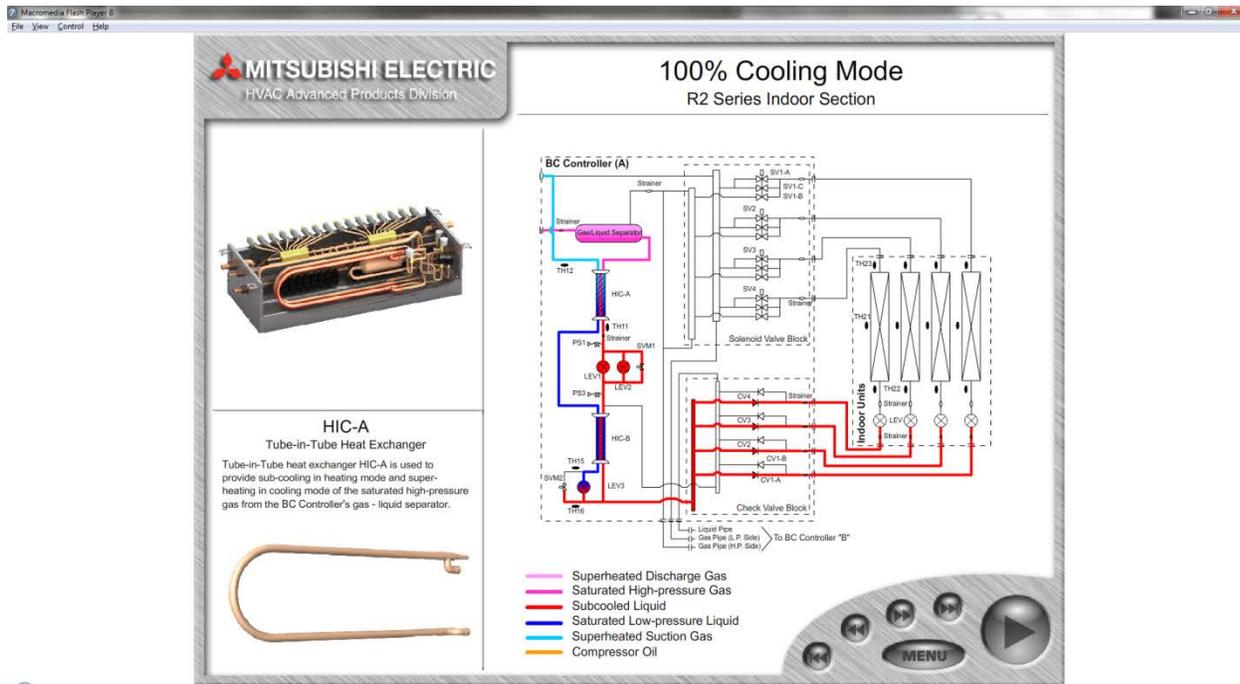


Figure 14

Note also that the CoolTools™ resource mentioned subsequently under Piping Systems is also a useful resource in the context of chilled water cooling systems.

## Heating Equipment

### Steam and Condensate Systems

The Department of Energy provides a number of free steam resources on their Best Practices web site including a publication titled [Improving Steam System Performance](#), [tip sheets](#) documenting savings for various things like valve insulation and trap repairs, and [software tools](#).

Steam systems seem to be particularly mysterious to new-comers to the industry. One of the best general “primers” out there is an article Bill Coad once wrote titled *Fundamentals Of Steam Heating Systems*, which appeared in *Heating/Piping/Air Conditioning*, November 1995. It also was published as an ASHRAE transaction paper

Wayne Kirsner specializes in training and accident investigation for steam systems and has [published several articles](#) that take an in-depth look at steam system accidents, including the details of the physics behind what went wrong. Working with steam should not be taken lightly, especially working with high pressure steam. Thus, taking the time to read at least one of Mr. Kirsner’s accident investigation articles will be time well spent in addition to providing a sobering insight into what can go wrong if you take things too casually.

Armstrong International publishes a free .pdf book titled [Steam Conservation Guidelines for Condensate Drainage](#). Since you sort of need to understand steam systems in general to understand the topic, it includes very good illustrations and discussions of steam system concepts and operating principles.

