Architectural Registration Examination

Building Systems- Intro

"Dr. Saum K. Nour, Ph.D."
PE Civil, PE Electrical, PE Mechanical, CPD, CIPE, CFPE, **LEED AP, AIA**

snour@Absoluteco.com

3839 Birch, Newport Beach, Ca 92660. 949 852 8700. 949 852 1918 fax

Covering the Nation

Building Systems- Intro

DIVISION STATEMENT

Evaluate, select, and integrate mechanical, electrical, and specialty systems in building design and construction.

Content Areas

1. CODES & REGULATIONS (5-8% Score)

Incorporate building codes, specialty codes, and other regulatory requirements in the design of mechanical, electrical, plumbing, conveying, and other specialty systems. Government and Regulatory Requirements and Permit Processes: Building and life-safety codes affecting mechanical, electrical, acoustic, and lighting systems including thermal and moisture protection and adaptive reuse.

2. ENVIRONMENTAL ISSUES (10-15% Score)

Apply sustainable design principles to the selection, design and construction of building systems.

3. PLUMBING (10-15% Score)

Principles: Analyze and design plumbing systems.

Materials & Technology: Evaluate and select materials and construction details related to plumbing systems.

4. HVAC (18-23% Score)

Principles: Analyze and design heating, ventilating, and air conditioning systems.

Materials & Technology: Evaluate and select materials and construction details related to HVAC systems

5. ELECTRICAL (10-15% Score)

Principles: Analyze and design electrical systems.

Materials & Technology: Evaluate and select materials and construction details related to electrical systems.

6. LIGHTING (18-23% Score)

Principles: Analyze and design natural and artificial lighting systems.

Materials & Technology: Evaluate and select materials and construction details related to natural and artificial lighting systems.

7. SPECIALTIES (14-19% Score)

Acoustics; Communications & Security; Conveying Systems; Fire Detection & Suppression

Vignettes

MECHANICAL & ELECTRICAL PLAN

Develop a reflected ceiling plan that integrates ceiling, lighting, mechanical, and structural systems and incorporates life safety considerations.

1. CODES & REGULATIONS

A. Incorporate building codes, specialty codes, and other regulatory requirements in the design of mechanical, electrical, plumbing, conveying, and other specialty systems.

1. Government and Regulatory Requirements and Permit Processes
Building and life-safety codes affecting mechanical, electrical, acoustic, and lighting systems including thermal and moisture protection and adaptive reuse.

Most stringent and restrictive code applies when there are two competing or conflicting codes:

Not: State code vs Local vs Federal code

The 2010 triennial edition of Title 24, California Code of Regulations (CCR) consists of the following 12 parts:

- Part 1 - California Building Standards Administrative Code
  - o Downloadable (PDF)
- Part 2 - California Building Code
- Part 2.5 - California Residential Building Code
- Part 3 - California Electrical Code
  - o Link to NFPA Codes & Standards
- Part 4 - California Mechanical Code UMC
- Part 5 - California Plumbing Code UPC
- Part 6 - California Energy Code - Downloadable (PDF)
- Part 7 - (No longer published in Title 24. See Title 8, CCR)
- Part 8 - California Historical Building Code
  - o Downloadable (PDF)
- Part 9 - California Fire Code
- Part 10 - California Existing Building Code
- Part 11 - California Green Building Standards Code (CALGreen Code)
  - o Downloadable (PDF)
  - o Guide to CALGreen (PDF)
- Part 12 - California Reference Standards Code
  - o Downloadable (PDF)

GSA

Federal Law. The Public Buildings Amendments of 1988, 40 U.S.C. 3312 (formerly section 21 of the Public Buildings Act of 1959, 40 U.S.C. 619), require that each building constructed or altered by GSA or any other federal agency shall, to the maximum extent feasible, be in compliance with one of the nationally recognized model building codes and with other applicable nationally recognized codes.

Nationally Recognized Codes. For all design and construction work performed on federal buildings by GSA or those functions under GSA's construction authority, GSA has adopted the technical requirements of the following nationally recognized codes referred to in this subsection. The technical requirements of these nationally recognized codes will supplement other GSA requirements mandated by Federal Laws and Executive Orders, as well as other GSA criteria noted within this document that has been established to meet our customers needs and their unique requirements. In addition, the latest edition of the nationally recognized codes, including the current accumulative supplements, in effect at the time of design contract award shall be used throughout design and construction of that project.

Building Code. The International Code Council (ICC) is a consolidated organization that is comprised of what was formerly the Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO), and the Southern Building Code Congress International, Inc. (SBCCI). Based upon this consolidation and consistent with GSA's established national policy, the GSA will utilize the technical requirements of the family of codes issued by ICC in lieu of the National Building Code (published by BOCA), the Uniform Building Code (published by ICBO), and the Standard Building Code (published by SBCCI).

The ICC family of codes includes, but is not limited to: International Building Code (IBC), International Fire Code (IFC), International Plumbing Code (IPC), International Mechanical Code (IMC), and the International Energy Conservation Code (IECC). The ICC family of codes is available through **www.iccsafe.org/** .

Furthermore, the National Fire Protection Association (NFPA) has established its own family of national model codes and standards. Consistent with GSA's long-standing policy to comply with local codes and standards to the maximum extent practicable, NFPA codes may be used (to the maximum extent practicable) in jurisdictions where NFPA codes have been duly adopted by that locality.

Life Safety Code. GSA has adopted the technical egress requirements of the NFPA, Life Safety Code (NFPA 101), in lieu of the technical egress requirements of the IBC. NFPA 101 is available through www.nfpa.org/.
National Electric Code. GSA has adopted the technical electrical requirements of the NFPA, National Electric Code (NFPA 70), in lieu of the technical electrical requirements of the ICC Electrical Code. The National Electrical Code is available through**www.nfpa.org/.**

State and Local Codes. GSA recognizes that the national building codes are typically the foundation of state and local building codes. However, state and local codes also represent important regional interests and conditions. As such, state and local building codes shall also be followed to the maximum extent practicable.

Legally, however, buildings built on federal property are exempt from state and local building codes. Notwithstanding, it is GSA's policy to comply with state and local building codes to the maximum extent practicable.

National Standards. The latest edition of the nationally recognized standards herein, in effect at the time of design contract award shall be used during design and construction.

Lease Construction. Lease construction is defined as new construction of a building for Government use in response to GSA's formal solicitation for offers. The construction may be either on a pre-selected site assigned by GSA to the successful offeror or on the offeror's site. Therefore, the building will be developed on private land and the building will be leased to GSA. In these cases, the applicable State and local government codes apply. The developer/owner (i.e., offeror) must also obtain the necessary building permits and approvals from the appropriate state and/or local government officials. The Facilities Standards do not apply to Lease Construction, it does, however, apply to Lease Construction with Government Option to Purchase and is recommended for significant build-to-lease buildings. For requirements for Lease Construction see SFO specific program, i.e. seismic, environmental, fire safety, accessibility, etc.
Lease Construction with Government Option to Purchase. In cases where GSA's formal solicitation for offers has an option for GSA to purchase the building at a future date, the GSA adopted nationally recognized codes and requirements apply as well as the applicable state and local government codes. Should a conflict exist between applicable State and local government codes and the GSA requirements, the GSA requirements

take precedence. However, GSA shall carefully consider each conflict based on adequacy, cost, and nationally accepted practice. In addition, the developer/owner must also obtain the necessary building permits and approvals from the appropriate state and/or local government officials as well as from GSA.

Conflicts between Nationally Recognized Codes and GSA Requirements. To ensure flexibility, it is GSA policy to make maximum use of equivalency clauses in all nationally recognized codes. Should a conflict exist between GSA requirements and the GSA adopted nationally recognized codes, the GSA requirement shall prevail. All code conflicts shall be brought to the attention of the GSA project manager for resolution.

Code Requirements for Alterations. Generally, involved building systems need only be upgraded to correct deficiencies identified by GSA, unless the entire building is being renovated. All new work is required to meet the applicable nationally recognized codes adopted by GSA and interpreted by the specific GSA Region. If only a portion of the building is being renovated, the IBC shall be evaluated to determine if the entire building must be brought up to code compliance. Any questions or concerns should be discussed with the GSA project manager.

Zoning Laws. During the planning process and development of associated environmental documentation for new construction and renovation projects, GSA shall consider all requirements (other than procedural requirements) of zoning laws, design guidelines, and other similar laws of the state and/or local government. This includes, but is not limited to, laws relating to landscaping, open space, building setbacks, maximum height of the building, historic preservation, and aesthetic qualities of a building. The project design team is to fully address such laws and requirements in their planning and design documents. Any proposed deviations from such laws are to be documented, fully justified, and brought to the attention of the GSA project manager for resolution.

Local regulations must be followed without exception in the design of systems that have a direct impact on off-site terrain or utility systems (such as storm water run-off, erosion control, sanitary sewers and storm drains and water, gas, electrical power and communications, emergency vehicle access, and roads and bridges).

With respect to the number of parking spaces, the requirements stated in the building program take precedence over zoning ordinances in all cases. Although GSA may not be able to directly compensate for displaced parking (as a result of site acquisition), the project team should seek creative alternatives and partnerships to address parking concerns brought about by GSA's development. Considerations may include shared parking facilities and strategies to encourage transit use.

In the case of leased facilities built on private land, all local zoning ordinances apply.

State and Local Government Consultation, Review, and Inspections. The GSA project manager shall provide to the appropriate state and/or local government officials the opportunity to review the project for compatibility with local plans, zoning compliance, building code compliance, and construction inspections. This must occur early in project design so that the design can easily respond to appropriate recommendations. This includes, but is not limited to the review of drawings and specifications, any on-site inspections, issuing building permits, and making recommendations for compliance with local regulations and compatibility with local fire fighting practices. The GSA project manager shall also inform the state and local government officials that GSA and its contractors will not be required to pay any amount for any action taken by the State and/or local government officials to carry out their mission. However, GSA shall review all recommendations made by state and local government officials. Each recommendation shall be carefully considered based on adequacy, cost, and nationally accepted practice. However, GSA has the final authority to accept or reject any recommendation from state and/or local government officials.

Zoning and other considerations relating to urban design issues. The design team should offer local officials an opportunity to informally review and comment on the design concept, for compatibility with local plans, zoning, and design guidelines. Key design milestones, such as at initial concepts and around the project's peer review sessions, offer logical timeframes for these reviews and can be especially helpful to the designers. If local officials choose to review the concept, the GSA project manager should establish a concise window in which comments can be accepted (e.g., no longer than 30 days), and this should be coordinated with the project design schedule. If local officials choose not to review the design concept, this should be noted in the project file.

Design review for code compliance. If the state and local government officials elect to review building designs for code compliance (i.e., final concepts, preliminary designs, and final working drawings), such design submissions will be officially forwarded to the appropriate local officials by the GSA project manager. Local officials will be provided 30 days for their review and comment in writing for each proposed design submission, with no time extensions. If comments are not received after the commenting period is over, the GSA project manager will proceed with project execution.

Construction Inspections. If the state and local government officials elect to perform code compliance construction inspections, the GSA project manager shall include special provisions in the A/E's and each contractor's contract to handle the additional requirement of coordinating their work with state and local government officials. Any findings resulting from such inspections by the state and local government officials shall be immediately communicated to the GSA project manager for consideration. It is to be clearly understood by all parties (e.g., state and local government officials, construction contractors, GSA, etc.) that the state and local government officials do not have the authority to reject, accept, or make changes to the work and is there only to assist GSA in achieving code compliance. State and local government recommendations. The GSA project manager should make an effort to incorporate state and local government recommendations when reasonable and when in the best interest of the government. Notwithstanding, it is GSA's policy to comply with state and local building codes to the maximum extent practicable. GSA shall review all recommendations made by state and local government officials. Each recommendation shall be carefully considered based on adequacy, cost, and nationally accepted practice. However, GSA has the final authority to accept or reject any recommendation. The GSA project manager shall maintain a record of all recommendations and comments from state and local government officials for the duration of the project.

2. ENVIRONMENTAL ISSUES

A. Apply sustainable design principles to the selection, design, and construction of building systems.

Average Reduced Air Pollution (lbs. Carbon Dioxide) = Energy Savings (kWh) x 1.6 lbs.

Average Reduced Air Pollution (g. Sulphur Dioxide) = Energy Savings (kWh) x 5.3 g.

Average Reduced Air Pollution (g. Nitrogen Oxides) = Energy Savings (kWh) x 2.8 g.

Pounds = Grams ÷ 454; Tons = Pounds ÷ 2,000

1. Building Design: Examine environmental and sustainable principles and theories affecting the design of building engineering systems.
2. Building Systems and their Integration: Consider relative environmental and sustainable design principles and details for integration into building engineering systems.
3. Implications of Design Decisions: Assess the impact of design decisions on aspects such as universal design, construction cost, operating costs, construction schedules, and flexibility.
4. Construction Details: Examine construction details for building engineering systems pertaining to environmental and sustainable design.
5. Indoor Air Quality: Examine the effects of building engineering systems and design on the quality of indoor air and related health issues.
6. Sustainable Design: Manage adaptive reuse, recycling, and renewable resources related to engineering building system selection and design. Analyze environmental design and principles of building engineering systems related to life cycle, operations and maintenance analysis. Review resource management and conservation principles affecting the use of materials and energy consumption in building design, including the selection and use of energy, energy conservation, and waste management.
7. Natural and Artificial Lighting: Utilize environmental design principles, theories, and details to determine the appropriate form of lighting such as daylight, solar control, energy consumption, and artificial lighting.

What Makes a Building Green?

A green building, also known as a sustainable building, is a structure that is designed, built, renovated, operated, or reused in an ecological and resource-efficient manner. Green buildings are designed to meet certain objectives such as protecting occupant health; improving employee productivity; using energy, water, and other resources more efficiently; and reducing the overall impact to the environment.

What Are the Economic Benefits of Green Buildings?

A green building may cost more up front, but saves through lower operating costs over the life of the building. The green building approach applies a project life cycle cost analysis for determining the appropriate up-front expenditure. This analytical method calculates costs over the useful life of the asset.

These and other cost savings can only be fully realized when they are incorporated at the project's conceptual design phase with the assistance of an integrated team of professionals. The integrated systems approach ensures that the building is designed as one system rather than a collection of stand-alone systems.

Some benefits, such as improving occupant health, comfort, productivity, reducing pollution and landfill waste are not easily quantified. Consequently, they are not adequately considered in cost analysis. For this reason, consider setting aside a small portion of the building budget to cover differential costs associated with less tangible green building benefits or to cover the cost of researching and analyzing green building options.

Even with a tight budget, many green building measures can be incorporated with minimal or zero increased up-front costs and they can yield enormous savings(Environmental Building News, 1999).

What Are the Elements of Green Buildings?

Below is a sampling of green building practices.

Site Selection

Start by selecting a site well suited to take advantage of mass transit.

Protect and retain existing landscaping and natural features. Select plants that have low water and pesticide needs, and generate minimum plant trimmings. Use compost and mulches. This will save water and time.

Recycled content paving materials, furnishings, and mulches help close the recycling loop.

Energy Efficiency

Most buildings can reach energy efficiency levels far beyond California Title 24 standards, yet most only strive to meet the standard. It is reasonable to strive for 40 percent less energy than Title 24 standards. The following strategies contribute to this goal.

Passive design strategies can dramatically affect building energy performance. These measures include building shape and orientation, passive solar design, and the use of natural lighting.

Develop strategies to provide natural lighting. Studies have shown that it has a positive impact on productivity and well being.

Install high-efficiency lighting systems with advanced lighting controls. Include motion sensors tied to dimmable lighting controls. Task lighting reduces general overhead light levels.

Use a properly sized and energy-efficient heat/cooling system in conjunction with a thermally efficient building shell. Maximize light colors for roofing and wall finish materials; install high R-value wall and ceiling insulation; and use minimal glass on east and west exposures.

Minimize the electric loads from lighting, equipment, and appliances.

Consider alternative energy sources such as photovoltaics and fuel cells that are now available in new products and applications. Renewable energy sources provide a great symbol of emerging technologies for the future.

Computer modeling is an extremely useful tool in optimizing design of electrical and mechanical systems and the building shell.

Materials Efficiency

Select sustainable construction materials and products by evaluating several characteristics such as reused and recycled content, zero or low off gassing of harmful air emissions, zero or low toxicity, sustainably harvested materials, high recyclability, durability, longevity, and local production. Such products promote resource conservation and efficiency. Using recycled-content products also helps develop markets for recycled materials that are being diverted from California's landfills, as mandated by the Integrated Waste Management Act.

Use dimensional planning and other material efficiency strategies. These strategies reduce the amount of building materials needed and cut construction costs. For example, design rooms on 4-foot multiples to conform to standard-sized wallboard and plywood sheets.

Reuse and recycle construction and demolition materials. For example, using inert demolition materials as a base course for a parking lot keeps materials out of landfills and costs less.

Require plans for managing materials through deconstruction, demolition, and construction.

Design with adequate space to facilitate recycling collection and to incorporate a solid waste management program that prevents waste generation.

Water Efficiency

Design for dual plumbing to use recycled water for toilet flushing or a gray water system that recovers rainwater or other nonpotable water for site irrigation.

Minimize wastewater by using ultra low-flush toilets, low-flow shower heads, and other water conserving fixtures.

Use recirculating systems for centralized hot water distribution.

Install point-of-use hot water heating systems for more distant locations.

Use a water budget approach that schedules irrigation using the California Irrigation Management Information System data for landscaping.

Meter the landscape separately from buildings. Use micro-irrigation (which excludes sprinklers and high-pressure sprayers) to supply water in nonturf areas.

Use state-of-the-art irrigation controllers and self-closing nozzles on hoses.

Occupant Health and Safety

Recent studies reveal that buildings with good overall environmental quality can reduce the rate of respiratory disease, allergy, asthma, sick building symptoms, and enhance worker performance. The potential financial benefits of improving indoor environments exceed costs by a factor of 8 and 14 (Fisk and Rosenfeld, 1998).

Choose construction materials and interior finish products with zero or low emissions to improve indoor air quality. Many building materials and cleaning/maintenance products emit toxic gases, such as volatile organic compounds (VOC) and formaldehyde. These gases can have a detrimental impact on occupants' health and productivity.

Provide adequate ventilation and a high-efficiency, in-duct filtration system. Heating and cooling systems that ensure adequate ventilation and proper filtration can have a dramatic and positive impact on indoor air quality.

Prevent indoor microbial contamination through selection of materials resistant to microbial growth, provide effective drainage from the roof and surrounding landscape, install adequate ventilation in bathrooms, allow proper drainage of air-conditioning coils, and design other building systems to control humidity.

Building Operation and Maintenance

Green building measures cannot achieve their goals unless they work as intended. Building commissioning includes testing and adjusting the mechanical, electrical, and plumbing systems to ensure that all equipment meets design criteria. It also includes instructing the staff on the operation and maintenance of equipment.

Over time, building performance can be assured through measurement, adjustment, and upgrading. Proper maintenance ensures that a building continues to perform as designed and commissioned.

2. Building Systems and their Integration
Consider relative environmental and sustainable design principles and details for integration into building engineering systems.

3. Implications of Design Decisions
Assess the impact of design decisions on aspects such as universal design, construction cost, operating costs, construction schedules, and flexibility.

4. Construction Details
Examine construction details for building engineering systems pertaining to environmental and sustainable design.

5. Indoor Air Quality
Examine the effects of building engineering systems and design on the quality of indoor air and related health issues.

What Causes Indoor Air Problems?

Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home. High temperature and humidity levels can also increase concentrations of some pollutants.

Pollutant Sources

There are many sources of indoor air pollution in any home. These include combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products; building materials and furnishings as diverse as deteriorated, asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products; products for household cleaning and maintenance, personal care, or hobbies; central heating and cooling systems and humidification devices; and outdoor sources such as radon, pesticides, and outdoor air pollution.

The relative importance of any single source depends on how much of a given pollutant it emits and how hazardous those emissions are. In some cases, factors such as how old the source is and whether it is properly maintained are significant. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted.

Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home, release pollutants intermittently. These include smoking, the use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides in house-keeping. High pollutant concentrations can remain in the air for long periods after some of these activities.

Amount of Ventilation

If too little outdoor air enters a home, pollutants can accumulate to levels that can pose health and comfort problems. Unless they are built with special mechanical means of ventilation, homes that are designed and constructed to minimize the amount of outdoor air that can "leak" into and out of the home may have higher pollutant levels than other homes. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a home, pollutants can build up even in homes that are normally considered "leaky".

How Does Outdoor Air Enter a House?

Outdoor air enters and leaves a house by: infiltration, natural ventilation, and mechanical ventilation. In a process known as infiltration, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors. In natural ventilation, air moves through opened windows and doors. Air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and by wind. Finally, there are a number of mechanical ventilation devices, from outdoor-vented fans that intermittently remove air from a single room, such as bathrooms and kitchen, to air handling systems that use fans and duct work to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the house. The rate at which outdoor air replaces indoor air is described as the air exchange rate. When there is little infiltration, natural ventilation, or mechanical ventilation, the air exchange rate is low and pollutant levels can increase. Read more about ventilation in buildings

Indoor Air Pollution and Health

Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later.

Immediate effects

Immediate effects may show up after a single exposure or repeated exposures. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment is simply eliminating the person's exposure to the source of the pollution, if it can be identified. Symptoms of some diseases, including asthma, hypersensitivity pneumonitis, and humidifier fever, may also show up soon after exposure to some indoor air pollutants.

The likelihood of immediate reactions to indoor air pollutants depends on several factors. Age and preexisting medical conditions are two important influences. In other cases, whether a person reacts to a pollutant depends on individual sensitivity, which varies tremendously from person to person. Some people can become sensitized to biological pollutants after repeated exposures, and it appears that some people can become sensitized to chemical pollutants as well.

Certain immediate effects are similar to those from colds or other viral diseases, so it is often difficult to determine if the symptoms are a result of exposure to indoor air pollution. For this reason, it is important to pay attention to the time and place symptoms occur. If the symptoms fade or go away when a person is away from home, for example, an effort should be made to identify indoor air sources that may be possible causes. Some effects may be made worse by an inadequate supply of outdoor air or from the heating, cooling, or humidity conditions prevalent in the home.

Long-term effects

Other health effects may show up either years after exposure has occurred or only after long or repeated periods of exposure. These effects, which include some respiratory diseases, heart disease, and cancer, can be severely debilitating or fatal. It is prudent to try to improve the indoor air quality in your home even if symptoms are not noticeable.

While pollutants commonly found in indoor air are responsible for many harmful effects, there is considerable uncertainty about what concentrations or periods of exposure are necessary to produce specific health problems. People also react very differently to exposure to indoor air pollutants. Further research is needed to better understand which health effects occur after exposure to the average pollutant concentrations found in homes and which occurs from the higher concentrations that occur for short periods of time.

About the Indoor Environments Division

The EPA's Indoor Environments Division (IED) is responsible for conducting research and educating the public about indoor environmental issues, including health risks and the means by which human exposures can be reduced. IED educates the public about health risks associated with a variety of indoor environmental pollutants and sources of pollution, including radon, mold and moisture, secondhand smoke, indoor wood smoke, and environmental asthma triggers.

The Indoor Environments Division has created partnership with public and private sector entities to help encourage the public to take action to minimize their risk and mitigate indoor air quality problems. In some cases, IED is able to provide funding support through cooperative agreements, such as with tribes, non-profit public health organizations and industry.

6. Sustainable Design

Manage adaptive reuse, recycling, and renewable resources related to engineering building system selection and design. Analyze environmental design and principles of building engineering systems related to life cycle, operations and maintenance analysis. Review resource management and conservation principles affecting the use of materials and energy consumption in building design, including the selection and use of energy, energy conservation, and waste management.

Sustainable Design

Sustainable design seeks to reduce negative impacts on the environment, and the health and comfort of building occupants, thereby improving building performance. The basic objectives of sustainability are to reduce consumption of non-renewable resources, minimize waste, and create healthy, productive environments.

Sustainable design principles include the ability to:

- optimize site potential;
- minimize non-renewable energy consumption;
- use environmentally preferable products;
- protect and conserve water;
- enhance indoor environmental quality; and
- optimize operational and maintenance practices.

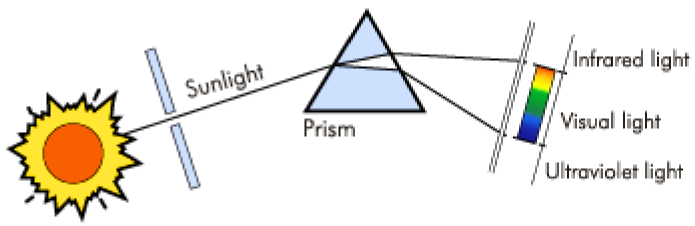
Utilizing a sustainable design philosophy encourages decisions at each phase of the design process that will reduce negative impacts on the environment and the health of the occupants, without compromising the bottom line. It is an integrated, holistic approach that encourages compromise and tradeoffs. Such an integrated approach positively impacts all phases of a building's life-cycle, including design, construction, operation and decommissioning.

7. Natural and Artificial Lighting

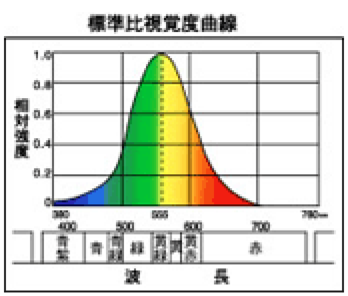
Utilize environmental design principles, theories, and details to determine the appropriate form of lighting such as daylight, solar control, energy consumption, and artificial lighting.

Natural and Artificial Light

When sunlight is directed through a prism and onto a screen, it is separated into a rainbow pattern on the screen. The colors are arranged in this rainbow pattern beginning with red, followed by orange, yellow, yellow-green, green-blue, blue, blue-violet and finally violet. This pattern is called the optical spectrum and represents the part of the electromagnetic spectrum visible to human eyes. Other parts of the spectrum invisible to human eyes include the infrared part of the spectrum which we can feel as warmth on skin, and the ultraviolet part of the spectrum which can be recorded on photographic film. These parts of the spectrum are utilized in a variety of ways. The portion of the optical spectrum which human beings perceive as brightest is yellow-green light with a frequency of 555nm.



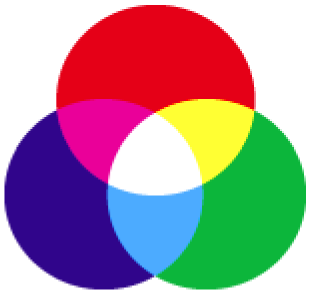
The intensity of light is perceived as brightness or darkness and serves as the basis for the brain's judgment of the light level. (Refer to the Standard Comparative Visual Sensitivity Chart)



Understanding Artificial Light

Artificial light sources are light sources which artificially combine just the necessary components of the optical spectrum. The way in which these components are combined determines the color rendering of the light source and thereby affects the way in which objects appear when illuminated with the light source

The Three Primary Colors of Light



Artificial light can be created by combining red (R), green (G) and blue (B) components as shown in the illustration. Changes in the RGB ratios change the characteristics of the light and therefore the mixture ratios of RGB fluorescent substances is an important point to be taken into consideration when creating artificial lights

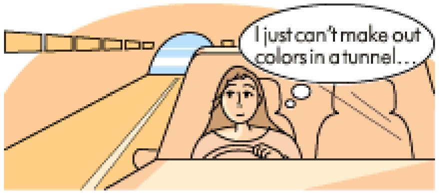
Three Band Fluorescent Lamps

HG X

HG X lamps are three band fluorescent lamps which apply the three primary colors of light. These bright lamps were developed to provide exceptional color rendering characteristics by increasing the yellow-green component which emphasizes brightness perception as compared with conventional fluorescent lamps and more carefully balancing the R, G and B components of the light

Why are Tunnels Colorless Worlds?

The orange colored low-pressure sodium vapor lights often used in tunnels provide monochromatic orange light Therefore your eyes perceive brightness but are unable to discriminate between colors



To Top of Page

8. Alternative Energy Systems and New Technologies

Investigate the environmental effects of the use of new energy systems, technological advances and innovative building products in building engineering systems design.

Examples of Alternative Energy Systems

- Wind turbine or wind power
- Hydro-electric
- Fuel cell technologies
- Geothermal power
- Solar power
- Biofuel and biodiesel applications

9. Adaptive Reuse of Buildings and/or Materials

Identify environmental issues related to the reuse of existing building engineering systems and the integration of new building engineering systems into existing or heritage buildings.

The analysis and selection of building materials and systems for a project. The materials specified for a particular project communicate the requirements and quality expected during construction. Specifications are included in a project manual that is used during bidding and construction.

- Prepare specifications based on performance criteria
- Research, select, and specify materials

- Adaptive reuse of buildings and/or materials
- Alternative energy systems and technologies
- Basic engineering principles
- Building design
- Building envelope
- Building Information Modeling (BIM) technology
- Building systems and their integration
- Characteristics and properties of construction materials
- Constructability
- Construction details
- Construction sequencing
- Critical thinking (e.g., analysis, synthesis, and evaluation of information)
- Design principles
- Furnishings, fixtures, and equipment
- Hazardous materials mitigation
- Implications of design decisions (e.g., cost, engineering, schedule)
- Indoor air quality
- Interior materials and finishes
- Interpersonal skills (e.g., listening, diplomacy, responsiveness)
- Life safety
- Managing quality through best practices
- Oral and written communications
- Problem solving

- Product evaluation, selection, and availability
- Project scheduling (e.g., construction document setup, storyboarding, staffing projections)
- Site design
- Specifications
- Sustainable design
- Technological advances and innovative building products
- Vertical circulation

Sun is lowest altitude from horizon in the sky in northern hemisphere on day of Winter Solstice

Not: Vernal or autumnal equinox, summer solstice

Potable Water: Water tested to be suitable for bathing, cooking, and consumption by humans

Not: Well water, ground water, grey water

Carbon monoxide, radon, formaldehyde, and nicotine are all classified as indoor-air contaminants

Not: Ventilation components, hydrocarbon-fuel emission, building-materials emission

Questions:

Environmental impact considered site analysis: Reflection, air movement, and sun & shadow patterns.
“Not” archeological finds

Development potential of parcel: Verify these issues: wetland/ endangered species/ hazardous waste.
Not: acid rain has nothing be controlled.

After “sight” what other senses is important: hearing. “Not”: Touch, smell, taste
To remove noise: best way increase distance to receiver

Sustainable design: Economics, aesthetics, environments, mechanical systems

Natural step: Organized 1996, preservation of ecosphere & bio sphere (-5 within each to +5 miles above surface of earth).

Natural step principles

-Zone of earth that supports human life is highly fragile eco system last 100 years has affected the earth "wrong" biosphere affecting human is relatively stable & resistant 5 mile in/ out

--Vast majority of technological building environment is inefficient. innovation has improved, but not there

-Toxic substance affect large areas beyond time & space are above "great lakes" is toxic with DDT many years after it has been banned, jet streams bring toxicity elements & pesticides in other continents

-Recycling is only beginning: More buildings to be recyclable & biodegradable

LEED: Cost of design for Engineers & Architects increase

Vandalism: Impact is to use impact resistance materials
In housing projects
-Exterior paths & entrance doors are visible
-Surveillance, well lighted, avoid cursed paths
-Durable & vandal & tamper proof of elements

Planning phasing sustainable projects:
-Use native landscaping- functional, aesthetic..

-Sun orientation (neighbors...) topographic relief
-Scale of other buildings
-Location of project with respect to public transportation

Elements in sustainable design:

-Solar shading devices
-Urban heat island effect
-Fenestration & glazing

Slope/ curve? based on topography

Sustainable goals: Use less, recycle, do not deplete natural resources, do not buy from long distance, least amount of demolition, keep existing

LEED indoor air quality: Sick building syndrome: Poor indoor Air Quality based on indoor tobacco smoking, inadequate ventilation, off gassing of fabrics and coatings

Leed substitution by Architects: Architectural supervision: Product substitution to insure original design standards are met

Leed: Requires Architect, Wetland Engineer, Energy Engineer Commissioners, Landscape Architect, Energy Model Engineers

3. PLUMBING

(10-15% Score)

Principles: Analyze and design plumbing systems.
Materials & Technology: Evaluate and select materials and construction details related to plumbing systems.

Fluid Mechanics, Hydraulics, Dynamics

Fluid (Continuously deforms under shear stress):

- Parameters
- Fluid Properties/Characteristics
  - Gas
  - Liquid
    - Ideal Fluid Flow- Viscosity is constant- Newtonian Flow
    - Non-Newtonian Fluid Flow
      - Psuedo-plastic
      - Dilatant
      - Bingham
- Static Fluids
- Fluid in motion
  - Open Channel Flow- Civil Engineers
  - Closed pipes ,… - all engineers

Fluid Characteristics/Properties

- Density
  - Incompressible- When density of fluid does not change during the flow
  - Compressible- When density of fluid changes during the flow (i.e. gas dynamics)
- Viscosity
  - Newtonian- Viscosity is constant
  - Non-Newtonian- When viscosity is not constant (i.e. plastics or chemical industry)
- Molecular spacing
  - Molecular density
  - Attraction
  - Gases (very apart)
- Shapes and Volume
  - Gas: fills to match shape
  - Liquid: fills based on gravity
- Pressure
- Shear Resistance
  - Deforms under shear depending on viscosity -Versus solids
  - Resistance to motion based on viscosity and surface contact
- Phase Flow
  - Single phase flow: Gas or liquid
  - Two phase flow:
    - Gas and liquid
    - Gas and solid
    - Liquid and Solid
  - Three phase flow: Gas, liquid, solid (Coal sludge pipeline)

Fluid Parameters:

Pressure

If you press a surface with your thumb, the force exerted on the area of the thumb is the pressure exerted. Larger force gives larger pressure and lesser area increases the pressure. A knife easily cuts through materials, since the area exerted is very small.

Pressure = Force/Area

There is another way of looking at pressure, the weight of a person over two areas of the shoes is the pressure exerted on floor by the person. Regular shoes goes through snow, and eskimos' large area shoes does not. The pressure surrounding us is the weight of the air above us. If you are at sea level and about 20 degrees C (Standard Temperature and pressure), the weight of 1 square inches of the air column al the way to the atmosphere is 14.7 lbs. The volume of air os 1"x1"x height of the air column to the atmosphere times density of air gives 14.7 lbs (approximately).
Pressure of atmosphere @Standard Temperature Pressure in other units are:

14.696	lbs/sq inches "Absolute"
1.0	Atmosphere
407.1	inches of water, inch water gage
33.93	feet of water, gage
29.921	inches of mercury
760	millimeter of mercury
760	Torr
1.13	Bars
1013	milliBars
1.013 x 105	Pa, Pascal
101.3	Kilo Pascal

Pressure (Under Force) versus Vacuum (Under suction):

The pressure in the atmosphere is near 14.7 psi (lbs per square inches). The zero (absolute pressure) psi pressure is at 14.7 psi lower than the atmosphere. If you purchase a pressure gage at the store, the gage needle shows zero value. This is known as zero gage pressure or 14.7 psi absolute pressure.

Absolute Pressure= 14.7 psi or P atmospheric + Gage pressure (measured value)

Under vacuum, same terminology is applied. The vacuum gages are set at zero at atmospheric pressure. Therefore all vacuum gage pressures have to consider the presence of atmospheric pressure surrounding them. If a container under vacuum is at 7 psi, gage pressure will show, 14.7-7 = 7.7 psi gage. If a pressure gage is shown to be 20 psi, the absolute pressure is 34.7 psi. In situations where the pressure is the difference in pressure, the 14.7 psi is cancelled out and it does not alter the naming of the pressure.

Change in Pressure = Absolute Pressure 2- Absolute Pressure 1= Gage Pressure 2 – Gage Pressure 1

Standard	**Temperature and**	**Pressure**
SI system	273.1˚K	101.325 K Pa
Scientific	0.0˚C	760 mm Hg
Natural Gas (Ca)	60˚F	14.696 Psia, 14.73, or 15.02 varies
Natural Gas (US)	60˚F	14.696 Psia, 14.73, or 15.02 varies
United States Engineering	0˚C= 32˚F	14.696 Psia

Density, specific Gravity, Specific Volume, and specific Weight

Density, r, is the ratio of mass to volume. **r =** Mass/Volume

Density @ STP of general fluids

Fluid	lbm/ft^3	kg/m^3
Air (STP)	0.0807	1.29
Air (70°F, 1 atm)	0.075	1.20
Alcohol	49.3	790
Gasoline	44.9	720
Glycerin	78.8	1260
Mercury	848	13600
Water	62.4	1000
Water	1.94 $slugs/ft^3$	1 kg/liter

Slug is to kilogram where pound force is to Newton. There is a distinction between lbm (pound mass) and lbf (pound Force). A person who is 100 kilogram mass is nearly 1000 newton weight (force). Same person who is 200 lbm is 200 lbf. Why?

F = ma (from Newton's Law)
1 lbf = 1 lbm * 32.2 ft/sec^2
G_C = 1 = 1 lbf/[1 lbm * 32.2 ft/sec^2]

Therefore,

F = ma
200 lbf= 200 lbm * G_C * 32.2 ft/sec^2
= 200 lbm * {1 lbf/[1 lbm * 32.2 ft/sec^2]} * 32.2 ft/sec^2
= 200 lbm

A man who weighs 200 lbm is (200 lbf /32.2 ft/sec^2=) 6.21 Slugs

Specific volume, u, or $1/r$, is the ratio of volume to mass. **u,** or $1/r$ = Volume/Mass, m^3/kg, ft^3/lb.

Specific Gravity (generally liquid) is the ratio of density of liquid to density of water. SG_{Liq}
Specific Gravity (Gas) is the ratio of density of liquid to density of air. SG_{Air}
Specific gravity is unit-less.

$SG_{Air} = r_{Air}/r_{Gas}$ = Molecular Weight (Gas)/Molecular weight (Air)= $MW_{Gas}/29.0 = R_{Air}/R_{Gas} = 53.3/R_{Gas}$

$$r_{Gas} = P/RT$$

$$r_{Air}/r_{Gas} = (P/RT)_{Air}/(P/RT)_{Gas}$$

Pressure and Temperature are constant

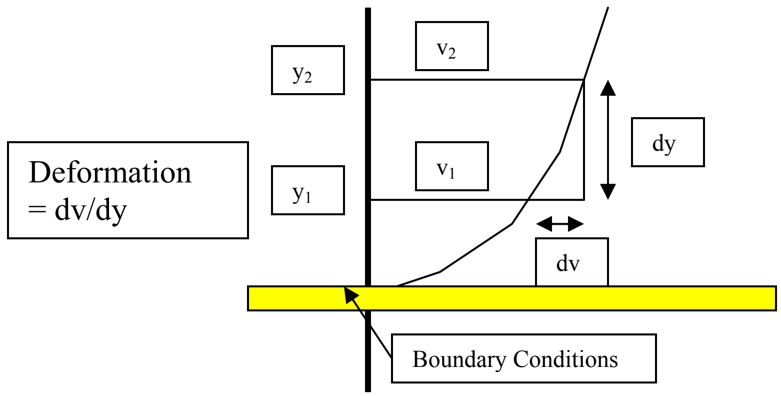
$$r_{Air}/r_{Gas} = R_{Air}/R_{Gas}$$

Specific weight, g, is the ratio of weight (versus mass) to volume.

$$g = rG = \text{Mass} * G/\text{Volume} = W/\text{Volume} = N/m^3 \text{ or } lbf/ft^3$$

Stresses, t

- t(P) = Surface stress vector at point P
- DF = Force acting on infinitesimal area DA
- DA = Infinitesimal area at point P
- t(P) = As limit of D A-> zero, DF/D A at point P
- t_n = Normal stress (90 degree perpendicular to surface) at point P
- t_t = Tangential stress (parallel to surfaces) at point P
- t_n = -P, pressure at point P
- t_t = mdv/dy= absolute dynamic viscosity of fluid (Velocity at boundary conditions/normal distance)
  Newton's law of friction or viscosity
- dv = Velocity at boundary condition (BC)
- dy = Normal distance, measured from boundary
- m = Absolute dynamics viscosity (measure of viscosity of fluid)



Modeling

Similarity (prototype):

- Mechanical
- Geometric
- Dynamic
- Viscous intertia
- Viscous versus intertia
- Inertia vs Gravitational
- Surface tension
-

Mechanical = geometric and dynamic
Geometric = Geometric scaling

Lr = size of modeling/size or prototype
Am/Ap= $(Lr)^2$
Vm/Vp= Lr^3

Dynamic= Ratio of all forces: Inertia, gravity, viscosity, elasticity, fluid compressibility, tension, pressure

Viscosity versus inertia; intertia versus gravity, inertia versus surface tension

Distorted models: Based on geometric modeling. Since dynamic ratio may not apply,

Dynamic Variations

Intertia versus Viscosity
Reynolds Number
$L_m V_m/\nu_m = Re_m = Re_p = L_p V_p/\nu_p$

Inertia/Viscous

MODELING

Interia versus Gravity
Froud Number
$Fr = V^2/Lg$

Velocity/gravity

$V_m^2/L_m g = Fr_m = Fr_p = V_p^2/L_p g$

$Re_m = Re_p$

$\nu_m/\nu_p = (L_m/L_p)^{3/2} = L_r^{3/2}$

(Sometimes partially similar)

Surface Tension
Weber Number, We
$We = LV^2 \rho / \sigma$

$We_m = We_p$

Inertia versus Surface Tension

Torpedoes/Submarines
Airfoils/aircraft subsonic
Drainage through tanks
Closed pipes
Flow meters
open channel- no waves

Surface ships/Bow waves
Oscillatory/surface waves
Surges and floods
Spillways, weirs
Closed channel
motion of fluid jet

Air entrapment
Bubbles
Droplets
Waves

Flow Measurements are divided into:
direct measurement and
indirect measurements.

