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Multidiscipline Engineering Basics (and Related Specialties) for Project Managers and Others

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Introduction

Do you ever wonder what other disciplines do, or are unsure which disciplines are needed for a project? Do you look at drawings of other trades with no or little comprehension? Are you unable to do basic troubleshooting in other disciplines (problems are sure to arise in a project)? Would you like to know the basics as to how to calculate heat gain, or figure out a pump size, or select a beam, size a footing, determine exhaust rates, determine the number of sprinkler heads, size a circuit, select a type and quantity of light fixtures, figure out how much stormwater runoff will occur when you build that new parking lot, etc.? In this course, material is presented that will benefit those interacting with or managing multidisciplines typically employed to design/implement a building project. Practical applications and fundamental understanding of other disciplines could be lacking that weakens the Project Manager's ability to successfully manage other disciplines or for others to properly interact. As well, the inability to troubleshoot certain problems in projects lessens the PM's effectiveness. This course is an introduction to the myriad of engineering and related disciplines/roles necessary to successfully manage, oversee, or coordinate a complex project. While the focus is generally on buildings, it is useful for other projects as well.

The intent is not to develop the learner in a short course to do multidiscipline design per se (a violation of the law), but to better understand other disciplines which can result in better relations, scoping, coordination, and project management. As the old saying goes, a little knowledge can make one dangerous. However, knowing what disciplines do will enable the Project Manager to better anticipate resource needs and write effective Requests for Proposals or Proposals to the client.

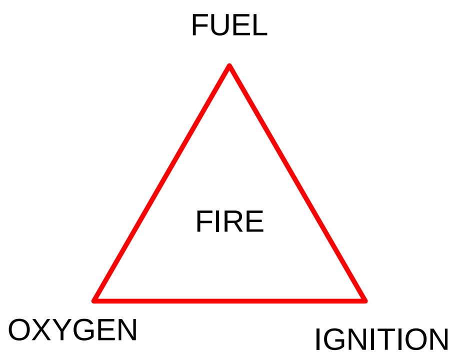
The course provides a general overview of the responsibilities of the various disciplines, along with examples and some basic formulas or applications. Practical experience from the Instructor is included. Some typical examples, formulas, and engineering fundamentals are provided to give better understanding. However, none of the examples should be considered engineering design or consulting for your specific project - each project must be carefully considered by disciplines with the proper experience and training.

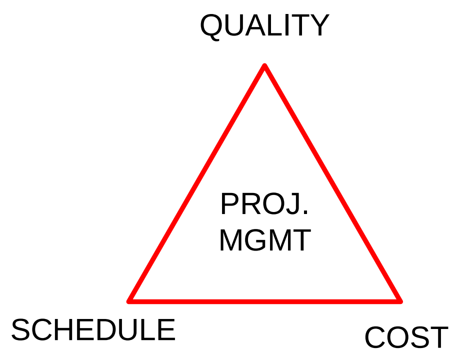
CONTENT

Project Manager

Before we even begin to look at the various disciplines, lets consider the responsibilities of a Project Manager. All projects need a primary point of contact within an organization. Owners need an overall project manager to coordinate external and internal resources, Consultants need a primary contact to interface with the Owner, and Contractors must have a point person accountable for the overall construction. Not to state the obvious, but Project Managers are to manage the project. Before we begin to review other disciplines, we must first understand this important role.

A project manager must be able to apply fundamental project management principles. Without applying the three elements of project management, the Project Management cannot effectively manage. An illustration of the fire triangle is helpful when understanding this; to have a fire, one must have fuel, oxygen, and ignition. Without any one of the three, there will be no fire. Similarly, for there to be true project management three elements must be in place; Quality, Schedule, and Cost.





- Schedule. Unfortunately, the idea of a schedule to many Project Managers is to give an end date and hope the project magically materializes. Some view projects as an act of fiat – speak it and it appears. Others have weak schedules that simply consist of a series of consecutively linked bars with major durations and illogical tasks. Effective schedules identify all the major tasks associated with the project and assign responsibilities. Tasks are logically linked with appropriate constraints. Some tasks are concurrent; others precedent; others with leads and lags. Another mistake is to first establish the end date, and then assign the tasks. The first step is to logically establish the tasks, relationships, and durations. If the end date then exceeds the desired completion date, more analysis on the schedule can be performed to determine more efficient task relationships and resources. A project cannot be successful and conflict cannot be avoided without having a properly developed schedule. Once developed, the schedule must be expedited. That is, an assigned individual must manage it. Much conflict results when schedules are not met and when there were no reminders along the way to complete certain tasks. The Owner should maintain a master schedule, and other assignees (such as the Consultants and contractors) should develop/maintain more detailed schedules with key milestone dates integrated into the master schedule.
- Cost. Accurately projecting and controlling cost is essential for a successful project. There exists no such thing as a "blank check," where costs can accumulate out of control. To control costs, the scope must be defined and be made firm early - few win when change orders

dominate. As well, a mechanism should be in place to properly monitor, track, and approve changes.

- Quality. Perhaps there is no less understood project management concept than quality. For many, quality is what they see when they are happy with the outcome of a project – it is that indescribable attribute that they only recognize when seen completed. The proper definition of quality is conformance to specifications. The project scope must conform to the requirements of the user or end product; the design must conform to the requirements of the project scope; the construction must conform the requirements of the design. Quality is never inspected in (although commissioning is an important element and must be performed to ensure quality), but built in. Quality should never be a nebulous immeasurable emotion – it can be quantified.

THE BIG THREE – CIVIL, MECHANICAL, AND ELECTRICAL ENGINEERING

When someone is introduced as an "engineer," the initial question is, "what is your discipline: Civil? Mechanical? Electrical?" Certainly, from an engineering perspective, these disciplines make up the majority of the engineering aspects of a building project. (See "Other" disciplines near the end of the course, which are also essential.) Within each discipline are specialties and sub-specialties.

Civil Engineering

The first engineering discipline we will review is Civil Engineering. This field covers a diverse assortments of other disciplines, such as the traditional Civil roles of site, surveying, and surface water design, in addition to structural, geotechnical/materials, traffic engineering, waste treatment, and construction management.

Civil (site design, surveying, storm sewer, etc.)

Site design is an important element of a project. The property must be surveyed and its boundaries established. Wetlands and other difficult features must be identified and resolved. Site drainage must be considered, as well as storm water retention (Civil Engineers often joke that the first lesson they learned is water runs down hill.) When developing a site, storm water runnoff becomes a major issue; by developing as site, the amount of runoff is increased by the addition of impervious surfaces. Most municipalities have a maximum amount of impervious surface that can be added and/or retention requirements when it is exceeded.

Example: An Owner is planning to construct a new facility on undeveloped property in a municipality far from its own. Whom should the Owner choose as its Civil Engineer?

Answer: The Owner could choose to stay with the Civil Engineer it has the most experience with. However, if the Civil Engineering firm has not worked in the new municipality, it will not be familiar with particulars of the requirements there. Often, it is recommended to use a firm local to the municipality for this reason.

The amount of stormwater runnoff calculated for a site depends on the location and projected severity (such as a "5 year" storm, etc., or one so severe it would only be statistically expected to occur every 5 years.) Most drainage systems are designed based on 2 to 5 year storms depending on the requirements of the municipality. As well, the duration required to be assumed must be known, usually 5 to 15 minutes. Once the desired intensity and duration are known, the rainfall intensity can be derived from available charts/graphs suitable to the area in units of inches per hour. The time of concentration, or the time required for water to flow across property, may be used to reduce the rainfall intensity for sizing sewers and channels (beyond the scope of this course). Finally, the areas and types of surfaces must be known so the "Coefficient of runoff" can be assigned. The Coefficient of runoff is greater for impervious surfaces (0.9-0.95), and less for wooded areas (0.01-0.2). The gallons/minute runoff is calculated as follows:

gpm = $540C_r iA$, where

- C_r = Coefficient of Runnoff
- i = Rainfall intensity in inches/hour
- A = area in acres

Example: A developer is planning to purchase a 10-acre site, half of which will become impervious, and the remainder to remain undeveloped. Assuming the rainfall intensity is five inches/hour, what is the expected runoff in gpm? (gallons per minute)

Answer: The total gpm = Σgpm = (540*0.95*5*5 acres) + (540*0.2*5*5 acres) = 15525 gpm

Once flow rates are know from various points and inlets, pipes/channels can be sized. Typical pipe sizing charts are readily available based on "Manning's" equation.

Traffic Engineering

For major expansions and greenfield projects, consider a traffic engineering study from a local consultant. The local municipality may require road widening, intersection rework, signalization, etc. These could be budget busters. As well, understanding traffic flow on the site is essential for efficiency.

Waste Treatment

Waste treatment is often thought of as belonging to the municipality. However, given the industrial nature of some clients, on-site waste treatment to some level may be required. On one extreme, complete treatment may be required before releasing water to local waterways. A more common application is to adjust PH before the waste-stream leaves the site into the common sanitary sewer system flowing to the municipality's waste-treatment facility.

Example: A customer creates a waste stream that sometimes has a low PH (acidic), and other times a high PH (alkaline.) However, the municipality has limits on PH levels they can handle at their final waste treatment facility. What engineering solution is needed?

Answer: A PH neutralization solution is needed. The waste stream is neutralized by adding acid when the PH is high, and caustic when the PH is low. An intermediate holding tank can provide more accurate dosing versus direct injection into the waste stream. The process can be automated via PLC (programmable logic controllers) and sensors. Remember to install alarms for when things go awry. Also remember to heat-trace caustic lines given its low freezing point.