Spirax Sarco provides [a number of good tutorials](#) on their web site, including discussions on heat transfer, engineering units, measurement of steam flow, etc. They also have [interactive steam tables and calculators](#) that you can use anytime you have web access. If you really are going to get into this, their The Steam and Condensate Loop Book, which is a paper version of their online tutorial among other things. This is one of the few resources on this list that is not free, but if you are working with steam, it's a valuable reference to have on your shelf.

*Steam heating has been around for a really, really long time. When you are working with existing buildings it is not unusual at all to encounter somewhat ancient steam heating equipment. For me an invaluable resource has been a book by Dan Holohan titled, appropriately enough [The Lost Art of Steam Heating](#). You will find more information on this topic along with other steam system resources in a blog post I wrote a while back titled [Steam Heating Resources](#).*

### Steam and Hot Water Boilers

Cleaver Brooks provides downloadable .pdf documents on the [Boiler Basics](#) page of their website on the following topics, which are a good general reference.

- [Boiler Selection](#)
- [Steam System Fundamentals](#)
- [Hot Water System Fundamentals](#)
- [General Hot Water System and Boiler Engineering Data](#)
- [Alternative Fuels](#)

### Steam and Hot Water Systems

There is also a class Ryan Stroupe and I offer at the Pacific Energy Center about once a year called Hot Water and Steam; Design, Performance and Commissioning Issues. It is a free class and usually offered as a webinar. You can find out more about that under the General Resources- Energy Centers - Pacific Energy Center (PEC) heading. And, typically, you can find the most recent slide set for the class via the link under 03 - Materials from Classes and Presentations on the right hand side of [my blog's opening page](#).

### Piping Systems

The references listed previously under *Pumps* include resources that will provide an understanding of piping system principles and practices.

### CoolTools™

CoolTools™, at the time I write this, consists of a [chilled water plant design guide](#) supported by two software resources.

- [A pipe size optimization tool](#) that takes a life cycle cost perspective to sizing piping.
- [A chiller bid and performance tool](#) that helps designers select a machine that will deliver best life cycle costs across the entire chiller plant operating spectrum.

### 3EPlus

One of the things that comes up with piping systems is insulation. The North American Insulation Manufacturer's Association provides [a free software tool called 3EPlus](#) that lets you quickly assess the losses and other metrics associated with different types and thicknesses of insulation. This can be a really valuable resource if you are trying to understand the parasitic losses from an insulated piping system. And the numbers can be surprisingly large.

For example, in the facility illustrated in Figure 14, I was looking for about 10-20 tons of parasitic load in the form of simultaneous heating and cooling. It turned out, that when you added it all up, there was something like 5-7 miles of hot water piping in each tower. A lot of that piping ran in what amounted to a return plenum.

### Coil Selection Software

For one of the analysis steps in the final module, we will be using coil modeling programs to assess various features and options. There are a number of free coil modeling programs out there including one from [USA Coil](#) and one from [Greenheck](#). I tend to use the USA Coil version because the release I have includes pricing information. I believe the newer releases no longer include that probably due to the volatility of copper pricing. But the downside to the USA Coil option is that you have to request the CD vs. downloading the package from the site. That's not a bad thing other than it takes a bit more time and if you don't react to this memo quickly, you may not have it in time for the class.

In contrast, the Greenheck package can be downloaded directly from the internet. I actually have both programs and use them both as they complement each other in terms of capability. For instance, the Greenheck software can model smaller tube sizes than the USA coil software, a desirable feature for reheat coils.

Note also that the *Engineering Software International HVAC Software* mentioned previously includes several modules that perform heating and cooling coil performance and diagnostic calculations.



**Figure 15 – The San Diego Marriott Marquis; There could easily be 5 – 7 miles of hot water piping in each of the towers.**

If you did the math, using a tool like NAIMA tool, you would discover that even with insulation, a piping system running at 180°F in a 72°F return air plenum could easily account for a significant percentage of the parasitic load I was looking for.

### Variable Flow Water Systems

There are two blog posts on the [Field Perspective on Engineering](#) web site that explore a variable flow primary/secondary system and then provide links to a significant number of additional resources on variable flow primary/secondary and variable flow primary only pumping systems. Many of the resources listed previously for Pumps and Piping Systems also will apply to this category.

Note also that the CoolTools™ resource mentioned previously under *Piping Systems* is also a useful resource in the context of chilled water cooling systems.

## Duct Systems

The references listed previously under Centrifugal Machines, in particular the resources dealing with fans, contain information that will also provide insights and understanding regarding duct systems.