Direct measurement measure are in three categories:
- Weight/mass,
- volume measurement, or
- positive displacement metering pump system.

Indirect Flow are subdivided into three types of measurements:
- velocity measurements.
- obstruction, and
- miscellaneous measurements.

Type of meters more detailed are:

Displacement meters: Gas and water utility meters. cyclical, fixed volume with counters to count number of cycles. Concept comes from devices like reciprocating pistons, helical screws, rotating disks.

Obstruction meters: venturi nozzles, orifice plates, flow nozzles and variable area use reduction in status pressure to convert to flow velocity. Pressure is lost through these measurements and has limited in range.

The velocity measurement is achieved by Static pressure, direction sensing, pitot static.

Miscellaneous slow measurement for indirect flow devices include turbine and propeller, hot wire anemometry, magnetic flow, sonic flow, and mass flow.

Ultra sonic flow meters: two transducers outside of pipe transmit and receive signals to measure the velocity wave through fluid depending on flow varies and compared to stationary fluid

Magnetic flow meters: ideal for liquid metals. Fluid must be conductive or sometimes conductive ions are added.
Hot wire anemometry: cooling effect of heated wires is transferred to resistivity and then converted to measurement. Temperature is constant.
Turbine: number of turns converted to level of flow/velocity/etc.

Fluid Velocity Distribution

The main types of flows are Creep, Laminar, and Turbulent flow.

Laminar flow, where the layers of fluid are travelling at low Reynolds number less than 2100.

V average, Vave = Q (volume flow rate)/Cross sectional Area = V max/2
The distribution of the velocity is parabolic, where the velocity is zero at the walls and maximum at the center.

Turbulent flow, chaotic and disturbed water has a more flat velocity distribution. Velocity at the wall is zero.

V_r (Velocity at radius r from center), $V_r = V_{max} [(r_o - r)/r_0]^{1/7}$ ….. 1/7 power law

V_{ave}/V_{max} ~ 0.75 @Re= 4000
~ 0.817 @Re= 10^5
~ 0.86 @ Re= 10^6

Type of flows:

- Laminar (viscous or stream line) Re < 2100;
- Creep ("ideal")
- Critical or mid rang very low Re between 2000 to 4000
- Turbulent Re > 4100

Re, Reynolds Number = Ratio of Inertia to viscous flow= $DV\rho$ / μ= Diameter * Velocity/Absolute Viscosity/Fluid density
Laminar flow: Friction factor, f = 64/Re not function of pipe material
Turbulent flow: f= [Re(D,V, ρ, μ), ϵ/D roughness of pipe to diameter] very complex formula

Example: Find Reynolds Number for Water at 4 ft/sec for 3” pipe.
D= 3/12 ft= 0.25 ft
V= 4 ft/sec
Density, ρ = 62.4 lb/ft 3
Absolute Viscosity, μ = 0.005

Re= $D V \rho / \mu$= [(0.25)(4)(62.4)/0.005] = 125,000 > 2100

Critical minimum velocity at 50 degrees F

Pipe Diameter	Critical Velocity, ft/sec	
	50 Degrees F	140 Degrees F
½”	0.676	0.247
1”	0.338	0.124
2”	0.169	0.0617

- **3. PLUMBING Basics - I**

A. PRINCIPLES

Analyze and design plumbing systems.

Plumbing system consists of providing:
Water, gas, sewer, and storm water drainage to a facility.
Design consists of providing proper fixtures and equipment in addition to associated piping to service the facility. Water and gas are fed under pressure into building, where sewer and storm water are mostly under gravity flow

Plumbing Designers Tasks:

1. Define the work: Definition/scope of the plumbing task varies from site to site and may vary during the course of design. Tasks are clear:
(a) Identify and transcribe step wise scope of work and verify with all teams for its accuracies;
(b) List and identify all parties in the project;
(c) notify all parties (project managers, architect, …) all work and the delineation of the ending of the work.

2. Construction budget: Verify type of building and provide cost per square ft or complete construction cost. The estimating books and soft wares must be current to the economic conditions and the area being served. There are several available on internet.

3. Authorities having jurisdictions, codes, laws, standards, and guidelines: Identify all local, state, federal, agencies, and amendments are critical. Personnel administering the process are also important: Plan checkers, inspectors, building officials, …. The areas of mechanical, fire, health, sewer, insurance, finance are all related to the plumbing coinstruction and design. There are many national and local codes: International Plumbing Code, Uniform Plumbing Code, American Disabilities Act, International Code Councils are some of the few to mention.

4. Utilities and utility companies: Investigate all local conditions; create site utility plans, water, sanitary, gas, electric, topography (contour lines), right-a-ways or easements, hardscapes or landscapes, capacities, sizes, pressures, and materials. Other groups such as civil engineer, other utilities (electric, cable, …), public works, and other related agencies must be coordinated and notified. Backflow devices may be required.

5. Sewer: Verify all utilities concerns. Verify all point of connections, elevations, pipe inverts, topography, manholes, loading capacities, insurance issues. Final connections, easements and routing must be verified.

6. Water: Verify all utilities concerns. Design issues are: water pressure, meters, valves, hydraulic calculations, backflow prevention devices, pressure capacities for fire, domestic water usage

7. Gas: Verify all utilities concerns. Issues concerning gas piping designs are: Meter, valves, length of pipes, pressures, gas rating consumptions of the building, materials, routing, …

1. Building Design
Apply theory and principles of plumbing systems as a component of building design.

Theories in the plumbing system vary depending on the type of system. Water and gas piping under pressure are based on pressurized closed system, Sewer and storm drain are based on open channel flow theories.

Plumbing Design is sub-divided into:

- Collection of Data as project initial task
- Specifications and design
- Construction Services
- Administration.

2. Implications of Design Decisions
Determine the effects of plumbing systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

Design of plumbing systems are based on:

- Drainage systems
  - Interior drainage- Sewer systems
    - Backflow prevention
  - Exterior Drainage system- Site work
  - Vent piping system
- Domestic Water
  - Domestic cold water
  - Domestic hot water
    - Expansion/contraction
  - Backflow prevention
- Storm Water
  - Roof drainage
  - Site drainage
- Fuel Gas
- Machines
  - Sumps/ejectors
  - Pumps

Interior Drainage System are subdivided:

- Stacks
  - Connections
  - Sizing
    - Procedures in sizing
  - Flow in stacks
    - Terminal velocity
    - Capacity
    - Hydraulic Jump
- Waste

  - Indirect Waste
  - Direct Waste
  - Special Waste
  - Rate of Flow
    - In fixture Drains
    - In branches
    - Drain Size
    - Sanitary drainage fixture unit
- Test of DWV: Drain Waste Vent Systems

Pipe Installations subjects are:

- Cleanouts
- House Drains
- Branch connections to stack offsets
- Connection to sanitary house drains
- Backwater valve
- Drainage systems below sewer systems
- > 140 degrees F Waste

B. MATERIALS & TECHNOLOGY
Analyze and design plumbing systems.

1. Building Systems and their Integration
Consider integration and effects of plumbing design principles, systems, and details on the overall design of a building with consideration to technological advances and innovative building products.

2. Construction Details and Constructability
Examine plumbing system details, including the aspects of constructability and thermal and moisture protection.

Components:
Cleanouts:
Cleanout pipe size to match pipe size up to 4". However, for larger pipe sizes, 4" clean-out is ok. Install them when:

a. Any changes in direction greater than 45 degrees
b. Inside/Outside of the Building at point of exit (Wye branch or House trap)
c. Up to 4" Pipe: Every 50 ft maximum distance
d. 4" to 10" pipe: Every 100 ft
e. Larger than 10": manholes are required at every 150 ft or directional change
f. Base of all stacks
g. Proper access (18-24 inches), for roto rooters, fixture removal (generally 30"-36" per code)

Waste (other than direct connections):
<u>Indirect Waste</u>: Indirect connections to sanitary must be trapped and vented. Discharge outlet must be 1.5 times indirect pipe size above flood level. Clean-outs are mandatory, since blockage is possible, in addition to very low velocity and low flow, extreme pneumatic effects. Examples are in sinks, lavatories, condensate drains.
<u>Special Waste</u>: (a) Tank overflows, tank empting lines, relieve valves discharge must be indirect waste drainage due to possible over pressurizations (b) Discharges with air breakers (floor sinks, roof drainage, …), (c)Cooling jackets, drip pans, steam expansion boiler overflows, …

Fluid Flow:
Rate of Flow in Fixtures, Q, gpm:

H	Mean vertical height, ft
D	Pipe diameter, inches

$$Q = 13.17\ D^2H^{1/2}$$

In branches, the flow is sum of of all fixtures to branch. It is uniform flow (assumed), branches are extended greater than 5 ft developed length for stability. Surcharging occurs from hydrostatic pressure. In short runs, due to high velocity, surcharging occurs. Branch flow rates are less than the stacks house. Stack pressure and branch pressures must be isolated when possible to avoid back pressure into branch. Stack flow is the sum of the stack as well as branches into the stack.

Scouring:

To insure all solid particles are at minimum terminal velocities (sand, grit, pebbles) within pipe, the flow must have minimum level. This will insure no deposition of blockage. 2 ft per second minimum and 4 ft per second for greasy fluid content is required. For 2" and 1 ½" pipe with full or half full flow velocities in sewer piping velocities are 1.98 and 1.85 ft per second. Minimize the length for these pipe sizes where possible.

Surcharging:

To accommodate overflow or certain peak loads, or when sewer and storm drainage are combined, surcharging is a possible event and must be accounted for. Vertical distances within manholes is measured for surcharging. This is measured from top of the pipes to the level surcharged within the vertical pipe or the manhole. Surcharging is used to permit smaller piping or less slope due to topography or for abnormal conditions.

Sewer Shapes:

Variable pipe shapes allow higher terminal velocity in low flow conditions and at higher flow rates, the velocity could remain the same. V= Q/A. As Q increases, A will increase, therefore the velocity remains constant (hydraulic radius increases)

Sanitary Sewer:

Public (when available) or private sewer in remote conditions for normal waste system must be fully contained and never at reach of human. Never mix the storm drain and sanitary unless treatments are provided.

Combined sewer and storm system: Now extremely rare. All combined system must be treated before reuse or discharge. Storm systems are used for overflow into the sewer system (flash floods).

Cleanout in a system is the location for rooting the clogs' at beginning or logistically located within the sewer pipes

Not: Vent, drain, or trap

Pressure relief valve in a diagram is a device to allow over pressure or temperature to vent out to approve location

Water closet-Plumbing fixture types is not permitted to connect to a waste stack vent

Not: Bidets, utility sinks, lavatories

Flush control for a handicapped accessible urinal is a maximum of 44" AFF.

Valve upstream of water heater circulation pump is a gate valve to be able to cut off pump and maintain it.

Not: Check valve and not exact use with Angle valve (90 degree bend), and globe valve

Vacuum breaker is not required for plumbing waste-drainage system

Not: Trap, vents, clean-outs are required for waste-drainage system

Plastic has the highest coefficient of thermal expansion.

Not: Steel, cast iron, glass

Air gap is required for refrigerators and sterilizers

Not: Heat recovery units, water closets, bathtubs, waste interceptors

Cleanout in a system is the location for rooting the clogs' at beginning or logistically located within the sewer pipes

4. HVAC

(18-23% Score)

Principles: Analyze and design heating, ventilating, and air conditioning systems.
Materials & Technology: Evaluate and select materials and construction details related to HVAC systems

DESIGN FORMULAS

Air Side

QTotal = CFM x (hi - hf) x 4.5 Btuh
QSensible = CFM x (ti - tf) x 1.085 Btuh
CFM = Q sensible BTU/Hr / (1.08 x Temperature Difference)
Btu/hr = cfm * 1.08 *delta T [W = L/S * 1.2 * delta T]
BTU/hr. = Specific Heat X Specific Density X 60 min./hr. = m. Cp. DT= CFMX Cp X DT
=.24 X .075 X 60 X CFM X DT = 1.08 X CFM X DT

QLatent = CFM x (Gri - Grf) x .068 Btuh
Humidification = CFM x (Grf - Gri) / 1,555 lbs/hr
CFM = l/s x 2.12
Air Pressure Drop (in. wg) = Pa / 249

Water Side

Q = USGPM x (ti - tf) x 500 Btuh
Q = USGPM x (ti - tf) x 450 Btuh (50% E.G.)
Q = USGPM x (ti - tf) / 24 Tons
USGPM = l/s x 15.85
Water Pressure Drop (ft. wg) = kPa x 0.3351.0 PSI = 2.31 wg

TON OF REFRIGERATION : The amount of heat required to melt a ton (2000 lbs.) of ice at 32°F . 288,000 BTU/24 hr.
12,000 BTU/hr; 1.0 Ton = 12 MBH = 12,000 Btuh

1.0 Therm = 100,000 Btuh = 100 MBH

COP = 3.516 / (kw / Ton)
EER = Tons x 12 / (Total kW input)
1 US Gallon = 8.33lbs
Latent heat of vaporization of steam in air (average) = 1,050 Btuh/lb

APPROXIMATELY 2 inches in Hg. (mercury) = 1 psi

WORK = Force (energy exerted) X Distance

Example: A 150 lb. man climbs a flight of stairs 100 ft. high
Work = 150 lb. X 100 ft; Work = 15,000 ft.-lb.

ONE HORSEPOWER = 33,000 ft.-lb. of work in 1 minute
ONE HORSEPOWER = 746 Watts; 1 Boiler HP = 33.48 MBH; HP = kW x 1.3405
CONVERTING KW to BTU: 1 KW = 3413 BTU's; Btuh = Watt x 3.412;

Example: A 20 KW heater (20 KW X 3413 BTU/KW = 68,260 BTU's)
Example: A 100,000 BTU/hr. oil or gas furnace (100,000 / 3413 = 29.3 KW)

Writing

$$U = \frac{k}{\Delta x},$$

where *U* is the conductance, in W/(m^2 K).
U FACTOR = Reciprocal of R factor = 1 / R = U

If R = 19: U = 1 / 19 = .05 (BTU's transferred / 1 Sq.Ft. / 1ºF / 1 Hour)

Fourier's law can also be stated as:

$$\frac{\Delta Q}{\Delta t} = UA(-\Delta T).$$

Btu/hr = UA Delta T

The reciprocal of conductance is resistance, R, given by:

$$R = \frac{1}{U} = \frac{\Delta x}{k} = \frac{A(-\Delta T)}{\frac{\Delta Q}{\Delta t}},$$

R = thickness of material /thermal conductivity of material

and it is resistance which is additive when several conducting layers lie between the hot and cool regions, because *A* and *Q* are the same for all layers. In a multilayer partition, the total conductance is related to the conductance of its layers by:

$$\frac{1}{U} = \frac{1}{U_1} + \frac{1}{U_2} + \frac{1}{U_3} + \cdots$$

R = R1 +R2 + R3 + ...

So, when dealing with a multilayer partition, the following formula is usually used:

$$\frac{\Delta Q}{\Delta t} = \frac{A(-\Delta T)}{\frac{\Delta x_1}{k_1} + \frac{\Delta x_2}{k_2} + \frac{\Delta x_3}{k_3} + \cdots}.$$

When heat is being conducted from one fluid to another through a barrier, it is sometimes important to consider the conductance of the thin film of fluid which remains stationary next to the barrier. This thin film of fluid is difficult to quantify, its characteristics depending upon complex conditions of turbulence and viscosity, but when dealing with thin high-conductance barriers it can sometimes be quite significant.

U = 1/Rt

Wall/Window combination: U * A = U Window * A Window + U Wall * A Wall

Roof/Skylight combination: U * A = U Roof * A Roof + U skylight * A skylight

Degree Days Celsius = 0.56 DD Fahrenheit
Heat Rejected = Btu/hr (W) *24 hrs * DD F (DD C)/Temperature differential
1 btu/hr/ft^2/F = 5.678 W/m^2/ C

WET AIR = Same as dry air plus water vapor

SPECIFIC DENSITY = 1/Specific Volume
SPECIFIC DENSITY OF AIR = 1/13.33 = .075 lbs./cu.ft.
STANDARD AIR = .24 Specific Heat (BTU's needed to raise 1 lb. 1 degree)

SENSIBLE HEAT FORMULA (Furnaces):
HVAC, Btu/year = Peak Heat Loss * full load hours/hear
Dollar/Year = Btu/year x Fuel Cost/fuel heat value x efficiency

ENTHALPHY = Sensible heat and Latent heat

TOTAL HEAT FORMULA (for cooling, humidifying or dehumidifying)

BTU/hr. = Specific Density X 60 min./hr. X CFM X DH
= 0.75 x 60 x CFM x DH = 4.5 x CFM x DH

RELATIVE HUMIDITY = Moisture present/Moisture air can hold
SPECIFIC HUMIDITY = grains of moisture per dry air
7000 GRAINS in 1 lb. of water

DEW POINT = when wet bulb equals dry bulb
TOTAL PRESSURE (Ductwork) = Static Pressure plus Velocity Pressure
CFM = Area (sq. ft.) X Velocity (ft. min.)

HOW TO CALCULATE AREA
Rectangular Duct Round Duct

A = L x W A = pi D^2/4 = pi r^2

RETURN AIR GRILLES – Net free area = about 75%
HEAT PUMP AUXILIARY HEAT – sized at 100% of load
ARI HEAT PUMP RATING POINTS (SEER Ratings) 47° 17°

28 INCHES OF WC = 1 psi

NATURAL GAS COMBUSTION:
Excess Air = 50%

15 ft.^{3} of air to burn 1 ft.^{3} of methane produces:
16 ft.^{3} of flue gases: 1 ft.^{3} of oxygen; 12 ft.^{3} of nitrogen; 1 ft.^{3} of carbon dioxide
2 ft.^{3} of water vapor

Another 15 ft.^{3} of air is added at the draft hood

GAS PIPING (Sizing – CF/hr.) = Input BTU's/Heating Value
Example: 80,000 Input BTU's/1000 (Heating Value per CF of Natural Gas)= 80 CF/hr.
Example: 80,000 Input BTU's/2550 (Heating Value per CF of Propane) = 31 CF/hr.

FLAMMABILITY LIMITS

Propane	Butane	Natural Gas
2.4-9.5	1.9-8.5	4-14

COMBUSTION AIR NEEDED	Propane	Natural Gas
(PC=Perfect Combustion)	23.5 ft.^{3} (PC)	10 ft.^{3} (PC)
(RC=Real Combustion)	36 ft.^{3} (RC)	+15 ft.^{3} (RC)
ULTIMATE CO2	13.7%	11.8%

DRY AIR = 78.0% Nitrogen; 21.0% Oxygen; 1.0% Other Gases

FURNACE EFFICIENCY:
% Efficiency = energy output/energy input

OIL BURNER STACK TEMPERATURE (Net) = Highest Stack Temperature minus Room Temperature

Example: 520° Stack Temp. – 70° Room Temp. = Net Stack Temperature of 450°
NET OIL PRESSURE = Gross Oil Pressure – Suction Pressure
COMPRESSION RATIO = Discharge Pressure Absolute/Suction Pressure Absolute

KELVIN TO CELSIUS: C = K – 273
CELSIUS TO KELVIN: K = C + 273

ABSOLUTE TEMPERATURE MEASURED IN KELVINS

GAS LAWS:
Boyle's Law: P1 V1 = P2 V2 P = Pressure (absolute)

V = Volume

Charles' Law: P1/T1 = P2/T2 P = Pressure (absolute); T = Temperature (absolute)

General
Gas Law: P1 V1/T1 = P2 V2/T2 P = Pressure (absolute); V = Volume; T = Temperature (absolute)

A. PRINCIPLES
Analyze and design heating, ventilating, and air conditioning systems.

- Fundamentals of Refrigeration
  - Cycles: Carnot Cycle, refrigeration cycle
  - The ideal and real vapor compression cycles.
  - Devices: Compressors, Controls devices
  - Fluids: Water, Ammonia, Refrigerants –types, properties, and the refrigerant chart.

- Fundamentals of Heat Transfer
  - Heat transfer modes (conduction, convection, and radiation)
  - Combined heat transfer and Basics of heat exchangers

- Fundamentals of Psychometric
  - Properties of moist air
  - The Psychometric chart
  - Representation and calculations of HVAC processes.
  - By-pass factor and apparatus dew point.

1. Building Design
Apply theory and principles of HVAC systems as a component of building design.

Cooling and Heating Load Calculation
- Load calculation methods.
- Load calculation psychometrics
- Internal heat gains
- Heat loss calculations
- Cooling load calculation using a modified CLTD/CLF method

- HVAC Equipment and System Selection
  - Unitary package equipment.
  - Unitary split system equipment.
  - Ground-source and water-loop heat pumps.
  - Chilled water systems.
  - Selection procedure for chilled water coils, air conditioners, and heat pumps.
  - Selection procedures for unitary heat pumps and furnaces.
  - Cooling towers
  - Economizers.

Design of Air Distribution Systems
- Space air diffusion
- Filtration
- Design considerations and air duct systems
- Duct layout and sizing
- Fans, fan laws, and flow control methods
- System curve and fan selection
- Design of fan-duct interface

Design of Water Distribution Systems

Piping loop systems
Head loss characteristics
Design methods
Piping layout and sizing
System head and pump selection

Controls

HVAC control component and circuits
Unitary controls and circuits
Central HVAC system controls

2. Implications of Design Decisions
Determine the effects of HVAC systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

Energy, Costs, and Economics

Low- and high- efficiency HVAC system demand calculations.
Energy consumption and cost calculations.
Maintenance and replacement costs
System Installation Costs.
Case study –calculation of duct cost using duct cost program.
Engineering economics and HVAC
Discounted economic analysis.

3. Indoor Air Quality
Apply principles and theory of HVAC systems and design effects to determine impact on the quality of indoor air and related health issues.

Thermal comfort, Indoor air quality, calculation of required ventilation rates, Dedicated ventilation air system Multiple-zone re-circulating system, Climate data, Heat Flow in Buildings, Thermal Properties of Building materials, Building heat transfer characteristics, Heat through duct work, Infiltration, Moisture control and migration

B. MATERIALS & TECHNOLOGY
Evaluate and select materials and construction details related to heating, ventilating, and air conditioning systems.

1. Building Systems and their Integration
Examine integration and effects of HVAC design principles, systems, and details on the overall design of a building considering technological advances and innovative building products.

- HVAC Equipment and System Selection
  - Unitary package equipment.
  - Unitary split system equipment.
  - Ground-source and water-loop heat pumps.
  - Chilled water systems.
  - Selection procedure for chilled water coils, air conditioners, and heat pumps.
  - Selection procedures for unitary heat pumps and furnaces.
  - Cooling towers
  - Economizers.

Controls
- HVAC control component and circuits
- Unitary controls and circuits
- Central HVAC system controls

2. Construction Details and Constructability
Identify and analyze HVAC system details including the aspects of constructability.

Design of Air Distribution Systems
- Space air diffusion
- Filtration
- Design considerations and air duct systems
- Duct layout and sizing
- Fans, fan laws, and flow control methods
- System curve and fan selection
- Design of fan-duct interface

Design of Water Distribution Systems
- Piping loop systems
- Head loss characteristics
- Design methods
- Piping layout and sizing
- System head and pump selection

Begin to Understand HVAC Systems?

The heating, ventilating and air conditioning (HVAC) systems drive occupant comfort in buildings. HVAC systems control the air temperature, of course, but also to intake outside air, exhaust or filter contaminated air and efficiently use energy. Since HVAC systems are complicated, many Construction Supervisors don't bother to learn about them. That's a mistake. Most of the occupant complaints about the buildings we build involve HVAC systems, so we should all be paying more attention to how these systems get designed and installed.

If you take the time to understand the basics of HVAC systems, you'll discover valuable knowledge that you'll use on every project. Start by watching these well done training videos by Price which show the Basics of HVAC.

Another excellent Price training video is Comfort Criteria, which explains how occupants actually experience the HVAC system in action.

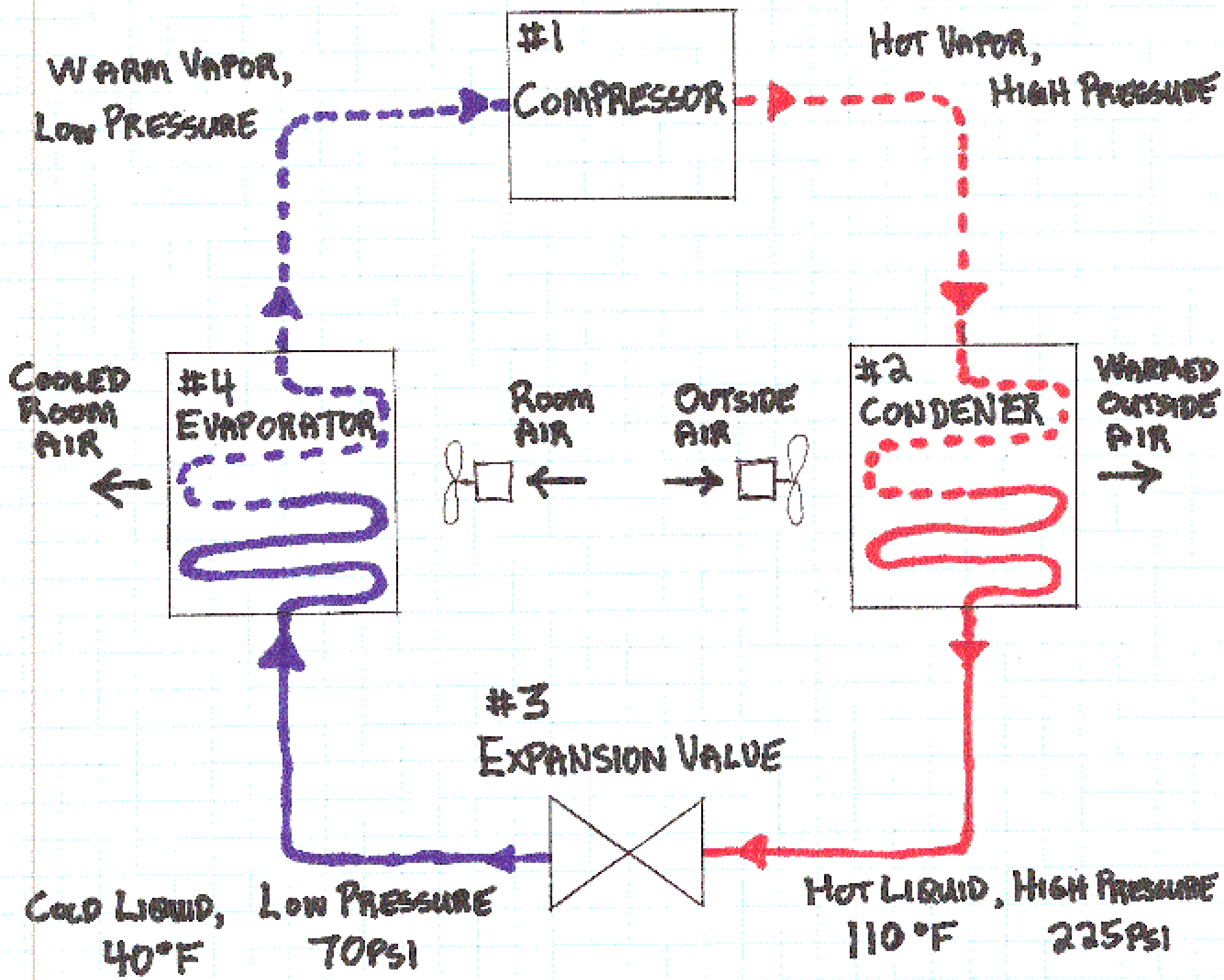
What are the Basic Types of HVAC Systems?

Whenever you consider an HVAC system, begin with a few basic questions.

1. What is the fuel used for heating? Gas, oil, coal, electricity, etc.
2. What is the type of cooling? Electric heat pump, electric air conditioner, chiller, gas air conditioner, etc.
3. How is the heat or cooling delivered to the occupant space? Hot and cold ducted air system, hot and cold water system (hydronic or steam), radiant heat system, etc.
4. What is the ventilation? Summer ventilation with intake louvers and fans, supply and return air with outside air introduced for ventilation, dedicated ventilation system, etc.

Unfortunately, answering the questions above doesn't lead you right into understanding the HVAC system because of the many options. Answering the questions above puts you on the right track for beginning to understand the system, though. The next step is to know about a few basic systems and recognize a common HVAC system when you see it.

For the rest of this section, I'll describe a few HVAC systems that you may encounter on the jobsite. Understanding the basics of how the system works will help you to understand more later. The first thing that you need to understand with almost any HVAC system is the basics of air conditioning. The sketch below explains the air conditioning cycle.



COOLING CYCLE

To understand the cooling cycle, follow the numbers below:

1. The compressor takes the low pressure refrigerant and compresses it, increasing both the temperature and the pressure. The actual temperature and pressure depend on the refrigerant being used.

2. The condenser blows outside air over the refrigerant vapor, turning it into a liquid, typically about 25 F above the outside air temperature. Hence the hot air blowing out of the condenser.

3. The expansion valve changes the refrigerant from a high pressure liquid to a low pressure liquid, dramatically lowering the temperature as well.

4. The evaporator allows the warm room air to blow over the coils with cold refrigerant liquid, transferring heat to change the cold liquid to a warmer gas. Refrigerants are selected by their ability to absorb significant amounts of heat as they change state from a liquid to a gas.

A good website for more detailed information on all aspects of HVAC work is the HVAC Prime Source.

Now I'll lead you through a few basic HVAC systems, to help you name a few common systems.

Heat Pumps: Like a refrigerator working in reverse, a heat pump extracts the heat from the air (or water) and uses it for heating. The cooling cycle is the normal vapor compression refrigerant process that's described above. The most common air to air heat pumps have the compressor and condenser in an outside unit. Then the refrigerant piping goes to an inside air handler unit which houses the expansion valve and the evaporator. These Split Systems normally have a 75' limit for the length of the refrigerant piping. During very cold weather, the heating side of the heat pump won't be able to pull enough heat from the outside air, so electric back-up resistive heaters are required. A separate system must be installed to bring outside air into the space. Heat pumps usually have one thermostat for the entire heat pump zone. System simplicity and low initial cost are the main benefit, while short life span (7 years is typical) and lack of control options are the principal drawbacks.

Roof Top Units (Packaged Units): These complete heating and cooling units sit on the roof or outside on the ground and duct the conditioned air into the space. The heating side often uses gas furnaces, but other fuel options are available. The complete cooling cycle shown on the above sketch happens in the roof top unit. Since the units are outside, the mixing of outside air with the return air can be done easily. These packaged units produce a certain air temperature that goes into the duct distribution. Often the roof top unit produces cool air and certain zones may need that air warmed with electric duct heaters. System simplicity and low initial cost are the main benefit, while the main drawbacks are large vertical ducts running floor to floor and system control options.

Water Source Heat Pumps: Also called a one pipe system, a single pipe carries water through the building which the individual water source heat pumps use for their heat source or heat sink. Typically the water in the loop pipe is about 80 F. This system requires a boiler to raise the loop water temperature and a cooling tower to lower the loop water temperature. Each zone, then, has a dedicated water source heat pump that is located inside the building. One of the benefits of this system is the ability to have a heat pump needing cooling and putting heat into the loop water while another heat pump calls for heating and takes heat out of the cooling loop. This system is extremely energy efficient during those times of the year. The main drawback is probably all the compressors located all through the interior, both for noise and maintenance.

Chillers: The above systems are all considered Direct Expansion (DX) systems because the units provide for direct expansion of the refrigerant in the air cooling coils. Chillers, on the other hand, make cold water that gets distributed by pipes to air cooling coils. Chiller systems also require boilers to make hot water for the heating cycle. A two pipe system either cools or heats and a system changeover must occur to go from cooling to heating. In the cooling cycle, the one pipe supplies the cold water while the other pipe returns the warmed water (warmed by passing through the cooling coils with air blowing over the coils). A four pipe system doesn't need a system changeover, as each cooling coil unit has both a hot water supply and return and a cold water supply and return piped to it. The energy efficiency of these systems and the excellent control options are the biggest benefits, while initial cost and maintenance complexity are the drawbacks.

Heaters: Hot air furnaces may burn gas, oil, coal, wood, etc. Radiant heaters, which produce infrared radiation which heats objects rather than the air adjacent to the heater, can be fueled by gas or electric. Electric resistance heaters are also common. Direct fired gas heaters, which use 100% fresh air and innovative fan distribution can also be an excellent heating solution for large spaces.

Fans and Ventilation: The use of fans to ventilate a space for cooling and/or expulsion of indoor pollutants can be done in many ways. From a simple toilet exhaust fan to huge wall fans interconnected with wall louvers used for summer cooling, there are many ways to ventilate.

How Does Air Distribution Work?

Since most of the HVAC systems installed in commercial buildings use air distribution, take some time to understand how air flows from diffusers. The training modules produced by Price do an excellent job of teaching the concepts in a few minutes. Review the space air diffusion video to learn more.

What Should I Know about Rough Sizing Systems?

Have you ever talked to the Project Owner as he contemplates adding a few rooms to the project? That type of discussion happens occasionally on the construction site, as Owner's seem to always be considering options and changes during construction. If an owner discusses adding 1000 sf of office, it's handy to know that about 3 tons of air conditioning will be needed. As I've mentioned before, that general knowledge of building provides a sense of competence that can carry you far.

So how do you have a sense of rough sizing HVAC systems? Consider the type of projects you build and consult the table below for the area factor. The above example used a 1000 sf office space, which has about 350 sf per ton of air conditioning. So 1000 sf/350 sf/ton = about 3 ton.

Building Type	SF/ton
Office areas or retail	350
Conference rooms	100 to 200
Dedicated computer rooms	50 to 100
Classrooms	250
Industrial	300
Arenas	150 to 200

Residential	600 to 700

Therefore, if you're building a school, just remember that every 1,000 sf will need about 4 tons of air conditioning. Of course, you need to remember that this rough sizing varies by the amount of insulation, the amount and orientation of glazing, the amount of exterior wall and the climate.

If you want to further rough size air duct systems, you may want to purchase a Ductulator, a hand held rotating calculator that aids in understanding air duct sizes, air velocities and air flows. These additional rules of thumb will help you use it:

1. Normal comfort air conditioning uses about 400 cfm per ton.
2. Precision air conditioning (for dedicated computer rooms) uses about 500 cfm per ton.
3. Dehumidification uses about 200 cfm per ton.
4. Air flow at diffusers should be 600 to 700 feet per minute to be fairly quiet.
5. Air flow in main ducts should be 1,000 to 1,200 feet per minute to be fairly quiet.
6. Air flow for kitchen exhaust hoods will be in the 2,500 feet per minute range.

What Should I Know about HVAC Energy Usage?

While we construct the buildings, other people will live and work and play in them for many years afterward. Learn to contemplate how the building will work for those future occupants. With the understanding of a few basic concepts, you can have a sense of how the building will use energy in the future.

The average amount spent on energy use for office buildings seems to be about $1.80/sf per year. So a 10,000 sf office building will pay about $18,000 per year for electric, gas and oil. Lighting tends to be the largest part of that cost for most commercial buildings. The new energy conservation codes require less than 1 watt/sf of lighting energy usage, but many existing buildings use 2 to 3 watts/sf for lighting. An example below illustrates:

LIGHTING

10,000 SF OFFICE BLDG

$$10{,}000\,SF \times \frac{2\,WATT}{SF} \times \frac{1\,KW}{1000\,WATT} \times \frac{12\,HR}{DAY} \times \frac{6\,DAY}{WK} \times \frac{52\,WK}{YR} \times \frac{\$.10}{KW\,HR} = \$7{,}488$$

CHECK CALC FROM US DOE ANNUAL LIGHTING TABLE LINK

$$10{,}000\,SF \times \frac{8.2\,KW\,HR}{SF} \times \frac{\$.10}{KW\,HR} = \$8{,}200$$ (CLOSE TO COST ABOVE)

THEREFORE LIGHTING COSTS ABOUT $.75/SF PER YEAR

TOTAL ENERGY

$$10{,}000\,SF \times \frac{\$1.80}{SF/YR} = \$18{,}000/YEAR$$

HVAC

$$\underset{TOTAL}{\frac{\$1.80}{SF/YR}} - \underset{LIGHTING}{\frac{\$.75}{SF/YR}} = \underset{HVAC}{\frac{\$1.05}{SF/YR}}$$ OR $10,500/YEAR

The energy use of commercial buildings is shown in this US Department of Energy report. The lighting use of commercial buildings is shown in this US DOE report. Finally, the costs per sf spent on energy are shown in this US DOE report.

What Public Domain Documents are Available for Further Study?

The Dept of Defense has created a manual for Heating, Ventilating, Air Conditioning and Dehumidifying Systems is an excellent introduction to HVAC. This 234 page handbook is officially called UFC 3-410-02N (June 2005).

The US Dept of Defense, HVAC Control Systems provides 454 pages of details regarding designing of an HVAC system. The name of this document is UFC 3-410-02A (May 2003).

If you want to follow a design for research laboratories (with lots of good practical discussion points), go to A Design Guide for Energy Efficient Research Laboratories.

Another resource, is the US Dept of Defense HVAC Air Supply Manual. It has 64 pages of information and is officially named UFGS-23 00 00 (October 2006).

For information on Central Heating Plants, review the 230 page manual issued by the US Dept of Defense, officially named UFC 3-430-08N (January 2004).

The US Dept of Defense has created a guide to Cooling Buildings by Natural Ventilation. This 183 page has the official name UFC 3-440-06N (January 2004).

The US Dept of Defense Ductwork and Accessories Manual provides 31 pages of information regarding HVAC ductwork and is officially namedUFGS-23 30 13.00 20 (July 2006).

The Dept of Defense has created a manual for designing Industrial Ventilation, officially named UFC 3-410-04N (October 2004).

The US Dept of Defense Industrial Ventilation provides 50 pages of details regarding ventilation systems. The name of this document is UFGS-23 35 19.00 20 (July 2006).

A Manual for Ventilation Assessment in Mechanically Ventilated Commercial Buildings is available from the US Dept of Commerce. This document is 124 pages, named NISTIR-5329.

Further information regarding HVAC System Testing is provided by the US Dept of Defense. This 33 page document is officially titled UFGS-23 08 01.00 20 (April 2006).

The Naval Facilities Engineering Command provides Maintenance and Operations of Ventilation Systems which is a 74 page document overview of HVAC systems. This document has the official name of SN-0525-LP-194-6400.

The Noise and Vibration Control Manual provided by the US Dept of Defense is a 152 page document, officially named UFC 3-450-01 (May 2003).

A complete guide to Thermodynamics, Heat Transfer, and Fluid Flow is provided in a 3-part manual. Volume I is titled DOE-HDBK-1012/1-92 (June 1992) and is 138 pages, Volume II is 32 pages and titled DOE-HDBK-1012/2-92 (June 1992), and Volume III titled HT-03 is 12 pages.

The Dept of Energy provides information on the Fundamentals of Valves, in this 52 page document officially named DOE-HDBK-1018/2-93

For information on compressed air systems, review the US Dept of Defense Compressed Air Manual, officially named UFC 3-420-02FA (May 2003).

Tricks of the Trade & Rules of Thumb for HVAC Basics:

1. HVAC stands for Heating, Ventilating and Air Conditioning and the main standard setter is ASHRAE, American Society of Heating, Refrigeration and Air Conditioning Engineers.