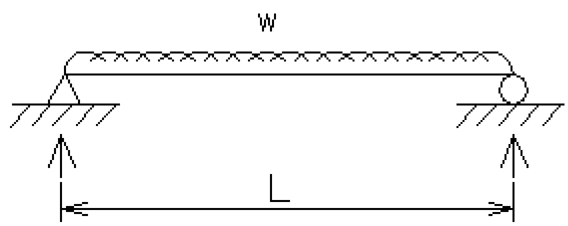
Structural

Structural Engineering is one of the more *risky* fields. This field designs systems to support people, whether it is bridges, dams, or building structures. The key to structural engineering success is to know when something will fail, the likely loads that will be applied, and then design systems with safety factors to prevent failure. When using non-homogeneous materials (such as naturally occur like wood or those that require precise placement of reinforcement such as concrete), higher safety factors are applied. Obviously, understanding materials and statics is important to this field. When hiring a Structural Engineer, it is important to inquire as to related experience; Structural Engineers tend to become further focused/specialized. Some may be excellent at post-tensioned concrete, and others at space frames. Some may be experienced as bridge design, and others high-rise buildings. Although practicing Structural Engineering requires considerable study of statics and strength of materials, the following are some design fundamentals useful for the project manager to understand. However, non-structural engineers should not design actual elements.

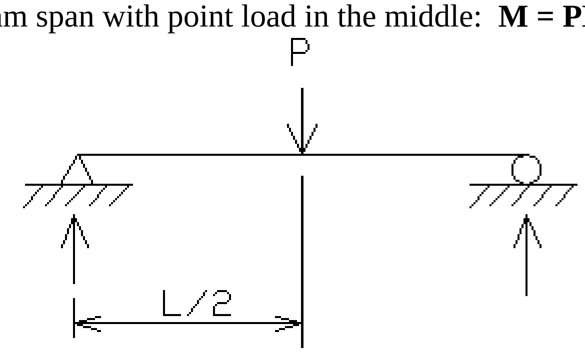
Design Fundamentals

- Loads: Loads come in two primary types - live and dead. Live loads are loads imposed after construction, and dead loads are the weight of the structural elements plus permanently applied loads. The success of any design will in part depend on the accuracy of predicting the amount and load path from the source to the footing.
- Moment: Beams fail from two primary mechanisms: shear or moment. Wood members, especially, are susceptible to shear failure, which actually occurs along the horizontal fibers. While shear is perhaps more obvious, what is moment? Moment is the structural version of torque, expressed in pound-feet or kip-feet (a kip = 1,000 pounds.) When a beam bends (in simple bending), there is compression in the top and tension at the bottom. When the moment is divided by *section modulus*, S_x, (a factor calculated based on the profile of the beam, and beyond the scope of this course), the maximum tensile or compressive stress is revealed in psi (assuming the units are correct.) There are also tables that provide allowable moments to enable easy selection. Because we know allowable stresses in materials, we can determine if the beam will carry the load. Long hand, moment is calculated via shear and moment diagrams, also beyond the scope of this course. However, there are standard formulas available for simple applications.

Simple beam span with uniform load: $\mathbf{M = WL^2/8}$ (W = uniformly distributed load in kip-feet)



F6.3.2.1: Simple beam span with point load in the middle: $\mathbf{M = PL/4}$ (P= load in kips)



Example: What is the maximum moment for a beam 20 feet long with 250 pounds/ft uniformly distributed ?

Answer: $M = WL^2/8 = [(250\ \#/ft)*(20ft)^2]/[(8)*(1000\ \#/ft)] = \underline{12.5\ k\text{-}ft}$

Example: What is the maximum moment for a beam 30 feet long with 2,000 pounds at its center?

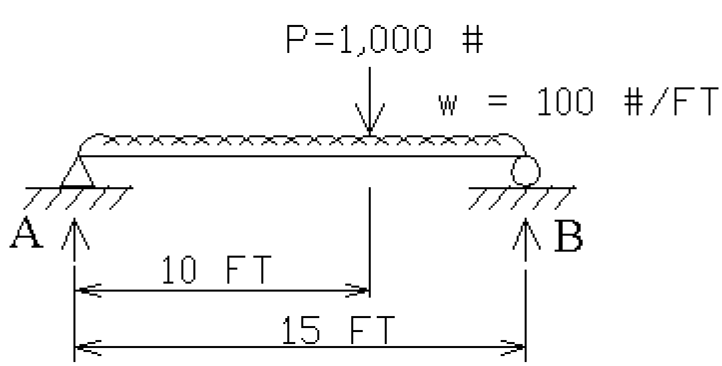
Answer: $M = PL/4 = [(2{,}000\ \#)*(30\ ft)]/[((4)*(1{,}000\ \#/ft)] = \underline{15\ k\text{-}ft}$

- Deflection/Sway: While systems may not fail, the amount of movement or sway may be excessive such as to feel uncomfortable or damage attached systems. Determining sway and deflection often involves complex calculations.
- Columns: Columns are designed considering their slenderness. For example, if you've tried to push on a long slender object like a dowel, you know by experience that you can apply more force near the tip than far away - the dowel will buckle to the side and break. Columns are designed using principles beyond the scope of the course. However, there are tables that give capacities of columns at various unsupported (laterally) lengths. When there are eccentric loadings (i.e. vertical loads not at the center of the column) or bending (horizontal loads), the column must be designed considering the combination of bending and axial loads. Loads or reactions from structures/beams to columns from simple beams are determined based on the principles of *statics*. For a structural system to remain static, the summation of moment around a hinge or the summation of forces must equal 0 (that is, if it doesn't equal 0, the system is not *static* but is in motion.)

Example: What is the axial force on the columns for the example below (R_A & R_B) using the following principles/equations?

$\Sigma M_A = 0$ or the summation of moments around any point in a static system must = 0

$\Sigma F = 0$ or the summation of forces around any point in a static system must = 0



Answer:
First, solve for the reaction, or column loading at "B" by applying the principle that

summation of moment at any point in a static system = 0:
ΣM_A = 0 = [(100 #/ft)*(15ft)*(15 ft/2 = center of gravity)] + [(1,000 #)*(10ft)] - [(R_B)*(15ft)] - [(R_A)*(0ft)] = 0; Solve for R_B= 1416.66# or 1.42k

Second, solve for the reaction, or column loading at "A" by applying the summation of forces of a static system (in this instance vertical) = 0:
ΣFv = 0 = [(100#/ft)*(15ft)] + [1000#] - [R_B = 1416.66] - R_A = 0; Solve for R_A = 1083.33# or 1.08k

- Foundations: The most common column foundation is rectangular. Given the subsurface characteristics, the Geotechnical Engineer assigns an allowable bearing load. When the load would be exceeded with a reasonable footing size, other foundation types are needed, such as piles or caissons. Strip footings are used for walls. Footings are constructed of concrete, with reinforcing and thickness determined by the Structural Engineer appropriate to the stresses.

  Example: A column imposes a 100k load on a footing. The soil capacity is 4 k/sf. What size footing is required?

    Answer: Size = 100/4 = 25 square feet, or 5' x 5'

  Example: A wall imposes 4k/ft load on a strip footing. The soil capacity is 2 k/sf. What minimum width footing is required based on soil bearing limitations?

    Answer: Width = (4/2) = 2 feet wide (Note: Codes and/or good practice often dictate a minimum width from each side of the wall which may make the footing wider than required.)

- Concrete Design: Although the complexities of concrete design would not allow treatment in this course, understanding the basics are useful. Concrete is excellent in compression, but poor in tension. That is why steel reinforcing is used in tensile zones. The more the bending in concrete, the greater the thickness/depth of the concrete and the larger the steel reinforcing. Reinforcing is also used to minimize/control shrinkage cracking. It is essential that reinforcing be carefully installed in the size and location/orientation designed by the structural engineer if the capacity is to be realized. Masonry design is similar to concrete, since masonry is excellent in tension but poor in tension (that is why may masonry retaining walls crumble that don't have reinforcing.)

Construction Engineering

The Construction Engineer focuses on tasks necessary to construct a designed project. Construction Engineering is often a field of or related to Civil Engineering. The elements of good project management are a part of this discipline, as well as skills in cost estimating, and understanding of construction trades. Understanding contracting laws and regulatory/permitting is essential. One strategy of a cost effective project is to properly parse out portions of a project to the appropriate vendors and subcontractors. The types of contracts/agreements are varied, but often fall in the following categories:

- Bid: This requires a project to be thoroughly scoped and designed prior to acquiring proposals from bidders. To minimize the likelihood that the "lowest bid" syndrome (i.e.: have a non-qualified bidder), consider prequalifying bidders before bidding. For subcontracts, this is the best approach in the Instructor's experience (if time permits) - this approach benefits from free market forces and overtime should maintain lowest cost while retaining quality.
- Negotiated: This approach is to negotiate with a single contractor for work to be performed. The disadvantage in this is that one may not be able to ensure a fair market rate is being offered unless the work is a near duplicate of previously bid work. This is especially difficult for proprietary systems, where sole sourcing often occurs.
- Time and Material: In this method, work is performed at pre-agreed-to labor rates and mark-ups on materials. While this enables work to begin quickly, the work must be closely monitored and can be difficult to manage from a budget viewpoint.
- Not-to-exceed (NTE): This approach is similar to the previous, except the contractor agrees to a maximum charge for the agreed-to scope. Keep in mind, however, scope changes are outside the NTE.