The Large Commercial Systems Design Guide on the [Energy Design Resources](#) website is focused VAV systems in large commercial buildings. However, the principles associated with duct design for VAV systems are universally applicable and thus, this guideline serves as a good general reference regarding duct design.

United McGill offers a very good duct design guide as a CD. To obtain a copy of the guide, you need to [register on their web site](#). Once you do that, you will also have access to product specifications that include a lot of useful engineering data.

Finally, [ASHRAE has developed an electronic duct fitting data base](#) that will allow you to quickly compare different duct fitting designs. The database is an electronic version of the duct fitting pressure loss tables contained in the Fundamentals handbook. The advantage is that it speeds up the process associated with assessing a fitting and comparing it to other fitting designs by allowing you enter the key parameters like duct height and width, flow rate, and other critical dimensions and then electronically accessing the tables. This can be a real time saver compared to manually looking up the required information, which, for a complex fitting, may require several steps using several tables. This resource is not free, but if you are doing duct design, is well worth the cost and will pay for itself in the time it saves you to optimize your fitting configurations.

## Economizers

There are a number of publically available resources that focus directly on economizers. The [Functional Testing and Design Guide](#) contains an [entire chapter dedicated to economizers](#) including their operating theory, operational issues, troubleshooting and maintenance and prefunctional and functional tests.

The functional testing checklist tool located on the same site includes an [economizer commissioning checklist](#) covering design review, prefunctional checks, integration with other processes, and the preparatory steps and precautions associated with testing and operating economizers. The checklist includes hot-links that will jump the user to applicable portions of the Functional Testing and Design Guide for more detailed information on a particular checklist item.

In the context of Economizers, the following chapters of the the Honeywell gray manual may be of particular interest:

- The *Control Fundamentals* chapter which contains an overview of HVAC fundamentals in addition to control system fundamentals.
- The Psychrometric Chart Fundamentals chapter.
- The Indoor Air Quality Fundamentals chapter.
- The Air Handling System Control Applications chapter, especially the Ventilation Control Processes section which discusses economizer processes.
- The Damper Selection and Sizing chapter.

The [Energy Design Resources web site](#) contains numerous design briefs on HVAC topics. In the context of the Economizer Class, the following briefs may provide additional insight into some of economizer processes.

- [Economizers](#) provides an overview of the economizer cycle, including what can go wrong, commissioning, and making proper operation persist.
- [Design for your Climate](#) looks at how climate conditions specific to a project's location can impact building design.
- [Building Commissioning](#) provides an overview of the commissioning process supported by case studies.
- [Air Conditioning and Ventilation](#) provides information on a number of ways to improve HVAC system efficiency, including the economizer process.

The blog post on the [Field Perspective on Engineering](#) web site titled [Working with the Honeywell W7212 Economizer Controller; Nuances of the Economizer Control Process, Part 2 –Economizer Basics](#) will provide a good overview of air side economizers and links to additional resources.

The [CoolTools](#) resource mentioned previously under the resources for **Error! Reference source not found.** includes information on wet economizer cycles.

## Make-up Air and Exhaust Systems

The [Energy Design Resources](#) website has a design brief titled [Commercial Kitchen Ventilation Design](#) that will provide insight into this topic in the context of Kitchen ventilation. The fundamental concepts discussed in this brief can also be applied to other make-up and exhaust processes including the systems providing make-up air to corridors so serve guest room exhaust needs and systems providing make up air to fitness centers and mechanical spaces.

Some of the concepts covered under the topics of Fans and Duct Systems also apply to this topic. Specifically, make-up air can be a significant load on the system providing it and typically the air is delivered and removed by air handling equipment and ductwork.

## Variable Air Volume

- The Large Commercial Systems Design Guide on the [Energy Design Resources](#) website is focused VAV systems in large commercial buildings and is an ideal resource for exploring this topic.
- The California Energy Commission's [Small HVAC System Design Guide](#) includes discussions regarding VAV applications for smaller facilities, typically served by packaged equipment. Thus, it is a good reference for understanding packaged equipment VAV applications where-ever they might occur.
- Some of the concepts covered under the topics of Centrifugal Machines and Duct Systems also apply to this topic. Specifically, VAV systems are a class of air handling system, thus the fundamental principles associated with fans and ducts apply to them.