2. 1 ton of cooling = 12,000 btu/hour (power)

3. 1 kilowatt-hour = 3412 btu (energy or work)

4. When thinking about air flows into and out of a room or a building, remember that inflows have to balance with outflows, just like for your checkbook.

5. Heat always transfers from warmer to cooler.

6. Always think about the control of moist air (and condensation) in HVAC systems.

7. Normal comfort air conditioning uses about 400 cfm per ton.

8. Air velocity over 100 feet/minute on occupants tends to annoy them.

9. Office buildings tend to pay about $1.80/sf per year for energy.

3. Thermal and Moisture Protection
Apply detailed principles and analysis of thermal and moisture protection of HVAC systems.

Fan coil with four pipe system carries two pipes for heating and two pipes for cooling:
Not: Evaporative cooling, domestic hot water circulation, high rise fire safety systems
In a setting where the fan is obligated to have a bend, bend with 45 degrees is far better than 90 degrees or variation thereof.

Constant volume reheat has the highest operating cost for a large office building.
Not: Single zone- constant volume (small office), variable air volume, Double duct-constant volume
Single duct, Variable Air Volume systems are more efficient than constant volume system because: in a VAV system, with variable-pitch blades or variable-speed fans allow air to modulate from zero to maximum
Not: Fan runs at efficient levels and air volumes are controlled by manual dampers, duct sizes are reduced to save initial cost, low voltage equipment are needed
In a house design, the presence of a tree is positioned, depending the am vs pm, the sun moves. In North direction, No sun. In East direction the sun is from east and tree in east will block in morning, and south, the tree shades vary from morning to afternoon and in west, the sun is straight through glazing, therefore the tree can be placed on west.

Cooling tower using the water takes the heat away from building by spraying water over coils and passing air to cool the water
Not: Cooling coil, dehumidifier, heat pump

Chiller/cooling tower steps: Cooling tower to chiller is water: water is pumped from chiller to cooling tower for heat removal, the Freon and chiller are getting cool by cooling tower water in a heat exchanger, finally water is pumped into room and removes heat from room in fan coils.

U value of wall assembly: includes Resistance of air, wall, studs, interior and exterior film
Not: Orientation
Source of a building's heat loss: Air infiltration
Not: Occupants, isolation, electric lightning
Psychometric chart plot factors: Relative humidity, air temperature
Not: Air motion, mean radiant temperature, convection current, surface temperature

Equation for U * area *temperature difference= heat gain: Often underestimates summer heat gain since roof color (cool roof), roof mass and time of day also affects the heat gain.

Not: Entropy, roof texture, relative humidity

Heat is described through: Convection, conduction, radiation, enthalpy

ELECTRICAL FORMULAS

COULOMB = 6.24 X 10^{18} (1 Coulomb = 1 Amp)

OHM'S LAW : Voltage (V) = Current in Amperes (A) x Impedance (Ohms) ; E = I x R; I = E / R; R = E / I
Where: E = voltage (emf); I = Amperage (current); R = Resistance (ohm)

WATTS (POWER) = Volts (V) x Current in Amperes (A) x Power Factor (PF); P(in KW) = (E x I) / 1000
VA (how the secondary of a transformer is rated) = volts X amps

Example: 24V x .41A = 10 VA
VA (how the secondary of a transformer is rated) = volts X amps

Example: 24V x .41A = 10 VA

ONE FARAD CAPACITY = 1 amp. stored under 1 volt of pressure
MFD (microfarad) = 1Farad/ 1,000,000

LRA/5 (Locked rotor amps) = FLA (Full Load Amps) or LRA = FLA x 5
RPM of motor = 60Hz x 120/ No. of Poles
1800 RPM Motor – slippage makes it about 1750
3600 RPM Motor – slippage makes it about 3450

3 PHASE VOLTAGE UNBALANCE =
100 x maximum deg. from average volts/ Average Volts

Demand for Power (kW) = System Input Wattage (W) ÷ 1,000
Energy Consumption (kWh) = System Input Wattage (kW) x Hours of Operation/Year
Hours of Operation/Year = Operating Hours/Day x Operating Days/Week x Operating Weeks/Year)

ECONOMIC FORMULAS

Simple Payback on an Investment (Years) = Net Installation Cost ($) ÷ Annual Energy Savings ($)
5-Year Cash Flow ($) = 5 Years - Payback (Years) x Annual Energy Savings ($)
Simple Return on Investment (%) = [Annual Energy Savings ($) ÷ Net Installation Cost ($)] x 100

SINE = side opposite COSINE = side adjacent
sin hypotenuse cos hypotenuse
TANGENT = side opposite/tan side adjacent

PERIMETER OF SQUARE: P = 4s P = Perimeter (s = side)
PERIMETER OF RECTANGLE: P = 2l + 2w P – Perimeter (l = length; w = width)
PERIMETER OF TRIANGLE: P = a + b + c P = Perimeter
a = 1st side; b = 2nd side; c = 3rd side

PERIMETER OF CIRCLE: C = pi D= Circumference= 2pi r
pi = 3.1416; D = Diameter; r = radius

AREA OF SQUARE: a = $s^{2;}$ a = Area; s = side
AREA OF RECTANGLE: A = l w; A = Area; l = length; w = width
AREA OF TRIANGLE: A = 1/2bh A = Area; b = base; h = height
AREA OF CIRCLE: A = pi r^2; A = Area; p = 3.1416
A = pi D^2/ 4; r = radius; D = Diameter

VOLUME OF RECTANGULAR SOLID:
V = l wh = Volume; l = length; w = width; h = height
VOLUME OF CYLINDRICAL SOLID:
V = pi r2 h= Volume; pi = 3.1416; V = pi D2 h/4; r = radius; D = Diameter; h = height

PYTHAGOREAN THEOREM:
$C^2 = a^2 + b^2$; c = hypotenuse; a & b = sides

A. PRINCIPLES

Analyze and design electrical systems.

1. Building Design

Apply theory and principles of electrical systems as a component of building design.

Electrical Systems Design

- Different types of services and service equipments.
- Understand the schematic and actual wiring diagram.
- Apply the actual wiring diagram in Electrical Systems Design.
- Understand the different parts of an electrical plan.
- Understand the proper way of sizing a conductor and circuit breaker.
- Understand the actual load analysis method of electrical design.
- Understand the proper way of sizing a conductor and protection for motor loads.
- Understand the proper way of sizing transformer and generator.
- Calculate the voltage drop for feeders.
- Understand the proper way of sizing low voltage switchgear.
- Understand the proper way of sizing the KAIC rating of a circuit breaker.

B) RESIDENTIAL BUILDING WIRING INSTALLATION

1) Different Types of Services
2) Service Equipments
3) Schematic Diagram
4) Actual Wiring Diagram

C) BUILDING ELECTRICAL DESIGN

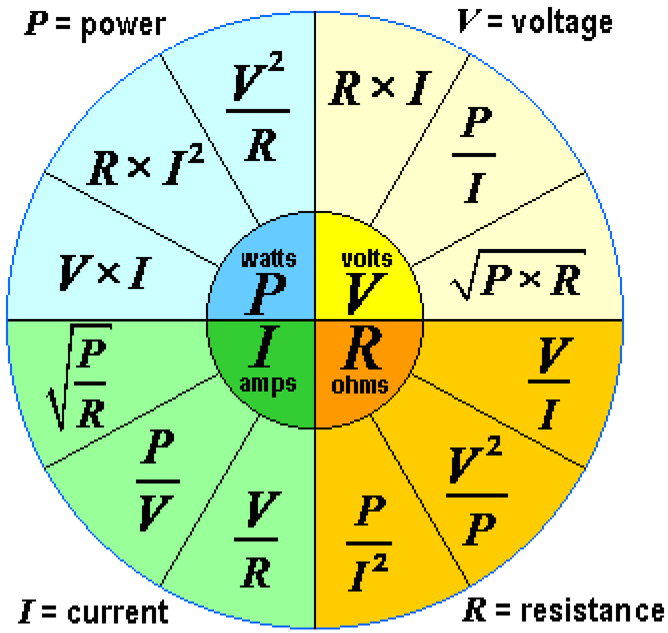
1) General Notes & Specifications
2) Legend & Symbols
3) Location Map
4) Power Lay-Out
5) Basic Motor Computation
6) Branch Circuit Conductor and Circuit Breaker Coordination
7) Lighting Lay-Out
8) Load Schedule
9) Riser or One Line Diagram
10) Service Entrance Computations

D) Grounding Installations for Commercial and Industrial Applications

1) Ungrounded Installations
2) Preventing Electrical Ground
3) Designing Grounding Installations

F) HIGH-RISE BUILDING
ELECTRICAL DESIGN

1) General Introduction
2) Pre-Design Factors
3) Building Description
4) Riser Diagram
5) Load Computation
6) Voltage Drop Computation
7) Feeder & Su b- feeder Computations
8) Transformer Sizing
9) Motor Load Computation
10) Elevator Load Computation
11) Main Feeder Computation
12) Emergency Systems Computation or Generator Sizing
13) Low Voltage Switchgear (LVSG) Computation
14) Fault Current Calculation
15) P r o t e c t i v e D e v i c e Coordination Analysis
16) Injection of Fault Currents a n d T r i p p i n g T i m e Evaluation
17) Customizing and Importing t h e T i m e C u r r e n t Coordination Graph
18) Practical Exercises (Short Circuit, Load Flow,



ELECTRICS DEPARTMENT

Basic electricity:

Electricity is the flow of electrons from one place to another. Electrons can flow through any material, but does so more easily in some than in others. How easily it flows is called resistance. The resistance of a material is measured in Ohms.

Matter can be broken down into:

- **Conductors:** electrons flow easily. Low resistance.
- **Semi-conductors:** electron can be made to flow under certain circumstances. Variable resistance according to formulation and circuit conditions.
- **Insulator:** electrons flow with great difficulty. High resistance.

Since electrons are very small, as a practical matter they are usually measured in very large numbers. A Coulomb is 6.24×10^{18} electrons. However, electricians are mostly interested in electrons in motion. The flow of electrons is called current, and is measured in AMPS. **One amp is equal to a flow of one coulomb per second** through a wire.

Making electrons flow through a resistance requires an attractive force to pull them. This force, called Electro-Motive Force or EMF, is measured in **volts**. A Volt is the force required to push 1 Amp through 1 Ohm of resistance.

As electrons flow through a resistance, it performs a certain amount of work. It may be in the form of heat or a magnetic field or motion, but it does something. This work is called Power, and is measured in Watts. One Watt is equal to the work performed by 1 Amp pushed by 1 Volt through a resistance.

NOTE:

AMPS is amount of electricity.
VOLTS is the Push, not the amount.
OHMS slows the flow.
WATTS is how much gets done.

There are 2 standard formulae that describe these relationships.

Ohm's Law: Where

R = Resistance (ohms)
E = Electro-motive Force (volts) <>I = Intensity of Current (amps) **R = E / I**

To express work done: **Power formula (PIE Law):**

Where:

P = Power (watts)
I = Intensity of Current (amps)
E = Electro-motive Force (volts)

P = IE

This law is often restated in the units of measure as the West Virginia Law:

W = VA
for
Watts = Volts x Amps

All this is important because all electrical equipment has a limit to how much electricity it can handle safely, and you must keep track of load and capacities to prevent failure, damage, or a fire.

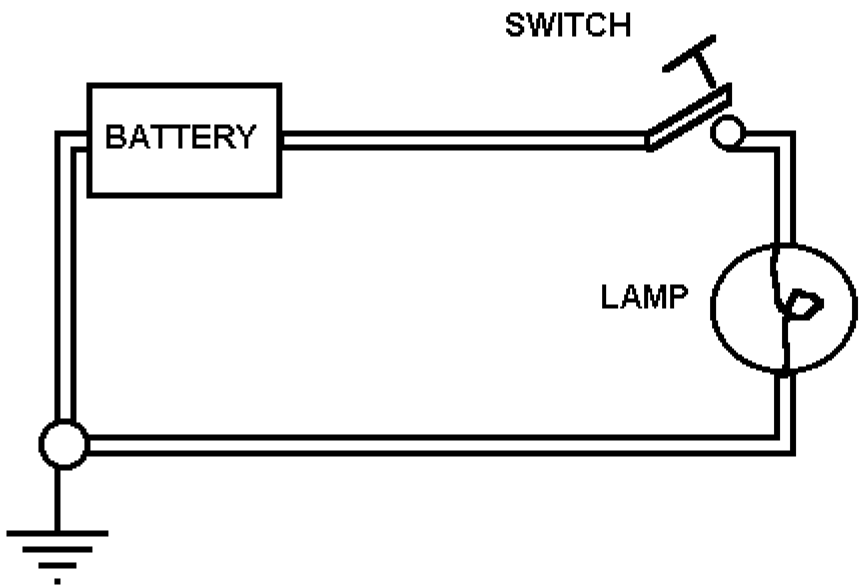
For example, a lamp is rated at 1000 w. @ 120 v. That means that at 120 volts it will use:

1000 w. / 120 v. = 8.33 a.

A common shortcut is to use 100 v. instead of 120. This makes calculating easier and builds in some headspace. So:

1000 w./ 100 v. = approx. 10 a.

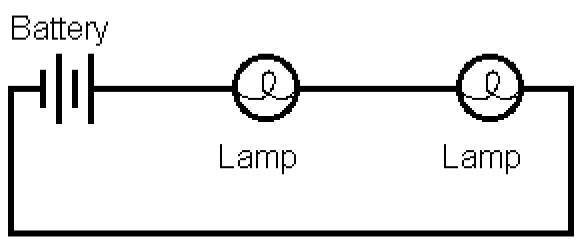
A Simple Circuit:



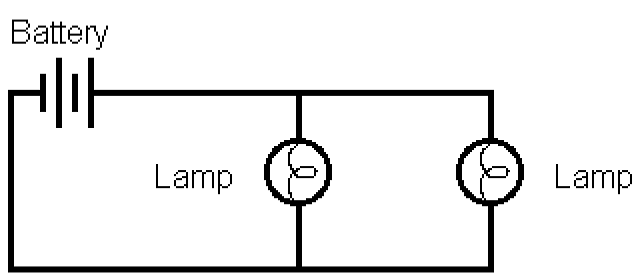
The simplest circuit has a power source, like a battery or outlet, a wire running from the "hot" side to a "load", then a wire from the load back to the power source. There is also usually a switch to "open" or "close" the circuit. The load will function only when the circuit is closed or complete.

In more complex circuits where more than one load is connected, they may be either in series or in parallel. In a series circuit, current must pass trough one to get to the next. Voltage is divided between them. If one goes out, they all go out.

SERIES



PARALLEL



In a parallel circuit, each load is electrically connected to the source at the same point, each gets the full voltage simultaneously. If one goes out, the rest stay lit.

Most circuits are combinations of the two types. Circuit breakers and fuses are in series with the load, but multiple loads on a circuit are paralleled.

Circuit breakers and fuses can be placed in the supply circuit **before** the plug, as in lighting circuits, or **between the plug and the load** internally, as in most sound equipment, or both.

Cable, connectors, and circuits are all rated in amps according to size.

Cable

There are many types of cable, but the electrical code allows only certain types to be used. Stage use is very hard on equipment. Cable may be walked on, runover by scenery or vehicles, pulled and dragged, and pinched. The emphasis is therefore on flexibility and durability.

For single circuit used, ONLY type S or SO cables are permitted. Type S is a heavy-duty rubber covered cable. Type SO is a heavy duty Neoprene (synthetic rubber, oil resistant) covered cable. It must be a three wire cable, with black, white and green conductors. Type SJ, with a lighter weight rubber covering, is specifically NOT permitted. For single conductor feeder cable use, welding cable was once common is specifically NOT permitted. It must be Types SC, SCE, PPE or similar Entertainment and Stage Cable, which has an extra-heavy duty cover and very flexible wire inside.

Wire gauge	**Ampacity**
#18	7 a.
#16	10 a.
#14	15 a.
#12	20 a.
#10	25 a.
#00 (2/0)	300 a.
#0000 (4/0)	405 a.

These are approximate values for the cables typically used in theatre. Other types and methods may be rated differently.

Connectors

Connectors allow temporary connections to be made and broken quickly and safely. Male connectors have exposed contacts. Female connectors have internal contacts inside an insulating shell with holes for plugging the two together. Think biology.

The male is always on the load side of a connection, the female on the line side; "the female has the power!"

parallel Blade (Edison): the standard household plug, this is found on much equipment but is not durable enough for stage lights. The standard configuration, two parallel blades and a U-ground, is rated at 15 a. only. Usually the"hot" terminal is copper colored and the "neutral" is silver colored, and the "ground" is green.

Stage Pin (a.k.a. NEMA designation, 5T-20): has round 1/4" pins, and is very durable. Most common dedicated stage connector. Rated at 20 a. The center pin is "ground", the outside pin nearest the ground is the "neutral", and the other is the "hot".

3-pin Twist Lock (a.k.a. NEMA L5-20): has three curved blades which are locked into the receptacle by rotating it 1/8 turn after insertion. Rated at 20 a. One blade has a tab bent towards center; that is the ground. The slightly larger blade with silver screw is "neutral", and the small blade with the copper screw is "hot".

Cam-locks: single wire connector for large wire, 2/0 or 4/0. Locked in place by rotating 1/2 turn after insertion. Comes in colors to indicate which leg is which. Rated at over 400 a. In most common size on stage. Also available in a mini-cam size for #1 cable, rated at 100 a.

Cable Accessories:

Two-fers: Y-cord with one male and two female connectors, for plugging two devices into one outlet.

Three-fers: same thing, 3 females.

Adaptors: a male connector on one end and a female of a different type on the other. Used to plug a device into a different type of outlet.

POWER DISTRIBUTION

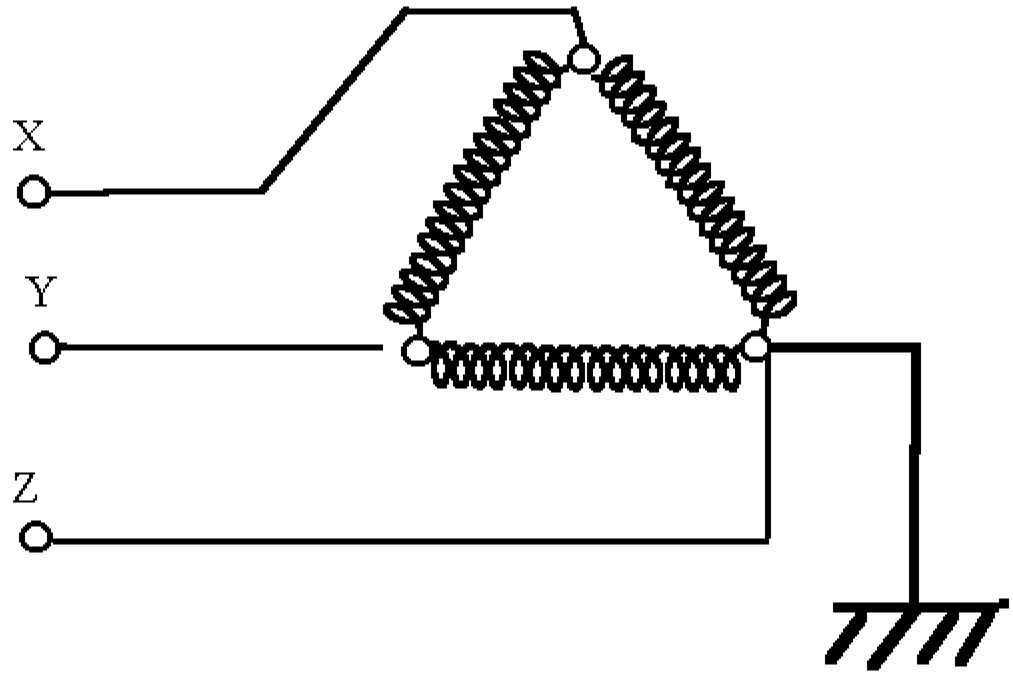
There are broadly two form in which electricity can be generated, Direct Current and Alternating current. **Direct Current** is the type of electricity supplied by a battery. One terminal is positively charged, the other negatively charged, and electricity flows from one to the other, always in the same direction. However, while it is simple to make and control, DC does not travel well over long distances; it gets used up by the resistance in the transmission lines, and is gone before it gets to where it is needed.

Alternating Current also has a positive and a negative terminal, but the polarity and the direction of flow alternates many times per second. In the United States, electricity alternates polarity 120 times per second, or 60 full cycles per second, i.e. 60 Hz. AC can travel well over long distances, and so it the choice for power distribution lines.

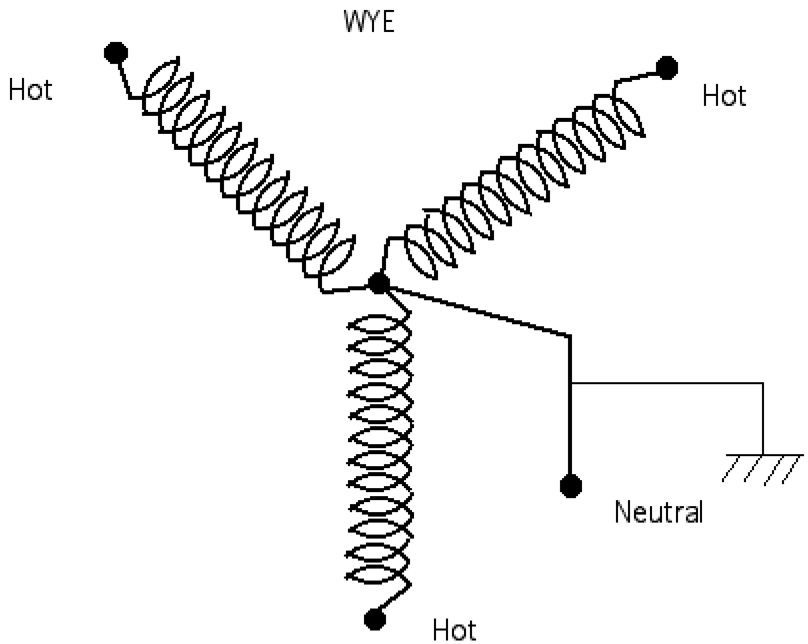
There is no difference between amps or volts between AC or DC. Some devices can ONLY operate on one type of system or the other, but otherwise a volt is a volt.

Road shows and concert tours typically bring in their own lighting and sound rigs, which means their dimmer racks and sound distribution boxes must be tied in to a power source able to supply large amounts of current.

Power is usually generated at a distance from where it is used. It is supplied as 3-phase power at very high voltages.This allows many kilowatts to flow through fairly small conductors because amperage is effectively small. There are 3 hots, each 120 degrees out-of-phase with the next when their sine waves are plotted against each other, hence the term "3 phase". There is no neutral. This configuration is called Delta, and is the same type (at much lower voltages) use to run 3-phase motors.

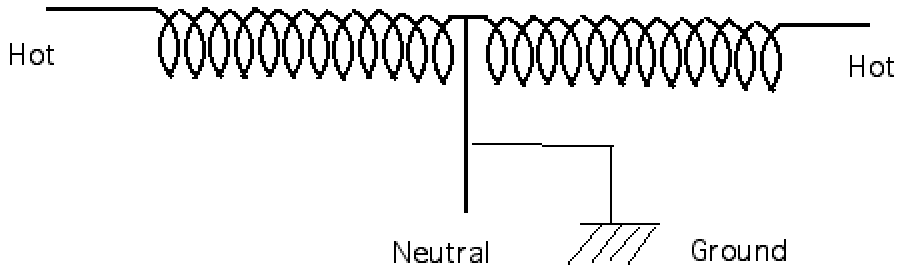


The power level is brought down through a series of substations. At each step transformers reduce the voltage and increase the amperage until it reaches the line transformers outside the building. At that point, the Delta service is converted to a Wye service, and is brought into the building at the "service entrance".



The Wye service has the same three hot legs, plus an electrical neutral created at the transformer. By this time in either Wye or Delta, the line voltage has been brought down to where each hot terminal is 120 volts above earth potential, called "ground", and in the case of a Wye service, each hot is also 120 v. above the Neutral as well. However, due to the geometry of the hot phases, there is a difference of 208 v. (not 240 v.) between any two hots in either type of 3-phase system.

This is different from the Single-phase system found in some older theatres, and commonly in private homes.



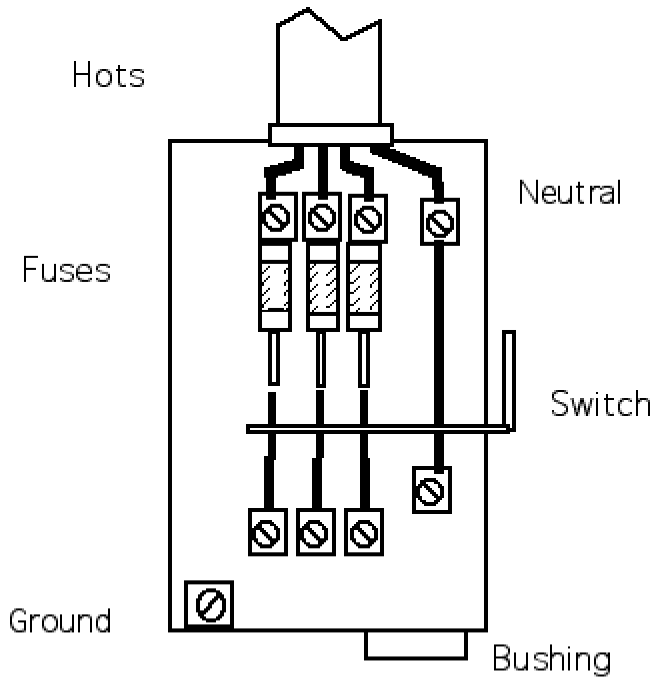
In this service two hots are drawn from each end of one phase of a Delta (hence Single phase), and a neutral created at the transformer. These are brought into the building at the service entrance. Between either hot and the neutral there is 120 v., just as in the Wye system. However, there is 240 v., not 208 v, between the two hots. Single phase is rarely found in industry, including theatre, because it is not as efficient for supplying the large amounts of power needed.

At the service entrance the Neutral of the Wye (or of a single phase) system must be bonded to a grounding system buried in the earth outside. It is VERY important that the ground and neutral NOT be connected at any other point, or an unsafe situation could be created.

Tying in Power

When in comes to permanent commercial wiring, the Electrical Code requires that only licensed electricians do the work. However, the Code has an exemption for the Entertainment industry. "Qualified Personnel" are allowed to make TEMPORARY hookups to an electrical service. That means that a qualified stagehand can tie a portable dimmer rack to a distribution box, but cannot run permanent wires to that box OR install a PERMANENT dimmer rack. The key phrase is "Qualified personnel". Only stagehands have who been trained to do so are allowed to make hookups. The Code also grants another exemption to theatre not found in other industries. Theatre is allowed to use single conductors and connectors (that is feeder cable with Camlock connectors). But as it is VITAL that the connections be made in the proper order, only trained and qualified personnel are permitted to make those connections.

The distribution box where temporary equipment is tied in to the electrical supply is called a Company Switch, a Distro, or a "Bull switch".



Inside the distro are lugs for connecting the wires. There are three lugs for connecting the "hot" wires, each of which is connected to a fuse or a circuit breaker. They are typically referred to as Leg A, B, and C; or leg X, Y, and Z. They may be black or marked with any color EXCEPT White, light grey, or green. There is also a lug for the Neutral, which does NOT have a fuse or breaker, which MUST be marked white or light grey, and a lug for the Ground wire, which is usually bolted directly to the metal distro box. (According to Code, the box and its conduit are suppose to be grounded, but if they are not, a separate grounding wire, marked with green, must be run to the box.) There will also be an access hole through which the temporary wires are passed. The hole should have a bushing to prevent the box from cutting through the insulation of the wire.

The proper procedure MUST be followed when connecting the cables, or an unsafe situation can occur. DO NOT TAKE SHORTCUTS!

- Lay out the feeder tails so they are ready to be connected. NOTE: Code requires the use tails which can be disconnected within 10 feet of the distro box). The tails should NOT be connected to the feeder cables yet.
- Turn off the bull switch if it is not already off (the box will not open if the switch is on unless the box is broken). Open the box and MAKE SURE the "hot" terminals are really "dead" using a meter or tester.
- Insert the Green tail wire and fasten securely to the ground lug.
- Insert the White white and fasten to the Neutral lug.
- Insert the Hot tails one at a time and attach them securely to the three "hot" terminals, the ones attached to the fuses or breakers. These wires are usually marked with Black, Red, and Blue. It does not really matter at this point which wire is connected to which hot terminal, but the convention is usually in the order: Black, Red, Blue.
- Close the box and make sure the connectors on the tails are clear. Turn on the Bull switch.
- Test each wire with a meter by carefully inserting the leads from the meter into the open feeder connectors. You should get:
    - Between Neutral and Ground: 0 volts.
    - Between each Hot wire and Neutral: 120 v.
    - Between each Hot wire and the Ground: 120 v.
    - Between each Hot and any other Hot: 208 v.

  If you get ANY OTHER READINGS, check your wiring again!

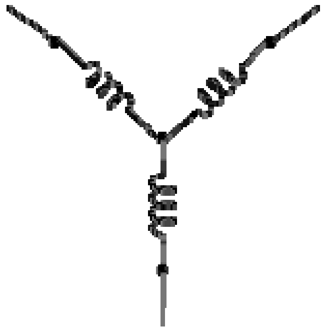
- If everything checks OK, turn off the Bull switch and inform the road electrician.

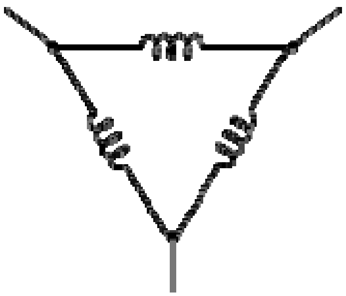
When the feeder cables are connected to the dimmer rack or sound distro, and when the feeders are connected to the tails, **CONNECT THEM IN THE SAME ORDER!**, That is: **first Green, then White, then the three Hots.** Connect them with the power turned off but always treat them as though the power is on anyway. Someday it may be!

Also, **NEVER PLUG THE HOTS IN FIRST!** The equipment may try to close a circuit through two hots and put 208 v. through a circuit meant for 120 v., and destroy the equipment, or worse yet electrocute someone!

Delta and Wye 3-phase circuits

- Phase voltage
- Line voltage
- Phase current
- Line current



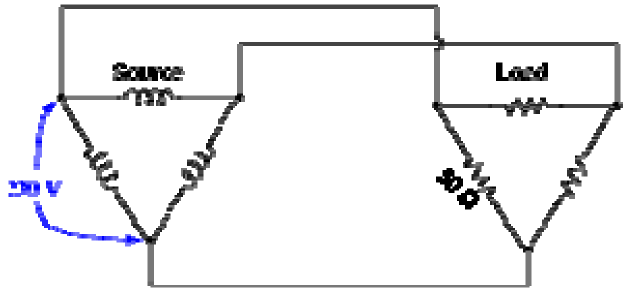


In which circuit (Y or Delta) are the phase and line currents equal? In which circuit (Y or Delta) are the phase and line voltages equal? Explain both answers, in terms that anyone with a basic knowledge of electricity could understand.
Where phase and line quantities are *un*equal, determine which is larger.

Explain the difference between a *balanced* polyphase system and an *unbalanced* polyphase system. What conditions typically cause a polyphase system to become unbalanced?

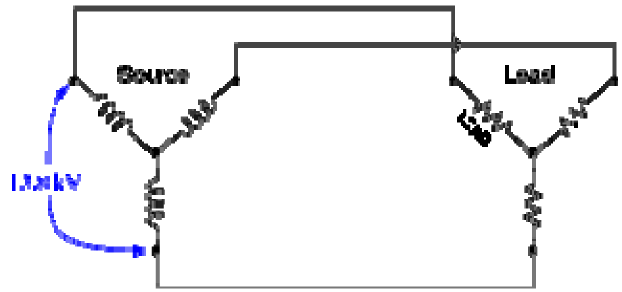
In a balanced Y-connected power system, calculate the phase voltage (E_{phase}) if the line voltage (E_{line}) is 480 volts.

Calculate all voltages, currents, and total power in this balanced Delta-Delta system:

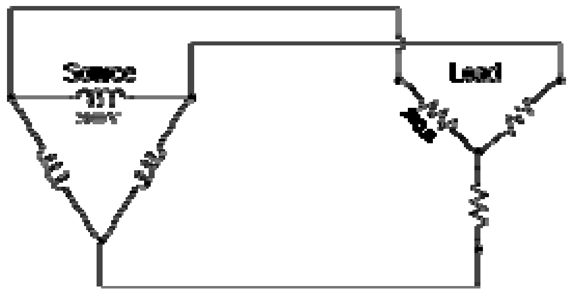


Question 5:

Calculate all voltages, currents, and total power in this balanced Y-Y system:

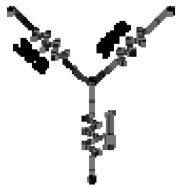


Calculate all voltages, currents, and total power in this balanced Delta-Y system:



Question 8:

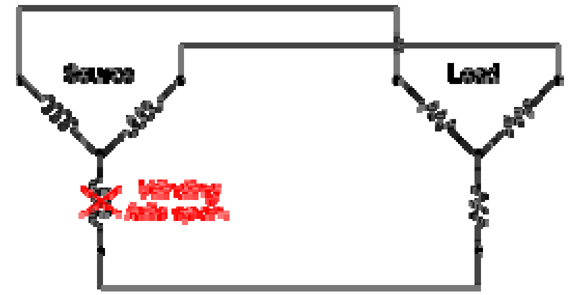
What resistor values would we have to choose in a Delta configuration to behave exactly the same as this Y-connected resistor network?

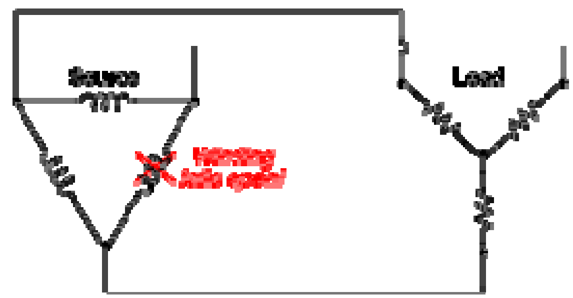


Reveal Answer

Question 9:

What will happen in each of these systems to the phase voltages of the load, if one of the source phases fails open?

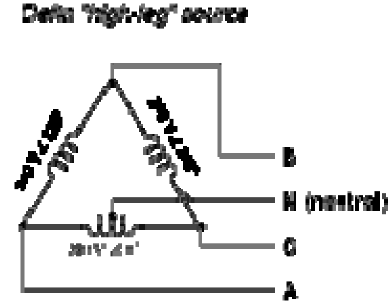




[Reveal Answer]

Question 10:

A common three-phase source connection scheme is the *Delta high-leg* or *Four-wire Delta*, where each phase coil outputs 240 volts:

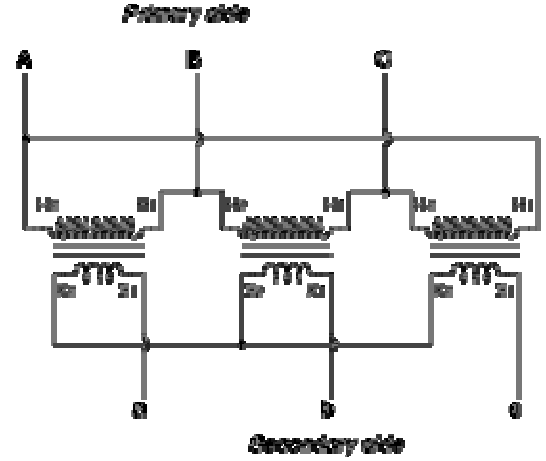


Identify the different voltages obtained from this coil configuration, and which connection points each voltage is measured between.

Reveal Answer

Question 11:

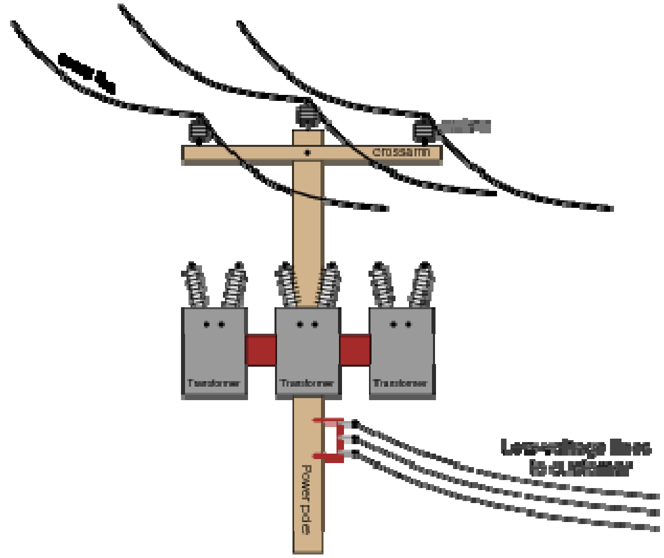
Identify the primary-secondary connection configuration of these three power transformers (i.e. Y-Y, Y-Delta, Delta-Y, etc.):



[Reveal Answer]

Question 12:

An electrical lineman is connecting three single-phase transformers in a Y(primary)-Y(secondary) configuration, for power service to a business. Draw the connecting wires necessary between the transformer windings, and between the transformer terminals and the lines:

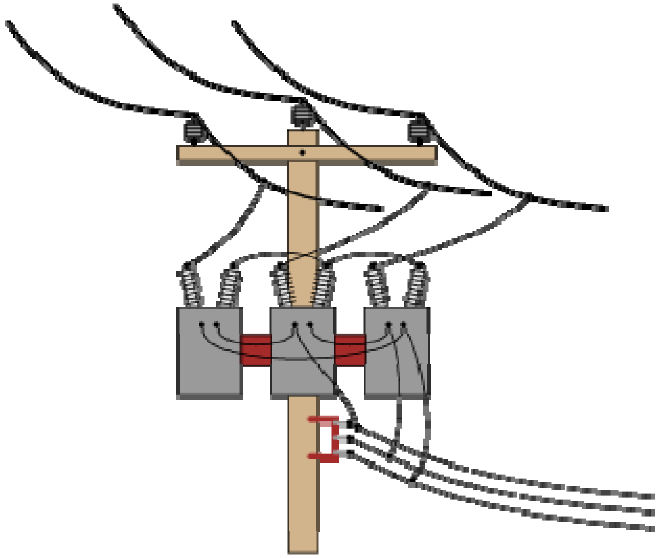


Note: fuses have been omitted from this illustration, for simplicity.

Reveal Answer

Question 13:

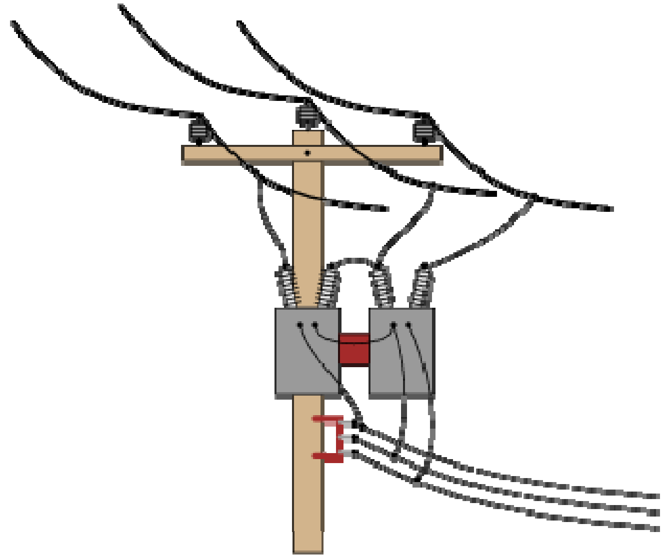
Identify the primary-secondary connection configuration of these pole-mounted power transformers (i.e. Y-Y, Y-Delta, Delta-Y, etc.):



Reveal Answer

Question 14:

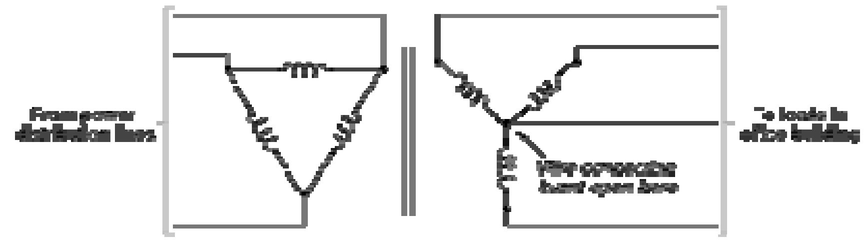
Identify the primary-secondary connection configuration of these pole-mounted power transformers (i.e. Y-Y, Y-Delta, Delta-Y, etc.):



Reveal Answer

Question 15:

One of the conductors connecting the secondary of a three-phase power distribution transformer to a large office building fails open. Upon inspection, the source of the failure is obvious: the wire overheated at a point of contact with a terminal block, until it physically separated from the terminal.