Delivery Methods: There are delivery methods as well to be considered. Methods may use one or combinations of the above. Some options are as follows:

- Design-Bid: In this approach, the design is completed and then competitively bid. This is an economical way to approach a project, but is the most lengthy to complete. Another disadvantage is not including a contractor early in the design decisions.
- Design-Build: This approach has been heavily marketed of late. Under this arrangement, a single contract exists between the Owner and Design-Build firm. The advantage that is purported is that there is a single point of contact/responsibility, expedited schedule, and costs are low. (It is in the Instructor's opinion and experience that this method is not the lowest cost in many cases.) This approach is best suited for highly defined or highly specialized/propriety projects, or small plant-type projects. One disadvantage is that often the Design-Build firm has a stronger expertise in one area (design vs. construction.) Another disadvantage is that unless the scope is highly defined, there can be cost overruns or insufficient engineered solutions or lower quality equipment/materials. Also, there can be conflict of interest between good engineering practice/ordinary care and financial goals of the constructor. Finally, there is a healthy tension between designers/constructors that is lost when under the same contract. If this approach is to be employed, consider a thorough preliminary engineering phase to define the expectations and scope. Despite the heavy marketing for this approach, use it with caution, especially for larger more complex projects. What is good for a Design Build firm may not always be to the Owner's advantage.
- Design-CM (Construction Management): In this approach, a separate Construction Manager is brought on early during the design to participate, do construability reviews, early bidding/purchasing, and estimates. The General Conditions (costs to manage the project) and Fee (the CM's overhead and project) can be bid once the basic scope is understood (usually 10-15 % of direct construction costs.) The CM then bids to vendors and subcontractors the complete design, or phases. Of late, many so-called "CM" firms have come about, but in actuality are program managers. The best CM for the Owner is in effect a GC (General Contractor) that is capable of performing the above. Require a NTE cost after bid day; if earlier, excessive contingencies will be added or there will be a hostile change-order environment. Beware of a CM that will not agree to a NTE arrangement. Also beware of a

CM that will not thoroughly parse out the contracts - the CM should not under most circumstances combine work under another GC (if done, this is a sign that the CM is really a program manager.) Another advantage to the CM approach is that long-term mutually beneficial relationships can be forged, and each project will not require a *learning curve*. Based on the experience of the Instructor, Design-CM is preferred for larger and multidiscipline projects that require GC-type oversight.

Contracts are important aspects to a Construction Manager's job, covered by other courses.

Geotechnical/Material Testing

Geotechnical Engineering is a specialty of Civil Engineering. Training in this specialty allows the engineer to evaluate subsurface conditions and to determine foundation methods/allowable loadings. For building projects, borings are taken to determine the soil profile. Various tests are performed on the soil to determine properties and allowable bearing. Recommendations for foundations and allowable bearing are provided in a Subsurface Investigation report - this is highly recommended for new construction projects.

A *Proctor* is performed to determine the density possible for backfill. The more the density, the higher the Proctor, and the higher the allowable bearing. Often, specs require compaction/backfill to be at 95% Proctor under structures. To size pavement, a CBR (California Bearing Ratio) is determined. Material testing is often a part of a Geotechnical Consultant's service offerings. It is important to test compaction, verify proper excavation, and backfill materials during a project. As well, it is important to test materials, especially concrete. Concrete is usually tested when it arrives for air content and slump. (Concrete is poured in a cone and rodded, and the amount of "slump" or sagging is measured. The less the slump, the stronger the concrete.) Concrete "cylinders" are also taken to allow "breaks" to be performed to confirm design compressive strength has been attained. As well, material testing is needed for welds, bolts, reinforcement placement, etc.

The following are a few practical suggestions:

1. As a practical matter, use local Geotechnical Engineers if possible, since they are most familiar with local conditions.
2. Translate requirements from the Subsurface Investigation report to the drawings and specs, and include in bid prices. For example, specify on drawings the type of backfill permitted, and compaction requirements.
3. Backfill: Usually, backfill should not be placed in lifts greater than 8 to 12 inches, and should be thoroughly compacted (95% Proctor under foundations, and 90% elsewhere).
4. Do not permit "washed" stone for general backfill. This is washed stone with the fines removed. Many contractors refer to this as "self-compacting stone;" God did not make such an animal. Even marbles will consolidate in a jar if shaken. Also, using this material will create a natural dam underground, where water will collect; over time, settlement will occur as well as other problems (such as water entering conduit, etc.) Use "washed" stone for a few inches of pipe bedding only, under slabs, and graveled roads and lots.
5. Get the subsurface investigation completed early - unusual foundation requirements can surprise the budget later. This activity is a small percent of a total project cost.
6. Contract to have an independent rep from the Geotechnical consultant present during construction at crucial steps - be careful not to permit items to be covered up.

Mechanical Engineering

For the building trades, we think of mechanical engineers as providing central utilities, HVAC, and plumbing. Often, mechanical engineers specialize in one of these areas. This section of the course examines fundamentals as well as practical considerations for mechanical engineering aspects of the building design process.

Plumbing/Piping

Building plumbing systems are necessary for sanitary and potable uses, as well as other utility systems. Piping systems are needed for steam, chilled water, reheat coils, hot water, domestic water, compressed air and other gases, fuel, etc. Regarding the most common and needed for most buildings, domestic water arrives from the municipality or local sources (primarily wells), and is sometimes filtered, or boosted to increase pressure. Pipe is sized to meet flow and pressure needs. Domestic water is needed for toilets/water fountains (remember to refer to local code for number of fixtures needed), and utility uses (make-up water for chilled water, steam, etc.) Sanitary drainage is needed to take wastes away, and vents are needed to ensure piping will not become airlocked.

Several factors are needed to size pipe, including desired flow rates (gpm), pressure loss (due to static – know the length and number/type of restrictions and fittings.) In any hydraulic system, proper design necessitates understanding Bernoulli's theorem, which is a way of expressing the law of conservation of energy as related to flow of a fluid in a pipe. The energy at any point in the pipe (Head or H) is equal to the sum of the elevation head (Z) or elevation energy, the pressure head (pressure/density of liquid), and the velocity head or kinetic energy (velocity of the fluid squared divided by 2 * acceleration of gravity = 32.2 ft/sec^2), expressed as follows:

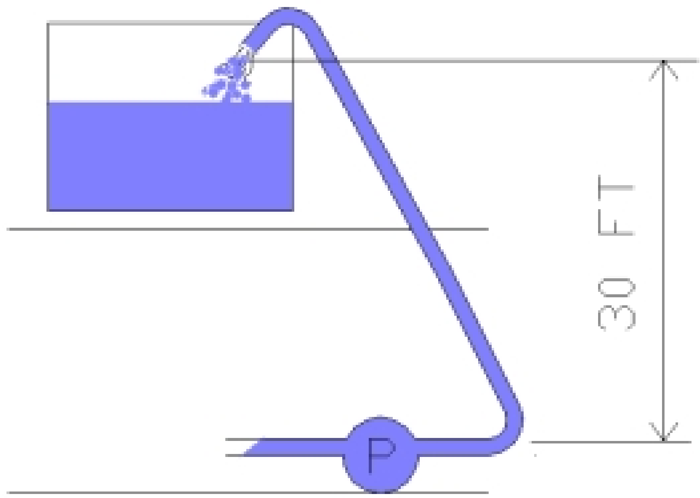
$$H = Z + P/\rho + v^2/2g$$

There will be a difference, however, in head between two points because of friction loss (h_L), but the total Head between the two points will equal as follows:

$$H = Z_1 + P_1/\rho + v_1^2/2g = Z_2 + P_2/\rho + v_2^2/2g + h_L$$

Headloss due to friction is based on pipe type, flow rate, obstructions such as elbows and tees, orifices, viscosity, constrictions/restrictions, etc. and explaining all the particulars is beyond the scope of this course. However, this calculation is the most essential after understanding Bernoulli's theorem. Friction losses are determined using various formulas. Charts and tables are easily available from texts and vendor materials to aid in calculating friction headloss. A reasonable upper limit for water velocity in pipes is six fps (feet per second[i] – confirm by checking "Reynolds" number for specific applications.) But the following illustrates an application of Bernoulli's equation, with assumptions made as to friction headloss:

Example: You need to select a pump to convey water from a tank to a higher floor. You are raising the water 30 feet. Assuming same diameter, water rushing out of an open pipe at the upper floor, and total head loss due to friction = 1 psi, what pressure must the pump be capable of (ignoring head at the tank supplying the pump or residual pressure before the pump)?



Answer: The elevation head at the starting point is zero, and at the discharge 30 ft. The pressure at the discharge is 0 (i.e.: outside the pipe). We need to solve for the pressure at the pump. Because the velocities will be the same at the pump and immediate pipe outlet, it can be canceled out on both sides of the equation. (Remember to convert those units! For example, convert head loss to feet by dividing by the unit weight of water and multiplying * 144 to change psi to psf.)

$$\cancel{Z_1} + P_1/\rho + \cancel{v_1^2/2g} =$$
$$(Z_2 = 30') + \cancel{P_2/\rho} + \cancel{v_2^2/2g} + [h_L = 1 \text{ psi} = (1*144/62.4) = 2.31 \text{ ft}]$$

$$P_1/\rho = 30' + 2.31'$$

$$P_1/\rho = 32.31'$$

$$P_1 = 32.3\rho = 32.31 \text{ ft} * 62.4 \text{ \#/ft}^2/(144 \text{ in}^2/\text{ft}^{2)} = \underline{14 \text{ psi}}$$

Note the above equation did not include flow volume (gpm). However, flow rate is an important design element, and would have been an element in determining the friction loss. Often, problems such as the above are iterative, requiring trying different pipe sizes or pumps and other techniques to determine flows in complex interconnected piping networks. Also, pipes may be limited to sizes that facilitate laminar flow. Obviously, software is also useful.