## Skill 04: Have a Firm Grasp of the System Concept and be able to apply it to Develop or Mentor the Development of System Diagrams

### System Diagrams and the System Concept

Having a system perspective is key to success in the commissioning arena and will be emphasized through-out the class. In fact there will be a module that is focused on using system diagrams as an assessment tool. Rather than focus on how to make a system diagram, the module will cover a few of the key points in the development process and then move on to an interactive exercise based on a case study of a system where numerous commissioning issues are evident from the system diagram.

The primary resources for this learning objective are a string of posts on the [Field Perspective on Engineering](#) blog. As of the time of this writing, that list includes the following posts.

- [System Diagrams; an Industry Concept but Not an Industry Standard](#)
- [System Diagrams: Physically Complex; Schematically Simple](#)
- [System Diagrams: “Untangle it; it should look like a ladder on its side”](#)
- [System Diagrams: Untangled in Action](#)
- [System Diagrams: Order of Connection Matters](#)
- [Developing a System Diagram: Untangling the Pacific Energy Center Ice Storage System](#)
- [Developing a System Diagram: Getting Started](#)
- [Developing a System Diagram: A Few Organizational Tips](#)
- [Developing a System Diagram: Elbows are Meaningless in a System Diagram \(Kinda, Sorta\)](#)
- [System Diagrams: Breaking the Rules; a Step by Step Guide \(Plus Some Condenser Water System Trouble Shooting Tips\)](#)
- [System Diagrams: Moving on from the Roof at the Pacific Energy Center](#)
- [System Diagrams: Applying My System Diagram Concepts to Air Handling Systems](#)
- [System Diagrams: The Envelope as Part of the Air Handling System](#)
- [System Diagrams: Key Features of my Air System Diagrams](#)
- [System Diagrams: An Update on Sources for Symbols](#)
- [System Diagrams: Practice Making a System Diagram](#)
- [System Diagrams: Practice Making a System Diagram –The Answer](#)

This particular topic is always evolving and new posts are added to it occasionally. So the list above only represents the content as of the time of this writing. If you want to find out if there any additional posts, all you need to do is use the “Categories” drop-down menu on the right side of the home page of the blog. If you select the “System Diagrams” topic from the drop down list, a list of all posts on the topic will show up in the blog’s main window. From there, you can simply click on the title of the post you are interested in to be taken to it.

## Skill 05: Be Familiar with the Trending Capabilities of Control Systems and Know How to Supplement Their Capabilities with Data Loggers

### Data Logging and Trending

Data logging and trending are key commissioning and retrocommissioning tools/skills. If you are familiar with trend analysis and data logging then you should be right at home when that part of a project comes up. But for those of you who are not as familiar, the series of articles on data loggers included in the appendix to this document will provide additional information on data logging techniques, trending techniques and on the related analysis techniques.

If you want to know more, [Portland Energy Conservation Incorporated \(PECI\)](#) wrote a best practice guideline on data loggers that can be [downloaded from their web site](#). They also published [an Energy Management System best practice guideline](#) which includes information about trending and data logging with an EMS as well as other topics that will be discussed in the class. And, the [California Commissioning Collaborative](#) includes manufacturer specific guides for using Andover, Siemens, and TAC America systems for data logging in [their on-line library](#).

If you have never deployed a data logger before, then you may find the [Motor Logger](#) video posted at the [On Demand Classes](#) link of the [PG&E Energy Efficiency Classes](#) page on the [Pacific Energy Center web site](#) to be helpful. In it, Bill Pottinger, the Tool Lending Library Program Coordinator walks you through the steps necessary to set up, deploy and deploy a simple motor logger. He also shows you how to get the data back out and start working with it.

A while ago, I wrote a string of articles for HPAC on data logging that are hard to find these days. So, they are included in appendix to this resource list under “Hard to Find Magazine Articles”.

There are also several posts on the Field Perspective on Engineering blog that discuss how to put together a monitoring plan including:

- [Developing a Monitoring Plan; The First Step in Data Logger Deployment](#) and subsequent posts.
- [Retrocommissioning Findings: Make Up Air Handling System Simultaneous Heating and Cooling – Data Logging and Testing](#)
- Anything you come up with by entering the term “monitoring plan” in the blog home page search box.