What is strange, though, is that the overheated wire is the *neutral* conductor, not any one of the "line" conductors. Based on this observation, what do you think caused the failure?
After repairing the wire, what would you do to verify the cause of the failure?

Basic Motor Formulas And Calculations

The formulas and calculations which appear below should be used for estimating purposes only. It is the responsibility of the customer to specify the required motor Hp, Torque, and accelerating time for his application. The salesman may wish to check the customers specified values with the formulas in this section, however, if there is serious doubt concerning the customers application or if the customer requires guaranteed motor/application performance, the Product Department Customer Service group should be contacted.

Rules Of Thumb (Approximation)

At 1800 rpm, a motor develops a 3 lb.ft. per hp
At 1200 rpm, a motor develops a 4.5 lb.ft. per hp
At 575 volts, a 3-phase motor draws 1 amp per hp
At 460 volts, a 3-phase motor draws 1.25 amp per hp
At 230 volts a 3-phase motor draws 2.5 amp per hp
At 230 volts, a single-phase motor draws 5 amp per hp
At 115 volts, a single-phase motor draws 10 amp per hp

Mechanical Formulas

$$\text{Torque in lb.ft.} = \frac{\text{HP} \times 5250}{\text{rpm}} \qquad \text{HP} = \frac{\text{Torque} \times \text{rpm}}{5250} \qquad \text{rpm} = \frac{120 \times \text{Frequency}}{\text{No. of Poles}}$$

Temperature Conversion

Deg C = (Deg F - 32) x 5/9
Deg F = (Deg C x 9/5) + 32

High Inertia Loads

$$t = \frac{WK^2 \text{ x rpm}}{308 \text{ x T av.}}$$

$$T = \frac{WK^2 \text{ x rpm}}{308 \text{ x t}}$$

WK^2 = inertia in lb.ft.^{2}
t = accelerating time in sec.
T = Av. accelerating torque lb.ft..

$$\text{inertia reflected to motor} = \text{Load Inertia} \left(\frac{\text{Load rpm}}{\text{Motor rpm}} \right)^2$$

Synchronous Speed, Frequency And Number Of Poles Of AC Motors

$$n_s = \frac{120 \text{ x f}}{P} \qquad f = \frac{P \text{ x } n_s}{120} \qquad P = \frac{120 \text{ x f}}{n_s}$$

Relation Between Horsepower, Torque, And Speed

$$HP = \frac{T \text{ x n}}{5250} \qquad T = \frac{5250 \text{ HP}}{n} \qquad n = \frac{5250 \text{ HP}}{T}$$

Motor Slip

$$\% \text{ Slip} = \frac{n_s - n}{n_s} \text{ x } 100$$

Code	KVA/HP		Code	KVA/HP		Code	KVA/HP		Code	KVA/HP
A	0-3.14		F	5.0 -5.59		L	9.0-9.99		S	16.0-17.99
B	3.15-3.54		G	5.6 -6.29		M	10.0-11.19		T	18.0-19.99
C	3.55-3.99		H	6.3 -7.09		N	11.2-12.49		U	20.0-22.39

D	4.0 -4.49		I	7.1 -7.99		P	12.5-13.99		V	22.4 & Up
E	4.5 -4.99		K	8.0 -8.99		R	14.0-15.99			

Symbols

I = current in amperes
E = voltage in volts
KW = power in kilowatts
KVA = apparent power in kilo-volt-amperes
HP = output power in horsepower
n = motor speed in revolutions per minute (RPM)
ns = synchronous speed in revolutions per minute (RPM)
P = number of poles
f = frequency in cycles per second (CPS)
T = torque in pound-feet
EFF = efficiency as a decimal
PF = power factor as a decimal

Equivalent Inertia

In mechanical systems, all rotating parts do not usually operate at the same speed. Thus, we need to determine the "equivalent inertia" of each moving part at a particular speed of the prime mover.

The total equivalent WK^2 for a system is the sum of the WK^2 of each part, referenced to prime mover speed.

The equation says:

$$WK^2_{EQ} = WK^2_{part} \left(\frac{N_{part}}{N_{prime\ mover}} \right)^2$$

This equation becomes a common denominator on which other calculations can be based. For variable-speed devices, inertia should be calculated first at low speed.

Let's look at a simple system which has a prime mover (PM), a reducer and a load.

$WK^2 = 100$ lb.ft.^{2}		$WK^2 = 900$ lb.ft.^{2} (as seen at output shaft)		$WK^2 = 27{,}000$ lb.ft.^{2}
PRIME MOVER		3:1 GEAR REDUCER		LOAD

The formula states that the system WK^2 equivalent is equal to the sum of WK^2_{parts} at the prime mover's RPM, or in this case:

$$WK^2_{EQ} = WK^2_{pm} + WK^2_{Red.}\left(\frac{\text{Red. RPM}}{P_M\text{ RPM}}\right)^2 + WK^2_{Load}\left(\frac{\text{Load RPM}}{\text{PM RPM}}\right)^2$$

Note: reducer RPM = Load RPM

$$WK^2_{EQ} = WK^2_{pm} + WK^2_{Red.}\left(\frac{1}{3}\right)^2 + WK^2_{Load}\left(\frac{1}{3}\right)^2$$

The WK^2 equivalent is equal to the WK^2 of the prime mover, plus the WK^2 of the load. This is equal to the WK^2 of the prime mover, plus the WK^2 of the reducer times $(1/3)^2$, plus the WK^2 of the load times $(1/3)^2$.

This relationship of the reducer to the driven load is expressed by the formula given earlier:

$$WK^2_{EQ} = WK^2_{part} \left(\frac{N_{part}}{N_{prime\ mover}} \right)^2$$

In other words, when a part is rotating at a speed (N) different from the prime mover, the WK^2_{EQ} is equal to the WK^2 of the part's speed ratio squared.

In the example, the result can be obtained as follows:

The WK^2 equivalent is equal to:

$$WK^2_{EQ} = 100 \text{ lb.ft.}^2 + 900 \text{ lb.ft.}^2 \left(\frac{1}{3} \right)^2 + 27{,}000 \text{ lb.ft.}^2 \left(\frac{1}{3} \right)^2$$

Finally:

$$WK^2_{EQ} = \text{lb.ft.}^2_{pm} + 100 \text{ lb.ft.}^2_{Red} + 3{,}000 \text{ lb.ft}^2_{Load}$$

$$WK^2_{EQ} = 3200 \text{ lb.ft.}^2$$

The total WK^2 equivalent is that WK^2 seen by the prime mover at its speed.

Electrical Formulas

To Find	Alternating Current	
	Single-Phase	Three-Phase
Amperes when horsepower is known	HP x 746	HP x 746

	E x Eff x pf	1.73 x E x Eff x pf
Amperes when kilowatts are known	$\frac{\text{Kw x 1000}}{\text{E x pf}}$	$\frac{\text{Kw x 1000}}{\text{1.73 x E x pf}}$
Amperes when kva are known	$\frac{\text{Kva x 1000}}{\text{E}}$	$\frac{\text{Kva x 1000}}{\text{1.73 x E}}$
Kilowatts	$\frac{\text{I x E x pf}}{1000}$	$\frac{\text{1.73 x I x E x pf}}{1000}$
Kva	$\frac{\text{I x E}}{1000}$	$\frac{\text{1.73 x I x E}}{1000}$
Horsepower = (Output)	$\frac{\text{I x E x Eff x pf}}{746}$	$\frac{\text{1.73 x I x E x Eff x pff}}{746}$

I = Amperes; E = Volts; Eff = Efficiency; pf = Power Factor; Kva = Kilovolt-amperes; Kw = Kilowatts

Locked Rotor Current (I_L) From Nameplate Data

Three Phase: $I_L = \frac{\text{577 x HP x KVA/HP}}{\text{E}}$

Single Phase: $I_L = \frac{\text{1000 x HP x KVA/HP}}{\text{E}}$

See: KVA/HP Chart

EXAMPLE: Motor nameplate indicates 10 HP, 3 Phase, 460 Volts, Code F.

I_L = 577 x 10 x (5.6 or 6.29)

460

I_L = 70.25 or 78.9 Amperes (possible range)

Effect Of Line Voltage On Locked Rotor Current (I_L) (Approx.)

$$I_L @ E_{LINE} = I_L @ E_{N/P} \times \frac{E_{LINE}}{E_{N/P}}$$

EXAMPLE: Motor has a locked rotor current (inrush of 100 Amperes (I_L) at the rated nameplate voltage ($E_{N/P}$) of 230 volts.

What is I_L with 245 volts (E_{LINE}) applied to this motor?

I_L @ 245 V. = 100 x 254V/230V

I_L @ 245V. = 107 Amperes

Basic Horsepower Calculations

Horsepower is work done per unit of time. One HP equals 33,000 ft-lb of work per minute. When work is done by a source of torque (T) to produce (M) rotations about an axis, the work done is:

radius x 2 πx rpm x lb. or 2 πTM

When rotation is at the rate N rpm, the HP delivered is:

$$HP = \frac{\text{radius} \times 2\pi \times \text{rpm} \times \text{lb.}}{33{,}000} = \frac{TN}{5{,}250}$$

For vertical or hoisting motion:

$$HP = \frac{W \times S}{33{,}000 \times E}$$

Where:

W = total weight in lbs. to be raised by motor
S = hoisting speed in feet per minute
E = overall mechanical efficiency of hoist and gearing. For purposes of estimating
E = .65 for eff. of hoist and connected gear.

For fans and blowers:

$$HP = \frac{\text{Volume (cfm) x Head (inches of water)}}{\text{6356 x Mechanical Efficiency of Fan}}$$

Or

$$HP = \frac{\text{Volume (cfm) x Pressure (lb. Per sq. ft.)}}{\text{3300 x Mechanical Efficiency of Fan}}$$

Or

$$HP = \frac{\text{Volume (cfm) x Pressure (lb. Per sq. in.)}}{\text{229 x Mechanical Efficiency of Fan}}$$

For purpose of estimating, the eff. of a fan or blower may be assumed to be 0.65.

Note: Air Capacity (cfm) varies directly with fan speed. Developed Pressure varies with square of fan speed. Hp varies with cube of fan speed.

For pumps:

$$HP = \frac{\text{GPM x Pressure in lb. Per sq. in. x Specific Grav.}}{\text{1713 x Mechanical Efficiency of Pump}}$$

Or

$$HP = \frac{\text{GPM x Total Dynamic Head in Feet x S.G.}}{\text{3960 x Mechanical Efficiency of Pump}}$$

where Total Dynamic Head = Static Head + Friction Head

For estimating, pump efficiency may be assumed at 0.70.

Accelerating Torque

The equivalent inertia of an adjustable speed drive indicates the energy required to keep the system running. However, starting or accelerating the system requires extra energy.

The torque required to accelerate a body is equal to the WK^2 of the body, times the change in RPM, divided by 308 times the interval (in seconds) in which this acceleration takes place:

$$\text{ACCELERATING TORQUE} = \frac{WK^2N \text{ (in lb.ft.)}}{308t}$$

Where:

N = Change in RPM
W = Weight in Lbs.
K = Radius of gyration
t = Time of acceleration (secs.)
WK^2 = Equivalent Inertia
308 = Constant of proportionality

Or

$$T_{Acc} = \frac{WK^2N}{308t}$$

The constant (308) is derived by transferring linear motion to angular motion, and considering acceleration due to gravity. If, for example, we have simply a prime mover and a load with no speed adjustment:

Example 1

PRIME LOADER		LOAD
WK^2 = 200 lb.ft.^{2}		WK^2 = 800 lb.ft.^{2}

The WK^2_{EQ} is determined as before:

$$WK^2_{EQ} = WK^2_{pm} + WK^2_{Load}$$

$$WK^2_{EQ} = 200 + 800$$

$$WK^2_{EQ} = 1000 \text{ ft.lb.}^2$$

If we want to accelerate this load to 1800 RPM in 1 minute, enough information is available to find the amount of torque necessary to accelerate the load.

The formula states:

$$T_{Acc} = \frac{WK^2_{EQ}N}{308t} \text{ or } \frac{1000 \times 1800}{308 \times 60} \text{ or } \frac{1800000}{18480}$$

$$T_{Acc} = 97.4 \text{ lb.ft.}$$

In other words, 97.4 lb.ft. of torque must be applied to get this load turning at 1800 RPM, in 60 seconds.

Note that T_{Acc} is an average value of accelerating torque during the speed change under consideration. If a more accurate calculation is desired, the following example may be helpful.

Example 2

The time that it takes to accelerate an induction motor from one speed to another may be found from the following equation:

$$t = \frac{WR^2 \times \text{change in rpm}}{308 \times T}$$

Where:

T = Average value of accelerating torque during the speed change under consideration.

t = Time the motor takes to accelerate from the initial speed to the final speed.

WR_2 = Flywheel effect, or moment of inertia, for the driven machinery plus the motor rotor in lb.ft.^{2} (WR^2 of driven machinery must be referred to the motor shaft).

The Application of the above formula will now be considered by means of an example. Figure A shows the speed-torque curves of a squirrel-cage induction motor and a blower which it drives. At any speed of the blower, the difference between the torque which the motor can deliver at its shaft and the torque required by the blower is the torque available for acceleration. Reference to Figure A shows that the accelerating torque may vary greatly with speed. When the speed-torque curves for the motor and blower intersect there is no torque available for acceleration. The motor then drives the blower at constant speed and just delivers the torque required by the load.

In order to find the total time required to accelerate the motor and blower, the area between the motor speed-torque curve and the blower speed-torque curve is divided into strips, the ends of which approximate straight lines. Each strip corresponds to a speed increment which takes place within a definite time interval. The solid horizontal lines in Figure A represent the boundaries of strips; the lengths of the broken lines the average accelerating torques for the selected speed intervals. In order to calculate the total acceleration time for the motor and the direct-coupled blower it is necessary to find the time required to accelerate the motor from the beginning of one speed interval to the beginning of the next interval and add up the incremental times for all intervals to arrive at the total acceleration time. If the WR^2 of the motor whose speed-torque curve is given in Figure A is 3.26 ft.lb.^{2} and the WR^2 of the blower referred to the motor shaft is 15 ft.lb.^{2}, the total WR^2 is:

$15 + 3.26 = 18.26$ ft.lb.^{2},

And the total time of acceleration is:

$$\frac{WR^2}{308}\left[\frac{rpm_1}{T_1} + \frac{rpm_2}{T_2} + \frac{rpm_3}{T_3} + \text{- - - - - - - - - -} + \frac{rpm_9}{T_9}\right]$$

Or

$$t = \frac{18.26}{308}\left[\frac{150}{46} + \frac{150}{48} + \frac{300}{47} + \frac{300}{43.8} + \frac{200}{39.8} + \frac{200}{36.4} + \frac{300}{32.8} + \frac{100}{29.6} + \frac{40}{11}\right]$$

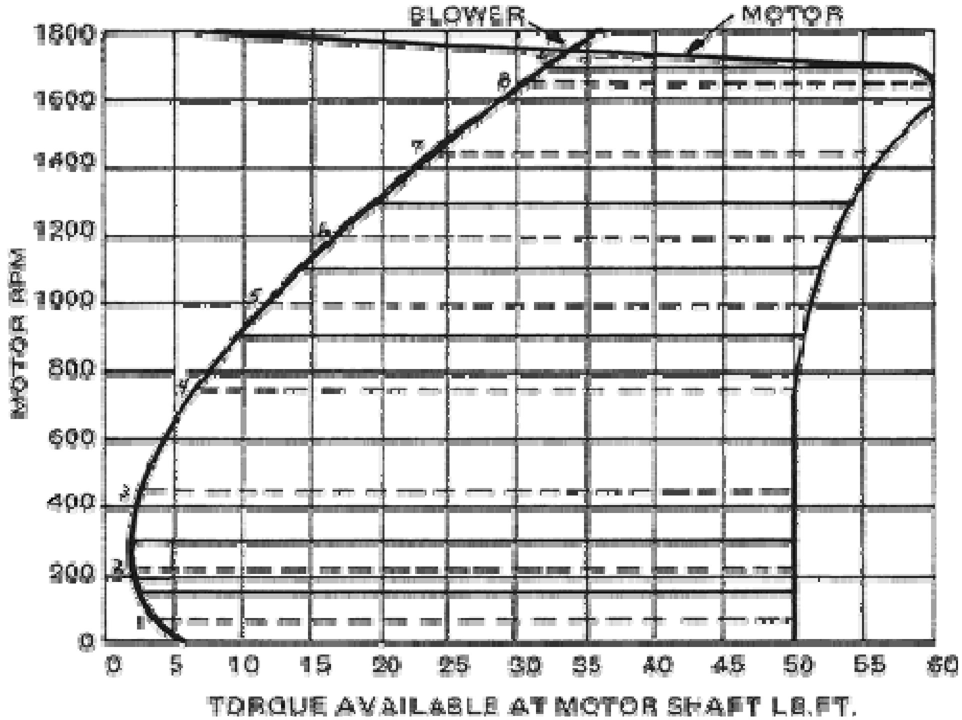
$t = 2.75$ sec.

Figure A

Curves used to determine time required to accelerate induction motor and blower

Accelerating Torques

$T_1 = 46$ lb.ft.	$T_4 = 43.8$ lb.ft.	$T_7 = 32.8$ lb.ft.
$T_2 = 48$ lb.ft.	$T_5 = 39.8$ lb.ft.	$T_8 = 29.6$ lb.ft.
$T_3 = 47$ lb.ft.	$T_6 = 36.4$ lb.ft.	$T_9 = 11$ lb.ft.



Duty Cycles

Sales Orders are often entered with a note under special features such as:

"Suitable for 10 starts per hour"

Or

"Suitable for 3 reverses per minute"

Or

"Motor to be capable of accelerating 350 lb.ft.^{2}"

Or

"Suitable for 5 starts and stops per hour"

Orders with notes such as these can not be processed for two reasons.

1. The appropriate product group must first be consulted to see if a design is

available that will perform the required duty cycle and, if not, to determine if the type of design required falls within our present product line.

2. None of the above notes contain enough information to make the necessary duty cycle calculation. In order for a duty cycle to be checked out, the duty cycle information must include the following:
    a. Inertia reflected to the motor shaft.
    b. Torque load on the motor during all portions of the duty cycle including starts, running time, stops or reversals.
    c. Accurate timing of each portion of the cycle.
    d. Information on how each step of the cycle is accomplished. For example, a stop can be by coasting, mechanical braking, DC dynamic braking or plugging. A reversal can be accomplished by plugging, or the motor may be stopped by some means then re-started in the opposite direction.
    e. When the motor is multi-speed, the cycle for each speed must be completely defined, including the method of changing from one speed to another.
    f. Any special mechanical problems, features or limitations.

Obtaining this information and checking with the product group before the order is entered can save much time, expense and correspondence.

Duty cycle refers to the detailed description of a work cycle that repeats in a specific time period. This cycle may include frequent starts, plugging stops, reversals or stalls. These characteristics are usually involved in batch-type processes and may include tumbling barrels, certain cranes, shovels and draglines, dampers, gate- or plow-positioning drives, drawbridges, freight and personnel elevators, press-type extractors, some feeders,presses of certain types, hoists, indexers, boring machines,cinder block machines, keyseating, kneading, car-pulling, shakers (foundry or car), swaging and washing machines, and certain freight and passenger vehicles. The list is not all-inclusive. The drives for these loads must be capable of absorbing the heat generated during the duty cycles. Adequate thermal capacity would be required in slip couplings, clutches or motors to accelerate or plug-stop these drives or to withstand stalls. It is the product of the slip speed and the torque absorbed by the load per unit of time which generates heat in these drive components. All the events which occur during the duty cycle generate heat which the drive components must dissipate.

Because of the complexity of the Duty Cycle Calculations and the extensive engineering data per specific motor design and rating required for the calculations, it is necessary for the sales engineer to refer to the Product Department for motor sizing with a duty cycle application

ELECTRICAL UNIT CONVERSIONS

The purpose of this document is to provide information, formulas and documentation to take certain electrical values and convert them into other electrical values. The formulas below are known and used universally but we use them here in association with computer, network, telecom and other IT equipment.

Background

It is often necessary to turn voltage, amperage and electrical "nameplate" values from computer, network and telecom equipment into kW, KVA and BTU information that can be used to calculate overall power and HVAC loads for IT spaces. The following describes how to take basic electrical values and convert them into other types of electrical values.

- NOTE #1:
  The informational nameplates on most pieces of computer or network equipment usually display electrical values. These values can be expressed in volts, amperes, kilovolt-amperes, watts or some combination of the foregoing.
- NOTE #2:
  If you are using equipment nameplate information to develop a power and cooling profile for architects and engineers, the total power and cooling values will exceed the actual output of the equipment. Reason: the nameplate value is designed to ensure that the equipment will energize and run safely. Manufacturers build in a "safety factor" when developing their nameplate data. Some nameplates display information that is higher than the equipment will ever need - often up to 20% higher. The result is that, in total, your profile will "over engineer" the power and cooling equipment. Electrical and mechanical engineers may challenge your figures citing that nameplates require more power than necessary.
- NOTE #3:
  Our advice: Develop the power and cooling profile using the nameplate information and the formulas below and use the resultant documentation as your baseline. Reasons: (1) it's the best information available without doing extensive electrical tests on each piece of equipment. Besides, for most projects, you are being asked to predict equipment requirements 3-5 years out when much of the equipment you will need hasn't been invented yet. (2) the engineers will not duplicate your work; they do not know what goes into a data center. They will only challenge the findings if they appear to be to high. If the engineers want to challenge your figures, it's OK but have them do it in writing and let them take full responsibility for any modifications. If you must lower your estimates, do so. But, document everything. There

will come a day in 3-5 years when you will need every amp of power you predicted. We've had projects where it was very evident within six months that what we predicted would come true - sometimes even earlier than we estimated.

- NOTE #4
  If you are designing a very high-density server room where you will have racks and racks (or cabinets and cabinets) of 1U and 2U servers tightly packed, you need to read our article entitled "IT Pros - Don't be Left in the Dust on IT Server Room Design".

To Find Watts

1. When Volts and Amperes are Known

POWER (WATTS) = VOLTS x AMPERES

- We have a small server with a nameplate shows 2.5 amps. Given a normal 120 Volt, 60 hz power source and the ampere reading from equipment, make the following calculation:

POWER (WATTS) = 120 * 2.5 ANSWER: 300 WATTS

To Find Volt-Amperes (VA)

1. Same as above. VOLT-AMPERES (VA) = VOLTS x AMPERES ANS: 300 VA

To Find kilovolt-Amperes (kVA)

1. SINGLE PHASE

KILOVOLT-AMPERES (kVA) = VOLTS x AMPERES
1000

Using the previous example: 120 * 2.5 = 300 VA 300 VA / 1000 = .3 kVA

2. 208-240 SINGLE-PHASE (2-POLE SINGLE-PHASE)

- Given: We have a Sun server with an amp rating of 4.7 and requiring a 208-240 power source. We'll use 220 volts for our calculations.

KILOVOLT-AMPERES (kVA) = VOLTS x AMPERES
1000

220 x 4.7 = 1034 1034 / 1000 = 1.034 kVA

3. THREE-PHASE

- Given: We have a large EMC Symmetrix 3930-18/-36 storage system with 192 physical volumes. EMC's website shows a requirement for a 50-amp 208 VAC receptacle. For this calculation, we will use 21 amps. Do not calculate any value for the plug or receptacle.

KILOVOLT-AMPERES (kVA) = VOLTS x AMPERES x 1.73
1000

208 x 21 x 1.73 = 7,556.64 7,556.64 / 1000 = 7.556 kVA

To Find Kilowatts

- Finding Kilowatts is a bit more complicated in that the formula includes a value for the "power factor". The power factor is a nebulous but required value that is different for each electrical device. It involves the efficiency in the use of of the electricity supplied to the system. This factor can vary widely from 60% to 95% and is never published on the equipment nameplate and further, is not often supplied with product information. For purposes of these calculations, we use a power factor of .85. This arbitrary number places a slight inaccuracy into the numbers. Its OK and it gets us very close for the work we need to do.

1. SINGLE PHASE

Given: We have a medium-sized Compaq server that draws 6.0 amps.

KILOWATT (kW) = VOLTS x AMPERES x POWER FACTOR
1000

120 * 6.0 = 720 VA 720 VA * .85 = 612 612 / 1000 = .612 kW

2. TWO-PHASE

- Given: We have a Sun server with an amp rating of 4.7 and requiring a 208-240 power source. We'll use 220 volts for our calculations.

KILOWATT (kW) = VOLTS x AMPERES x POWER FACTOR x 2
1000

220 x 4.7 x 2 = 2068 2068 x .85 = 1757.8 1757.8 / 1000 = 1.76 kW

3. THREE-PHASE

- Given: We have a large EMC Symmetrix 3930-18/-36 storage system with 192 physical volumes. EMC's website shows a requirement for a 50-amp 208 VAC receptacle. For this calculation, we will use 22 amps. Do not calculate the value of the plug or receptacle. Use the value on nameplate.

KILOWATT (kW) = VOLTS x AMPERES x POWER FACTOR x 1.73
1000

208x22x1.73 = 7,916.48 7,916.48 * .85 = 6,729.008 6,729.008/1000=6.729 kW

To Convert Between kW and kVA

- The only difference between kW and kVA is the power factor. Once again, the power factor, unless known, is an approximation. For purposes of our calculations, we use a power factor of .85. The kVA value is always higher than the value for kW.

kW to kVA kW / .85 = SAME VALUE EXPRESSED IN kVA
kVA TO kW kVA * .85 = SAME VALUE EXPRESSED IN kW

To Find BTUs From Electrical Values

- Known and Given: 1 kW = 3413 BTUs (or 3.413 kBTUs)
- The above is a generally known value for converting electrical values to BTUs. Many manufacturers publish kW, kVA and BTU in their equipment specifications. Often, dividing the BTU value by 3413 does not equal their published kW value. So much for knowns and givens. Where the information is provided by the manufacturer, use it. Where it is not, use the above formula.

Basic Electrical Theory for Ottawa Electricians

Series Direct Current Circuit Rules

Rule #1: The same current flows through each part of a series circuit.

Rule #2: Total Resistance of a series circuit is equal to the sum of the individual resistances.

Rule #3: The total voltage across a series circuit is equal to the sum of the individual voltage drops.

Rule #4: The voltage drop across a resistor in a series circuit is proportional to the size of the resistor.

Rule #5: The total power dissipated in a series circuit is equal to the sum of the individual power dissapations.

SUMMARY OF OHMS LAW FORMULAS

$$\text{AMPERES} = \frac{\text{VOLTS}}{\text{RESISTANCE}}$$

$$\text{RESISTANCE} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

VOLTS = AMPERES x RESISTANCE

Parallel Direct Current Circuit Rules

Rule #1: **The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.**

Rule #2: **The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.**

Rule #3: **The total current of a parallel circuit is equal to the sum of the currents of the individual branches of the circuit.**

Rule #4: **The total resistance of a parallel circuit is equal to the reciprocal of the sum of the reciprocals of the individual resistances of the circuit.**

Rule #5: **The total power dissipated in a parallel circuit is equal to the sum of the individual power dissapations.**

SUMMARY OF PARALLEL CIRCUIT RULES

TOTAL VOLTAGE =E(1) = E(2) = E(3) ...etc.

$$\text{TOTAL RESISTANCE} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

TO DETERMINE THE TOTAL RESISTANCE IN A PARALLEL CIRCUIT WHEN THE TOTAL CURRENT AND TOTAL VOLTAGE ARE UNKNOWN USE EITHER OF THE FOLLOWING FORMULAS:

$$RT = \frac{1}{\rule{4cm}{0.4pt}}$$

$$\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \text{......etc}$$

FOR TWO RESISTORS IN PARALLEL USE THIS FORMULA CALLED THE "PRODUCT OVER THE SUM"

$$RT = \frac{R(1) * R(2)}{R(1) + R(2)}$$

POWER IN SINGLE PHASE RESISTIVE CIRCUITS

WHERE POWER FACTOR IS 100 PERCENT

(THESE FORMULAS ARE COMMONLY USED TO SOLVE MOST CIRCUIT POWER PROBLEMS ON TESTS)

TO DETERMINE THE POWER CONSUMED BY AN INDIVIDUAL RESISTOR IN A SERIES CIRCUIT USE THIS FORMULA:

$$\text{POWER} = I^2 \times R$$

TO DETERMINE THE POWER CONSUMED BY AN INDIVIDUAL RESISTOR IN A PARALLEL CIRCUIT USE THIS FORMULA:

$$\text{POWER} = \frac{E^2}{R}$$

TO DETERMINE THE TOTAL POWER CONSUMED BY AN INDIVIDUAL CIRCUIT USE THIS FORMULA:

POWER = E (TOTAL VOLTAGE) x I (TOTAL CURRENT)

RULES OF THUMB:

- **THE TOTAL RESISTANCE OF RESISTORS IN PARALLEL IS ALWAYS LESS THAN THE VALUE OF ANY ONE RESISTOR.**
- **THE TOTAL RESISTANCE OF PARALLEL RESISTORS THAT ARE ALL THE SAME VALUE IS THAT VALUE DIVIDED BY THE NUMBER OF RESISTORS.**
- **ALWAYS USE THE PRODUCT OVER SUM RULE TO BREAK DOWN TWO PARALLEL RESISTORS INTO ONE RESISTOR. THIS IS MUCH EASIER THAN TRYING TO SOLVE LARGE ALGEBRAIC EXPRESSIONS.**
- **746 WATTS IS EQUAL TO ONE HORSEPOWER**
- **EFFICIENCY IS EQUAL TO OUTPUT DIVIDED BY INPUT**
- **IN INDUCTIVE CIRCUITS CURRENT LAGS VOLTAGE.**
- **IN CAPACITIVE CIRCUITS CURRENT LEADS VOLTAGE.**
- **POWER FACTOR IS A MEASURE OF HOW FAR CURRENT LEADS OR LAGS VOLTAGE.**

POWER IN ALTERNATING CURRENT CIRCUITS WHERE POWER FACTOR IS NOT 100 PERCENT

POWER = E x I x POWER FACTOR (FOR SINGLE PHASE)

POWER = E x I x 1.732 X POWER FACTOR (FOR THREE PHASE)

THIS POWER IS ALSO CALLED TRUE POWER OR REAL POWER AS OPPOSED TO APPARENT POWER FOUND BY CALCULATING VOLT-AMPERES.

VOLT-AMPERES = E x I (FOR SINGLE PHASE)

VOLT-AMPERES = E x I x 1.732 (FOR THREE PHASE)

IT CAN READILY BE DETERMINED BY ALGEBRA THAT

$$\text{POWER FACTOR} = \frac{\text{TRUE POWER}}{\text{APPARENT POWER}}$$

MOTOR APPLICATION FORMULAS

HORSEPOWER = <u>**1.732 x VOLTS x AMPERES x EFFICIENCY x power factor**</u>

(for three phase motors)746

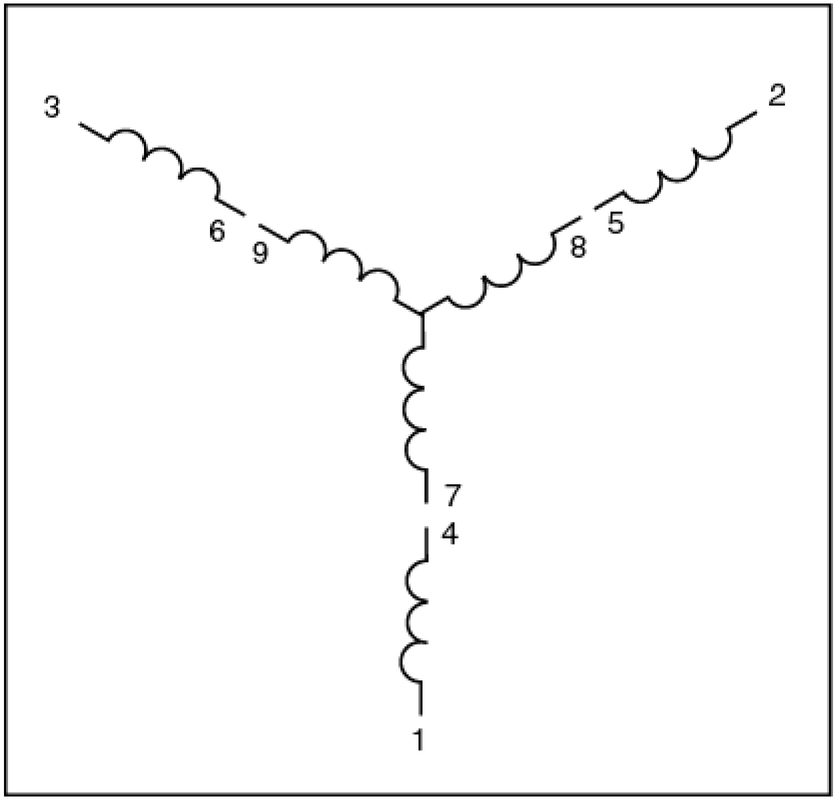
THREE PHASE AMPERES $= \frac{746 \times \text{HORSEPOWER}}{1.732 \times \text{VOLTS} \times \text{EFFICIENCY} \times \text{POWER FACTOR}}$
(for three phase motors)

SYNCHRONOUS RPM $= \frac{\text{HERTZ} \times 120}{\text{NUMBER OF POLES}}$

MOTOR MARKINGS AND CONNECTIONS

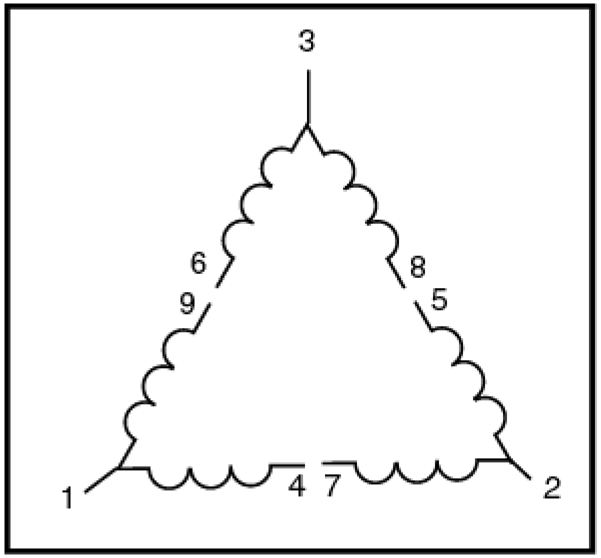
CONNECTIONS FOR NINE LEAD THREE PHASE MOTORS

THREE PHASE STAR OR Y



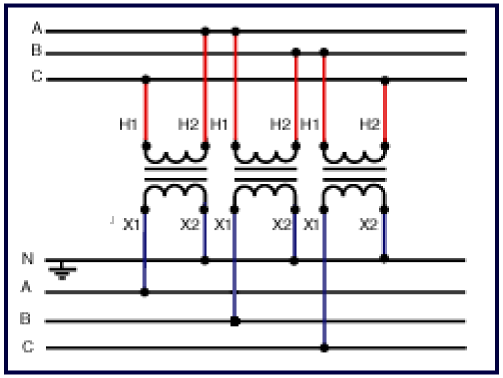
STAR CONNECTED				
Voltage	Line 1	Line 2	Line 3	Together
Low	1 & 7	2 & 8	3 & 9	4 & 5 & 6
High	1	2	3	4 & 7, 5 & 8, 6 & 9

THREE PHASE DELTA



DELTA CONNECTED				
Voltage	Line 1	Line 2	Line 3	Together
Low	1 & 6 & 7	2 & 4 & 8	3 & 5 & 9	NONE
High	1	2	3	4 & 7, 5 & 8, 6 & 9

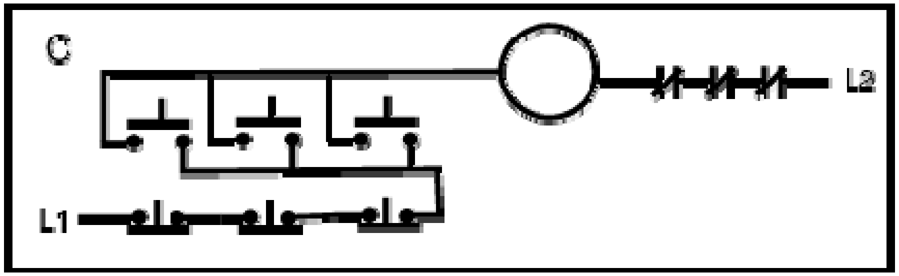
DELTA WYE HOOKUP FOR TRANSFORMER



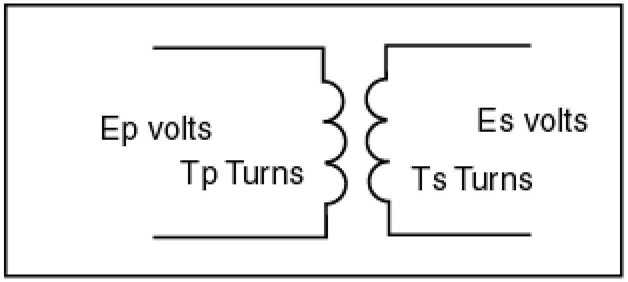
MOTOR CONTROLLER WITH THREE

START STOP STATIONS

(HOLDING CONTACTS NOT SHOWN)



TRANSFORMER TURNS RATIO



$$\frac{Ep}{Es} = \frac{Tp}{Ts}$$

Where
Ep is primary voltage
Es is secondary voltage
Tp is number of turns in primary
Ts is number of turns in secondary

	Maximum Horsepower for NEMA-Rated Motor Starters			
	Single-Phase		**Three-Phase**	
NEMA Size	**115 Volt**	**230 Volt**	**208/230 Volt**	**460/575 Volt**
00	1/3	1	1.5	2

0	1	2	3	5
1	2	3	7.5	10
2	3	7.5	10/15	25
3			25/30	50
4			40/50	100
5			75/100	200

NEMA RATING FOR ENCLOSURES

NEMA and other organizations have established standards of enclosure construction for control equipment. In general, equipment would be enclosed by an Ottawa Electrician for one or more of the following reasons:

1. Prevent accidental contact with live parts by an Ottawa Electrician.
2. Protect the control from harmful environmental conditions.
3. Prevent explosion or fires which might result from the electrical arc caused by the control.

Common types of enclosures per NEMA classification numbers are:

NEMA I - GENERAL PURPOSE

The general purpose enclosure is intended primarily to prevent accidental contact with the enclosed apparatus by an Ottawa Electrician. It is suitable for general purpose applications indoors where it is not exposed to unusual service conditions. A NEMA I enclosure serves as protection against dust and light indirect splashing, but is not dusttight.

NEMA 3 - DUSTTIGHT, RAINTIGHT

This enclosure is intended to provide suitable protection against specified weather hazards. A NEMA 3 enclosure is suitable for application outdoors, on ship docks, canal and construction work, and for application in subways and tunnels by an Ottawa Electrician. It is also sleet-resistant.

NEMA 3R - RAINPROOF, SLEET RESISTANT

This enclosure protects against interference in operation of the contained equipment due to rain, and resists damage from exposure to sleet. It is designed with conduit hubs and external mounting by an Ottawa Electrician, as well as drainage provisions.

NEMA 4 - WATERTIGHT

A watertight enclosure is designed to meet the hose test described in the following note: "Enclosures shall be tested by subjection to a stream of water. A hose with a one inch nozzle shall be used and shall deliver at least 65 gallons per minute. The water shall be directed on the enclosure from a distance of not less than 10 feet and for a period of five minutes. During this period it may be directed in any one or more directions as desired. There shall be no leakage of water into the enclosure under these conditions."

A NEMA 4 enclosure is suitable for applications outdoors on ship docks and in dairies, breweries, etc.

NEMA 4X - WATERTIGHT, CORROSION-RESISTANT

These enclosures are generally constructed along the lines of NEMA 4 enclosures except they are made of a material that is highly resistant to corrosion. For this reason, they are ideal in applications such as paper mills, meat packing, fertilizer and chemical plants where contaminants would ordinarily destroy a steel enclosure over a period of time.