Tables and charts are readily available to assist in determining headloss. There are also handy "equivalent length" tables for various fittings and other assemblies to convert headlosses into an equivalent length of pipe for ease of calculation. The following table is an example for water flowing in Schedule 40 new pipe:[ii]

Friction Loss for Water Flow

Average value—new pipe. Used pipe add 50%
Feet loss / 100 ft—schedule 40 pipe

US Gpm	1/2 in.		3/4 in.		1 in.		1-1/4 in.	
	v Fps	h_F FtHd	v Fps	h_F FtHd	v Fps	h_F FtHd	v Fps	h_F FtHd
2.0	2.11	5.5						
2.5	2.64	8.2						
3.0	3.17	11.2						
3.5	3.70	15.3						
4	4.22	19.7	2.41	4.8				
5	5.28	29.7	3.01	7.3				
6			3.61	10.2	2.23	3.1		
8			4.81	17.3	2.97	5.2		
10			6.02	26.4	3.71	7.9		
12					4.45	11.1	2.57	2.9
14					5.20	14.0	3.00	3.8
16					5.94	19.0	3.43	4.8

Friction Loss for Water Flow (cont.)

US Gpm	1-1/2 in.		2 in.		2-1/2 in.		1-1/4 in.	
	v Fps	h_F FtHd	v Fps	h_F FtHd	v Fps	h_F FtHd	v Fps	h_F FtHd
18	2.84	2.8					3.86	6.0
20	3.15	3.4					4.29	7.3
22	3.47	4.1					4.72	8.7
24	3.78	4.8					5.15	10.3
26	4.10	5.5					5.58	11.9
28	4.41	6.3					6.01	13.7
30	4.73	7.2					6.44	15.6
35	5.51	9.6					7.51	20.9
40	6.30	12.4	3.82	3.6				
45	7.04	15.5	4.30	4.4				
50			4.78	5.4				
60			5.74	7.6	4.02	3.1		
70			6.69	10.2	4.69	4.2	3 in.	
80			7.65	13.1	5.36	5.4	v Fps	h_F FtHd
100					6.70	8.2		
120					8.04	11.5	5.21	3.9
140					9.38	15.5	6.08	5.2
160							6.94	6.7
180							7.81	8.4
200							8.68	10.2

Equivalent lengths can be approximated for the previous tables as follows:

Equivalent Length of Pipe for Valves and Fittings

Screwed fittings, turbulent flow only, equipment length in feet.

Fittings	Pipe Size							
	1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3
Standard 90° Ell	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11
Long rad. 90° Ell	2.2	2.3	2.7	3.2	3.4	3.6	3.6	4.0
Standard 45° Ell	.71	.92	1.3	1.7	2.1	2.7	3.2	3.9
Tee Line flow	1.7	2.4	3.2	4.6	5.6	7.7	9.3	12
Tee Br flow	4.2	5.3	6.6	8.7	9.9	12	13	17
180° Ret bend	3.6	4.4	5.2	6.6	7.4	8.5	9.3	11
Globe Valve	22	24	29	37	42	54	62	79
Gate Valve	.56	.67	.84	1.1	1.2	1.5	1.7	1.9
Angle Valve	15	15	17	18	18	18	18	18
Swing Check	8.0	8.8	11	13	15	19	22	27
Union or Coupling	.21	.24	.29	.36	.39	.45	.47	.53
Bellmouth inlet	.10	.13	.18	.26	.31	.43	.52	.67
Sq mouth inlet	.96	1.3	1.8	2.6	3.1	4.3	5.2	6.7
Reentrant pipe	1.9	2.6	3.6	5.1	6.2	8.5	10	13
Sudden enlargement	Feet of liquid loss = $\frac{(V_1 - V_2)^2}{2_g}$							

where V_1 & V_2 = entering and leaving velocities

and g = 32.17 ft/sec^2

Adapted from "Numbers", Bill Holladay and Cy Otterholm, 1985

Example: You have a pipe you need to size for 20 gpm that is 48 feet long. It has four standard elbows and a gate valve at the end. Your pump can only handle 3 feet wg of pressure. What size is the pipe?

> Answer: From the table, try 1 ½" pipe, which has 3.4'/100' head loss. The equivalent length of the pipe = (48 + (4*7.4) + 1.2) = 78.8 feet. Head Loss = 78.8 * 3.4/100 = 2.68 ft wg. Therefore, use 1 ½" diameter pipe, since the allowable is greater than the actual.

Tables and charts are readily available for gravity flow in various piping materials needed to size storm and sanitary sewer drains. "Fixture Units" are assigned to plumbing fixtures to determine flow for potable water supply and drainage. Fixture Units are then converted from a chart to demand (such as on a "Hunter" curve.)

It is important to select the proper pipe material for the job. The following table illustrates typical pipe-types by application for industrial applications:

Typical Industrial Piping Materials

Application	**Piping Materials**
Sanitary and Storm Sewer below ground	Service weight cast iron hub and spigot pipe with neoprene compression joints
Above-ground Sanitary Sewer, Vent, and Storm Sewer	Service weight cast iron soil pipe, no-hub
Sanitary Piping (product contact)	316 Stainless Steel; other materials for special applications
Domestic Water	Type 'L' hard copper pipe (PVC for non-industrial applications)
Compressed Air	Type 'L' hard copper pipe Sanitary Areas – 316L stainless tubing
Chilled and Hot Water	2" diameter and larger: Schedule 40 black carbon steel
	2" and smaller, Hot Water: Type 'L' copper pipe
Cooling Tower Drain, AHU Condenser Drains and Refrigerant Relief	Schedule 40 Galvanized steel pipe
Steam	Schedule 40 black carbon Steel pipe
Condensate	2-1/2" and larger Schedule 80 black carbon steel Pipe

Central Utilities

Properly designed central utilities are essential. Utilities can include water treatment systems, steam, hot water, chilled water, electrical distribution, and compressed gasses. Utilities may be located in mechanical rooms, or in central plants or Central Utility Buildings for larger facilities and campuses. Specifically, the following are a few essential descriptions:

- Boilers: Boilers change domestic water into steam that is used for heating and processing. Fuels for boilers are typically natural gas or fuel oil. Boilers are rated in HP (horsepower.)
- Chillers: Chillers provide chilled water for space cooling and process cooling. Chillers are typically air-cooled (self-contained refrigeration) or water-cooled (utilize cooling towers that exhaust a portion of the heat to the air via water.) Chillers are rated in Tons. The amount of gpm required = Total load (BTU/hr)/(500 * water temperature delta T). Or, the required tonnage of a chiller equals the required chilled water flow (gpm) * water temperature difference ^{o}F/24.

Example: The total required chilled water flow is calculated to be 1,000 gpm at a temperature drop of 20 ^{o}F. What size chiller is needed?

Answer: tonnage = gpm*delta T/24 = 1000*20/24 = 833.33 tons

- Compressed Gases: The most common compressed gas is air, which must be compressed, cooled, and dried before being distributed. Be sensitive to the needs of the facility, and avoid oiled compressors where sanitation is an issue.

HVAC

Proper HVAC (Heating, Ventilation, and Air Conditioning) design is one of the most important elements of building design. Because each person has different comfort level, this assignment of this discipline is made more difficult. HVAC accomplishes the following goals:

1. Air quality: Air quality is affected by the moisture content and filtration, as well as the percent of outside air. Filtration levels are measured as ASHRA Dust Spot Efficiency, or of late MERV values. Some product environments and clean rooms require higher levels of filtration, for example, HEPA (High Efficiency Particulate Air), which are measured as a percent of 0.3 micron particles will be retained. Even higher grade filters are available (such as ULPA). Codes require a certain cfm/person fresh (outside) air – don't recirculate 100%.
2. Relative Humidity: Humidity is most comfortable to occupants between 40 and 60% RH. Low humidity begins to affect peoples' sinuses, and high humidity encourages mold propagation. Also, low humidity can cause excessive static electricity, a problem for sensitive electronics or flammable/dusty areas. Normal high humidity is limited by cooling the air, sometimes also requiring reheating it to satisfy space temperature requirements. As air is cooled, relative humidity increases until the dewpoint is reached at which point moisture begins to be relieved. For very low humidity requirements, other technologies are needed, such as desiccant wheels. Humidity is added by boiling off water (or via other technologies) into the airstream. As a practical matter, be aware of the source of the water and ensure no hazardous chemicals are added, such as amines from boilers, or poor water that could foul the equipment. Adding humidity is often required in areas of high outsider air introduction, flammables, or sensitive production materials.
3. Temperature/Creature Comfort: Temperature is maintained by cooling the air or heating it as needed. Adding heat can come from a variety of methods, such as local heat sources, hot water or steam coils in the air stream, furnace applications, or heat pump. Cooling is provided by refrigeration cycle or chilled water.
4. Pressurization: Buildings are usually pressurized to minimize infiltration. Also, production spaces may be pressurized to prevent the cross migration of airborne materials or flammable gasses. A formula for converting pressure in a duct or room to flow is as follows:

$$P_v = (V/4005)^2$$

   - P_v = Pressure in wg (water gauge or inches of water)
   - V = velocity in a duct or through openings/cracks, fpm

Example: In a pharmaceutical manufacturing room, the design criteria calls for a differential pressure between the room and airlock to be 0.05" wg. What will the exit velocity of air be through the conveyor opening from the room?