The [Facility Manager’s Guideline](#) and other resources on the [Onset website](#), including the videos and white papers that are there can be very helpful resources to you if you are learning about loggers. And Onset’s product line is very complete in terms of data logging capabilities. So poking around on their web site and simply reading about the various products will likely provide you with some education on the topic.

4-20 milliamp current loops provide a handy way to interface data loggers to field sensors. If you are unfamiliar with 4-20 ma current loops, there is a string of blog posts on the [Field Perspective on Engineering](#) website that describe them, starting with [4-20 milliamp Current Loops; Why Use Them?](#)

If you would like to build one of the DC power supply panels, the string of blog posts on 4-20 ma current loops contains all of the information you need to do that, including a wiring diagram and parts

list for a panel just like the one in the blog post. The number of posts on this topic expands occasionally. You can find all of the posts by using the Category dropdown menu on the right side of the blog and selecting the 4-20 ma Current Loops topic.

Finally, the Control Design Guide and ControlSpecBuilder resources listed in the *Skill10: Develop a Competency with Control Systems* section also provide resources on this topic.

## Skill 06: Be Familiar with Functional Testing Techniques

### Functional Testing Guide

The [Functional Testing Guide](#) is a work in progress that has been developed to its current level by projects funded with public benefit charges from various utility companies, primarily in California. It started out as a compilation of publically available functional tests and was expanded to include information on the theory behind the tests. In other words, the tests explained what to do and the content supporting them explains why. 3

The guide contains:

- A library of functional tests that can be saved and edited to reflect the needs of your projects,
- A general guideline outlining basic functional testing principles common to just about any testing process.
- An Air Handling System Reference Guide, with technical information on the various components found in a typical air handling system and the design and commissioning issues associated with them,
- Modules on Chillers, Boilers, Condensers, and Pumping; these modules will serve as the starting points for developing guides similar to the air handling system reference for each module. Each module includes functional testing field tips, test guidance, and sample test forms pertinent to the module topic
- An *Integrated Operation and Control* chapter that contains a hypothetical case study of a new construction commissioning project on a building in the Midwest, illustrating some of the experiences that happen to the commissioning team, why they happened, and how they were resolved. It's kind of a nerd novel centered on a commissioning project.
- An appendix detailing calculation techniques based on the fan power and energy equations.

The guide can be worked with interactively on-line or can be downloaded and run as HTML on your personal computer. Either way, it includes a library of tests and other Word and Excel tools that can be saved and edited to meet your own needs. There is also a checklist tool that can be used to develop functional tests for various processes or as a guide for design review since most commissioning issues start their life as unresolved design issues. The checklist tool also serves as a focused way to penetrate the functional test guide content by providing hyperlinks from specific checklist topics to the sections discussing those topics in the body of the guide.

Note that it is best to use Windows Explorer to view the FT Guide. And for newer versions of IE, you will need to turn on [compatibility view](#). While the guide will generally work with Firefox, there are a few bugs that will show up on occasion under that platform.

## NETA

The [International Electrical Testing Association](#) provides resources, establishes standards, and publishes specifications to support the electrical testing community. Their standards are frequently referenced in electrical commissioning specifications. Subscribing to their [NETA World Journal](#) is a great way to learn more about electrical systems and their commissioning issues. But even if you don't subscribe, you can still [access their feature articles](#) via the NETA website in an archive section.

## Integration and Interaction

HVAC systems can be highly interactive. To some extent, the commissioning process is all about understanding these interactions and tuning the systems so they are fully integrated with each other, the building, its occupants, and the climate. To gain some insight into this process, you may find the [Integrated Operation and Control](#) chapter of [The Functional Testing Guide](#) to be a useful reference.

The chapter follows the commissioning process for a hypothetical building in the Midwest that goes through a renovation; sort of a nerdy novel about commissioning you might say. All of the things that happen in the story actually happened to commissioning providers in various commissioning processes. They probably just didn't all happen on the same project (or at least let's hope not). The chapter includes an [appendix](#) with pertinent information about the systems that went through the commissioning process for reference.

## Skill 07: Be Familiar with Data Analysis Techniques

While the [Universal Translator](#) tool will not help you learn how to speak Klingon, it will allow you to do many useful things with your data including:

- Combining your data with other data sets,
- Create new data streams based on calculations from the data streams you already have,
- Quickly sort your data
- Compare your data patterns to built-in diagnostic patterns.