NEMA 7 - HAZARDOUS LOCATIONS - CLASS I

These enclosures are designed to meet the application requirements of the National Electrical Code for Class I hazardous locations. In this type of equipment, the circuit interruption occurs in air.

"Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures."

NEMA 9 HAZARDOUS LOCATIONS - CLASS II

These enclosures are designed to meet the application requirements of the National Electrical Code for Class II hazardous locations.

"Class II locations are those which are hazardous because of the presence of combustible dust."

The letter or letters following the type number indicates the particular group or groups of hazardous locations (as defined in the National Electrical Code) for which the enclosure is designed. The designation is incomplete without a suffix letter or letters.

NEMA 12 - INDUSTRIAL USE

The NEMA 12 enclosure is designed for use in those industries where it is desired to exclude such materials as dust, lint, fibers and flyings, oil see page or coolant see page. There are no conduit openings or knockouts in the enclosure, and mounting by an Ottawa Electrician is by means of flanges or mounting feet.

NEMA 13 - OILTIGHT, DUSTTIGHT

NEMA 13 enclosures are generally of cast construction, gasketed to permit use in the same environments as NEMA 12 devices. The essential difference is that, due to its cast housing, a conduit entry is provided as an integral part of the NEMA 13 enclosure, and mounting by an Ottawa Electrician is by means of blind holes, rather than mounting brackets.

2. Implications of Design Decisions
Determine the effects of electrical systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

B. MATERIALS & TECHNOLOGY
Evaluate and select materials and construction details related to electrical systems.

1. Building Systems and their Integration
Examine electrical design principles, systems, and details and determine the effects of integrating into the overall design of a building considering technological advances and innovative building products.

2. Construction Details and Constructability
Identify and analyze electrical system details including the aspects of constructability.

Ground rod is a 8 to 10 ft copper rod (1/2" or ¾") stabbed into earth soil to provide grounding for any electrical metering system.

Not: Breaker, disconnect switch, switch box

For large 16 story building, the best electrical distribution for minimum wire size and voltage drop is 277/480 volts, three phase 4 wire

Not: three wire of any voltage, 120/208 volt 4 way

Lightning protection can be provided by: A system of lightning rods and conductors extended to the ground, an overhead grid of wire conductors extended to the ground, a system of lightning rods connected to the building steel frame and then to the ground

If all electric building has a very smooth electric power profile: Retrofit of this building for lighting is the best reduction of power consumption.

GFI protection is required in residential restrooms

Not: No lower than 4'AFF, below toilet or lavatory fixtures, minimum 6 ft from tub or shower

Brach circuit breakers are in last panels downstream of feeders feeding the appliances.

6. LIGHTING

Lumens/Footcandle

A **foot-candle** (sometimes **foot candle**; abbreviated fc, lm/ft², or sometimes ft-c) is a non-SI unit of illuminance or light intensity widely used in the lighting industry. The name "footcandle" conveys "the illuminance cast on a surface by a one-candela source one foot away."

The unit is defined as the amount of illumination the inside surface of a 1-foot radius sphere would be receiving if there were a uniform point source of one candela in the exact center of the sphere. Alternatively, it can be defined as the illuminance on a 1-square foot surface of which there is a uniformly distributed flux of one lumen. This can be thought of as the amount of light that actually falls on a given surface. The foot-candle is equal to one lumen per square foot.

The SI derived unit of illuminance is the lux. One footcandle is equal to approximately 10.764 lux, although in the lighting industry, typically this is approximated as 1 footcandle being equal to 10 lux.

In the lighting industry, footcandles are a common unit of measurement used to calculate adequate lighting levels of workspaces in buildings or outdoor spaces. Footcandles are also commonly used in the museum and gallery fields, where lighting levels must be carefully controlled to conserve light-sensitive objects such as prints, photographs, and paintings, the colors of which fade when exposed to bright light for a lengthy period.

Since light intensity is the primary factor in the photosynthesis of plants,horticulturalists often measure and discuss optimum intensity for various plants in foot-candles. Full, unobstructed sunlight has an intensity of approximately 10,000 fc. An overcast day will produce an intensity of around 1,000 fc. The intensity of light near a window can range from 100 to 5,000 fc, depending on the orientation of the window, time of year and latitude.

Footcandle versus lux: FC = Lux x .0929; LUX = FC x 10.76 - (ie: 50 FC = 538 LUX)

ILLUMINANCE: (old term: ILLUMINATION)

Definition: (density of luminous flux on a surface)
Symbol: E
Unit: Footcandle (fc) = (1 lumen per sq. foot); Lux (lx) = (1 lumen per sq. meter)

EQUATIONS

$$FC = \frac{\text{Candela}}{\text{Distance square (ft.)}} \qquad FC = \frac{\text{Lamp Lumens}}{\text{Area (sq.ft)}}$$

$$LUX = \frac{\text{Candela}}{\text{Distance square (m.)}} \qquad LUX = \frac{\text{Lamp Lumens}}{\text{Area (sq. m.)}}$$

Calculating Light Level at a Point

For planes perpendicular to the direction of candlepower (Inverse Square Law):
Footcandles (fc) = $I \div D^2$
I = Candlepower in candelas (cd)
D = Direct distance between the lamp and the point where light level is calculated

Many workplanes are not perpendicular to the direction of light intensity, which is why calculating light level at a point is useful for such applications. In these cases, we often must determine light levels on workplanes that are not horizontal and perpendicular but tilted or even vertical. For tilted- horizontal or vertical planes:
Horizontal Footcandles (fc_h) = $(I \div D^2) \times H$
Vertical Footcandles (fc_v) = $(I \div D^2) \times L$

I = Candlepower in candelas (cd)
D = Direct distance between the lamp and the point where light level is calculated
H = Distance between the lamp and the point direct below on the workplane
L = Distance between that point and the point where light level is being calculated
D = Square Root of $(H^2 + L^2)$ or $D^2 = H^2 + L^2$

Lighting System Efficacy (Lumens per Watt or LPW) = System Lumen Output ÷ Input Wattage
Unit Power Density (W/sq.ft.) = Total System Input Wattage (W) ÷ Total Area (Square Feet
FC (Lux) = Lumens/Area sqft (sqm) =
(Lamp Lumens * lamps per fixtures * No. of fixtures * coefficient of utilization * Light Loss factor)/ area sqft (sqm)
No. of Luminaires = (FC * Floor area)/(Lumens * coefficient of utilization * Light Loss factor)

Required Light Output/Fixture (Lumens) = (Maintained Illumination in Footcandles x Area in Square Feet) ÷ (Number of Fixtures x Coefficient of Utilization x Ballast Factor x Light Loss Factor)
DFav (Datlight Factor) = 0.2 x (window area/floor area) for space with sidelighting or toplighting with vertical monitors

Example:

AREA OF THE SKYLIGHT: 339 SF
LEVEL 2 FLOOR AREA: 2400 SF

HORIZONTAL SKYLIGHTS: DFav = 0.35 (skylight glazing area/ floor area)
DFav = 0.35(339/2400)=0.0494

WINDOW OR SKYLIGHT AREA: DFav= 0.2(window (or skylight) area/ floor area)
DFav = 0.2(339/2400)= 0.0282
SIDELIGHTING: DFav=0.2 (window area/ floor area) ; DFmin= 0.1 (window area/floor area)

EAST: DFav=0.2 (190/2400)=0.0158 ; DFmin = 0.1(190/2400)=0.0079
WEST: DFav=0.2(191/2400)=0.0159 ; DFmin =0.1(191/2400)= 0.0080

Light Loss Factors (more on Light Loss)

Light Loss Factor (LLF) = Ballast Factor x Fixture Ambient Temperature Factor x Supply Voltage Variation Factor x Lamp Position Factor x Optical Factor x Fixture Surface Depreciation Factor x Lamp Burnouts Factor x Lamp Lumen Depreciation Factor x Fixture Dirt Depreciation Factor x Room Surface Dirt Depreciation Factor

Lamp Burnout Factor = 1 - Percentage of Lamps Allowed to Fail Without Being Replaced

Zonal Cavity Method (determining cavity ratios)
Room Cavity Ratio (for regular rooms shaped like a square or rectangle) =
[5 x Room Cavity Depth x (Room Length + Room Width)] ÷ (Room Length x Room Width)
Room Cavity Ratio (for irregular-shaped rooms) = (2.5 x Room Cavity Depth x Perimeter) ÷ Area in Square Feet
Ceiling Cavity Ratio = [5 x Ceiling Cavity Depth x (Room Length x Room Width)] ÷ (Room Length x Room Width)
Floor Cavity Ratio = [5 x Floor Cavity Depth x (Room Length x Room Width)] ÷ Room Length x Room Width
Room surface reflectance can be predicted in a new design or measured in an existing facility. If existing facility:
Room Surface Reflectance (%) = Reflected Reading ÷ Incident Reading

Reflected Reading =
Measurement from a light meter holding it about 1.5 feet away from the surface with the sensor parallel and facing the surface.
Incident Reading = Measurement from a light meter held flat against the surface and facing out into the room.
Calculating Number of Lamps And Fixtures And Spacing
Required No. of Fixtures =
(Lumens/Lamp x No. of Lamps x Coefficient of Utilization x Light Loss Factor x Area in Square Feet) ÷
(Lumens/Lamp x Lamps/Fixture x Coefficient of Utilization x Light Loss Factor)

Required Lamps = Required Lumens ÷ Initial Lumens/Lamp
Maximum Allowable Spacing Between Fixtures= Fixture Spacing Criteria x Mounting Height
Fixture Spacing Criteria: See the manufacturer's literature
Mounting height: Distance in feet between the bottom of the fixture and the workplane

Spacing Between Fixtures = Square Root of (Area in Square Feet ÷ Required No. of Fixtures)
Number of Fixtures to be Placed in Each Row (N_{row}) = Room Length ÷ Spacing
Number of Fixtures to be Placed in Each Column (N_{column}) = Room Width ÷ Spacing
For the above two formulas, round results to the nearest whole integer.

Spacing row = Room Length ÷ (Number of Fixtures/Row - 1/3)
Spacing column = Room Width ÷ (Number of Fixtures/Column -1/3)

If the resulting number of fixtures does not equal the originally calculated number, calculate impact on the designed light level:

% Design Light Level = Actual No. of Fixtures ÷ Originally Calculated No. of Fixtures

To calculate fixtures mounted in continuous rows:

Number of Luminaries in a Continuous Row = (Room Length ÷ Fixture Length) - 1

Number of Continuous Rows = Total Number of Fixtures ÷ Fixtures Per Row

MAINTENANCE

Lamp Life

Calendar Lamp Life (Years) = Rated Lamp Life (Hours) ÷ Annual Hours of Operation (Hours/Year)

Lamp Burnout Factor

Lamp Burnout Factor = 1 - Percentage of Lamps Allowed to Fail Without Being Replaced

Group Relamping Cost

Annualized Cost ($) = A x (B + C)

A = Operating Hours/Year ÷ Operating Hours Between Relampings

B = (Percentage of Lamps Failing Before Group Relamping x Number of Lamps) x (Lamp Cost + Labor Cost to Spot Replace 1 Lamp)

C = (Lamp Cost, Group Relamping + Labor Cost to Group Relamp 1 Lamp) x Number of Lamps

Spot Relamping Cost

Average Annual Cost ($) = (Operating Hours/Year ÷ Rated Lamp Life) x (Lamp Cost + Labor Cost to Replace 1 Lamp) x Total Number of Lamps

Cleaning Cost

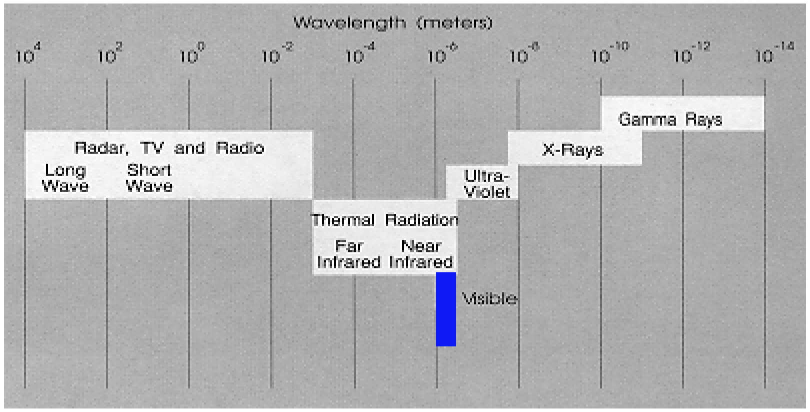
Cleaning Cost ($) = Time to Wash 1 Fixture (Hours) x Hourly Labor Rate ($) x Number of Fixtures in Lighted Space

A. PRINCIPLES
Analyze and design natural and artificial lighting systems.

Basic Theory

Light is a form of radiant energy that travels in waves made up of vibrating electric and magnetic fields. These waves have both a frequency and a length, the values of which distinguish light from other forms of energy on the electromagnetic spectrum.

Visible light, as can be seen on the electromagnetic spectrum, represents a narrow band between ultraviolet light (UV) and infrared energy (heat). These light waves are capable of exciting the eye's retina, which results in a visual sensation called sight. Therefore, seeing requires a functioning eye and visible light.



Lighting Systems

Light can be produced by nature or by humans. "Artificial" light is typically produced by lighting systems that transform electrical energy into light. Nearly all lighting systems do so either by passing an electrical current through an element that heats until it glows, or through gases until they become excited and produce light energy.

Incandescent light sources are an example of the first method, called incandescence. Current is passed through a filament, which heats until it glows. Because this method is considered wasteful (most of the energy entering the lamp leaves it as heat instead of visible light, other light sources were pioneered that rely on the gaseous discharge method, including fluorescent, high-intensity discharge (HID) and low-pressure sodium light sources.

A typical lighting system is comprised of one or more of these light sources, called the **lamps**. Fluorescent, HID and low-pressure sodium lamps operate with a **ballast**, a device that starts the lamp and regulates its operation. Lamps and ballasts in turn are part of the l**uminaire**, or **light fixture**, which houses the system and includes other components that distribute the light in a controlled pattern.

Designing the Lighting System

To produce a new lighting system in a construction or renovation scenario, it must be designed. The designer must determine desired light levels for tasks that are to be performed in a given space, then determine the light output that will be required to meet those objectives consistently, taking into account all the factors that degrade both light output and light levels over time. Equipment must then be chosen and placed in a layout to produce the desired light distribution. The designer must also consider a range of quality factors in his or her design choices and equipment selection, including color, minimizing glare, safety and if required, aesthetics.

Managing the Lighting System

To properly manage an existing system, many types of professionals may be involved, from electrical contractors to facilities manager - - for our purposes in this case, we will call them lighting managers. The lighting manager must ensure that the existing lighting system consistently provides the most effective lighting at the lowest operating and maintenance cost. This may entail retrofitting or upgrading the system to reduce energy costs and/or increase performance, a planned maintenance program to keep the system operating at peak performance, and other activities that will ensure that the lighting system is continuously doing its job.

1. Building Design
Apply theory and principles of electrical systems as a component of building design.

It can be daunting trying to figure out what all the different terms of lighting mean and how to use them to devise a lighting plan. Here are some common terms and their meanings.

Beam Angle or spread - This is the shape of the light emitted from a bulb with reflective properties. The beam expressed in the form of an angle measurement can be wide, normal or narrow.

Color Rendering Index (CRI) - This is a scale of 1 to 100 to determine how the light will show the color of an object. With 100 being sunlight, that is the reference point. An object will appear as the color it should to the human eye. A lower CRI number will distort the color of an object.

Color Temperature - This is used to measure the color appearance of light. It is measured in units called Kelvin or K. Light sources below 3200K are considered warm and have reddish overtones. 4000K and above are considered cool and have bluish overtones. For reference a normal home will be in the 3000K area while Offices and retail establishments will be in the 4000K area. 5000k is reserved for such areas as an operating room or jewelry store.

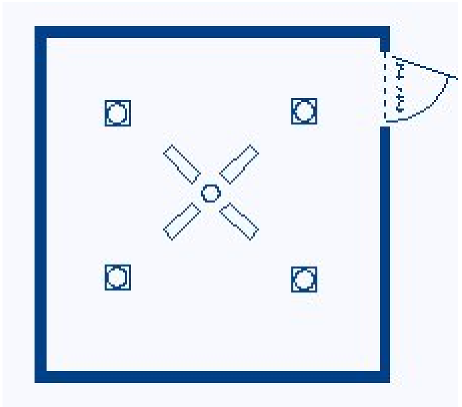
Compact Fluorescent (CFL) - This is a term used for fluorescent bulbs that are made to take the place of incandescent lamps and are manufactured in shapes and sizes to accomplish this task. They outlast an incandescent about 10 times and use energy much more efficiently.

Foot candle - This is was originally the unit of measurement based on how much light will reach the surface of an object one foot away from a candle. It is now considered equivalent to a lumen which is the illumination of one square foot.

Work Plane - The work plane is considered to be an area about 30" off the floor. Lighting this plane should be your goal as this is where the majority of tasks are done.

it comes to recessed lighting which is when the layout is usually in question, it's all about spacing. Once you can visualize what pattern the light form you are using has, you can then accurately lay out the lighting properly.

The three factors that are most important when designing a lighting plan that works are the type of light, the color of the light and the spacing. The type of light fixture will determine the light pattern. Once a pattern is established the spacing can be figured out. Several factors can help when choosing the color of the light. Fluorescents tend to be colder or emit more of a blue light. Today there are some very good full spectrum bulbs that make fluorescent light a little warmer. Incandescent are the friendliest of all the colors and provide a welcoming and warm feeling. They do however, cast a yellow tone over everything in the room. In some cases this is a good thing. In other situations this may not be the best solution. Some wood cabinets, such as a bleached birch, tend to look yellow under incandescent light. Using a halogen bulb in these cases solves the problem. Below is a basic room lighting plan to give you ideas.



This is a 12 x 12 room, a typical bedroom. By placing these lights about 3 feet out from the corners we get a nice even distribution of light in the room. Using this plan we are also able to add a ceiling fan in the room with no adverse effects on the lighting plan

Lighting Principles and Terms

To choose the best energy-efficient lighting options for your home, you should understand basic lighting principles and terms.

Light Quantity

Illumination: The distribution of light on a horizontal surface. The purpose of all lighting is to produce illumination.
Lumen: A measurement of light emitted by a lamp. As reference, a 100-watt incandescent lamp emits about 1600 lumens.
Footcandle: A measurement of the intensity of illumination. A footcandle is the illumination produced by one lumen distributed over a 1-square-foot area. For most home and office work, 30–50 footcandles of illumination is sufficient. For detailed work, 200 footcandles of illumination or more allows more accuracy and less eyestrain. For simply finding one's way around at night, 5–20 footcandles may be sufficient.

Energy Consumption

Efficacy: The ratio of light produced to energy consumed. It's measured as the number of lumens produced divided by the rate of electricity consumption (lumens per watt).

Light Quality

Color temperature: The color of the light source. By convention, yellow-red colors (like the flames of a fire) are considered warm, and blue-green colors (like light from an overcast sky) are considered cool. Color temperature is measured in Kelvin (K) temperature. Confusingly, higher Kelvin temperatures (3600–5500 K) are what we consider cool and lower color temperatures (2700–3000 K) are considered warm. Cool light is preferred for visual tasks because it produces higher contrast than warm light. Warm light is preferred for living spaces because it is more flattering to skin tones and clothing. A color temperature of 2700–3600 K is generally recommended for most indoor general and task lighting applications.

Color rendition: How colors appear when illuminated by a light source. Color rendition is generally considered to be a more important lighting quality than color temperature. Most objects are not a single color, but a combination of many colors. Light sources that are deficient in certain colors may change the apparent color of an object. The Color Rendition Index (CRI) is a 1–100 scale that measures a light source's ability to render colors the same way sunlight does. The top value of the CRI scale (100) is based on illumination by a 100-watt incandescent light bulb. A light source with a CRI of 80 or higher is considered acceptable for most indoor residential applications.

Glare: The excessive brightness from a direct light source that makes it difficult to see what one wishes to see. A bright object in front of a dark background usually will cause glare. Bright lights reflecting off a television or computer screen or even a printed page produces glare. Intense light sources—such as bright incandescent lamps—are likely to produce more direct glare than large fluorescent lamps. However, glare is primarily the result of relative placement of light sources and the objects being viewed.

Lighting Uses

Ambient lighting: Provides general illumination indoors for daily activities, and outdoors for safety and security.
Task lighting: Facilitates particular tasks that require more light than is needed for general illumination, such as under-counter kitchen lights, table lamps, or bathroom mirror lights.
Accent lighting: Draws attention to special features or enhances the aesthetic qualities of an indoor or outdoor environment.

2. Implications of Design Decisions

Determine the effects of lighting systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

3. Natural and Artificial Lighting

Design principles and theories related to daylight, solar control, energy consumption, and artificial lighting.

B. MATERIALS & TECHNOLOGY

Evaluate and select materials and construction details related to natural and artificial lighting systems.

1. Building Systems and their Integration

Examine integration and effects of lighting design principles, systems, and details on the overall design of a building considering technological advances and innovative building products.

2. Construction Details and Constructability

Identify and analyze lighting system details including the aspects of constructability.

Familiarize yourself with the basic steps of the lighting design process for a more accurate project price tag

Most lighting design articles seem to focus on lamp efficiency, lamp life, CRI, luminaire aesthetics, cost, and all the claimed benefits of one lamp compared to another. The one topic that always seems to be missing, however, is the properly applied steps of a true lighting design. Most electrical contractors I work with don't use engineering data in their lighting projects. Instead, they rely on layouts from past jobs or just replicate what others are doing. By knowing the basic steps of the lighting design process, you'll be able to more accurately price a project and present it to your customer.

At the start of the design process, always consider the following:

- **Required footcandle (fc) requirement of an area, including what the customer may wants as far as lighting levels and quality of lighting.**
- **Code restrictions for energy savings, expressed as maximum watts per square feet, in specified areas. The two basic requirements come from the IECC (or COMcheck), which is supported by the U.S. Department of Energy (DOE) and is required by most states and jurisdictions, and California Title 24, which is more restrictive than COMcheck but also allows more flexibility.**
- **Photometric data, which can be obtained from most lighting manufacturers.**

A good way to show you how to use this information is to address each of these items through several example situations. So let's jump right in.

Office Space Example

Let's say we have a 10-ft × 12-ft office with an 8-ft-high T-bar ceiling. The Illuminating Engineering Society (IES) recommendation for fc lighting level in an office space is 50 fc to 100 fc, depending on the age of occupants and the specific task requirements. We'll use 50 fc as a target. The maximum watts-per-square-foot requirement for office space is 1.0. Using the COMcheck requirements, this allows for 120W of lighting.

Next, let's consider the following luminaires we might use in this space:

- **Luminaire #1 –** 2 × 4 grid, acrylic lens, three T8 lamps at 96W
- **Luminaire #2 –** 2 × 4 grid, acrylic lens, two T8 lamps at 64W
- **Luminaire #3** – 2 × 2 grid, acrylic lens, two T8 lamps (F17) at 34W
- **Luminaire #4** – 2 × 2 grid, indirect, low brightness, two T5 high output lamps at 54W
- **Luminaire #5** – Recessed specular reflector, two 26W double twin-tube (DTT) lamps at 52W

Luminaire #1 Calculations

Use the following equation to determine the appropriate number of luminaires needed for this space:

Number of luminaires = (Required fc × sq ft of space) ÷ [(lumen output of lamps) × (coefficient of utilization) × (light loss factor)] = [(50 fc) × (120 sq ft)] ÷ [(8,550 lumens) × (0.54) × (0.8)] = 1.6 fixtures

Thus, we would install two luminaires to meet the lighting requirements of this space.

Note: The values used in the above equation were acquired from the photometric report shown in the **Figure** (click here to see **Figure**) and the coefficient of utilization **Table** (click here to see **Table**). Three 32W linear fluorescent T8 lamps provide an output of 8,550 lumens. The coefficient of utilization (CU) is defined as the ratio of the lumens received on the work plane (i.e., the top of the desk) to the lumens emitted by the lamps. This is an important number and is simple to obtain. From the Figure, you can see that I chose an 80% ceiling reflectance (from the white T-bar grid), a 70% wall reflectance (from a light-colored paint), and a room cavity ratio (RCR) of 6.7 (rounded off to 7). RCR is simply the lighting efficiency of an enclosed space, and it can be easily found in lighting manuals or spec sheets. Light loss factor (LLF) is a number obtained by multiplication of all losses of light involved (i.e., dirt accumulation, lamp light losses, ballast losses, etc.). In this example, I simplified this calculation and plugged in a value of 0.8.

Installing two #1 luminaires in this space would provide a total wattage level of 192. However, because this is much larger than the 120W requirement noted earlier, it may not be a wise choice.

Do we have another alternative? Yes. We can use another value in the Figure to determine the number of luminaires required for this space.

The max candlepower distribution (CD) or candlepower is shown as 2,623 CD. This value is directly below the fixture. By dividing this CD value by the square of the distance in feet from the bottom of the luminaire to the top of the desktop, you will determine a new fc level. (Note: assume a distance of
5.5 ft from bottom of luminaire to top of desk.)

fc = 2,623 ÷ (5.5)2 = 87 fc

If we again assume a LLF of 0.8, then we end up with a final fc level of 70 (87 × 0.8).

This series of calculations shows a single luminaire provides an fc level well above the minimum recommended value of 50, which means this may be a good choice for this space. Based on this calculation method, we see that one luminaire would provide an fc level of 70 over the work desk and not exceed the maximum energy requirement of 120W.

Luminaire #2 Calculations

Following the same steps we used for Luminaire #1, we see that Luminaire #2 offers 5,700 lumens and 0.55 CU. Our initial calculations reveal that three luminaires would be needed to exceed the 50-fc requirement. Using the CD method results in an fc level of 52. This gives you the option of using two luminaires. (Note: the values for Luminaire #2 were pulled from a different photometric report, which is not included in this article due to space constraints.)

Luminaire #3 Calculations

Our calculations reveal that either method would require the use of six luminaires to exceed the 50-fc requirement. (Note: the values for Luminaire #3 were pulled from a different photometric report, which is not included in this article due to space constraints.)

Luminaire #4 Calculations

Our calculations reveal that either method would require the use of four luminaires to exceed the 50-fc requirement. (Note: the values for Luminaire #4 were pulled from a different photometric report, which is not included in this article due to space constraints.)

Luminaire #5 Calculations

Our calculations show that either method would require the use of five luminaires to exceed the 50-fc requirement. (Note: the values for Luminaire #5 were pulled from a different photometric report, which is not included in this article due to space constraints.)

A quick look back at our five different luminaire options and respective calculations reveals the best option is a balance between fc levels (and/or what the customer wants) and the maximum lighting energy that can be used in that space. In this case, luminaire #1 comes out on top.

Manufacturing Space Example

Let's say we are asked to design a lighting system for a manufacturing space that is 200 ft by 200 ft in size with a finished floor to bottom of luminaire height of 30 ft. The owner wants a light level of 50 fc maintained at ground level. In this case, "maintained" means including an LLF. We'll use a value of 0.7 for a dirty environment.

The maximum watts-per-square-foot requirement for manufacturing space is 1.0. For this example, we'll use Title 24 requirements, which allows 40,000W of lighting. Two different luminaire options will be analyzed.

- **Luminaire #1 – a high-bay fixture with a 350W high-output metal-halide lamp in a concentrated aluminum optical enclosure, rated at 400W.**
- **Luminaire #2 – a high-bay fluorescent fixture with six T5 high-output lamps and a task beam white reflector (concentrated downlight), rated at 363W.**

3. Natural and Artificial Lighting
Design components and details related to daylight, solar control, energy consumption, and artificial lighting.

Coefficient of utilization in lighting level calculations is the percentage of lamp lumens to reach the work plane

Not: Leave the luminaries, the amount lost due to age, lost due to environmental dust

Controlling lights within two spaces is a double switch

Not: Two single-pole, double-throw switch

7. SPECIALTIES

(14-19% Score)

Acoustics; Communications & Security; Conveying Systems; Fire Detection & Suppression

A. ACOUSTICS

Evaluate, select, and design acoustical systems.

Introduction

The sources of compressor station noise are generally well understood. They include engine and compressor casing noise, engine air intake and exhaust, and cooler inlet and outlet noise. Addressing noise generation at the design stage will clearly reduce the level of supplemental noise attenuation equipment yet, incredibly, the majority of compressor packagers continue to pound out compressors with conventional building designs, including acoustically transparent windows, translucent roof panels and ridge vents. Even when acoustic considerations are addressed in initial building design, much of the effort falls short of the mark, or introduces other operating complications.

Basic Acoustic Building Design

Conventional acoustic building design includes acoustic insulation and perforated liners. This approach is a good start and reduces internal noise for the operators as well as outside building noise. However, these buildings may still incorporate other elements that create noise sources.

High Elevation Noise Sources in Building Design

Ridge vents remain a common building component, even in acoustic building designs. Some operators measure acoustic building performance at a distance too close to the building to fully reflect noise emanating from the ridge vent, before it's reached the ground. As a result, that noise source may be more relevant further out from the building than the operator realizes. Some operators understand the problems windows pose in noise transmission and will specify windowless buildings. However, they're sometimes offset with the use of roof mounted translucent panels building lighting. Unless properly selected, translucent panels can remain a significant noise source with the operator again falling prey to the same misleading conclusions about the level of long distance noise attenuation.

Acoustic Ventilation in Building Design

Where acoustic building ventilation is incorporated, it is tempting for operators to use fewer but larger capacity ventilation hoods and fans to reduce capital costs. There can be a couple of problems with this approach. Concentrated, rather than evenly spaced ventilation can result in some portions of the building being improperly swept. A second, parallel problem has to do with gas detection. Gas detectors require a minimum retention time to work properly. In the event of gas leaks, improper building ventilation can render gas detectors ineffective or leave pockets or areas within the building improperly swept clean of leaking gases. As a result the operator may be unaware of explosive mixtures within the building and on sour sites H_2S can escape undetected into the building and surrounding environment In extreme cases the airflow through the building can be so severe as to weaken the building's structural integrity or interfere with the safe operation of doors and undermining emergency exit safety considerations. Another cost saving building ventilation technique is to steal some of the airflow from forced draft fan coolers and sweep that air through the building. One problem with this approach is the reduction in gas and engine cooling duty by 5 to 15%. Operators don't always consider the economics of the revenue loss arising from the lost gas production. Further, this ventilation provides some cooling around the engine but doesn't sweep the compressor end of the building. Finally, the static head on this air source is low raising the question of overall adequate building ventilation. Process cooling and building ventilation requirements both need to be properly sized and then a deliberate assessment made as to whether it is more effective and economic to use a larger than necessary cooler fan to also accommodate building ventilation, or size the cooling fan to it's process requirements and size the building ventilation for its needs.

Acoustics:

Classroom Acoustics

Since the 1990's the Acoustical Society of America has taken a leadership role in promoting improved acoustics in classrooms. ASA has published two American National Standards on this subject:

ANSI/ASA S12.60-2010/Part 1 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 1: Permanent Schools - Click Here to Access Part 1

ANSI/ASA S12.60-2009/Part 2 American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools, Part 2: Relocatable Classroom Factors - Click Here to Access Part 2

These two standards were developed by ANSI-Accredited Standards Committee S12, Noise. They are available for immediate download from the ASA Online Store at no cost to the end-user using the "Click Here" links above. You will be asked to establish a user name and password but no credit information need be supplied since there is no cost.

The ASA Technical Committee on Architectural Acoustics published the booklet Classroom Acoustics I – A resource for creating learning environments with desirable listening conditions. This booklet is reproduced on this page below.

The ASA Technical Committee on Speech Communication published the booklet Classroom Acoustics II – Acoustical barriers to learning which can be downloaded as a PDF file. Click Here to Download Booklet II

Classroom Acoustics - A resource for creating learning environments with desirable listening conditions

The intent of this publication is to create a supplemental resource for architects, educators, and school planners for use with new construction or renovation of learning environments. The publication is not intended to replace the services of a professional acoustical consultant. It is to be used as an aid in the understanding of the elements of desirable listening conditions in classrooms.

This publication was prepared for the Technical Committee on Architectural Acoustics of the Acoustical Society of America by Benjamin Seep, Robin Glosemeyer, Emily Hulce, Matt Linn, and Pamela Aytar who, at the time of publication preparation, were senior students in the Architectural Engineering program at the University of Kansas. Supervision of this endeavor was provided by Bob Coffeen, FASA, a member of the the University of Kansas Architectural Engineering faculty.

This publication was printed in August, 2000.

Introduction

The United States is currently in the midst of the largest campaign of school construction and renovation in history. With the increased emphasis on education, we must seize the opportunity to end a long-standing American practice: the building of classrooms with inferior acoustics. This invisible problem has far-reaching implications for learning, but is easily solved.

Excessive noise and reverberation interfere with speech intelligibility, resulting in reduced understanding and therefore reduced learning. In many classrooms in the United States, the speech intelligibility rating is 75 percent or less. That means that, in speech intelligibility tests, listeners with normal hearing can understand only 75 percent of the words read from a list. Imagine reading a textbook with every fourth word missing, and being expected to understand the material and be tested on it. Sounds ridiculous? Well, that is exactly the situation facing students every day in schools all across the country.

Many educators feel it is important to improve acoustics in classrooms used by children with hearing problems, but unnecessary to do so in those used by students with normal hearing. Yet many populations of students with "normal hearing" also benefit from better classroom acoustics. These include students with learning disabilities, those with auditory processing problems, and those for whom English is a second language. Often, such students are not placed in separate classrooms with enhanced acoustics, but are main-streamed with other students. Another group for whom learning is especially dependent on good acoustics is young children, who are unable to "predict from context." With their limited vocabulary and experience, if they miss a few words from a teacher's lecture, they are less able than older students to "fill in" the missing thoughts. Given these considerations, it is clear that a wide range of students benefit from improved classroom acoustics.

Why should classroom acoustics problems be endemic, when solutions are not prohibitively expensive? The main reason is not lack of funds, but lack of awareness of the problem and its solutions. In 1998, an incredible $7.9 billion was spent on school buildings nationwide. For only a fraction more, all these spaces could have been designed or renovated to provide good listening conditions. For this to happen, however, school planners and architects must begin the design process with classroom acoustics in mind. The best way to solve acoustics problems is to prevent them beforehand, not correct them after the fact. During the design process, acoustics problems can usually be avoided with a bit of forethought and a different arrangement of the same building materials. Renovation of poorly designed classrooms is much more expensive. Even then, the cost of renovation is small compared to the social costs of poor classroom acoustics that impair the learning of millions of children.

The need for good classroom acoustics and the methods for attaining them have been known for decades, but this information has not been made readily available to architects, school planners, administrators, teachers, and parents. This booklet is designed to provide a general overview of the problems and solutions concerning classroom acoustics for both new construction and renovation. Straightforward, practical explanations and examples are given in the text; the Appendix provides quantitative definitions and calculations, as well as resources for more detailed information. The design of spaces with special acoustical requirements, such as theaters or music rooms, or any spaces with complex noise problems, are best handled by a professional acoustical consultant.

top

The Basics

We often talk about wanting to build rooms with "good acoustics," but this has become a vague and almost meaningless term. There is no single, all-encompassing set of criteria that will yield "good acoustics" for all rooms and uses. Small classrooms, large lecture rooms, auditoriums, music rooms, cafeterias, and gymnasiums all have different acoustical requirements. To understand how these different spaces should be designed, we must first familiarize ourselves with a few basic properties of sound.

In the first century B.C., the Roman architect Vitruvius explained in De architectura, his famous 10-volume treatise on architecture, that sound "moves in an endless number of circular rounds, like the innumerably increasing circular waves which appear when a stone is thrown into smooth water – but while in the case of water the circles move horizontally on a plane surface, the voice not only proceeds horizontally, but also ascends vertically by regular stages." While Vitruvius did not understand everything about sound, he was correct about this particular point. In general, sound radiates in waves in all directions from a point source until it encounters obstacles like walls or ceilings. Two characteristics of these sound waves are of particular interest to us in architectural acoustics: intensity and frequency. Intensity is a physical measurement of a sound wave that relates to how loud a sound is perceived to be. We can also measure the frequency of a sound wave, which we perceive as pitch. For example, on a piano, the keys to the right have a higher pitch than those to the left. If a sound has just one frequency, it is called a pure tone, but most everyday sounds like speech, music, and noise are complex sounds composed of a mix of different frequencies. The importance of frequency arises when a sound wave encounters a surface: the sound will react differently at different frequencies. The sensitivity of the human ear also varies with frequency, and we are more likely to be disturbed by medium-to high-frequency noises, especially pure tones.

Think of sound as a beam, like a ray of light, passing through space and encountering objects. When sound strikes a surface, a number of things can happen, including: Transmission-- The sound passes through the surface into the space beyond it, like light passing through a window. Absorption-- The surface absorbs the sound like a sponge absorbs water. Reflection-- The sound strikes the surface and changes direction like a ball bouncing off a wall. Diffusion-- The sound strikes the surface and is scattered in many directions, like pins being hit by a bowling ball. (See Figure 1.) Keep in mind that several of these actions can occur simultaneously. For instance, a sound wave can, at the same time, be both reflected by and partially absorbed by a wall.

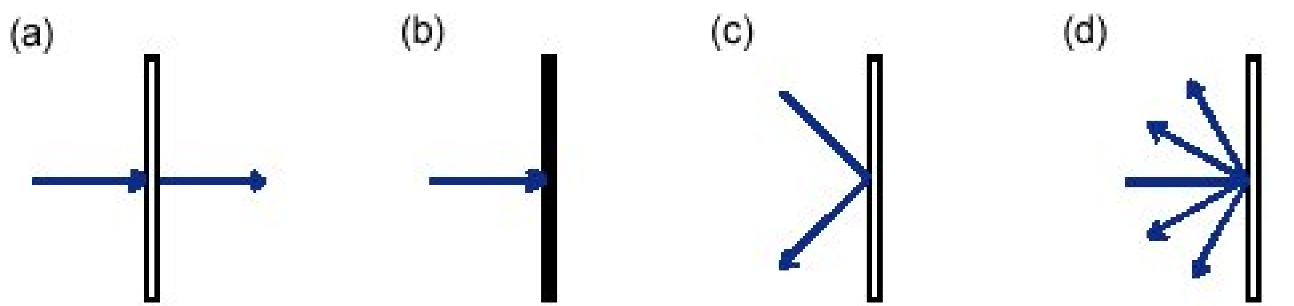


FIGURE 1. Sound/Surface Interaction: (a) transmission, (b) absorption, (c) reflection, (d) diffusion

As a result, the reflected wave will not be as loud as the initial wave. The frequency of the sound also makes a difference. Many surfaces absorb sounds with high frequencies and reflect sounds with low frequencies. The **Absorption Coefficient**(a) and **NRC** (noise reduction coefficient) are used to specify the ability of a material to absorb sound.

A special problem that results from reflected sound is that of **discrete echoes**. Most people are familiar with the phenomenon of shouting into a canyon and hearing one's voice answer a second later. Echoes can also happen in rooms, albeit more quickly. If a teacher's voice is continuously echoing off the back wall of a classroom, each echo will interfere with the next word, making the lecture difficult to understand. Echoes are also a common problem in gymnasiums.

Another type of echo that interferes with hearing is **flutter echo**. When two flat, hard surfaces are parallel, a sound can rapidly bounce back and forth between them and create a ringing effect. This can happen between two walls, or a floor and ceiling.

Sound intensity levels and sound pressure levels can be measured in **decibels (dB)**. In general, loud sounds have a greater dB value than soft sounds. Because the decibel scale is logarithmic rather than linear, decibels can not be added in the usual way.

An important acoustical measurement called **Reverberation Time (RT or RT(60))** is used to determine how quickly sound decays in a room. Reverberation time depends on the physical volume and surface materials of a room. Large spaces, such as cathedrals and gymnasiums, usually have longer reverberation times and sound "lively" or sometimes "boomy". Small rooms, such as bedrooms and recording studios, are usually less reverberant and sound "dry" or "dead".

The **Noise Reduction (NR)** of a wall (also expressed in dB) between two rooms is found by measuring what percentage of the sound produced in one room passes through the wall into the neighboring room. (See Figure 2.) The NR is calculated by subtracting the noise level in dB in the receiving room from the noise level in the source room.