Answer: The pressure P_v = 0.05" = $(V/4005)^2$ Solving for V we get 895.5 fpm (feet per minute)

5. Air Turnover: Air turnover in spaces is typically determined by heating/cooling requirements, but also may be needed to *clean* or purge the spaces. The higher the air turnover rate, the quicker spaces will be purged. Air Turnover is measured in ACPH (air changes per hour.)

   ACPH = Σcfm to the space * 60/room volume in cubic feet

   Example: You need 14 airchages in a room that is 20' x 40' x 14'; what cfm will you need to the room?

   Answer: ACPH = 14 = cfm*60/(20*40*14); solve for cfm = 2613 cfm

The types of HVAC systems for buildings are typically DX or Chilled water, with a variety of heating methods in a central air handler(s). DX is "direct expansion," or a self-contained air handler with refrigeration equipment integral. Chilled water systems are simpler, and provide cooling via a coil with chilled water provided from a separate chiller. Chilled water systems for multiple units are often more energy efficient, although some redundancy is lost.

Typically, spaces are heated and cooled by forcing air from the air handler to the spaces via ductwork through diffusers. Air is usually returned to the unit, or directly to the outside. Sometimes, VAV (variable air volume) boxes and/or reheats are provided near the spaces to respond to changing and varying space conditions via local thermostats.

HVAC systems are sized given heat and cooling load requirements of the spaces. The sources of heat to the space must be identified and quantified. Internal heat sources can include people, computers, equipment, and lighting. External heat sources are solar gain, and temperature. Total air-conditioning loads are represented by *sensible* and *latent* loads. Sensible loads are simply increases in temperature from heat energy, and latent loads are moisture-laden loads. Latent loads can be understood by observing how water boils. When the water approaches 212 degrees F, it takes awhile for steam to appear - significant energy is absorbed to change the state of water to steam. Therefore, when latent loads occur (as from people and other moisture giving activities) it takes additional "cooling" energy to bring the temperature down when the air reaches the dewpoint. Understanding latent loads is essential if air conditioning (cooling) is to be properly sized. Total air conditioning loads equal sensible cooling load plus latent cooling load. Cooling needs are often expressed in units of tons. Heating needs are expressed in BTUH or BTU (British Thermal Unit) per hour (BTU/hr), and are calculated understanding the expected temperature drop outside in the winter. A BTU is the amount of heat needed to raise the temperature of one pound of water 1^oF, or cool by the same amount. Cooling (which is actually the removal of heat) is typically expressed in tons of refrigeration, which is the amount of heat needed to melt one ton of ice in 24 hours. One ton of refrigeration = 12,000 BTU/hr.

To calculate the amount of heating and cooling loads, it is important to understand the insulating factors of the building materials and the surface area. "R" factors are the resistance to temperature changes between two sides of an assembly, and a "U" factor is the heat transfer coefficient (the reciprocal of the sum of the R values for an assembly.) The amount of heat energy transferred is simply calculated by multiplying U * delta T * surface area.

BTUH = U * Delta T * A

Example: What is the heat loss in the winter through a wall 100 sf, with a U of 0.9, and inside temperature of 70^{o}F and outside 14^{o}F?

Answer: Heat Load = 0.9 * 100 * (70-14) = 5040 BTUH

Example: Heat gain into a space in the summer is calculated to be 20,000 BTU/hr. How many tons of cooling are needed?

Answer: 20,000/12,000 = 1.67 tons

Note: Sometimes BTU/hr is described as BH or BTUH. Also, MBH = 1000 BTU/hr

Heat gains in a space must be determined by items in the space. The following are a few examples of heat gains/formulas.

Heat Source	**Sensible heat, BTU/hr**	**Latent heat, BTU/hr**
Electric motors	Motor hp/efficiency *2,544	N/A
Lighting	Kilowatts * 3413	N/A
People, inactive	210/person	140/person
People, moderate activity	315/person	325/person
People, very active (sports, etc.)	635/person	1165/person

Also consider heat gains and losses through infiltration. ASHRAE provides tabular guidance as to the amount of leakage that can be expected.

The amount of air coming into a space is determined by the temperature in the space, the supply air temperature, and the cooling or heating load. The total cooling load (BTU/hr) equals air volume (cfm) * 4.5 (h_1-h_2), where h_1 = total heat at entering wetbulb temperature, and h_2 = total heat at leaving wetbulb temperature. This formula represents *total heat* or *enthalpy*.

The formula for converting air supply to BTUH for *sensible* load is as follows:

BHS = 1.08 * cfm * delta T

This formula is derived from the universal heat flow formula involving heat flow in any type of medium that is flowing as follows:

BTUH = lb/h x specific heat x delta T, where

- Lb/h = pounds per hour of the medium
- Specific heat of the medium
- Delta T = temperature difference or drop

Example: For a space that has 10,000 BTUH heat loss, how much air must be ducted in if the desired space temperature is 70 degrees F, and the supply air from the air handler is 59 degrees F?

Answer: cfm = BTUH/(1.08 * delta T) = 10000/(1.08*(70-59)) = 842 cfm (cubic feet/minute)

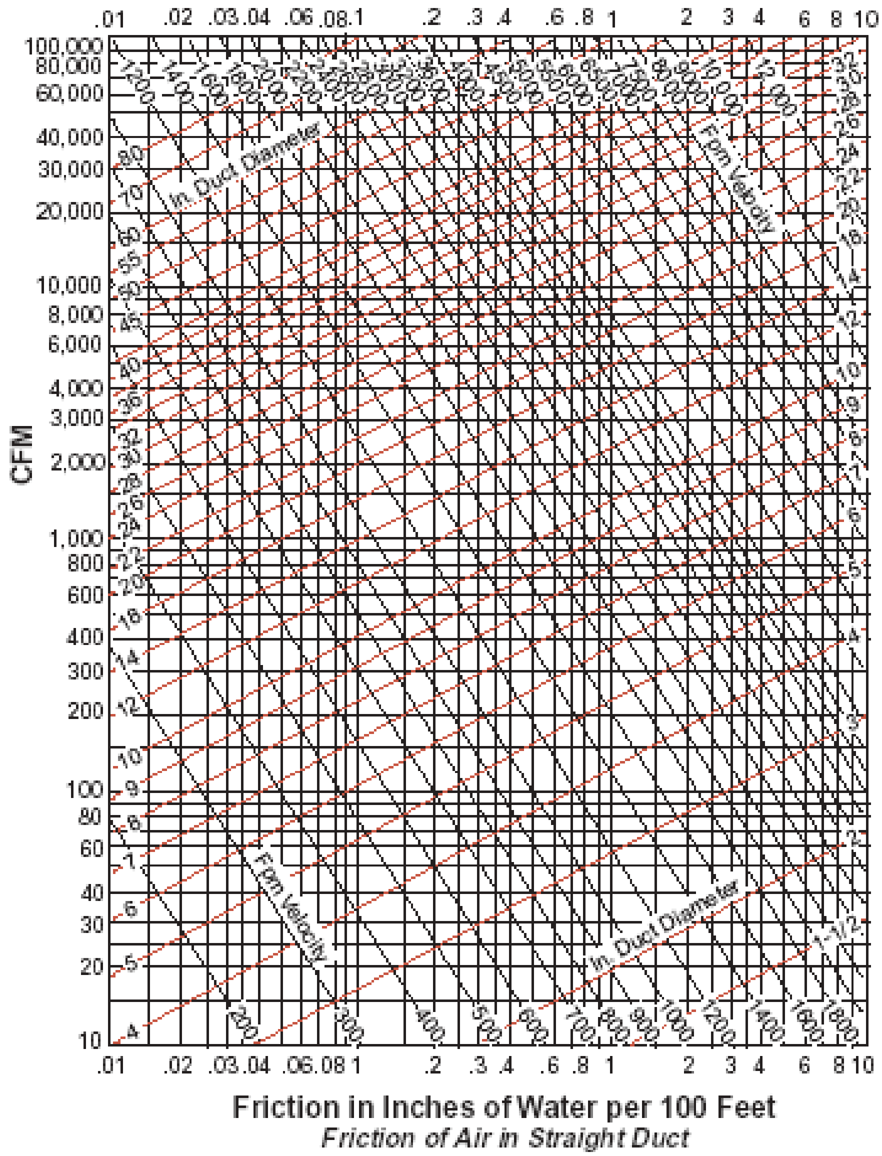
For cooling loads, the *latent* heat should also be considered, which is calculated by the following formula: (Applying this formula requires understanding of psychometrics beyond the scope of this course).

BHL = cfm x delta G * 0.68, where

- Delta G = change in the specific humidity of an airstream expressed in grains of moisture per pound of air.