If you are not comfortable with Excel, you may find it easier to work with your data using this resource in its place. If you are comfortable with Excel, you may find that this resource allows you to do some things more quickly than you can do them in Excel. Either way, it is a good tool to have in your repertoire.

[ECAM](#) an Energy Charting and Metrics tool is a powerful Excel spreadsheet plug-in that, once mastered, can help you look for patterns in your data. Onset has supported the development of a number of [webinars and training videos](#) to show how to use this tool with their products. The tool is in a constant state of evolution so it is a good idea to check the website occasionally for updates.

Most commissioning case studies are excellent ways to learn data analysis by studying the techniques of others. The [California Commissioning Collaborative](#) web site includes an extensive library of case studies that can be quickly searched for an issue similar to the one you are dealing with. The [Field Perspective on Engineering](#) technical blog contains many examples of data analysis and is always expanding its content.

## Skill 08: Be Familiar with Basic HVAC and Energy Calculations

As was the case for the Skill 07: Be Familiar with Data Analysis Techniques, case studies are excellent ways to learn about energy calculations by studying the techniques of others. The [California Commissioning Collaborative](#) web site includes an extensive library of case studies that can be quickly searched for an issue similar to the one you are dealing with. The [Field Perspective on Engineering](#) technical blog contains many examples of energy calculations and is always expanding its content.

## Skill 09: Be Familiar with Return on Investment (ROI) Calculations

The [LBNL reports on the costs and benefits of commissioning](#) provide valuable, citable metrics on the energy and non-energy benefits of commissioning processes, including an appendix full of additional references for data.

There have been a number of papers published that identify and document the savings potential associated with non-energy benefits. Two of the most useful were presented [ACEEE 2000](#) and [ACEEE 2002](#) and can be downloaded as .pdf documents by following the links.

Mark Jewell's company website [sellingenergy.com](#) offers a lot of resources for understanding the financial end of the energy efficiency business including a blog. There is even an Iphone app that you can download for free to get a daily update on Marks insights and ideas regarding selling energy efficiency

## Skill10: Develop a Competency with Control Systems

Control systems are the brains and central nervous systems that make our buildings run. Thus, they are critical elements in ensuring peak performance and efficiency.

### General Information

If you are looking for a bit more information on control systems you may find the following resources useful.

- Honeywell used to publish a book called *Engineering Manual of Automatic Control*, which in the industry is commonly called "the Honeywell gray manual". The book was used as a handbook/resource for Honeywell control engineers and, in addition to control theory, includes an overview of general HVAC principles and concepts. This publication is now available on-line in either a [down-loadable .pdf format](#) or an [interactive html format](#).
- [DDC Online](#): This website is hosted by the Iowa Energy Center and provides both an online tutorial on DDC systems as well as a generic comparison of the equipment from a number of the major manufacturers.
- [Energy Management Systems: A Practical Guide](#): This is a guideline developed by PECEI that explores the topic of energy management systems from evaluating an existing system or selecting a new system, to developing contract documents, developing optimization strategies and obtaining service contracts.
- [ControlSpecBuilder](#): This is a free web based resource that will help you put a control project together, including the specifications, system diagrams, point lists, and sequences. While the resource was developed by Automated Logic, it is totally non-proprietary. The documents are

developed in Word<sup>®</sup>, can be saved locally on your computer and you can even totally edit ALC out of your project as a qualified bidder if you wanted to. ALC's philosophy in developing the tool was that it would level the playing field; they don't have a problem competing on a level playing field. Their problem is competing in an environment where the features they offer are desired but not required by the documents. So, they created a tool that was designed to help designers ensure that everything they wanted was clearly defined in the contract documents, opening the door to all qualified players.

- ***The Control Design Guide:*** This guideline is a supplement to the [Functional Testing Guide](#) and can be viewed on the web or downloaded for off-line use. It starts out by looking at the control design process from the perspective of the key players in the process and then looks at a design approach that has been successfully used to address the concerns that can arise. It also includes a chapter that looks at control system sensors in detail, including selection and application guidelines. It concludes with a chapter that provides an overview of the most common HVAC system types along with point list recommendations for each system type in the form of spreadsheet tool that you can download and use on your own projects.