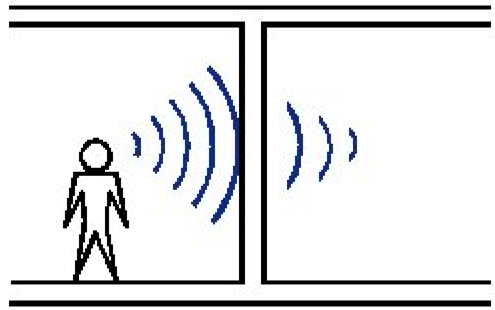


FIGURE 2. Noise Reduction between two spaces by a dividing wall.

Signal-to-Noise Ratio (S/N) is a simple comparison that is useful for estimating how understandable speech is in a room. The sound level of the teacher's voice in dB, minus the background noise level in the room in dB, equals the S/N in dB. The larger the S/N, the greater the speech intelligibility. If the S/N is negative (i.e., the background noise is louder than the teacher's voice), the teacher will be hard to understand. Note also that the S/N varies throughout the room as the signal and noise levels vary. Typically, the S/N is lowest either: (1) at the back of the classroom, where the level of the teacher's voice has fallen to its minimum value; or (2) near the noise source, where the noise level is at its maximum, such as near a wall air conditioning unit. Studies have shown that, in classrooms having a signal-to- noise ratio of less than +10 dB, speech intelligibility is significantly degraded for children with average hearing. Children with some hearing impairment need at least a +15 dB S/N ratio.

Speech intelligibility can be evaluated in existing rooms by using **word lists**. Several tests are performed wherein one person recites words from a standard list, and listeners write down what they hear. The percentage of words listeners correctly hear is a measure of the room's speech intelligibility.

For those interested in learning more about these topics, additional information is provided in the Appendix.

top

Acoustical Guidelines for Classrooms

Now that we have familiarized ourselves with these fundamentals of acoustics, we can learn how to apply them to achieve satisfactory hearing conditions in classrooms. The following guidelines are designed for a typical classroom of approximately 30 students, where lecturing is done from the front of the room or students work in small groups. Recommendations for gymnasiums, cafeterias, and auditoriums are given in a following section.

Reverberation

Though long reverberation time (RT) is the common cold of bad classroom acoustics, there is a cure. Ideally, classrooms should have RTs in the range of 0.4-0.6 seconds, but many existing classrooms have RTs of one second or more. Figure 3 gives suitable reverberation times for various rooms typically found in educational facilities. The RT can be estimated fairly easily for both built and unbuilt classrooms with the use of the Sabine equation (see page 10). The variables are the physical volume (ft 3) of the room, the areas (ft 2) of different surface materials, and the absorption coefficients of those materials at certain frequencies. The absorption coefficient is a measure how much of the energy of a sound wave a material will absorb.

There are two ways to reduce the RT of a room: either the volume must be decreased or the sound absorption must be increased. Though decreasing the volume is not always an option, it is a viable alternative for many older classrooms with high ceilings. In such spaces, adding a suspended ceiling of sound-absorbing tile can significantly improve the acoustics by simultaneously decreasing the volume and increasing absorption. However, adding a suspended ceiling often requires new light fixtures and can interfere with tall windows. The case study presented later shows an alternative solution for classrooms with high ceilings.

Increasing the absorption in a room is accomplished by adding more soft materials, such as fabric-faced glass fiber wall panels, carpet, or acoustical ceiling tiles. Many products are commercially available for this purpose, and - with forethought - it is possible to design a classroom with an acceptable RT using common building materials. Absorptive materials work best when spread throughout the room and not concentrated on just one wall or the floor or ceiling. In many classrooms, a suspended ceiling of acoustical ceiling tiles alone will decrease reverberation time to the desired range; however, this will not address the problem of echoes from the walls. Nor are all acoustical ceiling tiles created equal. Check the specifications and look for ceiling tiles with an NRC of 0.75 or better. In order to absorb both low- and high-frequency sounds, it is necessary to suspend the ceiling below the structural ceiling. Simply adding carpeting to a classroom floor will not significantly reduce reverberation time, especially at low frequencies, but carpeting will reduce noise resulting from students sliding their chairs or desks on the floor.

For those interested in calculating the RT of an existing classroom or estimating how much absorption is necessary, the Appendix includes examples and a table of absorption coefficients for some common materials.

Undesirable Reflections

As mentioned above, echoes interfere with speech intelligibility. Echoes can be controlled using absorption and/or diffusion. When locating absorptive materials to reduce reverberation time, consider how they might help reduce echoes as well. Placing an absorptive material on the rear wall of a classroom prevents the teacher's voice from reflecting back to the front of the room. While absorption is one way of minimizing reflected energy into the classroom, another approach utilizes diffusion. Placing a diffusing element on the rear wall of the classroom scatters the sound into many directions, so that the level in any one particular direction is greatly reduced. Flutter echo is a particularly significant problem when it occurs between the walls at the front of the room where the teacher is speaking. A simple way to test whether flutter echo is a problem is to stand near the center of the classroom, between parallel surfaces, and clap hands once sharply. If flutter echo exists, a zinging or ringing sound will be heard after the clap as the sound rapidly bounces back and forth between two walls. Try turning in different directions and clapping again to determine which walls are causing the flutter echo. To eliminate flutter echo between two hard, parallel walls, cover one or both of them with fabric-faced glass fiber panels or a similar sound-absorbing material. This works well if the panels are staggered along the opposite walls so that a panel on one wall faces an untreated surface on the opposite wall. Splaying two walls at least eight degrees out of parallel will also eliminate flutter echo between them.

Useful Reflections

So far we have discussed methods for reducing reflections in classrooms, but in some cases we want to reinforce certain reflections. This is especially true in large classrooms that have short reverberation times. The sound energy of the teacher's voice can be absorbed by the soft ceiling before it reaches students at the back of the room. The teacher's voice can be spread throughout the room by shaping a sound-reflecting gypsum board ceiling over the front of the room, or by making the center of the ceiling a hard, reflecting surface. These surfaces will reflect sound toward the rear of the room. In order to maintain a low reverberation time with reflectors in the room, it will likely be necessary to add absorptive materials on the side and rear walls. The need for reflectors depends on the teaching methods used. For example, reflectors are useful in rooms used mostly for lecturing, but are not needed in rooms used only for small-group work or as laboratories.

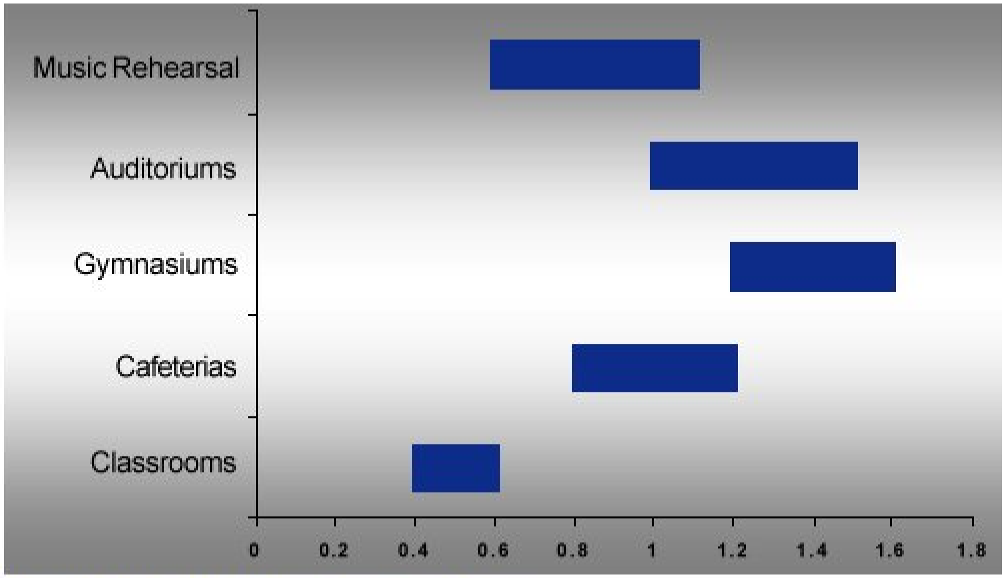


FIGURE 3. Suitable Reverberation Times (in seconds) for various rooms typically found in educational facilities.

Mechanical Equipment Noise

High ambient noise from mechanical equipment such as noisy heating, ventilation and air conditioning (HVAC) systems is all too common in existing schools. This is a serious problem for teachers and students alike. Teachers must raise their voices to maintain the +10 dB signal-to-noise ratio necessary for good speech intelligibility. That results in many teachers taking several sick days each year as a result of vocal strain, costing taxpayers money that would have been better spent on quiet mechanical equipment. At the same time, students must either struggle to hear or else become distracted and stop paying attention. Mechanical noise is primarily the result of poor planning and can be difficult and expensive to fix in existing classrooms. However, excessive mechanical noise can be eliminated at little or no extra cost if the system is designed properly in the first place. Mechanical engineers are sometimes unaware of or insensitive to this problem, and should be reminded that noise control is a critical issue that must be handled during the design and purchasing process.

Common Mechanical Noise Problems

Problem: The air in the ducts is traveling too fast, creating a whistling, rushing, or hissing sound as it passes dampers, turning vanes, and diffusers.

Identification: Listen to the sound at different fan speeds to hear if it is reduced at slower air speeds. Open and close dampers, remove diffusers, and listen for changes in the noise.

Solutions: Use slower fan speeds, increase duct sizes, relocate dampers, and/or use quieter diffusers.

Problem: Noise from the air handler (fan) is traveling through the ducts (supply or return) into the room.

Identification: Compare the noise in the room to the noise up close to the air handler. Listen for characteristic whines or low rumbling.

Solutions: Replace bare sheet metal duct with duct lined with sound-absorbing duct liner (keep in mind that this reduces the inside area of the duct and increases air speed, so the lined duct might need to be upsized). Reroute the ductwork to create a longer path from the air handler to the room. Insert a duct silencer near the air handler. Replace the air handler with a quieter model.

Problem: Nearby fan-coil units or variable air volume (VAV) boxes are generating noise which is transmitted into the room through the ductwork or the ceiling.

Identification: Turn unit on and off and listen for changes in noise. If possible, remove lay-in ceiling tiles and look/listen for noisy units.

Solutions: Move the unit away from the room (perhaps into an adjacent corridor in the case of a VAV box), eliminate it, or replace it with a quieter model. Add lining or a silencer after the unit in the path of sound travel. Acoustically isolate the unit by surrounding it with a box built of

There are many methods for measuring the loudness of mechanical noise. A good guideline is that the noise level in classrooms should not exceed NC 25 to 30. The NC, or Noise Criteria, rating is determined by measuring noise levels at certain frequencies, plotting these levels on a graph, then comparing the results to established NC curves. (A more detailed explanation is contained in the Appendix.) Another useful guideline is that the noise level should not exceed 35 dBA. This is an easily measured, single-number rating of the noise level over all frequencies that reduces the indicated noise level at lower frequencies to simulate the sensitivity of the ear. Typically, the noise level of a room in dBA is 5 to 7 dB higher than the NC rating. (Converting sound levels as measured in octave frequency bands to dBA is also explained in the Appendix.)

Finding the source of mechanical noise in a room is sometimes as difficult as finding the proverbial needle in a haystack. The noise can originate from one or many sources, and complex cases are best handled by a professional acoustical consultant with the skills and equipment to locate and reduce the levels of all noise sources. Bearing that in mind, Figure 4 lists a few common problems you can look for in an existing classroom with excess mechanical noise resulting from a central mechanical system that distributes air to the rooms through ductwork.

For mechanical system noise the old adage, an ounce of prevention is worth a pound of cure, is certainly true. To limit such noise, keep the following guidelines in mind when designing new classrooms:

1. Locate rooftop mechanical equipment, VAV boxes, and fan-coil units away from critical listening spaces such as classrooms. Positioning units over hallways and running ducts to nearby classrooms is one good solution. Avoid placing any major mechanical equipment inside, above, below, or adjacent to classrooms.
2. Select air handlers with low sound-level ratings.
3. Size ducts large enough to permit low air velocities. Select diffusers with NC ratings below 20 to 25.
4. Spend a little extra on longer duct runs. This pays dividends in reduced mechanical noise and crosstalk (the transmission of sound between rooms via ductwork). See Figure 5 for an example of good and bad duct arrangement.

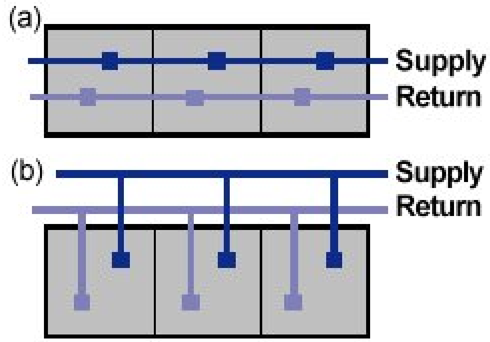


FIGURE 5. Duct Arrangements
(a) bad duct arrangement - sound travels through the duct work from room to room, instead (b) good duct arangement - sound has a longer path to travel though lined duct between adjacent rooms.

5. 5. Avoid using unit ventilators, fan coil units and ductless split systems in classrooms. These units contain fans and sometimes compressors that are notoriously loud and difficult to treat due to their position in the classroom.

Interior Noise Sources

Noise from adjacent rooms disrupts the learning process, especially during quiet reading times or test-taking. Fifty years ago, when school walls were typically built of heavy brick or concrete block, this was not as much of a problem. In recent decades, the need to lower construction costs has led to the use of thin, lightweight wall materials that provide little noise reduction. Even worse, in the 1960s and 1970s many open plan classrooms were built with no partitions whatsoever between classrooms. In some schools, such spaces have since been partitioned, but noise reduction between rooms may still be insufficient.

If you are unsure whether the wall between two existing classrooms is adequate, try this simple test: Set up a television or video monitor in one room and set the sound level so it can be comfortably heard in the back of the classroom. Then go into the neighboring classroom and listen for sounds from the equipment next door. If sounds are faint or inaudible, the barrier is sufficient. If sounds are fairly loud, and especially if words are intelligible, the partition between the rooms needs to be improved.

Figure 6 shows examples of both good and bad gypsum board wall construction. In general, as the mass of a wall is increased, its noise reduction also increases. However, a thick, solid wall is usually too expensive and heavy and wastes valuable floor space. Therefore, an effective compromise is to construct a wall of a layer of heavy material, an airspace, and another layer of heavy material. A typical example would be a stud wall having two layers of 5/8 inch thick gypsum board on each side. When constructing such a wall, be sure to overlap the layers of gypsum board so the joints on both layers do not line up and create a gap that sound can pass through. Adding glass fiber or mineral fiber insulation to the cavity in the middle of the wall can also reduce noise transmission.

In terms of noise reduction, a wall is like a chain: it is only as strong as its weakest link.

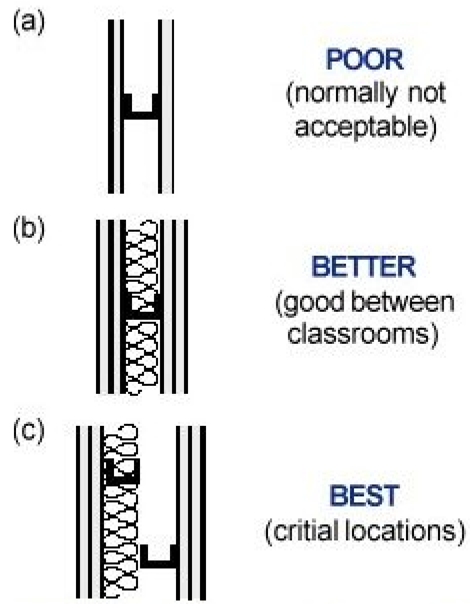


FIGURE 6. Gypsum Board Wall Constructions in order of least to most sound isolating (a) 1 layer gypsum wall board (GWB) each side (b) 2 layers GWB, glass fiber insulation, 2 layers GWB (c) 2 layers GWB, 2 sets of studs, glass fiber insulation, 2 layers GWB

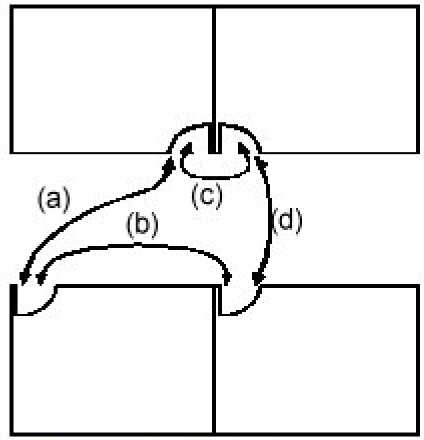


FIGURE 7. Door Layouts Paths (a) and (b) represent good layouts because the sound has a longer path to travel from one room to the next, paths (c) and (d) represent bad layouts because the distance between is short.

Windows, doors, small gaps, cracks, grilles, louvers, etc. can completely negate a wall's effectiveness. Gaps between walls and the floor and ceiling should be sealed with an acoustical sealant. Thin or hollow-core doors with large gaps under them commonly cause sound leaks in otherwise good walls. Solid doors with tight-fitting, sealed frames are best. Their location also matters. For example, it is best not to pair up doors to adjacent rooms, as this provides a short path through which sound may travel from one room, through the doors, and into the next room. (Figure 7 shows both good and bad layouts.) Also, classroom doors should not be placed directly across a hall from one another. Staggering doors across a hallway creates a longer, less direct path for noise to travel from one room to another.

To be effective, partition walls should extend from the structural floor to the structural ceiling. Otherwise, sound from one room can easily pass through a lay-in acoustical tile ceiling, over the partition wall, and down through the lay-in ceiling of the next room. (See Figure 8.) This is commonly overlooked when walls are added during renovations, such as when open-plan classrooms are partitioned.

Preventive design can often eliminate the need for thick, expensive walls. During the design process, consider which rooms will be noisy (mechanical rooms, gymnasiums, cafeterias, music rooms, industrial design shops, etc.) and use buffer areas (hallways, storage rooms, and restrooms) to separate these spaces from critical listening areas (classrooms, libraries, special education areas, and offices).

Exterior Noise Sources

The noise reduction of exterior walls is also important since many noisy and potentially disruptive activities go on outside the school. Most schools are built with brick or concrete block exterior walls, which are good sound barriers, but with inadequate windows that permit considerable sound transmission. To provide noise reduction, windows must be well sealed. Double-paned glass provides better noise reduction than single-paned glass (as well as better thermal insulation and decreased energy costs). Other common sound leakage culprits are wall-mounted unit ventilators that duct directly outside. These units not only transmit exterior noise but generate ample noise themselves; they should be avoided whenever possible.

During site planning, consider external noise sources that could disrupt learning and attempt to locate classrooms away from such areas. Common noise sources include: aircraft flyovers, busy roads, idling school buses, playgrounds, playing fields, exterior mechanical equipment, dumpsters being emptied by garbage trucks, lawn mowers, and noisy machinery in nearby buildings.

Sound Reinforcement

Sound reinforcement systems, often referred to as soundfield or soundfield FM systems, are sometimes suggested as relatively inexpensive solutions for classrooms with poor signal-to-noise ratios.

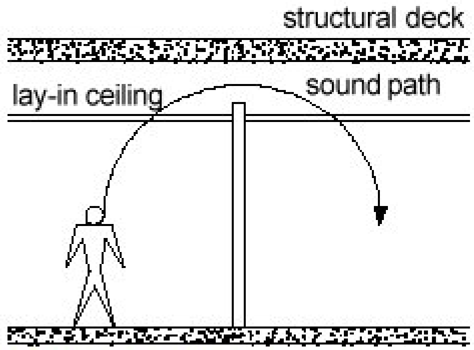


FIGURE 8. Sound Travels over the partition wall, through lay-in ceiling. Partitions must continue all the way to structural deck to be effective sound barriers.

FIGURE 9. Open Plan Classrooms While advantageous for certain teaching methods or student interaction, they have serious drawbacks acoustically. Although partial-height partitions or operable partitions eliminate visual distractions, they provide very little noise reduction between classrooms.

A typical system consists of a wireless microphone worn by the teacher and one or more loudspeakers located at the front of the room, in the ceiling, or along the walls to distribute the sound to the students. Amplifying the teacher's voice raises the signal-to-noise ratio, which improves speech intelligibility and reduces vocal strain. This can be useful in a room with a moderate amount of mechanical noise that would otherwise be difficult or expensive to silence. However, such systems also have their limitations. An overly-reverberant classroom, for example, will cause the sound from the loudspeakers to build up and remain unintelligible. Whether or not a sound reinforcement system is used in the classroom, it is vital to employ acoustical treatments that reduce reverberation time.

Another drawback to sound reinforcement systems is that they amplify only the teacher. Students are not amplified when they ask the teacher questions or talk among themselves while working in groups. Some systems provide an extra handheld microphone that students can pass around. However, this is a cumbersome solution that interferes with spontaneous discussions. Also, if the microphone is not kept close to the person speaking, it will pick up as much ambient noise as speech, and the S/N will not be improved. Still another problem is that the amplified sound will become noise for adjacent classrooms. Despite these shortcomings, sound reinforcement systems can be cost-effective improvements for classrooms with high noise levels, and are usually better than no modifications at all.

Examples of Good and Bad Classrooms

How do all of these pieces of the puzzle fit together? This section provides examples of good and bad classroom acoustics to illustrate how architectural finishes can be used to control reverberation and echoes.

From an acoustical standpoint, open-plan classrooms are perhaps the worst. While they can be advantageous for certain teaching methods or student interaction, they have serious acoustical drawbacks. Students are easily distracted by acoustical and visual signals that spill over from adjacent classes. And if students with hearing impairment or attention deficit disorders have difficulty concentrating on the teacher's voice in a classroom with loud mechanical noise, consider their plight in a classroom where the background noise is not random but rather an intelligible signal. To combat these problems, many open-plan classrooms have been divided with partial-height partitions or operable partitions that slide out like curtains. While these barriers do help students focus by eliminating visual distractions, they provide little noise reduction between classrooms. (Figure 9 shows an example of an open plan.)

Another undesirable design is the classroom with a tall plaster or gypsum board (hard) ceiling, hard walls and hard tile floor. In such a classroom, echoes and reverberation tend to destroy speech intelligibility, especially for young children. Unlike mechanical noise, reverberation cannot be overcome by raising the level of the teacher's voice. An acoustical treatment must be added to increase absorption and reduce harmful echoes. (See Figure 10a.) For suggestions on materials, refer to the section in the Appendix on reverberation time. For a nontraditional solution, read the case study below.

Simply including a sound-absorbing lay-in ceiling and thin carpet on the floor will usually result in good classroom acoustics and low reverberation time. This solution is inexpensive for new construction and is also an affordable way to renovate existing classrooms. For small to moderate-sized classrooms, the lay-in ceiling will provide an acceptable reverberation time, provided that acoustical ceiling tiles with an NRC greater than 0.75 are used. The carpet adds some high-frequency absorption, but primarily serves to reduce self-noise from the students. (Refer to Figure 10b.) Unfortunately, this approach does nothing to control echoes from the walls. However, thoughtful arrangement of furniture such as cabinets and bookcases can help break up large, flat walls and reduce echoes.

The best design for a lecture-style classroom would be to move some of the absorption from the ceiling to the walls and keep the middle of the ceiling hard to reflect the teacher's voice toward the back of the room. This seemingly complex, partially absorptive and partially reflective ceiling can be easily built with a standard ceiling grid. Simply place acoustical ceiling tiles around the perimeter of the ceiling and gypsum board panels in the center of the grid. To reflect more sound to the back of the room, the ceiling can be shaped over the teacher's location at the front of the room. This reflecting surface should be built from a hard material like plywood or gypsum board, and can be painted to match the room. Placing absorptive materials on the walls simultaneously reduces reverberation time and kills echoes. Fabric-covered, 2 inch thick glass fiber panels are a good choice because they are attractive, fairly rugged, and provide some absorption at low frequencies. Add thin carpeting to the floors, and the result can be an acoustically wonderful classroom, with a low reverberation time, no echoes, proper distribution of reflections, and low self-noise, all achieved with common building materials. (See Figure 10c.)

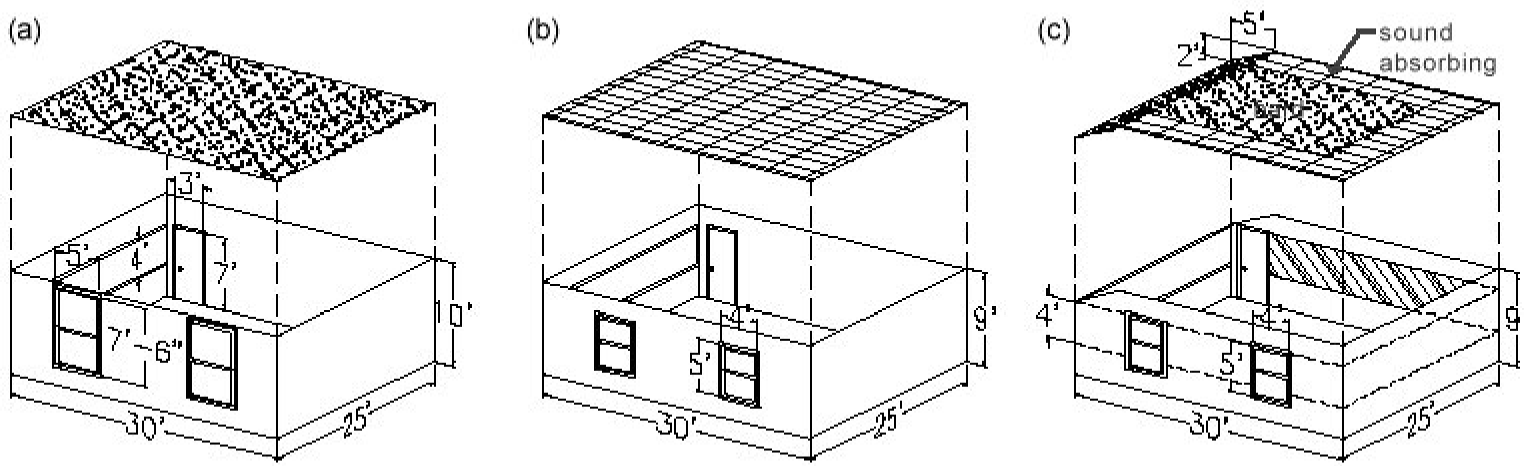
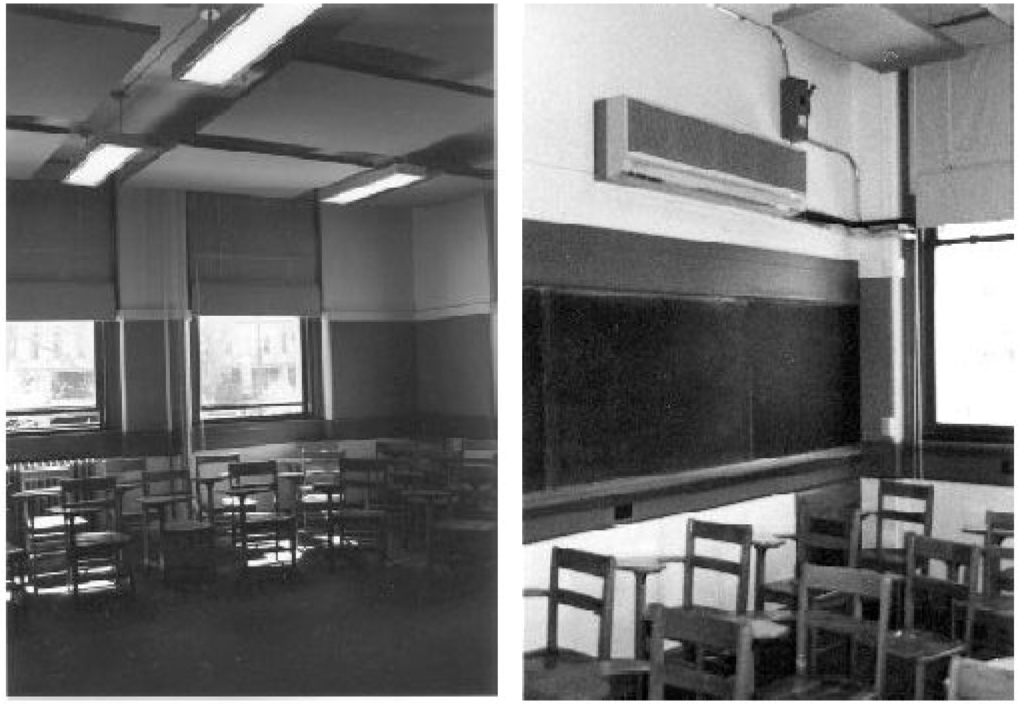


FIGURE 10. Classroom Layouts Classroom (a) is a typical undesirable room with no sound absorbing material and no useful reflection patterns. Classroom (b) is better with an acoustical lay-in, sound absorbing ceiling and thin carpeting. Classroom (c) is a desirable room with sound absorbing wall treatment on three walls, thin carpet, a sloped ceiling reflector at the front, and a ceiling with reflecting surfaces in the center and sound absorbing surfaces around the perimeter.

Case Study -Older Classroom

The topic of this case study is a classroom in an older university building that was the subject of complaints from teachers about the generally poor acoustical conditions including high noise levels and poor speech intelligibility. While this is a university classroom, its design is typical of many classrooms in older elementary and secondary schools. The room, shown in Figure 11, has high plaster ceilings and many tall windows. The building was originally constructed with no central air conditioning system, so several window air conditioners were added, which were very noisy. In order to properly prepare recommendations for improving the acoustical conditions of this room, the ambient noise levels as established by the window air conditioning units were measured and the reverberation times of the room were also measured. It was important that acoustical conditions be improved without adversely affecting room aesthetics.



(a) (b)

FIGURE 11. Older Classroom Improvements Photograph (a) shows the added sound absorptive material in the form of hanging fabric faced glass fiber panels, wall mounted fabric faced glass fiber panels and carpeting. Photograph (b) shows the relatively noisy wall mounted air conditioning unit with two fan speeds.

Due to the high ceiling and lack of absorptive materials in the room, reverberation time was an unsatisfactorily long 1.5 seconds at middle frequencies. Adding a suspended ceiling of acoustical ceiling tiles would have improved the space acoustically but not visually. To avoid interfering with the tall windows, the suspended ceiling would have to be sloped up at the sides, and a new lay-in ceiling would not have matched the traditional architecture of the classroom. Instead, 2 inch thick, dense glass fiber panels, covered with fabric that complemented the color scheme in the room, were suspended from the ceiling at the same level as the existing pendant-mounted lighting fixtures. This resulted is an aesthetically pleasing solution without the expense of replacing the lighting fixtures, which would normally be necessary when adding a suspended ceiling. Fabric faced glass fiber panels were also mounted on the walls between the windows to prevent echoes and further decrease reverberation time. After modification, the unoccupied reverberation time was reduced to a desirable 0.5 seconds in the middle frequencies. Similar solutions could be applied to many classrooms where suspended acoustical tile ceilings are not suitable.

The air conditioning system for this room was also modified with mixed acoustical results. The original window air conditioners created an unacceptably high noise level described by NC-57. The school decided to replace the window units with a wall mounted, two speed fan/coil unit and with the compressor properly located outside. This improved room cooling but it did not completely solve the noise problem. With the fan at high speed, the noise in nearby seating areas is NC-47, 10 points lower than the original NC-57, but still not suitable. On the opposite side of the room the noise is NC-43. with the fan at low speed the noise is NC-36 and NC-33. With low speed operation the noise is relatively close to the criteria (see page 4). But, at high speed the noise is significantly above the criteria. When in-room fan/coil units must be used for economic or physical reasons, multi-speed units should be employed, and the units should be capable of handling the cooling task with low speed fan operation.

Acoustical Guidelines for Special Rooms

Though this booklet is primarily intended to provide guidelines on classroom acoustics, this section addresses acoustical issues for other common schoolrooms. While these guidelines are not as comprehensive as the material on classrooms, much of the material presented earlier, such as the need to eliminate mechanical noise and provide effective noise reduction, also applies to rooms such as cafeterias, gymnasiums, and auditoriums. This section does not attempt to cover music education rooms since the acoustics of these spaces are especially critical. Special purpose rooms are complex and best handled by a professional acoustical consultant.

The most common problem plaguing cafeterias and gymnasiums is excessive reverberation time (RT), since they typically have both large physical volume and hard surface materials. In cafeterias, this long RT causes noise buildup, with students having to speak louder and louder to hear each other until there is a continuous roar. In gymnasiums, which are frequently used for pep rallies and assemblies, combining poor acoustics with a badly designed sound system produces speech that is nearly unintelligible and wreaks havoc on music.

Several options are available for improving sound absorption in these large spaces. In new construction, if the ceiling is constructed as an exposed metal deck, consider using metal deck with perforations on the bottom and glass fiber above to absorb sound. This will significantly reduce reverberation time without adding unduly to construction costs. Another option for either new construction or renovation is to hang absorptive baffles or banners from the ceiling. Baffles and banners are commercially available products made of several inches of glass fiber covered with thin plastic or cloth. They are easily installed, available in a rainbow of colors, and do not detract from the appearance of the room. Placing glass fiber or wood fiber panels on the walls will also reduce both RT and echoes.

Gymnasiums and cafeterias tend to be noisy spaces, and this noise can also disrupt nearby classrooms. Thus, separate these areas from classrooms, and do not place classrooms beneath gymnasiums. The impact noise from bouncing basketballs and the like is a severe problem that is expensive to correct in new construction and even more expensive in renovations.

School auditoriums accommodate a variety of activities, including speech, theater, dance, and music. All these activities require good acoustics, but each has different acoustical requirements. To meet the needs of all these activities, an auditorium's acoustics must either be compromised so it performs adequately for all functions, but favorably for none, or else a technique called variable acoustics must be used to adapt its acoustics to suit each function. Variable acoustics involves the use of panels, drapery, and other materials that can be easily rearranged to alter reflections, reverberation time, and other acoustical properties. To achieve satisfactory results for these complex rooms , it is best to seek the assistance of a professional acoustical consultant. That said, the following paragraphs provide a few design guidelines to follow and common pitfalls to avoid.

Combining the auditorium with the cafeteria or gymnasium is a tempting way to save both money and square footage. Unfortunately, this rarely, if ever, results in an acoustically satisfactory auditorium since the rooms have conflicting requirements. In an auditorium, the objective is to reinforce sound from a single location, while in cafeterias and gymnasiums the goal is to suppress noise from many sources. This conflict cannot be resolved effectively, so these room combinations should be avoided. In an auditorium, the shape of the room is important to properly reflect sound into the audience. Avoid wide, fan-shaped halls with concave rear walls having a radius centered on the stage. A concave rear wall will focus disturbing echoes back to the performers on stage, and if the side walls are splayed too wide, they will not provide useful early reflections into the seating. To allow reflected sound to reach those seated in the back, under balcony depth should be less than twice the distance to the floor below. A flat ceiling will send all reflections to the back of the hall, so sections of the ceiling should be angled to spread reflections throughout the audience. Convex diffusing panels shaped like pyramids or cylinders or special QRD diffusers help scatter sound throughout the auditorium and reduce discrete echoes. Walls can be covered with heavy drapery that slides horizontally or rises vertically to add absorption when necessary and remove it when unnecessary.

NOTE: An ANSI Standard on classroom acoustics is presently under development. Contact the Acoustical Society of America for further information. (See the back cover for the address, phone number and website.)

Appendix

Frequency

Frequency is an important factor in most acoustical measurements. Sound occurs when a vibrating source causes small fluctuations in the air, and frequency is the rate of repetition of these vibrations. Frequency is measured in hertz (Hz), where 1 Hz = 1 cycle per second. A young person with normal hearing can detect a wide range of frequencies from about 20 to 20,000 Hz. In order to deal with such a large spectrum, acousticians commonly divide the frequency range into sections called octave bands. Each octave band is identified by its center frequency. For the standard octave bands these center frequencies are: 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. As you can see, the ratio of successive frequencies is 2:1, just like an octave in music. This also correlates with the sensitivity of the ear to frequency, since a change in frequency is more readily distinguished at lower frequencies than at higher ones. For example, the shift from 100 to 105 Hz is more noticeable than the shift from 8000 to 8005 Hz. Higher-frequency octave bands contain a wider range of frequencies than lower-frequency octave bands, but we perceive them as approximately equal. To obtain a more detailed indicator of the spectrum of sound power, measurements are often made in the one-third octave frequency bands. Standard center frequencies for the one-third octave bands are: 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000 Hz, etc. Note that an octave band contains the one-third octave band at the standard octave band center frequency plus the one-third octave bands on each side.

Decibels

The most common measure of a sound's level is Sound Pressure Level, or SPL, expressed in decibels, abbreviated dB. Decibels are not typical units like inches or pounds in that they do not linearly relate to a specific quantity. Instead, decibels are based on the logarithmic ratio of the sound power or intensity to a reference power or intensity. Sound power and intensity are not easy to measure. However, sound pressure is easily measured with a sound level meter. Sound pressure may also be expressed in dB since sound pressure squared is proportional to sound power or intensity. We use dB instead of the actual amplitude of the sound in units of pressure because its logarithmic value represents the way our ears interpret sound and because the numbers are more manageable for our calculations. Most sounds fall in the range of 0 to140 dB, which is equivalent to waves with pressures of 20 to 200,000,000 micropascals (or 2 x 10 -10 to 2 x 10 -2 atm). To help you get a feeling for sound pressure levels (in dB), the approximate SPLs of some common sound sources are given in Figure 12.

Source	SPL(dBA)
Faintest audible sound	0
Whisper	20
Quiet residence	30
Soft stereo in residence	40
Speech range	50-70
Cafeteria	80
Pneumatic jackhammer	90
Loud crowd noise	100
Accelerating motorcycle	100
Rock concert	120
Jet engine (75 feet away)	140

FIGURE 12. Sound Pressure Levels of common sound sources.

A simple sound level meter combines sound pressure levels over all frequencies to give the overall SPL in dB. More complex meters have filters that can measure the SPL in each octave band or one-third octave band separately so we can identify the level in each band, thus identifying the spectrum of the sound. Sound level meters can also weight the sound pressure level by adjusting the level in different frequencies before combining the levels into a weighted overall level. For example, A-weighting reduces the level of sounds at low frequencies to simulate the variations in sensitivity of the ear to different frequencies. A-weighted values are denoted as dBA to differentiate them from unweighted dB levels. Similarly, C-weighted values are labeled dBC. C-weighting slightly reduces the level of sounds below 50 and above 5000 Hz, but is nearly flat in between, and can be used to approximate an unweighted reading on sound level meters that only offer A- or C-weighting. Comparing A- and C-weighted levels for a noise source can provide a rough estimate of its frequency distribution. If the two levels are within 1 or 2 dB, most of the noise is above 500 Hz. If the two levels vary by more than a few dB, a significant amount of the noise is in the lower frequencies. To convert unweighted octave band sound pressure levels into weighted A or C levels, add or subtract the amounts noted in Figure 13 from the corresponding frequency bands. Next, sum the octave band levels (two at a time as explained below) to arrive at the overall dBA or dBC value.

	Octave Band Center Frequency (Hz)								
	31	63	125	250	500	1000	2000	4000	8000
A-weighting	-40	-26	-16	-9	-3	0	+1	+1	-1
C-weighting	-2	0	0	0	0	0	0	0	-3

FIGURE 13. Frequency Discrimination in dB for A and C weighting.

As mentioned earlier in the text, calculating the SPL of two sources together is not as simple as adding their individual decibel levels. Two people speaking at 70 dBA each are not as loud as a jet engine at 140 dBA. To combine two decibel values, they must be converted back to pressure squared, summed, and converted back to decibels. The mathematics may be approximated by using Figure 14.

Difference between two decibel values	Amount added to higher value
0 or 1	3
2 or 3	2
4 to 9	1
10 or more	0

FIGURE 14. Decibel "Addition"

If one sound is much louder than the other, the louder sound drowns out the softer sound, and the combined decibel level is just the level of the louder sound. If the two sounds are equally loud, then the combined level is 3 dB higher. More than two sources can be combined, but they must be considered two at a time. For example, an unbuilt classroom is expected to have 34 dBA of mechanical system noise, a computer that generates 32 dBA of noise, and an overhead projector that generates 43 dBA. What will be the total sound pressure level from the three noise sources? The difference between the first two decibel values is: 34- 32=2, so add 2 dB to the higher value: 34+2=36 dBA. Then combine this with the projector noise: 43-36=7, so add 1 dB to the higher value: 43+1= 44 dBA total from the three noise sources. If the SPL of the teacher's voice is 55 dBA, what is the signal-to- noise ratio in the room? 55-44= +11 dB, which is sufficient for good speech intelligibility. How much louder is the total 44 dBA than each of the individual noise sources? Due to the response of our ears, we can just notice a difference of 3 dB. An increase of 10 dB sounds approximately twice as loud, and an increase of 20 dB sounds about four times as loud.