Airhandling equipment (including fans, dampers, and coils) are sized based on the calculated heat load. Ductwork is sized based on the calculated cfm requirement to and from various spaces, within limitations on static loss. Higher static pressure in the duct requires larger fans. Static pressure is a result of air flowing over surfaces/restrictions and over a distance. The smaller the duct, the faster the velocity and thus the higher the static. The longer the duct the more the surface area and the more the static. A quick way to size ductwork is with a hand chart, sometimes referred to as a ductolator. Knowing desired static loss/100 ft and flow, a range of sizes can be selected. Or, charts can be used as well. The following is an example of a Duct sizing chart[iii]:

Duct Resistance



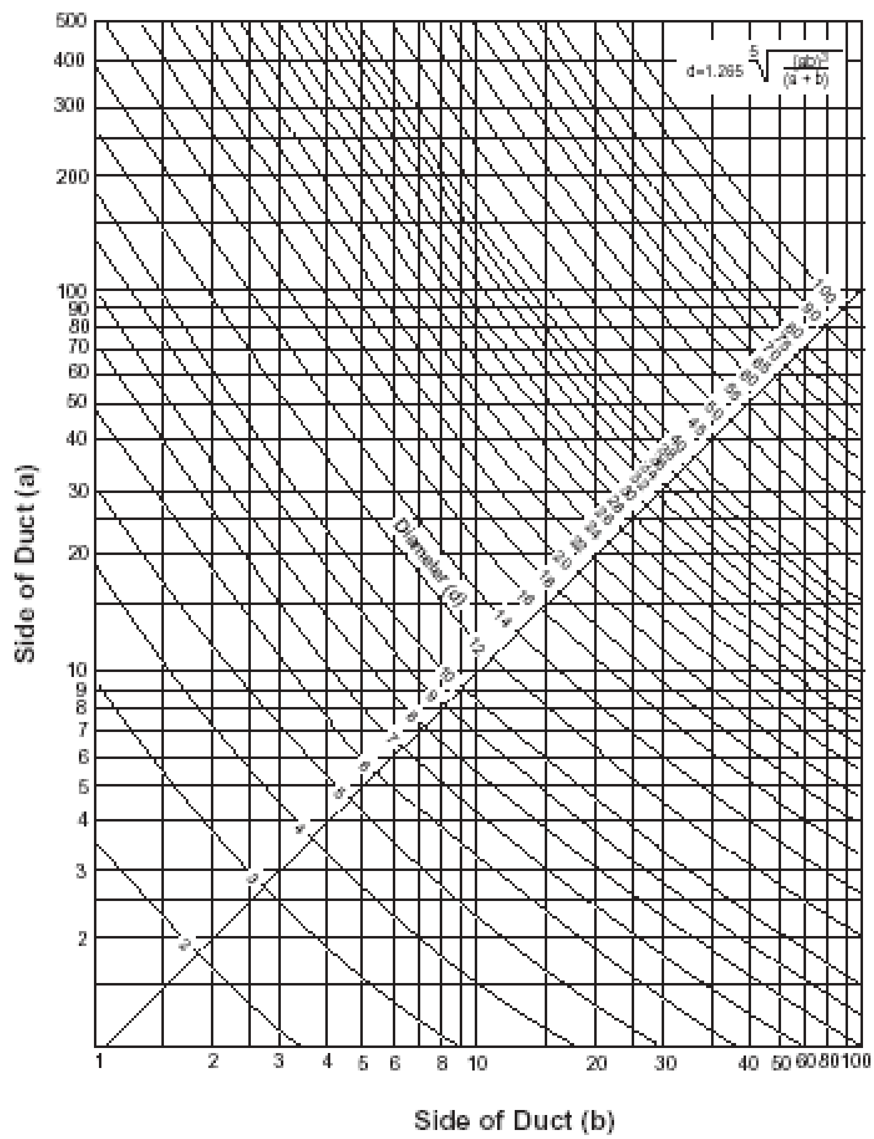
One way to use the chart as a practical matter is to use 0.1" wg/100 feet for low pressure duct, and 0.4" wg/100 ft for high pressure duct.

Example: In a previous example, we determined we needed 842 cfm supply. For low pressure duct, what diameter duct would we need?

Answer: Use 14" diameter duct.

Ducts are usually rectangular, which requires another conversion. The following table converts diameter to rectangular dimensions.

Rectangular Equivalent of Round Ducts



Example: Using the previous example and required 14" diameter duct, what size should a rectangular section be if we are limited in one direction to 10"?

Answer: Approximately 17"

Fans: The selection of a fan to move the required air is an important design element. For a given fan type/size, duct system, and air density, the basic principles of fans (Fan Laws) are as follows:

1. Volume of air per unit of time varies directly to the fan speed

$$Q_2/Q_1 = RPM_2/RPM_1$$

2. Total fan head and fan static pressure vary as the square of the fan's speed

$$SP_2/SP_1 = (RPM_2/RPM_1)^2$$

3. The fan brake horsepower varies as the cube of the fan speed

$$HP_2/HP_1 = (RPM_2/RPM_1)^3$$

Fan horsepower is calculated by the following equation (Note: the following formula is based on sea level. Multipliers are needed when above sea level. A few are 1.079 @ 2,000 ft; 1.257 @ 6,000 feet; and 1.464 @ 10,000 feet.):[iv]

Fan horsepower = 0.0158 x cfm x wg/e where:

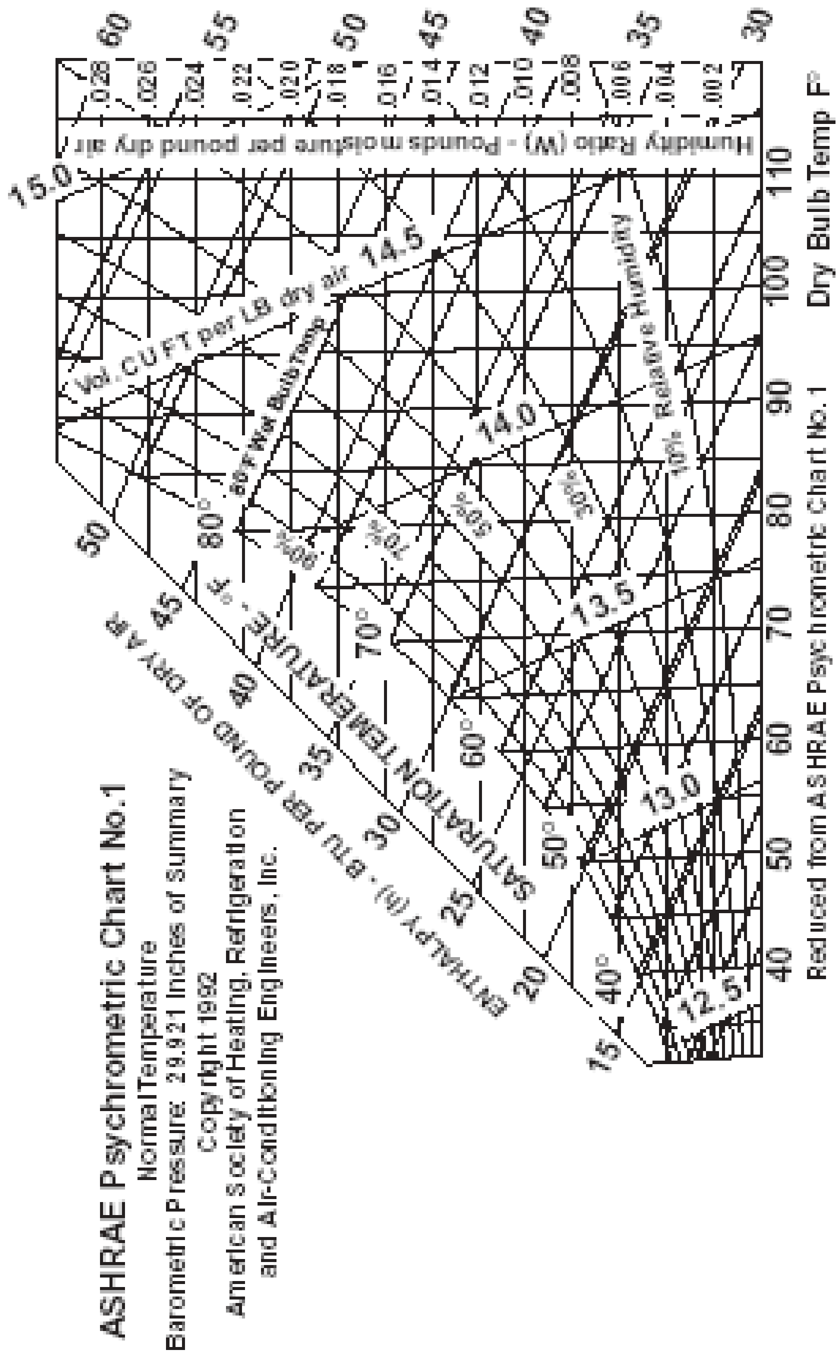
- cfm = Cubic feet/minute of air
- wg = Pressure or suction in inches water gauge (needed to overcome static demands in ductwork elements)
- e = Percent of fan efficiency. Typical efficiencies are as follows:
  - Paddle bladed and forward curved: 45-60%
  - Backward curved blades: 60-75%
  - Radial tipped: 50-65%
  - Aerofoil: 70-80%

Example: You need to select a motor for an aerofoil fan for 200 cfm at 0.5" wg static. What is the horsepower?

Answer: (0.0158*200*0.5)/0.7 = 2.3 hp (say 3)

Upon completion of an HVAC system installation, it is important to thoroughly commission the unit beginning with a factory-rep start-up, and test-and-balance. Airflows must be adjusted to meet design requirements to the different spaces via manual dampers, and water flow to coils must also be adjusted.