## Logic and Ladder Diagrams

Control logic is critical to the success of any building system and conveying the required logic is often on the critical path to success. Flow charts and logic diagrams are a common way to accomplish this and there is a free resource to help you develop this sort of documentation. If you are interested, download Eikon Logic Builder, a free resource from Automated Logic. To learn more about Eikon and download a copy, you can read the post I did on my blog titled [A Free Control Logic Development Resource](#).

Ladder diagrams have been used for years to depict relay logic for hard wired control circuits and are based on Joint Industry Council symbols contained in National Machine Tool Builders Association (NMTBA) specification EGPI-1967. Programmable controllers have to a large extent replaced hard wired relay logic. But, because they evolved out of that industry, the programming language used is ladder logic and the program literally look like the ladder diagrams for hard wired circuits of yesteryear. The Womack Machine Supply Co. has made a .pdf copy of these [symbols available for download](#) on their website if you would like to reference them. If you want to test your skills, [Wisc-Online](#) has a set of [ladder diagram flash](#) cards in their resource library.

Most logic and all computer operations come back to digital technology. Boolean algebra is algebra of two states, like "On" and "Off, or "1" and "0" and thus is a method of depicting how computers think. We will not dwell extensively on this topic in class, but if you are interested in learning more, there is a resource on line that can be downloaded for free titled [The Art of Assembly Language](#). You will note that there are a number of versions. The current version is available for sale or download, but the previous versions can be accessed on line at no cost. While the book itself is more than you probably care to know unless you really are going to do assembly language programming, chapter 2 of the DOS version (which is available for free) is dedicated to Boolean algebra.

If you want to see what a control design standard that is based on using logic diagrams and applying some of the principles discussed in Jay's articles on control design (see the section titled *Control System Design* below) then you are in luck. The [University of North Carolina at Chapel Hill](#) has just such a standard and they have [made it available on line as a series of .pdf documents](#) to be used as a resource

by their design consultants. The content includes [general guidance regarding the fundamental principles](#) behind the guideline, the [relevant specification sections, and logic diagrams](#) for the standard air handling systems used by the University.

For those who are interested in really digging into this topic and learning how to implement it in their own design and acquisition process, Jay Santos (FDE Principle) teaches a course titled [DDC Controls](#) that goes into the process in great detail. The course is offered through the [University Of Wisconsin Department Of Engineering Professional Development](#). The class is typically offered several times a year, at least once in Madison, WI and at least once in Las Vegas, CA.

The University also offers a course under the same department titled [Commissioning DDC and Pneumatic Controls for New and Existing Buildings](#) that includes some of the specification and logic diagram elements but focuses more on the commissioning process rather than the acquisition process.

## Control Hardware and Sensors

### Packaged Economizer Controller

I started a string of blog posts a while back that looked at a packaged economizer controller in detail, and am working on more. The first post in the series, titled [Working With the Honeywell W7212 Economizer Controller; How I Came to Write This String of Posts](#) will give you some insight into the problem, which comes down to integration of multiple parties and their hardware into a working system. This is actually one of the main challenges you will face as a commissioning provider and major element of the commissioning process.

### 4-20 ma Current Loops

Control systems are only as good as the inputs they receive. And a common way of providing these inputs is to use a 4-20 ma current loop. I have done several blog posts on this topic, which include links to additional resources if you are not familiar with the concept.

- [4-20 milliamp Current Loops; What They Are and How They Work](#) and [4-20 milliamp Current Loops; Interpreting Current Loop Information](#) explain the basics behind current loops. If you are not familiar with this technology, then at a minimum, you probably should read these two posts.
- [4-20 Milli-amp Current Loops – Power Supply Panel Parts](#) and the two that follow tell you how to put together the power supply panel you will need if you want to use 4-20ma transmitters with data loggers. This is a handy thing to know since it opens the door to doing data logging on pneumatic control systems, something that you frequently encounter working with existing buildings. The posts include details about each component and a wiring diagram and terminal strip arrangement drawing.
- [Using the DC Power Supply Panel in the Field – Picking Cable](#) and the post that follows look at some of the issues you need to think about when you use the panel in the field and need to select cables to connect your sensors to the power supply.
- [Demonstrating HVAC Filtration Savings with Data Loggers](#) looks at the power supply panel in action in a field trial we are doing that compares low pressure drop filters with more conventional filters.

- [Current Loops, Scaling Resistors, and Tubular Screw Clamp Terminals](#) looks at some of the details that can come up in a wiring system and how they might impact the accuracy of your measurements.