Reverberation Time

Over 100 years ago, a Harvard physics professor named Wallace Clement Sabine developed the first equation for reverberation time, which has since been named after him and is still used today. Reverberation time is defined as the length of time required for sound to decay 60 dB from its initial level. Sabine's simple formula is:

$$RT(60) = \frac{0.05V}{(?\ S?\ )}$$

where:

RT(60) = reverberation time (sec)
V = room volume (ft3)
S = surface area (ft 2)
? = absorption coefficient of material(s) at given frequency
? indicates the summation of S times ? for all room surfaces

To use this formula, the volume of the room, surface area of each material in the room, and absorption coefficients for those materials must be known. Absorption coefficients are measured in specialized laboratories, and represent the fraction of sound energy (not sound level-dB) the material will absorb as a decimal from 0 to 1. Figure 15 gives absorption coefficients for common classroom materials.

	Sound Absorption Coefficient (α)					
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Glass Fiber Ceiling Tile	0.70	0.85	0.75	0.85	0.90	0.90
Fiberglass Wall Panel - 2 inch thick	0.30	0.50	0.80	0.90	0.80	0.75
Concrete Block, painted	0.10	0.05	0.06	0.07	0.09	0.08
Gypsum Wall Board	0.25	0.15	0.08	0.06	0.04	0.04
Plaster Wall or Ceiling	0.14	0.10	0.06	0.05	0.04	0.03
Linoleum or Tile Floor	0.02	0.03	0.03	0.03	0.03	0.02
Thin Carpet, on concrete	0.05	0.10	0.25	0.30	0.35	0.40
Wood Door	0.15	0.11	0.09	0.07	0.06	0.06
Glass	0.35	0.25	0.18	0.12	0.07	0.04
Chalkboard	0.01	0.01	0.01	0.01	0.02	0.02

FIGURE 15. Typical Absorption Coefficients for building materials commonly used in educational facilities.

A commonly used one-number rating called NRC, Noise Reduction Coefficient, is simply the average of the absorption coefficients at 250, 500, 1000, and 2000 Hz. This simple, one-number rating can be useful for comparing the relative absorption of two materials; however, examining absorption coefficients in each octave band gives a better idea of the performance of a material at various frequencies.

Reverberation time is often calculated with the room unoccupied. Since people and their clothing provide additional sound absorption, an unoccupied room is the worst-case scenario, though not an unreasonable one, since occupancy of most classrooms varies. In a complete analysis, this calculation should be performed for each octave band, as the RT can vary widely at different frequencies. However, for a quick estimate, the RT of a classroom can be calculated for just one octave band representative of speech frequencies, such as 1000 Hz. If this RT is acceptable, then the RT throughout the speech range will likely be acceptable.

To demonstrate the use of the Sabine equation, Figure 16 provides an example calculation of the RT at 500 Hz for the acoustically poor classroom example given in Figure 10a. Try calculating the RT at 500 Hz of the acoustically satisfactory classroom in Figure 10b with only a sound-absorbing ceiling added. Note that the ceiling is lower in that example, so the volume and surface areas will change. The RT of the satisfactory classroom is approximately 0.4 seconds.

Material	S(ft²)	a (500Hz)
Tile floor	(25)(30) = 750	0.03
Windows	(2)(5)(7.5) = 75	0.18
Door	(3)(7) = 21	0.09
Chalkboard	(4)(25) = 100	0.01
Plaster (walls and ceiling)	750+(10)(110) -75-21-100 = 1654	0.06

$$V = (30\text{ ft})(25\text{ ft})(10\text{ ft}) = 7500\text{ ft}^3$$

?????? S? ? = (750)(0.03) + (75)(0.18) + (21)(0.09) + (100)(0.01) + (1654)(0.06) = 138

$$RT(60) = \frac{(0.05)(7500)}{(138)} = 2.7\text{ sec at 500 Hz}$$

FIGURE 16. RT Calculation example.

	Octave Band Center Frequency (Hz)								
	63	125	250	500	1000	2000	4000	8000	NC
Window air conditioners	62	67	63	60	55	50	50	40	57
Fan coil Unit		46	47	54	48	41	30	23	50
Background noise	51	42	32	24	25	16	10	6	23

FIGURE 17. Sound Pressure Levels for noise sources measured in the case study. See Fig. 18 for the plotted NC Curves.

Speech Intelligibility

There are many methods for measuring or predicting speech intelligibility, ranging from a simple A-weighted sound level to the complex **Speech Transmission Index (STI)**. For classrooms, speech intelligibility can be predicted from reverberation time and signal-to- noise ratio. A classroom with a 0.5 second RT and +10 dB S/N will have approximately 90 percent speech intelligibility. If the RT is kept at 0.5 seconds but the S/N is reduced to 0 dB, intelligibility falls to about 55 percent. Similarly, if the S/N is +10 dB but RT is increased to 1.5 seconds, intelligibility drops to around 75 percent. And if the S/N falls to 0 dB and RT is 1.5 seconds, intelligibility falls dramatically to approximately 30 percent. Sadly, this last condition does exist in some U.S. classrooms.

Speech intelligibility tests can be used to measure intelligibility in existing classrooms. Such tests can take many forms. Typically, a speaker reads nonsense syllables, monosyllabic words, or sentences, and listeners record what they hear, or choose from a list of possible alternatives. The percentage of test items correctly heard is a measure of speech intelligibility. Standardized tests have been developed that outline test procedure, selection of listeners, training of speakers and listeners, and so on. Also available are recordings of standardized word lists that can be reproduced instead of having a speaker read from a list. This eliminates lip reading cues and variations in different speakers' speech characteristics and speech levels. Before beginning actual testing, listeners should practice taking the tests in a quiet environment until they are familiar with the procedure and their scores reach a stable level. (Words used are randomly chosen from a standardized list so listeners cannot simply memorize the order of the words.)

When testing in a classroom, the speaker should read the list from the teacher's usual speaking location. To assure conservative results, several listeners should be seated together in whichever area of the classroom has the poorest signal-to-noise ratio. This is typically in the back, or near the loudest source of mechanical noise. Any noises present during normal classroom use, such as mechanical noise, outdoor noise, or corridor noise, should be present to ensure representative values of speech intelligibility.

Adults average roughly 10 percent better than young children on speech intelligibility tests. For example, in a first-grade classroom in which adult listeners score 90 percent, typical students will likely score only 80 percent. Students with hearing or learning disabilities, or for whom English is a second language, will show even lower scores. If speech intelligibility in a classroom is less than 90 percent, acoustical treatments should be implemented to reduce reverberation and/or improve signal-to-noise ratio.

NOTE: Speech intelligibility testing is not a simple procedure and professional advice is suggested. The school audiologist may be a good resource in this regard.

Noise Criteria Rating

The noise level in a space can be effectively described with a single-number rating called the noise criteria (NC) rating. The NC rating is determined by measuring the sound pressure level of the noise in each octave band, plotting these levels on a graph, and then comparing the results to established NC curves. The lowest NC curve not exceeded by the plotted noise spectrum is the NC rating of the sound. On most graphs, NC curves are shown in intervals of 5 to save space, but the NC rating can be given as any whole number in between, not just as a multiple of 5. To illustrate this, we will find the NC rating for the window air conditioners, unit ventilator, and background noise from the case study presented above. (See Figures 17 and 18.) A blank NC chart has been provided. (See Figure 19.)

Sound Level vs. Distance

We all know that sound level decreases as the distance from a sound source increases. This decrease in sound level is quantified by the inverse square law. That is, the sound energy decrease is proportional to the square of the distance increase. For example, if the listening distance from a sound source is increased by a factor of 2 (doubled), the direct sound energy is decreased by a factor of 4 or 2 squared (2 times 2). This translates to a 6 dB reduction in the sound intensity level and the sound pressure level of the direct sound for each doubling of the distance from the sound source.

Let's assume that, in a particular classroom, the average difference between the sound level of the teacher's voice and the level of the classroom background noise produced by the air conditioning system is 10 dB at a student's listening position 10 feet from the teacher. With this 10 dB signal-to-noise ratio the intelligibility of the teacher's speech is probably satisfactory as discussed in the previous section on speech intelligibility. But, if the distance from the teacher to the student is doubled to 20 feet, the signal-to-noise ratio is reduced to about 4 dB (assuming that the background noise remains constant). At a distance of 30 feet the level of the direct sound produced by the teacher is reduced by about 10 dB and the signal-to-noise ratio is 0 dB, with low speech intelligibility. Thus, it is most important that the background noise level be acceptable in all classroom locations if a proper S/N ratio is to be maintained allowing satisfactory speech intelligibility.

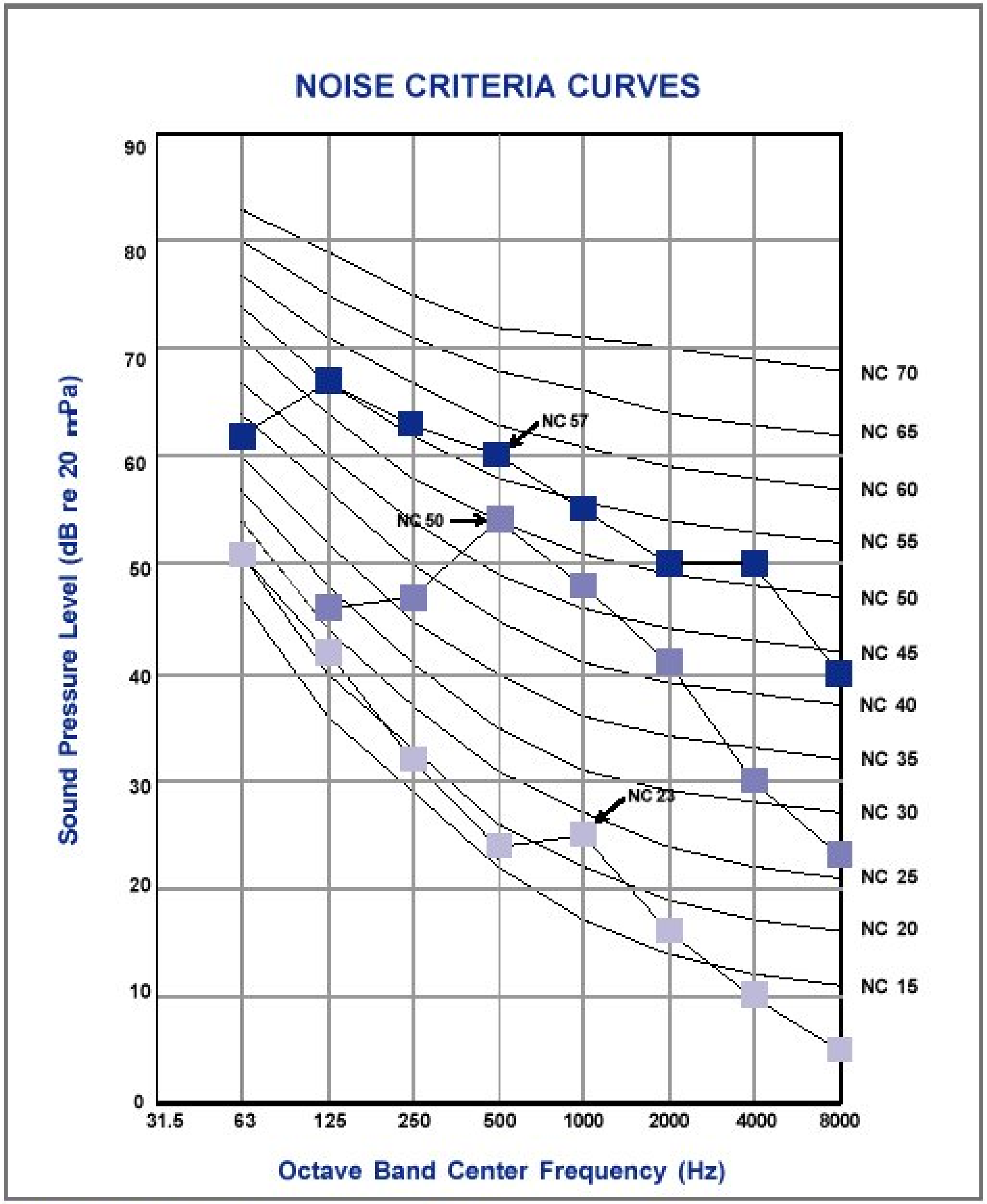


FIGURE 18. Noise Criteria Rating for the case study: ■ - window air conditioner, ■ - fan coil unit, ■ - background noise.

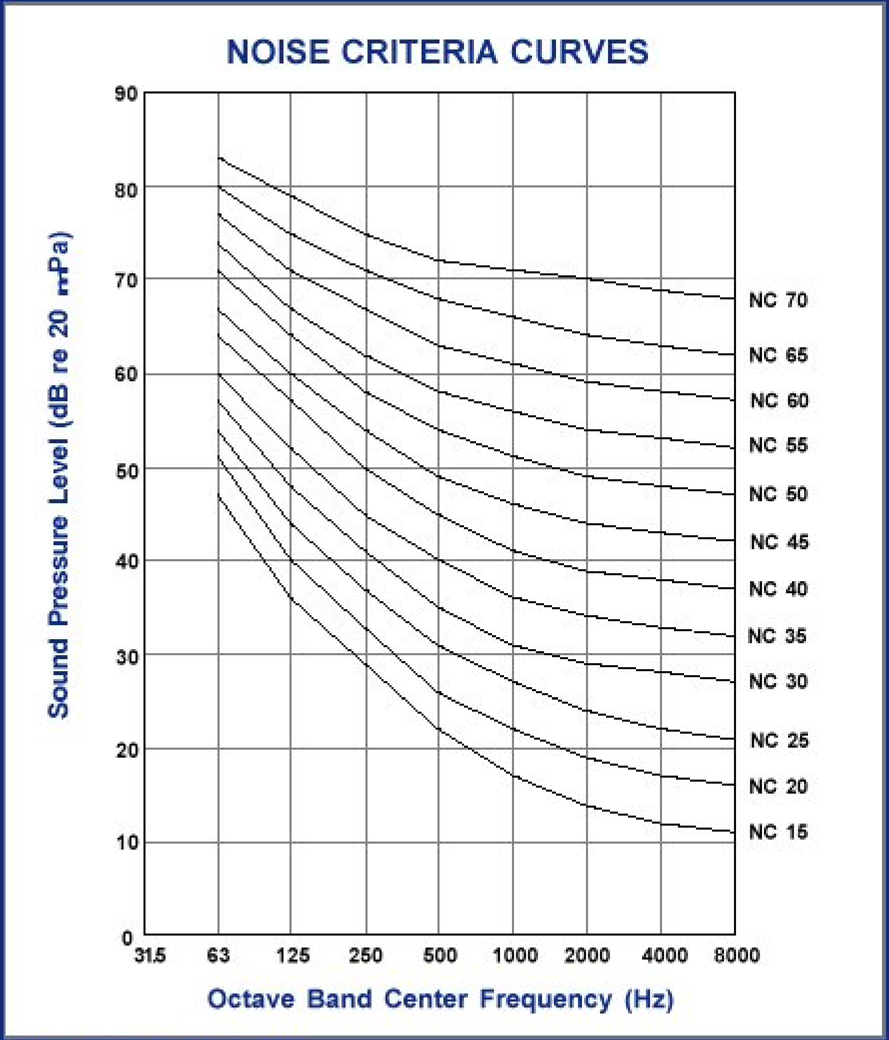


FIGURE 19. Noise Criteria Curve

RESOURCES

The information provided in this publication is not intended to replace the professional acoustical consultant, but to aid in the understanding of the elements that will produce desirable learning conditions. Further information on room acoustics and noise control can be obtained from the following publications:

M. Mehta, J. Johnson and J. Rocafort. *Architectural Acoustics, Principles and Design*. Prentice Hall, Columbus, Ohio, 1999

W. J. Cavanaugh and J. A. Wilkes. *Architectural Acoustics: Principles and Practice*. John Wiley & Sons, New York, 1999

C. M. Salter, Ed. *Acoustics, Architecture, Engineering, the Environment*. William Stout Publishers, San Francisco, 1998

C. M. Harris. *Noise Control in Buildings*. Institute of Noise Control Engineering, Poughkeepsie, New York, 1997

R. E. Apfel. *Deaf Architects and Blind Acousticians? A Guide to the Principles of Sound Design*. Apple Enterprises Press, New Haven, Connecticut, 1998

M. D. Egan. *Architectural Acoustics*. McGraw Hill, New York, 1988

L. K. Irvine and R. L. Richards. *Acoustics and Noise Control Handbook for Architects and Builders*. Krieger Publishing Co., Melbourne, Florida, 1998

Sound Lambda, wavelength, ft (m) = C, velocity of sound, fps (m/s) /f, frequency of sound, Hz

NR, Noise reduction, dB =TL Barrier transmission loss, dB, -10 log S/AR where
S = Area of barrier wall, ft2 [m2]; AR = Total absorption of receiving room, sabins, ft2 [m2]

NRC = a/s

where
NRC= Noise reduction coefficient
a = Total sabins (sound absorbing units)
s = Total surface area in the room

TR, Reverberation time in seconds
= K V/TA seconds
where
K = A constant, equal to 0.05 when measurements are in feet and 0.16 when in meters
V = Room volume, ft3 or m3
TA = Total room absorption, sabins (ft2 or m2) at that frequency

1. Building Design

Apply theory and principles of acoustic systems as a component of building design.

Acoustics and Design

1. Introduction

What is covered:

- Basic acoustic terminology.
- Noise sources, design criteria for different buildings and spaces, assessment of noise levels, and noise control.
- Design issues associated with acoustic performance inside buildings due to internal or external noise sources.

What is not covered:

- Buildings where there are special acoustic constraints e.g. auditoria.
- Factories (and buildings where there is 24 hour work, e.g. hospitals) where it may be important to assess the effect of noise generated on adjacent dwellings.
- Sound systems in buildings. These may be required for emergency warning (e.g. fire alarm), paging system, lecture and conference rooms, sports stadia, railway stations etc.

Examples

- External environment: buildings adjacent to motorways where there may be a need for a sealed building with mechanical ventilation; How noisy can it be before a building cannot be naturally ventilated?
- Internal environment: Office space within factories next to noisy process plant. How can sound levels in offices be made acceptable?

Acoustic assessments through the design process: stages of design

STAGE	ISSUES
Site	Rural or industrial - planning regulations

	Transportation noise - roads/rail/aircraft (prediction of future levels)
	Industrial noise sources
	Airborne noise and/or vibration
Building form	Site planning and screening
	Ventilation - natural or mechanical
	Location of plant rooms
Detailed design	Room-to-room noise
	Outside-to-inside noise
	HVAC noise
	Room acoustics
	Sound insulation
	Sound systems
Supervision	Quality of construction
Commissioning	Compare actual noise levels to intended levels and criteria
Retrofit	Remedial action

References:

- CIBSE Vol A1 for criteria for design; Vol B12 for sound control in building services.
- British Standard Code of Practice BS8233:1987 Sound insulation and noise reduction for buildings.
- Croome DJ, Noise Buildings and People, Pergamon, 1977.
- Smith BJ, Peters RJ and Owen S, Acoustics and Noise Control, Longman 1982.

2. Basic Acoustic Terminology

- Sound power and sound pressure are expressed in dB - i.e.as a ratio relative to some reference level.

Sound Power Level = PWL = 10 $\log_{10}(W_{source}/W_{ref})$ dB
where: W_{ref} is 10^{-12} W; W_{source} is sound power in W.
If sound power increases by a factor of 2, this is equivalent to a 3dB increase.

Sound Pressure Level = SPL = 10 $\log_{10}(P^2 / P_{ref}^2)$ dB
where $P_{ref} = 2 \cdot 10^{-5}$ Pa; P = sound pressure in Pa

For ducts with no attenuation, sound pressure propagation is 1-dimensional and the SPL is constant.
For spherical spreading, a doubling of distance results in a 6dB reduction in SPL.

- Octave band calculation/measurement:
  The absorbing/insulating properties of materials vary significantly with frequency of the sound source. Thus measurements and calculations often need to be undertaken in octave bands (or 1/3 octave bands for more detailed work). A crude approximation sometimes used for broad-band noise is that transmission/absorption characteristics over the full acoustic spectrum is similar to the response at 500Hz. Note that the human ear responds to frequencies in the range 20Hz to 20kHz approximately.

- dB; dBA;
  The ear also responds in a non-linear way, with maximum sensitivity around 2 or 3 kHz and much lower sensitivity at low frequencies. A commonly used metric is the A-weighted dB (dBA) which is weighted according to the typical human ear's frequency response.

- L_{eq}; L_{A10}; L_{A90}

  L_{eq} is the time averaged sound pressure level and is used for time-varying signals.
  L_{A10} is the SPL which is exceeded for 10% of the time.
  L_{A90} is the SPL which is exceeded for 90% of the time (the "background" level).

- Absorption and insulation

  Absorption is quantified as the absorption coefficient - the proportion not reflected
  Insulation is quantified as the Sound Reduction Index SRI (in dB) - a measure of the reduction in transmission. It is a property of the building construction only.

- Reverberation time - the time it takes for a sound to decay by 60dB. It is governed by the absorption characteristics for the room.
  Sabine's formula is commonly used:
  T = 0.161 V / A
  where T is the reverberation time (s); V is room volume (m^3); A is total absorption (room surface area * average absorption coefficient + absorption of furniture/people, m^2).

- Level difference is simply the difference between source and received sound levels for airborne noise.
  The level difference is affected by the level of absorption and thus the reverberation time in the receiving room. It is therefore usually standardised (D_{nT}) to allow for the fact that most occupied domestic rooms have a reverberation time of about 0.5s.

- For impact noise, a standardised impact SPL is used - obtained by measurement with a standard source.

3. Noise Sources

3.1 Central Plant

Fans: Primarily resulting from turbulent fluctuations in air pressure, but can also result from vibrations. Axial fans generally have lower noise output than centrifugal fans except at low frequencies.

Pumps:

Other equipment: Boilers, motors, compressors etc.

3.2 Noise in Airflow Systems

Larger diameter ducts - lower air velocity, less noise.

- also need to reduce abrupt transitions to avoid turbulence Can add sound absorbent lining or attenuators(silencers).
- beware of possibility of breakout at any airgaps.

Diffusers - data from manufacturer, or estimate from CIBSE:

$$PWL = 32 + 13 \log_{10} A + 60 \log_{10} v$$

where A is the minimum open area in m^2 ; v is air speed in m/s
(e.g. for an air speed of 4m/s and a 200mm * 200mm opening; PWL ~50dB)

3.3 External Noise

- Road traffic
    - calculation of predicted SPL for new roads
    - measurement or calculation for existing roads
- Aircraft
- Rail
- Industrial sources - in general requires site survey to BS4142
- External equipment and plant

4. Design Criteria

4.1 Regulations

- Noise at Work Regulations - legal duties of employers (and equipment suppliers) to minimize hearing damage.
- Town and Country Planning Regulations - define environmental assessments for any major projects of more than local importance, or projects in sensitive areas.
- Detailed Building Regulations - performance criteria by conforming to design or by measurement - but only for housing.

4.2 Houses

For houses, background noise in the house due to external noise sources should be:

- <35 dB L_{Aeq} for the period 23:00 to 07:00 in bedrooms;
- <40 dB L_{Aeq} for the period 07:00 to 23:00 in living and dining rooms;
- <50 dB L_{Aeq} for the period 07:00 to 23:00 in less sensitive rooms.

The Building Regulations give acceptable constructions and connections for all parts of the building.

4.3 Other buildings

For other buildings, Noise Rating criteria are used:

- NR curves
- recommended noise ratings for spaces
- speech intelligibility (privacy)

There are no regulations governing acceptable noise levels in offices. BS8233:1987 recommends 40-45dB L_{Aeq} for private offices and small conference rooms, and 45-50dB L_{Aeq} for open-plan offices. This indicates that where external noise levels are in excess of 60dB L_{Aeq} (e.g. from road traffic noise), then a sealed office with mechanical ventilation will be required.

4.4 Reverberation Time

Acceptable reverberation times can be specified for rooms for best reception for speech or music. This is primarily of interest to large specialised spaces - auditoria, lecture theatres etc.

5. Assessment of Room Sound Level

To find the total sound pressure levels in a room: define individual noise sources and their PWL, include the modifying characteristics of the transmission paths (e.g. SRI), apply the acoustic properties of the receiving room (amount of acoustic absorption), and sum.

5.1 Outside Noise Environment

This is important, as it has implications for ventilation, and possibly glazing/constructions e.g. near airports or busy roads. Considerations include:

- external barriers around site - height is critical: note the potential impact on shading;
- magnitude of noise sources by measurement, or in case of traffic, calculation based on vehicle flow rates, speed, ratio of heavy/light vehicles, road surface, gradient, distance from road to building, screening correction.
- distance is important: with vegetation and <4m reception point, as high as 7dBA for doubling of distance; with a hard surface or water only 3dBA for a doubling of distance.

5.2 Internal Noise Environment

Consider paths for transmission in buildings.

$$SPL_r = SPL_s - SRI + 10 \log_{10} (S_w / A)$$

where: SPL_r is the sound pressure level in receiving room; SPL_s is the sound pressure level in source room; SRI is the sound reduction index; S_w is area of separating wall; A is total absorption in receiving room (surface area * average absorption coefficient + absorption of furniture/people, m^2).

6. Control of Noise

In all cases consider (in order) source, transmission path and receiver.

6.1 Planning to Control External Noise

- Control of source usually not possible (except by planning constraints).
- Transmission path can be influenced by:
    - location of the building on the site;
    - screening of the site;
    - internal planning of the building;
    - building form and orientation.
- Control at receiver by improving insulation of the building envelope, but the site itself may not be protected, so gardens/public areas may be noisy. The building must be well sealed to give maximum insulation, requiring mechanical ventilation.

6.2 Planning to Control Internal Noise

- Reduce noise at source where possible (e.g. acoustic enclosures for noisy machinery).
- Internal planning - ensure that adjacent rooms are compatible in terms of noise sensitivity and noise production.
- Improve room-to-room sound insulation.

6.3 Use of Mass

The sound insulation of any single-leaf wall or floor built without gaps depends mainly on its MASS. According to the MASS LAW, there will be an increase in sound insulation of about 5dB if the mass/unit area is doubled. The insulation also increases by about 6dB for a doubling of frequency. However, this is only true up to a critical frequency, beyond which there will be a dip in insulation. The critical frequency is about 100Hz for a one-brick wall, 200Hz for a half-brick wall. Critical frequencies in the range 100Hz to 1000Hz should be avoided.

6.4 Use of Isolation

Double leaf walls give good insulation if they are completely decoupled. For example, 2 sheets of plasterboard bonded together will give 30dB attenuation; this would increase to 50dB if they were perfectly isolated. In practice, attenuation may vary according to how rigid the link is between the two leaves and the width of the airgap. Absorbent quilt in the airgap improves performance - not because it is a good sound absorber, but because it helps to isolate the two leaves of the partition.

High levels of insulation can be achieved with care and expense - for example, separation of multiplex cinema auditoria of weighted standardised level difference (D_{nT}) of 65dB to over 70dB has been achieved by using 2 layers of 15mm plasterboard on separate studs, a large cavity with 100mm quilt inlay and careful head, base and edge detailing.

6.5 Control of Flanking Transmission

Detailing for houses are given in the Building Regulations. If flanking constructions are not properly specified (and constructed), the flanking transmssion can equal or even exceed direct transmission.

6.6 Quality of Detailing

Small flaws in construction can lead to large differences in insulation. For example, this may be due to:

- Small airgaps in mortar joints or under skirting boards. For example, an opening of area $0.1m^2$ (SRI of 0dB) in a facade of area $25m^2$ (SRI of 50dB) reduces the overall SRI value to 24dB.
- Mechanical bridging of air gaps (nails through floating floors etc).
- Excessive flanking transmission.

7. Example of Design Considerations: Hotels

Main Issues

- Hotels vary in standards, but many are near busy roads or airports, or in city centres.
- The main acoustic issues are noise break-in from outside, pnvacy between rooms, and ventilation noise.

Windows

- Windows in hotels have opening lights even in noisy situations; good weatherstripping and double glazing are essential.
- Balconies can give some protection from noise.

Privacy

- A reasonable standard is attained with separating walls and floors having an SRI of 50dB.
- Creation of a lobby outside the en-suite bathroom will isolate corridor noise.
- Cross-talk attenuation to bathroom extracts will prevent plumbing sounds being transmitted.
- Single door to corridors should be rated at 35dB.
- Room televisions should not be fixed directly to room separating walls.

Ventilation Noise

- This should be kept within NR35 in any hotel and down to NR25 in good standard bedrooms.
- Connections to outside and chiller plant should be remote from bedrooms, or well-screened and attenuated.

8. Example of Design Considerations: Offices

Main Issues

- Complaints from office workers arise from intrusive outside noise, high noise levels within offices and poor insulation between cellular offices.
- BS8233: 1987 recommends 40-45dB L_{Aeq} for private offices and office conference rooms, and 45-50dB L_{Aeq} for open-plan offices.
- Above a general level of 57 dBA, occupants have to raise their voices to offset the background noise, which further raises internal levels.

Outside Noise Levels

- This can influence the form of the office complex: natural ventilation for a 15m deep template or natural ventilation plus ventilated core for an 18m deep template allows in traffic and industrial noise. A deep plan sealed fully mechanically ventilated office building gives a more controlled environment.
- 4/12/6 glazing is usually adequate, but better glazing combinations (6/20/10) or even double windows may be required in exceptional circumstances.

Atria

- Glazing panels act as low frequency absorbers but are otherwise strongly reflective.
- With hard floor and wall surfaces, the space will be reverberant without absorptive panelling on about 25 % of the wall surface. Trees and furniture can help as sound absorbers; water features can help to mask sound.
- There is little data available but two centres monitored had ambient noise levels around NC50 (similar to NR50) due to ventilation plant and continuous escalator operation. Sound levels were very uneven.

Internal Noise Levels

- These can be kept reasonable with a sound-absorbing ceiling, carpet and screened workstations.
- Modern office equipment is much quieter than older equipment (e.g. laser printers are typically 64dBA at 1m compared to 83dBA for mechanical printers).

Privacy

- There is a usually a hierarchy of privacy in offices: senior management have offices with greater privacy and lower ambient noise.
- Privacy between workstations is only typically around 17-20dBA in open-plan offices - less than required for speech privacy. There is some evidence that resulting interruptions can lead to loss of productivity: improving privacy can improve productivity by 3-10%.

Relationship of background noise and annoyance in offices

Activity + ventilation noise (dBA)	**Staff in an adjacent workstation**

	annoyed by normal speech (%)
35	65
40	40
45	25
47	16
55	4

- Good quality partitioning with care at the ceiling and floor junctions is required to improve insulation.
- In cellular offices, proprietary 50mm metal-skinned panels with mineral wool core can achieve 30-35dB average SRI if well-installed, or 40-45dB if high performance panels are used.
- Sound conditioning systems can be used to generate broadband noise to mask speech from surrounding workstations, but it is difficult to set the correct levels.

Computer rooms

- These have inherently high noise levels, the acceptability of which is dependent on the occupants.
- If staff workstations are within the computer room, a background level of NR45-50 should apply; NR60 may be acceptable for intermittent occupation.
- Measures to reduce noise in the room air handling units include lower air velocities, ducted supply and return with silencers, and double skin casings.

2. Building Systems and their Integration

Examine integration and effects of acoustic design principles, systems, and details on the overall design of a building considering technological advances and innovative building products.

3. Implications of Design Decisions

Determine the effects of acoustic systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

4. Construction Details and Constructability

Identify and analyze acoustic system details including the aspects of constructability.

COMMON ACOUSTIC CONSTRUCTION MATERIALS

Wood and metal studs and joists – construction framing members with which most of you are familiar. The most common framing for walls is either 2x4 wood studs or 3.5" metal studs. Which is more cost effective – metal or wood – will largely depend on the relative price of wood and steel in different parts of the country. For acoustical purposes, metal does offer resiliency benefits worth considering for maximum benefit. For those of you that are not used to building things, bear in mind when figuring your dimensions that lumber is not really the actual dimensions indicated by the name. For instance, a 2x4 is not; it is actually 1½"x3½". A 2x6 is 1½"x5½", etc.

Gypsum wallboard ("GWB," "drywall," "SheetRock") is commonly available in ½" and ?" thicknesses. It is far and away the most common building material in North America for interior finish construction. Unless you have a home built prior to the 1950s, you probably have gypsum board finish to your walls and ceilings. (Plaster on lathe was much more common – and incidentally much better for sound isolation than gypsum board – in homes prior to the construction boom of the 1950s.)

Plywood is usually ¾" (but is available in a variety of thicknesses from larger lumber yards) and is either available with flat edges, or with tongue and groove edges for tight floor construction.

The **Particleboard** family:

• Low density fiberboard, or LDF, is typically called chipboard. It's the stuff out of which most inexpensive, DIY furniture is made.
• Medium density fiberboard, or MDF, is more typical of shelving and loudspeaker enclosures. It has some very good acoustical properties and we like using it for many varied applications.
• High density fiberboard, or HDF, is also available, but is quite rare and quite heavy. Very high-end cabinetry will often employ HDF.
• Oriented strand board, or OSB, is often used in residential construction as a low-cost floor underlayment.
• Straight up particleboard is usually a version of LDF, but can also be the name given to a higher grade of OSB.
• Other materials we make mention of in Acoustics 101 include gypsum board screws of various thread sizes and lengths, construction adhesives including vinyl flooring adhesive, silicone caulk, etc. Wherever possible, we have provided make, model and cost information as appropriate for any non-Auralex materials we mention.

Reverberation: Persistent sound reflection from enclosed space

Not: Creep, Dampening, frequency

Vibration isolator: is springs, plastics, or dampening device to reduce vibration of equipment on walls, floors, etc.

Not: Resilient hanger, flexible coupling, paver pedestal

Duct lining is most effective reduction of low frequency noise

Not: Mufflers, dampers, turning vanes

Sabins: Units of sound absorption

Not: Watts, decibels, degrees

Absorption is best effective control of noise generated in a space

Not: Reflection, focusing, diffusion

B. COMMUNICATIONS & SECURITY

Evaluate, select, and design communications and security systems.

Suppliers of **fire prevention** systems, **linear heat detection** systems, **fire alarm systems** , and **suppression systems** , as well as facility communications and **security systems, early warning fire detection** systems, **early warning air sampling fire detection** systems, and **linear heat detection** systems.

Fi**re protection** and **fire warning** are key in ensuring the safety of your employees and assets. We employ **early warning system** s much more sophisticated than a simple **smoke detector** . By the time **smoke detection** occurs, in many cases it is already too late. That's why we offer **linear heat detection** systems that often can sense potential fire hazards due to overheating before combustion occurs. We also have fire **suppression systems** that can control or eliminate a fire before it gets out of control. We also offer a **fire alarm service** that includes **monitoring** from our **central station** . All of our fire safety products comply with the **Life Safety** Code established by the National **Fire protection** Association.

Systems provides:

- System Design
- Fire Detection
- **Smoke Detection**
- Fire **Suppression systems**
- **Fire Prevention**
- Hand Held Extinguishers
- **Early Warning System**
- Kitchen Hood Suppression
- **Fire alarm service**
- **Fire alarm systems**
- **Early Warning fire detection**
- Fire System Inspection
- Facility Security
- Communications Systems

All of **fire protection** and **fire warning** systems are **Life Safety** Code compliant. One provides a complete range of customized life, property and productivity protection systems statewide - with the important benefits of local ownership and operation.

CONCEPT and DESIGN

We at Mac Systems evaluate your specific needs and develop a plan for you. A plan you can count on to provide facility safety and compliance with state and local regulations. Our in-house engineers utilize the latest Computer Aided Design and Electronic software to prepare detailed engineering drawings of the proposed installation.

INSTALLATION
Components selected for reliability and cost effectiveness are installed quickly and efficiently according to specifications. Each yyyy Systems crew takes pride and satisfaction in knowing your project is installed professionally.

INSPECTION, TESTING and MAINTENANCE
To maintain confidence in your **fire alarm systems** , fire suppression and **security systems** and to comply with the multitude of insurance, state and local regulations, yyyy Systems employees teams specially dedicated to inspection, testing and maintenance. We provide you and the regulatory agencies with factual, detailed information on system readiness and compliance. No other **fire alarm service** is as comprehensive and trough in their testing, inspection and maintenance.

.

1. Building Design
Apply theory and principles of acoustic systems as a component of building design.

2. Building Systems and their Integration
Examine integration and effects of communications and security design principles, systems, and details on the overall design of a building considering technological advances and innovative building products.

3. Implications of Design Decisions
Determine the effects of communications and security systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

4. Construction Details and Constructability
Identify and analyze communications and security system details including the aspects of constructability.

Evaluate, select, and design elevators, escalators, moving walkways, and other conveying systems.

Elevators

- An elevator is a button-controlled popular form of commercial building transportation that moves people and products from floor to floor. For example, in a 12-story building the elevator is designed to stop at each floor. Attached to one end of a steel cable, an elevator is like a steel cage, with cables moving up and over a sheave (a grooved drive wheel) and downward toward a counterweight of iron blocks. The elevator is powered by an electric motor which moves the car as well as the counterweight between the enclosed staff and steel guide rails.

Escalators

- Escalators, another form of commercial transportation, consist of a chain of moving steps that transport large number of people between floors. The step treads remain horizontal while moving people. Like elevators, escalators are used all over the world. However, escalators transport pedestrian traffic to places where elevators are impractical. Shopping malls, department stores and hotels as well as public buildings use escalators.

Moving Walkways

- Moving walkways, usually found in airports, are designed to move people over long distances, usually between different terminals. Moving walkways are similar to an escalator. The only difference is that the steps lay flat, like a conveyor belt. Passengers are able to move from gate to gate or from one baggage area to the next. Moving walkways, like elevators and escalators, offer a smooth and convenient ride for people while providing outstanding energy efficiency for commercial building operators.

1. Building Design

Apply theory and principles of conveying systems as a component of building design.

2. Building Systems and their Integration

Examine integration and effects of conveying systems design principles and details on the overall design of a building considering technological advances and innovative building products.

3. Implications of Design Decisions

Determine the effects of conveying systems design decisions and selection on issues, such as construction cost, operating costs, construction schedules, and flexibility.

4. Construction Details and Constructability

Identify and analyze conveying system details including the aspects of constructability.

D. FIRE DETECTION AND SUPPRESSION

Evaluate, select, and design fire detection and suppression systems.

Detector:

A device suitable for connection to a circuit that has a sensor that responds to a physical stimulus such as heat or smoke.

Air Sampling–Type Detector, A detector that consists of a piping or tubing distribution network that runs from the detector to the area(s) to be protected. An aspiration fan in the detector housing draws air from the protected area back to the detector through air sampling ports, piping, or tubing. At the detector, the air is analyzed for fire products.

Automatic Fire Detector, A device designed to detect the presence of a fire signature and to initiate action. For the purpose of this Code, automatic fire detectors are classified as follows: Automatic Fire Extinguishing or Suppression System Operation Detector, Fire–Gas Detector, Heat Detector, Other Fire Detectors, Radiant Energy–Sensing Fire Detector, Smoke Detector.

Automatic Fire Extinguishing or Suppression System Operation Detector, A device that automatically detects the operation of a fire extinguishing or suppression system by means appropriate to the system employed.

Combination Detector, A device that either responds to more than one of the fire phenomena or employs more than one operating principle to sense one of these phenomena. Typical examples are a combination of a heat detector with a smoke detector or a combination rate-of-rise and fixed-temperature heat detector. This device has listings for each sensing method employed.

Electrical Conductivity Heat Detector, A line-type or spot-type sensing element in which resistance varies as a function of temperature.

Fire–Gas Detector, A device that detects gases produced by a fire.

Fixed-Temperature Detector, A device that responds when its operating element becomes heated to a Pre-determined level.

Flame Detector, A radiant energy–sensing fire detector that detects the radiant energy emitted by a flame.

Heat Detector, A fire detector that detects either abnormally high temperature or rate of temperature rise, or both.

Line-Type Detector, A device in which detection is continuous along a path. Typical examples are rate-of-rise pneumatic tubing detectors, projected beam smoke detectors, and heat-sensitive cable.

Multi-Criteria Detector, A device that contains multiple sensors that separately respond to physical stimulus such as heat, smoke, or fire gases, or employs more than one sensor to sense the same stimulus. This sensor is capable of generating only one alarm signal from the sensors employed in the design either independently or in combination. The sensor output signal is mathematically evaluated to determine when an alarm signal is warranted. The evaluation can be performed either at the detector or at the control unit. This detector has a single listing that establishes the primary function of the detector.