To understand, design, or troubleshoot a HVAC system, it is imperative to understand and use the psychrometric chart[v]. This tool graphically illustrates air moisture/temperate relationships for near infinite possibilities. By plotting conditions on the chart, equipment can be sized and problems identified. Using the chart is covered under a separate course.



The control system method is also important to consider. Of late, computerized control systems (often referred to as BMS or Building Management System or BAS/Building Automation System) are popular versus pneumatics or local controls/thermostats. These systems are often DDC, or Distributed Digital Control. Local panels (that are actually computers) talk via a network to a server or front-end PC. Graphic interface allows the user to visualize the system, trend, receive alarms, and troubleshoot. One of the best practices after installing such a system is to perform a Sequence of Operation Challenge, which verifies the operation and intent from the design. Often, A/E's are weak in defining the sequence of operation which results in a poor and problematic design.

Exhaust Systems

When designing exhaust systems, it is important to understand the nature of the items being exhausted. Various flow velocities are needed, increasing with larger, heavier particle sizes to be ventilated. The following are rules-of-thumb[vi] velocities for various applications (refer to local codes, ASHRAE, etc. for your specific applications – the following are examples only):

Typical processes	Typical fpm (feet per minute)
Vapors, gases, fumes, very fine dusts	1000-3000
Fine dry dusts	3000
Average industrial dusts	3500
Large particles, heavy loads, most materials, pneumatic conveying	4500 and higher

Example: You need to exhaust a fine dry dust into a 4" diameter duct. What velocity do you need? What cfm?

Answer: With a 4" diameter duct, you need the following cfm:

$$cfm = V \times A = (3000)*(\Pi*4^2/4)/144 = 262 \text{ cfm}$$

Fire Protection

Depending on building classification and construction type, or insurer requirements, fire protection may be required. Adequate water supply and pressure is needed, whether from the municipality and local sources, and on-site storage/booster pumps may be needed. The following systems are most common fire suppression systems:

1. Wet-Pipe System: The most typical system is wet pipe, which is simply pressurized water in piping routed throughout the building. When heat melts a fusible link in a sprinkler head, water sprays the affected area. Unlike as portrayed in the movies, each sprinkler head is an individual unit.
2. Dry-Pipe System: Dry pipe systems may be used where freezing is a concern. In this system, compressed air in lieu of water is present in the pipe. When a sprinkler head activates, the airpressure drops and automatically opens the dry pipe valve, letting in water. However, this system is less efficient than a wet-pipe system because it takes more time to deliver water.
3. Preaction System: This is used when sensitive equipment is present where an accidental discharge could damage the equipment (also, it is not uncommon for sprinkler heads to be hit while working in the area.) It is similar to a dry-pipe system, except water supply is provided when a heat and/or a smoke detector activates the preaction valve, filling the pipe with water until a sprinkler head activates.
4. Deluge System: This system act the same as a Preaction system except the sprinkler heads do not have fusible links, and begin to spray water as soon as the water supply arrives. This system is used in high-hazard occupancies where the immediate application of large amounts of water is needed.
5. Other suppression systems may be used for flammables and computer rooms - dry chemical systems are popular.

Typically, the A/E defines the density requirements, and the suppression system is design-build by the installing contractor. Municipalities vary in requirements, and insurers may have more stringent requirements. There are two kinds of piping systems used as follows:[vii]

1. Pipe schedule systems: These systems use three standard layouts that were developed in 1940. There is a "light hazard pipe schedule" for such applications as offices, hospitals, and schools. Next, there is the "ordinary hazard pipe schedule" that is used in such areas as machine shops where flammable oils are used, or in wood manufacturing plants. Last, there is an "extra-hazard pipe schedule" which has the largest diameter pipe to deliver large quantities of water for such areas as flammable liquids and other high-hazard fire areas. Refer to your local codes to see the Pipe schedule system is applicable. (You may be required to store the relieved fire water for some classifications via underground tanks or other means.)
2. Hydraulically designed – These systems are designed specifically for the application. Some insurers have concerns with this approach because of the following:
    a. The occupancy could change, compromising sprinkler protection.
    b. There may be a low margin of error
    c. Because of a low margin of error, degradation over time could result in scale or lower pressure, leaving a less-than-robust system.

Once the hazard classification is determined, the spacing and squarefootage/head can be calculated. The following are typicals as recommended by Factory Mutual Insurance:[viii]

Hazard	Max. dist. between sprinklers	Maximum sq ft per sprinkler
Light	15 ft	225
Ordinary	15 ft	130
Extra	12 ft	100

Example: You are building a 10,000 sf building, ordinary hazard. How many sprinkler heads are needed?

Answer: 10,000/130 = 77

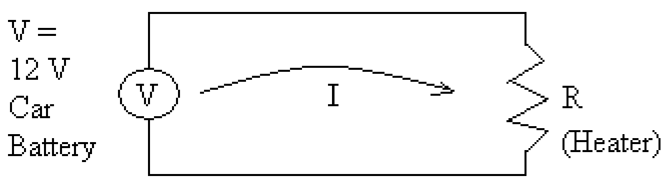
Electrical Engineering

Of all the disciplines, perhaps electrical is the most difficult to comprehend for the others. It's just difficult to comprehend those little electrons moving around. Electrical engineering has multiple specialties, such as power generation and transmission, building power, controls, and electronics. The focus in this course on understanding electrical engineering is primarily related to the building focus. Other areas are covered by other courses. But first, lets examine some of the electrical engineering fundamentals.

1 Ohm's Law – the relationship between voltage, amps (current), and resistance

- E = IR, or Voltage = Current x Resistance. The easy way to remember it is "Eagle, Indian, Rabbit." Amperage is electrical current, or electron flow. Resistance is the resistance of the current flow. Voltage is electrical pressure, or the force that causes current to flow.

- Example: A small 12V heater is purchased for an RV, and has a resistance of 24 ohms. How much current is flowing through the following heater?



Answer: E= IR; I=E/R; I = 12/24 = 0.5 amps

2 Electrical Power

The basic formula for power is P=EI (Watts = Volts * Amps). But electricity used in buildings comes in two different phases – single phase versus 3 phase. Single Phase consists of a single alternating current. Three phase is preferred for industrial applications, and consists of three alternating currents of the same frequency but differing in phase of 120 degrees from each other. Power is expressed in Kilowatts, and is a product of volts and amperes. However, for 3 phase, a 1.732 factor is also needed to calculate power. For both, a Power Factor is needed to compensate for a phase shift between voltage and current (in layman's terms, this is a ratio of true power or watts to apparent power or volt amps). The formulas are as follows:

Single Phase Power = KW = EI (PF)/1000

Three Phase Power = KW = EI(PF)(1.732)/1000

Example: Assuming PF = 1, what is the power draw on a 1 ph 120V/20A circuit? For a 3 ph 480V/20A circuit?

Answer: 2.4 KW; 16.7 KW: See the difference? The 3 ph is much more powerful at the same amperage.

3. Horsepower (output)
    a. Single phase = I x E * efficiency * PF/746
    b. Three phase = I x E * 1.73 * efficiency * PF/746

Basic building power

Power typically arrives from the utility at a higher voltage than needed. (Higher voltages yield more power at lower amperage, which minimizes transmission wire and equipment size as well as limiting voltage drop.) Voltages are reduced to single or three phase, and come in to a facility's central panel (for small application) or larger switchgear. Power is routed to load centers throughout the plant and/or local panels. Further transformers are added to accommodate specific equipment loads. Modern panels contain breakers rated for the amperage draws for required circuits; fault current protection is needed when there is a short in the system and to avoid overstressing the electrical system. Emergency power is needed for life-safety items or to prevent business loss (i.e.: for data centers, product cooling, to preserve batches during processing, etc.) Emergency power is provided by emergency generators connected to automatic transfer switches, which automatically switch between utility and emergency power when needed. For systems that should not be interrupted, consider UPS (Uninterrupted Power Supply) systems to maintain power between the utility loss and the time it takes the generator to start and switches to engage.

Circuits are sized by adding up all the connected loads and then applying a demand factor (all circuits will not be fully loaded at the same time, allowing a reduction in capacity needed for various elements.) The National Electric Code is the "bible" for electrical engineers. For example, the NEC provides circuit ratings and wire size for typical types of circuits. In addition to a plethora of electrical design requirements, we can find tables listing allowable ampacities of conductors (wiring) for various wire sizes and resistance. Wire sizes are listed in AWG and MCM. Wire sizing begins with determining the load in amps, and then selecting a wire size based on the allowed ampacity. Then, resistance is calculated and the voltage drop determined. If the voltage drop is within the NEC allowable for a specific application, the wire size can be used. The NEC also addresses conduit size requirements.

> Example: A wire is expected to handle 10,000 VA (volt-amps). The voltage is 120V single phase. We are hoping to keep the voltage drop under 5%. The length of the wire is 100 feet. What size should the wire be?
>
> > Answer: First, calculate the amps needed. P=VA or A=P/V = 10,000/120 = 83 amps. From an ampacity table, we chose AWG 4 wire, which has a resistance of 0.424 ohms/1000 feet. Then, calculate voltage drop from ohms law; E=IR = 83*0.424*100/1000 = 3.5; Percent drop = 3.5/120 = 3% which is under our 5% goal. (Note: See NEC for actual application-specific voltage drops.)