Many of the concepts discussed in this string of posts can be applied in the broader sense to other sensing technologies.

### Economizer Change-over and Control

The Functional Testing Guide (also referenced elsewhere in this document) includes [an entire chapter on Economizers](#), including a discussion of change-over strategies and related hardware.

Drybulb based strategies are one of the more persistent approaches to handling economizer high limit /change over requirements. Steve Taylor and C. Hwakong Cheng , both of Taylor Engineering recently wrote an article, published in the November 2010 ASHRAE journal titled *Economizer High Limit Controls and Why Enthalpy Economizers Don't Work* which provides a thorough discussion of the topic. If you are an ASHRAE Member, you can obtain a copy at no charge by accessing the [ASHRAE journal archives](#). Non- members will need to pay a small charge to purchase a copy from the ASHRAE bookstore.

### Humidity Sensors

Humidity is integral to many HVAC processes. But measuring it can be tricky and costly. The [National Building Control Information Program](#) did laboratory and field testing of a number of humidity sensors, all of which were blind purchased from the manufacturers. The results, including a discussion of the various measurement technologies, are included in their report titled [Duct-Mounted Relative Humidity Transmitters](#) and the related supplement, which looks at the sensor performance in the long term.

### CO<sub>2</sub> Sensors

NBCIP also did a study that was similar to the one mentioned above on humidity sensors, but focused on wall mounted CO<sub>2</sub> sensors. The results are published in a [basic report](#) covering the technology and out of the box performance, and a [supplement](#) which focuses on long term performance.

### PID Loops and Tuning

Proportional plus Integral plus Derivative (PID) control loops are very common in the building control system environment. There are a number of resources, free and otherwise that you might find beneficial and I talk about them in a blog post titled [Resources for Understanding PID Control](#).

### Control System Design

The ability to assess an existing BMS for its suitability as a commissioning tool can be critical to understanding what can and can't be done during an EBCx process. This in turn, can impact the cost of the process and the potential benefits to be achieved as well as their persistence. Lessons learned also provide valuable insights for future reference during design and shop drawing review processes.

For these reasons, and, because 90% or so of all commissioning problems have their roots in control system issues, the class will spend some time focused on control system procurement issues and optimizing control sequences. Jay wrote a series of articles on this topic for HPAC and Consulting/Specifying Engineer, and I also wrote a couple of articles on the topic for HPAC. Many of

them are difficult to find on line these days so we have included those as an attachment at the end of this memorandum. The two more recent articles that will be useful references are:

- [How to Write Control Sequences](#) , which was written by Jay and appeared in the February 2008 issue of [Consulting Specifying Engineer](#) and can be accessed from the digital edition in magazine archives on their web site.
- [The Joy of Writing Control Sequences](#) is an article I wrote (if you didn't think I was a bit nerdy before this, now you probably do) that was published in the September 2007 edition of [Heating, Piping, and Air Conditioning](#). You can access the article via the [back issue section of the web site](#) or via the [digital edition of the magazine](#).

This is another topic that is discussed once a year or so in a class Ryan Stroupe and I offer at the Pacific Energy Center called *Controls; Design, Performance and Commissioning Issues*. If you like hands-on experience, this is a class you will not want to miss since the afternoon consists of rotating lab sessions where you work with actuators, linkage systems, current loops, a VAV terminal, graphic programming, and PID loops in interactive lab sessions. It is a free class and usually, the lecture part is offered as a webinar. You can find out more about that under *the General Resources- Energy Centers - Pacific Energy Center (PEC)* heading. And, typically, you can find the most recent slide set for the class via the link under *03 - Materials from Classes and Presentations* on the right hand side of [my blog's opening page](#).

## Appendix 1

### HVAC Term Glossary

This is the current draft of the glossary associated with a guideline that is being developed by the National Building Control Information Program on return fan control strategies for variable air volume systems.

## Appendix 2

### Hard to Find Magazine Articles

These articles were originally published in HPAC's *Control Freaks* column but are currently unavailable in the on-line archive because it is being re-structured.

## Appendix 3

### Data Logger Articles

These articles were originally published in HPAC but are currently unavailable in the on-line archive because it is being re-structured.

## Appendix 4

### CLTD Technique and Tables

The following pages were scanned from the 1989 ASHRAE Handbook of Fundamentals.