Lighting Design

To understand lighting design, we must first understand the basic concepts and definitions. The first concept is "lumen" which expresses light quantity, or the light-producing capacity of a lamp. The second is "footcandle" which expresses the level of illumination on a surface, measured as lumens per squarefoot. The higher the footcandle rating, the more the illumination. Tables are readily available for recommended footcandle levels for various applications. Another concept is the "reflectance factor," which is the measure of the ability to reflect incident light from a surface. For example, white plaster has a surface reflectance of 90-92%, while cocoanut brown is only 19%. A "Coefficient of Utilization" (CU) is the ratio of light lumens that reach a surface to the amount of lumens produced by the lamps. A CU is determined from manufacturers' tables for the desired lamp, based on the ceiling cavity reflectance (ρ_{cc}), wall reflectance (ρ_w), and the Room Cavity Ratio (RCR). The ceiling cavity reflectance (ρ_{cc}) is determined from a table published by IES given the ceiling reflectance, wall reflectance, and the Ceiling Cavity Ratio (CCR).

CCR = 2.5*ceiling cavity wall area/ceiling area

FCR = 2.5*floor cavity wall area/floor area (often assumed to be 20%)

RCR = 2.5*room cavity wall area/work plane area

Another factor needed to determine the number of lamps is the Maintenance Factor (MF), which allows for degradation over time due to lamps getting dirty, and general loss of lumen output overtime with usage. The MF is normally 0.6 to 0.8. Two factors multiplied together equal MF; LLD or luminaire dirt depreciation factor and LLD or lamp lumen depreciation factor. The formula for the number of lamps or fixtures required is as follows:

Lamps required = (fc * floor area)/(lumens/lamp * CU * MF)

Example: For a large open office area of 50' x 50', you wish to have 70 footcandles. You do calculations to determine the ratios needed for CU selection from the fixture manufacturer's table, and you determine CU = 0.55. The fixture selected provides 3000 lumens/lamp. The MF = 0.7. How many lamps will you need?

Answer: Lamps required = (70*50'*50')/(3000*0.55*0.7) = 152

<u>More Practical Considerations</u>

Some additional practical considerations for building electrical systems

1 Power Factor Correction – Consider when there is a surcharge and the power factor correction will result in a beneficial cost payback
2 Transformers – Evaluate best options for who owns the initial transformers that interface with the power company. Some providers offer reduced rates that yield favorable payback. However, consider how to handle downtime (backup transformers, or ensure local availability, or rentals, etc.)
3 Periodically monitor equipment via infrared cameras to see where connections and circuits are overheating.
4 Consider power monitoring connection/software to monitor power and troubleshoot.
5 Provide reasonable spare circuit breakers or spaces in panels for unanticipated future loads.
6 Remember to balance loads across phases.
7 Develop an accurate utility matrix on equipment to be installed as early as possible. Reworks are expensive.
8 Ensure specifications include the standards of the facility – it is expensive to store spares.
9 Carefully consider emergency power needs, and fuel type and supply limitations.

OTHER ESSENTIAL DISCIPLINES

Industrial Engineering

IE's are an essential discipline in the business planning that is the foundation of many projects. For example, IE's are helpful in projecting cost/labor savings to justify a project, understand queuing, efficient production methods/streamlining that must be considered in a project, pallet counts, production traffic patterns, etc. Often, IE's reside as part of the Owner's staff.

Architecture

There always seems to have been a subtle tension between architecture and engineering. The former views the latter as only interested in the quantitative, and the later views the former as trying to build a monument to himself/herself. Yet, an architect is an important discipline whenever a space is being planned. Obviously, aesthetics are important. Aesthetics are not only important for the visual, but for the practical (appealing to a client, or encouraging performance by working in a pleasing environment, attracting/retaining staff, etc.) As well, an efficient space aids in an efficient operation. There are more technical aspects to architecture that might not be apparent to many engineers. In a building, egress (emergency exit paths) must be considered, properly located with an adequate quantity, with a limiting travel distance. Another important point to remember is that every building has a particular classification and construction type. While classifications may differ between codes, it is important to understand if the facility is assembly, storage, factory, residential, et all. Similarly, the type of construction relates to flammability. Depending on the building type and construction classification, square footages (before a firewall), height, and number of stories are limited. Often, spaces are planned to be renovated without including an architect, and codes are violated.

> Example: A client has asked for a building of multiple stories at a certain square feet per floor, and constructed of combustible materials. However, the municipality will not allow the building to be built for the desired occupancy given the construction type. An architect is brought in - what can she do?
>
> > Answer: Several options are considered. For example, firewalls could be added to reduce the fire area, or materials could be changed to less combustible, or fire protection (sprinklers) could be added, etc.

A good architect has the training and experience to specify and detail primary building elements, especially those which we see, touch, and feel. Things he or she designs include wall, floor, and roof systems, paint, carpet/floor covering, ceilings, doors, windows, glazing and more - the kind of things that would drive many engineers nuts.

Interior Design

Another often unappreciated discipline is the Interior Designer, which is an important element in spaces occupied by people (especially offices.) Interior Designers work with Architects to effectively layout spaces for efficiency and a pleasant environment. The most common role of the Interior designer is to select finish types/texture and colors. A practical and effective way to get "customer" participation is to develop two to three fully stocked color boards that include paint selections, swatches of fabric, photos of furniture/casework, and carpet. Too few choices can leave the occupant feeling not included, and too many can be overwhelming or result in a "menu" that can result in a poor interior design. Another important role today for the Interior Designer is to participate in the selection and layout of systems furniture (often referred to as cubicles.)

Landscape Architect

Landscape Architects provide a valuable, and essential, service in land development. Many municipalities require a landscape plan to accompany site drawings. Considerations include screening, buffers, and minimal planting quantities. Although Landscape Architects often work for Civil Engineering consultants, they are a distinct discipline. As a helpful hint, use a Landscape Architect in the municipality of a project - he or she will be better versed at the local zoning requirements, as well as plantings that will remain robust for the area. In addition to meeting regulatory requirements, the work of a Landscape Architect has a more practical and aesthetic purpose as well. Well-groomed sites simply are more pleasing places in which to shop and do business, and attract people. As well, we are designed to function in a world created for us. We need grass, trees, and plantings for our emotional well-being. Obviously, there are ecological benefits as well.

> Example: The Landscape Architect is hired to develop a landscape plan for a new parking lot to meet local ordinances. What practical design features should he or she consider?
>
> > Answer: When designing plantings in parking islands, consider using smaller or non-deciduous trees (who wants to clean leaves from drains?) A sprinkler system is also necessary (remember to install the piping before paving!) if a long-life or low maintenance of the island plantings is expected. The paved area is impervious, preventing adequate water supply to the plantings. Also consider the landscaping capability of the Owner - if not available or limited, consider more robust plantings that require less care.

Environmental and Safety Engineering

Environmental Engineering has become a more important element of building construction in recent years. For renovations on buildings constructed before the asbestos ban, an asbestos survey is needed. If not done, this can be a budget buster. Asbestos can be found in unsuspected places, such as floor and ceiling tile, siding, roofing materials, pipe and elbow insulation, laboratory hoods, etc. Municipalities may require that the permit application certify asbestos will be properly dealt with. For a greenfield site, the environmental engineer should investigate the history of the site, as well as place a few sample wells in some instances. A careful review of any building to be purchased or renovated is also advised. Environmental engineering addresses a host of important areas, such as waste handling and disposal, sanitary sewer and waste treatment requirements, site runoff, etc.

Safety engineering is important in the execution of a construction project. In particular, OSHA rules should be understood and enforced. These include such items as ladder safety, electrical safety/lock-out/tag-out, cranes/swinging loads, tie-offs and safety rails, etc. As well, safety considerations in designs are of interest, such as egress/escape route and signage, emergency lighting, exit signs, occupancy postings, etc.

Packaging Engineering

In the Instructor’s industry (pharmaceuticals), Packaging Engineering is an essential discipline. But it is important to other industries as well. Packaging Engineering can include package design, as well as actual equipment design and selection. Understanding equipment needs is important to the building designer so architectural and MEP (Mechanical, Electrical, Plumbing) requirements can be incorporated. Two important items are needed for the building designer from the Packaging Engineer: a GA (General Arrangement) that accurately reflects the equipment, access, and material storage, and a Utility Matrix (that delineates all the power, water, and compressed gas requirements.)

Process Engineering

Process Engineers are often Chemical Engineers (sometimes mechanicals). A basic understanding of electrical and mechanical engineering is needed, mixed in with significant chemistry. Process Engineers generally specialize in Product Development, or Product Processing.

- Product Development: Process Engineers are essential in product development and translating a concept to a produced product. They work with scientists in the development and scale-up steps.
- Product Processing: Process Engineers design and select processing equipment, control systems, piping, pumps, etc. Understanding the chemical steps are essential, as well as technologies to deliver results.

Systems or Computer Engineering

Often Systems engineers are from an electrical discipline, and are instrumental in designing and implementing process control systems (such as PLC or programmable logic controllers) and BMS. Of late, programmers call themselves IT Engineers (Information Technology), although their educational background is often more programming than traditional engineering (statics, strength of materials, hydraulics, thermo, etc. are usually lacking.) IT professionals are helpful in assigning networks and the intricacies of servers.

COURSE SUMMARY

In this course we reviewed the primary deliverables/concepts for the various disciplines as it primarily relates to buildings. As well, examples and basic formulas were presented. It is important for the Project Manager to understand the disciplines he or she manages or coordinates with if success is to be expected.

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