Multi-Sensor Detector, A device that contains multiple sensors that separately respond to physical stimulus such as heat, smoke, or fire gases, or employs more than one sensor to sense the same stimulus. A device capable of generating multiple alarm signals from any one of the sensors employed in the design, independently or in combination. The sensor output signals are mathematically evaluated to determine when an alarm signal is warranted. The evaluation can be performed either at the detector or at the control unit. This device has listings for each sensing method employed.

Other Fire Detectors, Devices that detect a phenomenon other than heat, smoke, flame, or gases produced by a fire.

Pneumatic Rate-of-Rise Tubing Heat Detector, A line-type detector comprising small-diameter tubing, usually copper, that is installed on the ceiling or high on the walls throughout the protected area. The tubing is terminated in a detector unit containing diaphragms and associated contacts set to actuate at a predetermined pressure. The system is sealed except for calibrated vents that compensate for normal changes in temperature.

Projected Beam–Type Detector, A type of photoelectric light obscuration smoke detector wherein the beam spans the protected area.

Radiant Energy–Sensing Fire Detector, A device that detects radiant energy, such as ultraviolet, visible, or infrared, that is emitted as a product of combustion reaction and obeys the laws of optics.

Rate Compensation Detector, A device that responds when the temperature of the air surrounding the device reaches a predetermined level, regardless of the rate of temperature rise.

Rate-of-Rise Detector, A device that responds when the temperature rises at a rate exceeding a predetermined value.

Smoke Detector, A device that detects visible or invisible particles of combustion.

Spark Ember Detector, A radiant energy–sensing fire detector that is designed to detect sparks or embers, or both. These devices are normally intended to operate in dark environments and in the infrared part of the spectrum.

Spot-Type Detector, A device in which the detecting element is concentrated at a particular location. Typical examples are bimetallic detectors, fusible alloy detectors, certain pneumatic rate-of-rise detectors, certain smoke detectors, and thermoelectric detectors.

Clean Agent

Several Clean Agents are available for consideration. This firm is active in **FM200(ECS & ADS), NOVEC1230, FE-13, Argonite, CO2,** and **Stat-X (aerosol).**

***FM200 (FE227ea)** is both UL listed and FM Approved. N.F.P.A 2001, *Standard on Clean Agent Fire Extinguishing Systems,* approves this agent for total flooding purposes. The agent is discharged within 10 seconds and therefore minimizes by-products of combustion and damage due to loss by fire. FM200 is clean and leaves no residue, therefore eliminating costly after fire clean up. FM200 is colorless and odorless. FM200 is acceptable for use in occupied spaces. The operating temperature is 32F to 130F.

FM200 systems are intended to protect:

- Data Processing Facilities
- Telecommunications facilities
- Process Control Rooms
- High Value Medical Facilities
- High Value Industrial Equipment Areas
- Libraries, Museums, Art Galleries
- Anechoic Chambers
- Flammable Liquid Storage Areas
- Petrochemical Installations
- Gas Turbines
- Steam Turbines
- Power Generation Plants
- Packaging Plants

FM200 systems are designed for the following classes of fire:

- Class A Surface Type fires (wood or other cellulose type materials)
- Class B; Flammable Liquids

- Class C; Energized Electrical Equipment

*** FM200 is NOT acceptable for all classes of fire.

***NOVEC1230** is both UL listed and FM Approved. N.F.P.A 2001, *Standard on Clean Agent Fire Extinguishing Systems,* approves this agent for total flooding purposes. The agent is discharged within 10 seconds and therefore minimizes by-products of combustion and damage due to loss by fire. NOVEC1230 is clean and leaves no residue, therefore eliminating costly after fire clean up. NOVEC1230 is colorless and odorless. *It is also ZERO in Ozone depletion and has an atmospheric life of 5 years so is very high on the "Green" list for suppression agents.* NOVEC1230 is acceptable for use in occupied spaces. The operating temperature is 0F to 130F.

NOVEC 1230 systems are intended to protect:

- Data Processing Facilities
- Telecommunications facilities
- Process Control Rooms
- High Value Medical Facilities
- High Value Industrial Equipment Areas
- Libraries, Museums, Art Galleries
- Anechoic Chambers
- Flammable Liquid Storage Areas
- Petrochemical Installations
- Gas Turbines
- Steam Turbines
- Power Generation Plants
- Packaging Plants

NOVEC 1230 systems are designed for the following classes of fire:

- Class A Surface Type fires (wood or other cellulose type materials)
- Class B; Flammable Liquids
- Class C; Energized Electrical Equipment

*** NOVEC1230 is NOT acceptable for all classes of fire.

***Argonite** is a blend of inert gas (50% / 50% pure argon / nitrogen). Both gases are naturally occurring substances and present in the atmosphere, and as such, have no ozone depletion potential and no direct global warming risk. The operating temperature is -20F to 130F.

Argonite systems are intended to protect:

- Electric and Electronic Equipment Rooms
- Data Centers
- Telecommunications
- Flammable Liquids
- Subfloors and Concealed Spaces
- Delicate Artifacts
- High Value Assets
- Places Where Other Extinguishing Media Could Be Directly Destructive
- *** Argonite is NOT acceptable for all classes of fire.

***FE-13** is a compound of carbon, fluorine, and hydrogen. It is colorless, odorless and electrically non-conductive. FE-13 is both UL listed and FM Approved. N.F.P.A 2001, *Standard on Clean Agent Fire Extinguishing Systems* approves this agent for total flooding purposes. It is approved for use in occupied spaces. FE-13 is clean and leaves no residue, therefore eliminating costly after fire clean up. The operating temperature is -40F to 130F.

FE-13 systems are intended to protect:

- Industrial High Ceiling Spaces
- Locomotives
- Mining equipment
- Offshore Oil Platforms
- Oil And Gas Processing Facilities
- Pumping Stations
- Refinery Control Areas
- Turbine Enclosures
- Unheated Storage Areas
- Snow Making Control Houses

FE-13 systems are designed for the following classes of fire:

- Class A Surface Type fires (wood or other cellulose type materials)
- Class B; Flammable Liquids
- Class C; Energized Electrical Equipment

*** FE-13 is NOT acceptable for all classes of fire.

CO2 is 99% carbon dioxide. A naturally-occurring atmospheric element, Carbon Dioxide dissipates into the air allowing an almost immediate return to “business as usual” without the interruption of a costly clean-up and the expense of damage to assets from suppressant residue. This results in fewer repair costs and reduced downtime. Carbon Dioxide (CO2) is a colorless, odorless, electrically-nonconductive gas whose density is approximately 50% greater than air. A Kidde Carbon Dioxide System suppresses fire by providing a blanket of heavy gas that absorbs heat from the fire and reduces the oxygen content of the atmosphere to a point where combustion becomes impossible. Because Carbon Dioxide is an ideal suppressant for a wide variety of industrial applications, three system configurations are efficient to protect different hazard types: Total Flooding—ideal for enclosed hazard areas, Local Application—used to protect a specified hazard area in an open floor plan, or a Local Hose Line— cost effective protection for fighting smaller fires throughout a hazard.

CO2 systems are intended to protect:

- Flammable Liquid Storage Areas
- Marine Applicationsb
- Quench And Dip Tanks
- Large Commercial Fryers
- Engine And Electrical Rooms
- Spray Booths And Paint Lockers
- Turbine Generators
- Printing Presses
- Rolling Mills
- Dust Collectors
- Industrial Ovens
- Mixing Operations

CO2 systems are designed for the following classes of fire:

- Class A Surface Type AND Deep Seated fires (wood or other cellulose type materials)
- Class B; Flammable Liquids
- Class C; Energized Electrical Equipment

*** CO_2 is NOT acceptable for all classes of fire.

Dry Chemical

GENERAL SPECIFICATION

A pre-engineered, fixed pipe, automatic dry chemical fire suppression system shall be provided and installed for the hazard including work area, plenums and all exhaust ventilation pits and associated ductwork requiring protection.

CODES/STANDARDS COMPLIANCE

The system shall conform to, and be in accordance with, the following:

1. UL 1254, Underwriters Laboratories Standard for Fire Extinguishing Systems for Protection of Industrial Hazards

2. FM Approvals, where applicable

3. NFPA 17, Standard on Dry Chemical Extinguishing Systems

4. NFPA 33, Standard for Spray Application Using Flammable or Combustible Materials

5. NFPA 34, Standard for Dipping and Coating Processes Using Flammable or Combustible Liquids

6. The manufacture Instruction Manual and all applicable addenda, as identified by Underwriters Laboratories.

7. All applicable insurance company requirements.

8. All applicable local and state codes and standards,

9. NFPA 70 – National Electrical Code (NEC)

10. NFPA 72 – National Fire Alarm Code

11. Requirements of the Local Authorities Having Jurisdiction (AHJ).

The types of hazards and equipment that can be protected using dry chemical extinguishing Systems include the following:

- Flammable or combustible liquids
- Flammable or combustible gases
- Combustible solids, including plastics, which melt when involved in fire
- Electrical hazards such as oil-filled transformers or circuit breakers
- Textile operations subject to flash surface fires
- Ordinary combustibles such as wood, paper, or cloth
- Restaurant and commercial hoods, ducts, and associated cooking appliance hazards such as deep-fat fryers

Dry chemical extinguishing systems shall not be considered satisfactory protection for the following:

- Chemicals containing their own oxygen supply, such as cellulose nitrate
- Combustible metals such as sodium, potassium, magnesium, titanium, and zirconium
- Deep-seated or burrowing fires in ordinary combustibles where the dry chemical cannot reach the point of combustion

Multipurpose dry chemical shall not be used on machinery such as carding equipment in textile operations and delicate electrical equipment. Before dry chemical extinguishing equipment is considered for use in protecting electronic equipment or delicate electrical relays, the effect of residual deposits of dry chemical on the performance on electronic equipment shall be evaluated.

Multiple Systems Protecting a Common Hazard:

Where two or more systems are used to protect a common hazard, they shall be arranged for simultaneous operation. Operation of a single actuator shall cause all systems to operate.

Systems Protecting Two or More Hazards:

Where two or more hazards could be simultaneously involved in fire by reason of their proximity, the hazards shall be protected by either of the following:

- Individual systems installed to operate simultaneously
- A single system designed to protect all hazards that could be simultaneously involved

- Any hazard that will allow fire propagation from one area to another shall constitute a single fire hazard.

Dry Chemical Requirements and Distribution:

The following factors shall be considered in determining the amount of dry chemical required:

- Minimum quantity of dry chemical
- Minimum flow rate of dry chemical
- Nozzle placement limitations including spacing, distribution, and obstructions
- High ventilation rates, if applicable
- Prevailing wind conditions, if applicable

Compensation for Special Conditions.

Additional quantities of dry chemical and additional nozzles, if necessary, shall be provided to compensate for special condition(s) such as high ventilation rates or prevailing wind conditions that could adversely affect the extinguishing effectiveness of the system.

Special Considerations:
Where systems protect hazards that are normally heated, the power or fuel supply to heaters shall be shut off automatically upon actuation of the extinguishing systems. Where systems protect hazards that have flowing flammable or combustible fluids or gases, the systems shall be provided with automatic means to ensure shutoff of power and fuel valves upon operation of the extinguishing systems. Where systems protect hazards that have conveyors moving flammable or combustible materials or commodities, the conveyors shall be automatically shut off upon operation of the extinguishing systems. All shutoff systems shall be fail-safe. All shutoff systems shall require manual resetting prior to restoration of the operating conditions existing before operation of the extinguishing systems. All shutoff devices shall function with the system operation. Expellant gas that is used to pneumatically operate shutoff devices shall be taken prior to its entry into the dry chemical tank.

Personnel Safety:
Where total flooding and local application systems are used and there is a possibility that personnel could be exposed to a dry chemical discharge, suitable safeguards shall be provided to ensure prompt evacuation of such locations. Safety

procedures shall provide a means for prompt rescue of any trapped personnel. Safety items to be considered shall include, but not be limited to, the following:

- Personnel training
- Warning signs
- Pre-discharge alarms
- Discharge alarms
- Respiratory protection

Total Flooding Systems:

A total flooding type of system shall be used only where there is a permanent enclosure surrounding the hazard that adequately enables the required concentration to be built up. The total area of unclosable openings shall not exceed 15 percent of the total area of the sides, top, and bottom of the enclosure. Where unclosable openings exceed 15 percent of the total enclosure surface area, a local application system shall be used to protect the entire hazard. Pre-engineered total flooding systems shall be permitted to protect permanent enclosures having unclosable openings greater than 15 percent, only when listed for such use. Deep-seated fires involving solids subject to smoldering shall be protected by multipurpose dry chemical systems where the dry chemical can reach all surfaces involved in combustion.

Hazard Specifications:

Enclosure. In the design of total flooding systems, the characteristics of the enclosure shall be as specified in 6.2.1.1 through 6.2.1.4. The total area of unclosable openings for which no compensation is provided shall not exceed 1 percent of the total area of the sides, top, and bottom of the enclosure. Unclosable openings having an area in excess of 1 percent and not exceeding 5 percent shall be compensated for by the provision of additional dry chemical. Unclosable openings having an area in excess of 5 percent of the total enclosure area and not exceeding 15 percent shall be screened by local application of additional dry chemical. Pre-engineered systems shall be permitted to protect the permanent enclosures with unclosable openings using different amounts of dry chemicals from those specified only when listed for such use.

Leakage and Ventilation. The leakage of dry chemical from the protected space shall be minimized because the effectiveness of the flooding system depends on obtaining an extinguishing concentration of dry chemical. Where possible, openings such as doorways, windows, and so on, shall be arranged to close before, or simultaneously with, the start of the dry chemical discharge. Where forced-air ventilating systems are involved, they shall be either shut down or closed before, or simultaneously with, the start of the dry chemical discharge.The quantity of dry chemical and the flow rate shall be sufficient to create a fire-extinguishing concentration in all parts of the enclosure.

Volume Allowances. In calculating the net volume to be protected, allowance shall be permitted for permanently located structures that materially reduce the volume

Local Application Systems:
Local application systems shall be used for the extinguishment of fires in flammable or combustible liquids, gases, and shallow solids (e.g., paint deposits) where the hazard is not enclosed or where the enclosure does not conform to the requirements for total flooding.

Extent of Hazard. The hazard shall be isolated from other hazards or combustibles so that fire will not spread outside the protected area. The entire hazard shall be protected. The hazard shall include all areas that are or might become coated by combustible or flammable liquids or shallow solid coatings and all associated materials or equipment that might extend fire outside or lead fire into the protected area. The design of the system shall consider the location of the hazard, which might be indoors, partly sheltered, or completely outdoors. For flammable liquid fires, the nozzles shall be placed tankside or overhead, or a combination of tankside and overhead within the limits of the listing, and located to prevent splashing during discharge.

Coated Surfaces. Coated surface areas shall be treated as if they were deep-layer flammable liquid areas (because no distinction has been made in this standard).

Duration of Discharge. The minimum effective discharge time shall be determined by the required minimum quantity of dry chemical and the minimum application rate. Minimum effective discharge time for pre-engineered systems shall be determined with NFPA 17 Chapter 9.

Pre-Engineered Systems:

Pre-engineered systems shall be installed to protect hazards within the limitations of the listing.

Fire-extinguishing systems referenced in NFPA 17, chapter 9.1.1 shall comply with ANSI/UL 1254, *Pre-Engineered Dry Chemical Extinguishing System Units*, or equivalent listing standard. Only system components referenced in the manufacturer's listed installation and maintenance manual or alternative suppliers' components that are listed for use with the specific extinguishing system shall be used.

Pre-engineered dry chemical systems shall be of the following types:

- Local application
- Total flooding
- Hand hose line
- Combination of local application and total flooding

What is Water-Mist ?

Water-Mist systems utilize clean water as fire-fighting agent.

Water is the oldest, the most widely used, and the most widely available fire fighting agent in the world:

- Non-toxic
- Environmentally friendly
- Has superior fire fighting capabilities in a wide range of applications

Water-Mist systems distribute water in fine spray of small droplets

Size of droplets defined as *Water-Mist* is specified in the relevant standards

Use and Limitations:
Water mist systems shall be permitted for use with a wide range of performance objectives, including the following:

- Fire extinguishment
- Fire Suppression
- Fire Control
- Temperature Control
- Exposure Protection

Water mist systems shall not be used for direct application to materials that react with water to produce violent reactions or significant amounts of hazardous products. Such materials include the following:

- Reactive metals, such as lithium, sodium, potassium, magnesium, titanium, zirconium, uranium, and plutonium
- Metal alkoxides, such as sodium methoxide
- Metal amides, such as sodium amide
- Carbides, such as calcium carbide
- Halides, such as benzoyl chloride and aluminum chloride

- Hydrides, such as lithium aluminum hydride
- Oxyhalides, such as phosphorus oxybromide
- Silanes, such as trichloromethylsilane
- Sulfides, such as phosphorus pentasulfide
- Cyanates, such as methylisocyanate

Water mist systems shall not be used for direct application to liquefied gases at cryogenic temperatures (such as liquefied natural gas), which boil violently when heated by water. When selecting water mist to protect a hazard area, the effects of water runoff on the environment shall be considered.

Water mist systems shall be described by the following four parameters:

- System application
- Nozzle type
- System operation method
- System media type

System applications shall consist of one of the following three categories:

- Local-application systems
- Total compartment application systems
- Zoned application systems

Local-Application Systems. Local-application systems shall be designed and installed to provide complete distribution of mist on or around the hazard or object to be protected. Local-application systems shall be designed to protect an object or a hazard in an enclosed, unenclosed, or open outdoor condition.
Local-application systems shall be actuated by automatic nozzles or by an independent detection system.

Total Compartment Application Systems. Total compartment application systems are designed and installed to provide complete protection of an enclosure or space. The complete protection of an enclosure or space shall be achieved by the simultaneous operation of all nozzles in the space by manual or automatic means.

Zoned Application Systems. Zoned application systems are a subset of the compartment system and are designed to protect a predetermined portion of the compartment by the activation of a selected group of nozzles. Zoned application systems shall be designed and installed to provide complete mist distribution throughout a predetermined portion of an enclosure or space. This shall be achieved by simultaneous operation of a selected group of nozzles in a predetermined portion of the space by manual or automatic means. Zoned application systems shall be actuated by automatic nozzles or by an independent detection system.

Nozzle Types.

Water mist nozzles shall be classified as one of the following three types:

- Automatic
- Nonautomatic
- Hybrid

System Requirements.

Deluge Systems.
Deluge systems shall employ nonautomatic nozzles (open) attached to a piping network connected to the fluid supply(ies) through a valve controlled by an independent detection system installed in the same area as the mist nozzles. When the valve(s) is activated, the fluid shall flow into the piping network and discharge from all nozzles attached thereto.

Wet Pipe Systems. Wet pipe systems shall employ automatic nozzles attached to a piping network pressurized with water up to the nozzles.

Preaction Systems.
Preaction systems shall employ automatic nozzles attached to a piping network containing a pressurized gas with a upplemental, independent detection system installed in the same area as the nozzles. Operation of the detection system shall actuate a tripping device that opens the valve, pressurizing the pipe network with water to the nozzles. The pressurized piping in all preaction systems shall be supervised to ensure piping integrity.

Dry Pipe Systems.
Dry pipe systems shall employ automatic nozzles attached to a piping network containing a pressurized gas. The loss of pressure in the piping network shall activate a control valve, which causes water to flow into the piping network and out through the activated nozzles.

Media System Types.

Water mist systems shall be classified by two media system types:

- Single fluid
- Twin fluid

1. Building Design

Apply theory and principles of fire detection and suppression systems as a component of building design.

SPRINKLERS

How Do Sprinkler Heads Work?

Did you ever notice that a common gag for TV sitcoms is to have the automatic fire protection sprinklers go off? It's always the same, some smoke happens and all these sprinkler heads soak the hapless suckers standing there. Since almost none of us ever experience a sprinkler head discharge, the TV show experience seems true to many people. Please understand that it's completely false.

Smoke sets off smoke alarms, not sprinkler heads. Only heat makes sprinkler heads flow water. A typical sprinkler head has a thermal fuse of 174 °F that must melt to release water flow. The head next to it won't go off unless it too melts. So intense heat sets off sprinkler heads, and only the actual heads that experience the intense heat.

Sprinkler heads have either a glass bulb heat sensitive mechanism or a metal fusible link. With this type of activation, only the sprinkler heads directly above the fire tend to flow water. Therefore, the maximum amount of water douses the hottest fire location.

Different temperature sprinkler heads are used for various situations. The table below shows common options.

Color of liquid inside bulb	Temp in °F	Temp in °C
Orange	135	57
Red	155	68
Yellow	174	79
Green	200	93
Blue	286	141
Mauve	360	182
Black	440	227

You can find much more information on sprinkler heads at Tyco Fire and Building Products or at Reliable Sprinkler.

What Should I Know About Sprinkler Systems?

A wet sprinkler system has a series of water distribution pipes and sprinkler heads throughout every space in a facility. The sprinkler heads are typically located between 10' and 15' on center in both directions. The pipes are full of water, so if heat from a fire raises the temperature, the fusible link or glass bulb will break and allow water to flow onto the fire. The amount of water may be in the 15 to 40 gallons per minute range, which is much less than a fire hose that may flow 250 to 1000 gallons per minute. In theory, the sprinkler system will control the fire with much less water damage to the facility.

Generally systems have control valves for maintenance and repairs that must be monitored with anti-tamper switches. Flow controls also are typically monitored so any flow in the system, especially during non-occupied times, gets reported quickly. If you want a much more detailed explanation of sprinkler systems, go to the Stanford University Intro to Automatic Fire Protection Systems.

While sprinklers aren't required in all buildings, the current US building codes (IBC and UBC) provide many design advantages for buildings that include sprinklers. Egress requirements, building construction type, fire separation requirements and many more design items have relaxed requirements in sprinklered buildings. Hence many Design Professionals specify sprinklers and consider it an overall cost savings.

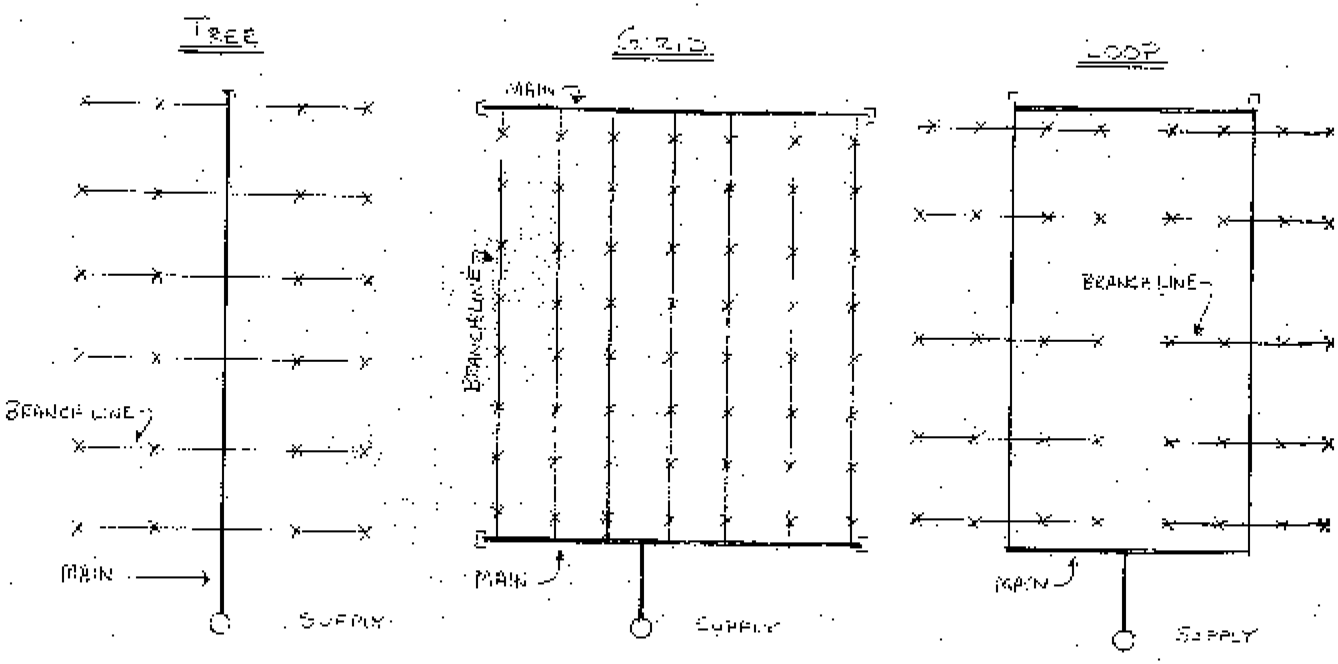
Where water may freeze in the pipes, a dry sprinkler system can be used. An air compressor must provide air at a pressure higher than the water pressure in the sprinkler system so the dry system remains full of compressed air. When a sprinkler head activates, the air rushes out and the water soon (less than one minute) follows. Dry systems have several complications not found with wet systems, so only get used where pipe freezing is a concern.

Deluge systems don't use sprinkler heads to control the water flow. The piping is open at the point of water discharge and the water flow is controlled by a valve connected to the fire alarm system. A deluge system will have water flowing from all discharge points simultaneously, as soon as the fire alarm calls for flow. Only in special occupancies in which rapid fire spread is a major concern do deluge systems get installed.

Pre-action sprinkler systems provide another layer of safety from accidental sprinkler discharge. You can imagine a museum or a library could sustain tremendous losses from water damage, so they want to assure that sprinkler heads don't discharge by mistake. Though system types vary, generally an action (the flowing of water at a head location) must be proceeded by a pre-action (a smoke or heat alarm confirming that a fire is likely in progress). So a Pre-Action sprinkler system has a double check prior to water flowing.

What Piping Configurations are Common?

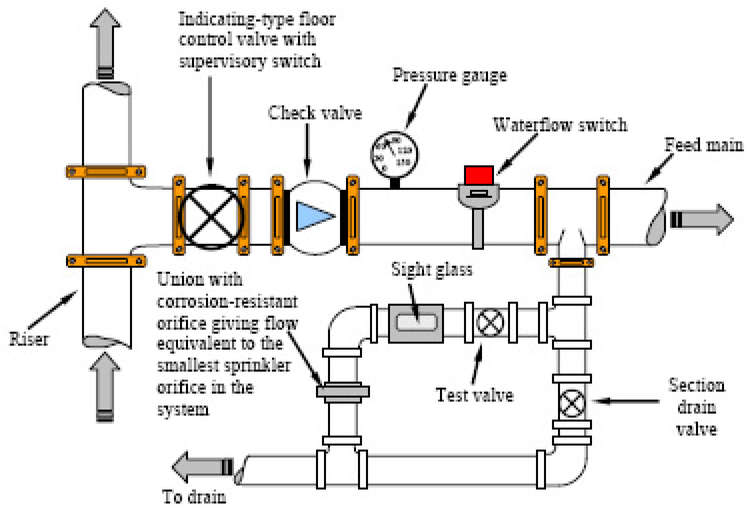
The sketch below shows various common piping configurations.



SPRINKLER PIPING CONFIGURATIONS

The other component of the sprinkler piping is the control valving. While requirements vary based on local rules, the following US Department of Defense sketch shows a typical layout.

Figure 4-1 Floor Control Valve Assembly



What are the Basics of Sprinkler System Design?

It's a good idea to understand sprinkler system design (the basics aren't too complicated). The National Fire Protection Association (NFPA) sets the design standards in the publication NFPA-13. The following few steps show the process.

1. Determine the level of fire hazard for the building.
   1. Light Hazard (offices, churches, hospitals, nursing homes, gyms, schools, theaters, residential, etc.)
   2. Ordinary Hazard Group 1 (bakeries, dairy plants, electronic plants, glass manufacturing, parking garages, etc.)

3. Ordinary Hazard Group 2 (chemical plants, mercantile, paper mills, repair garages, woodworking shops, etc.)
4. Extra Hazard Group 1 (aircraft hangars, plywood manufacturing, printing, textile plants, etc.)
5. Extra Hazard Group 2 (asphalt saturating, flammable liquid spraying, manufactured home plants, plastics processing, etc.)

2. Find the Design Area and Density
0. Design Area = the worst case area in a building where a fire could burn
    1. Design Density = the gallons per minute of water per square foot that should flow onto the Design Area
3. Sprinkler Head locations and piping design

An example always helps. An office building has a light hazard classification, the Design Area is the most remote 1,500 sf and the Design Density is 0.1 gallons per minute/sf. Therefore this system requires 1,500 sf x 0.1 gpm/sf = 150 gallons per minute to be discharged over that most remote 1,500 sf area. If we look instead to a manufacturing facility, the Design Density changes to 0.2 gpm/sf. Therefore, we'd need 300 gpm to be spray over the most remote 1,500 sf area.

The table below from the US Department of Defense provides some of the design basics. To really understand the design work, you need a copy of NFPA-13, but this table shows the basic concept.

Table 4-1 Sprinkler System and Water Supply Design Requirements for Sprinklered Facilities

OCCUPANCY CLASSIFICATION[a]	SPRINKLER SYSTEM		HOSE STREAM ALLOWANCE L/Min (GPM)	DURATION OF SUPPLY Minutes
	DESIGN DENSITY L/min/m² (GPM/ft²)	DESIGN AREA m² (ft²)[b]		
Light Hazard	4.1 (0.10)	280 (3000)	950 (250)	60
Ordinary Hazard Group 1	6.1 (0.15)	280 (3000)	1900 (500)	60
Ordinary Hazard Group 2	8.2 (0.20)	280 (3000)	1900 (500)	90
Extra Hazard Group 1	12.2 (0.30)	280 (3000)	2840 (750)	120
Extra Hazard Group 2	16.3 (0.40)	280 (3000)	2840 (750)	120

[a] Refer to Appendix B for occupancy hazard classification.
[b] See paragraph 4-2.3.3.

Note: The protection requirements identified in Table 4-1 are based on standard commercial practices followed throughout civilian industry for highly protected risk (HPR) properties. Table 4-1 represents the minimum requirements necessary to establish minimum comprehensive life, mission, and property loss prevention. Table 4-1 was adapted as a result from detailed studies by Factory Mutual of loss experience from 1956 to 1965, loss experience in selected occupancies from 1966 to 1977 and from 1981-1990, and fire test data.

The Dept of Defense has created a manual for Fire Protection Engineering for Facilities which is an excellent introduction to sprinkler systems. This 129 page handbook is officially called UFC 3-600-01 (September 2006).

Tricks of the Trade & Rules of Thumb for Sprinkler Basics:

1. Sprinkler heads act independently, only discharging water when the temperature at that head exceeds the allowable range.
2. A sprinkler head flows about 40 gpm, while a fire hose flows in excess of 250 gpm.
3. Pre-Action sprinkler systems provide a double check prior to water flowing.

2. Building Systems and their Integration

Examine integration and the effects of fire detection and suppression design principles, systems, and details on the overall design of a building considering technological advances and innovative building products.

3. Implications of Design Decisions

Determine the effects of fire detection and suppression systems design decisions and selection on issues such as construction cost, operating costs, construction schedules, and flexibility.

4. Construction Details and Constructability

Identify and analyze fire detection and suppression system details including the aspects of constructability.

Dry Pipe sprinkler system (versus wet-pipe sprinkler) is designed so that sprinkler water pipe will not freeze in unheated spaces (very cold areas)

Not: since it is lighter and less expensive, fewer valves and fittings, no water corrosion

scale.

uestion Excerpt From Building Systems 3 final review

Q.1) The altitude angle is

A.the angle between the horizon and the sun's position above the horizon
B.the angle along the horizon between the projected position of the sun and the solar south
C.the angle between the horizon and true south

Q.2) the azimuth angle is

A.the angle between the horizon and the sun's position above the horizon
B.the angle along the horizon between the projected position of the sun and the solar south
C.the angle between the horizon and true south

Q.3) the altitude of the sun is highest in

A.summer
B.winter
C.spring
D.fall

Q.4) the azimuth angle is also called the

(2 words)

Q.5) the daily maximum altitude of the sun

A.decreases as a location approaches the equator
B.increases as a location approaches the equator
C.is not related to the distance between the location and the equator

Q.6) sunpath projections can be used to

A.assess site conditions and orient a building
B.provide information critical for passive solar design
C.do all of the previous

Q.7) a sunpeg chart

A.shows the exact position of sun penetration and shadow on a model of any scale, on any date, and at any time of the day between shortly after sunrise and shortly before sunset

B. shows the exact position of sun penetration and shadow on a model of a particular scale, on any date, and at any time of the day between shortly after sunrise and shortly before sunset.

C. shows the exact position of sun penetration and shadow on a model of any scale, in the summer only, and at any time of the day between shortly after sunrise and shortly before sunset.

Q.8) **the Pilkington calculator diagrams are based on**

A. the horizontal or equidistant sunpath projections
B. the vertical sunpath projections
C. the sunpeg charts

Q.9) **South orientation receives**

A. more sun in the winter and less sun in the summer than any other orientation
B. more sun in the winter and in the summer than any other orientation
C. less sun in the winter and more sun in the summer than any other orientation

Q.10) **For south facing windows the most effective shading device is**

A. the horizontal overhang
B. vertical fins
C. either a horizontal overhang or vertical fins

Q.11) **on east and west facing windows a horizontal overhang is effective when**

A. the sun is at high positions in the sky
B. the sun is at lows altitude angles
C. the sun is at high positions in the sky or at low altitude angles

Q.12) **Shading devices made of a combination overhangs and vertical fins are called**

Q.13) **In early design stages, it is advisable to orient spaces to face**

A. north or south
B. east or west
C. east

Q.14) **the overheated period of the year is a function of**

A.climate
B.building type
C.both climate and building type

Q.15) **envelope-dominated buildings have a**

A.large surface-to-volume ratio
B.small surface-to-volume ratio
C.large internal heat gains

Q.16) **Internally dominated buildings have a**

A.large surface-area-to-volume ratio
B.small surface-area-to-volume ratio
C.modest internal heat gains

Q.17) **The Balance Point Temperature (BPT) is**

A.the outdoor temperature below which heating is required
B.the outdoor temperature above which cooling is required
C.the optimal indoor temperature

Q.18) **a key design strategy for passive cooling and to reduce cooling loads on active HVAC systems is**

A.to shade windows from solar heat gain
B.to shade windows from solar heat lose
C.to open windows to solar heat gain

Q.19) **It is important but less important than shading glazing to**

A.shade the opaque envelope
B.shade the dominate envelope
C.shade the transparent envelope

Q.20) **For _______ -facing windows, in the summer and due to high sun altitude the most effective shading device is the horizontal overhang.**

A.north

B.south
C.east
D.west

Q.21) **on the __________-facing windows a horizontal overhang is effective when the sun is at high positions in teh sky but not at low altitude angles**

A.north and south
B.east and west
C.north
D.south
E.north and east

Q.22) **Direct solar gain through east- and west-facing windows can be a great**

A.heat gain liability and can produce thermal and visual discomfort
B.heat loss liability and can produce thermal and visual pleasure
C.heat gain liability and can produce thermal and visual pleasure
D.heat loss liability and can produce thermal and visual discomfort

Q.23) **in the early design stages, orient spaces to face _________ to avoid the east/west sun's low angle**

A.north or south
B.east or west
C.north
D.south
E.east and north

Q.24) **Eggcrate shading devices are**

A.combination of overhangs and movable fins
B.combination of overhangs and vertical fins
C.combination of horizontal and vertical fins

Q.25) **________-facing windows receive direct solar radiation in the summer in the early morning and near sunset when the sun's altitude is very low**

A.north

B. south

C. east

D. west

Q.26) **Operable shading devices are useful because**

A. they respond to daily and seasonal variations in solar and weather patterns.

B. they respond to daily and hourly variations in solar and weather patterns

C. they respond to daily and seasonal variation in cooling and heat patterns

Q.27) **horizontal movable fins are very effective at blocking low sun angles from**

A. north and south

B. west

C. east and west

D. south

Q.28) **From an energy point of view buildings can be divided into 2 types**

A. envelope- internally- dominated

B. envelope and dominated

C. envelope- externally- dominated

Q.29) **Envelope-dominated buildings are**

A. very much affected by the climate

B. have large surface-area-to-volume ratio

C. have modest internal heat sources

D. all the answer

Q.30) **What are natural shading devices**

(**or** 3 words **or** 2 words)

Q.31) **Internally dominated buildings have**

A. a small surface-area-to-volume ratio

B. large internal heat gains from machines, lights, people, etc.

C. a large surface-area-to-volume ratio

D.a small surface-area-to-volume ratio and large internal heat gains from machines, lights, people, etc.

Q.32) **the BPT for internally dominated bulidings is**

A.60 degrees Fahrenheit
B.70 degrees Fahrenheit
C.65 degrees Fahrenheit
D.80 degrees Fahrenheit

Q.33) **the BPT for envelope-dominated buildings is**

A.65 degrees Fahrenheit
B.50 degrees Fahrenheit
C.55 degrees Fahrenheit
D.70 degrees Fahrenheit

Q.34) **the overheated period of the year starts when the BPT of a building increases**

A.10 degrees Fahrenheit
B.15 degrees Fahrenheit
C.20 degrees Fahrenheit
D.25 degrees Fahrenheit
E.30 degrees Fahrenheit

Q.35) **The comfort zone is generally from**

A.50 to 70 degrees Fahrenheit
B.58 to 78 degrees Fahrenheit
C.65 to 85 degrees Fahrenheit
D.68 to 78 degrees Fahrenheit

Q.36) **designing tighter building envelopes in the 1970's helped conserve energy but also resulted in decreased air leakagfe leading to indoor air quality concerns and the syndrome known as**

(3 words)

Q.37) **Wall U-factors are somewhat complicated by framing members interrupting insulation. This is known as**

(2 words)

Q.38) Thermal Conductance (C) is

A. the heat transferred by conduction through a non-homogeneous material of a particular thickness per unit of time when a given temperature difference is applied to a unit area

B. the heat transferred by conduction through a homogeneous material of a particular thickness per unit of time when a given temperature difference is applied to a unit area

C. the heat transferred by conduction through a substance of a particular thickness per unit of time when a given temperature difference is applied to a unit area

Q.39) the reciprocal of the thermal conductance (C) is known as

A. the R-value or Thermal Resistance
B. the U-factor
C. the Thermal conductivity

Q.40) Thermal Resistance is

A. directly proportional to the density of the material
B. inversely proportional to the density of the material
C. is not related to the density of the material

Q.41) the best resistor of heat flow in buildings is

A. a layer of still air
B. water
C. masonry

Q.42) In an effort to increase the resistance of double-glazing, manufacturers tried increasing the air thickness between panes. they discovered that thermal resistance increases slightly as the layer is thickened to about ________ in. and then stops to increase with further increase in air thickness because ____________. separate answer by comma

(**or** 2 words)

Q.43) a layer of metal foil or aluminum foil within or on either side of the airspace can eliminate most of

A. conductive transfer
B. radiative transfer
C. convectional transfers

Q.44) **Specific heat is**

A.a measure of the amount of heat required to raise the temperature of a given mass of material by 1 degree
B.an indicator of the ability of a material to store heat
C.the thermal resistance of material

Q.45) **Thermal Capacity is**

A.a measure of the amount of heat required to raise the temperature of a given mass of material by 1 degree
B.an indicator of the ability of a material to store heat
C.the thermal resistance of a material

Q.46) **the difference in temperature through a cross-section of a construction assembly is known as**

(2 words)

Q.47) **according to a rule of thumb, areas that have long cold winters have more than**

A.5,500 HDDs per year
B.4,000 HDDs per year
C.2,000 HDDs per year

Q.48) **The initials HDDs stand for**

(3 words)

Q.49) **the initials CDDs stand for**

(3 words)

Q.50) **In order to consider heat loss by air movement, calculation methods**

A.assume only one condition: infiltration or ventilation
B.add heat losses from infiltration and ventilation
C.consider only heat loss by ventilation and the effect of infiltration is ignored

Q.51) **Heat flows are of 2 types**

A.sensible and latent heat
B.sensible and low heat
C.latent and stupid heat

Q.52) **sensible heat is**

A.results in a change in temp
B.results in a change in moisture content of the air
C.results in a change of the heat loss of a structure

Q.53) **Latent heat is**

A.results in a change in temp.
B.results in a change in moisture content of the air
C.results in a change in heat lose of a structure

Q.54) **Heat flows from areas of**

A.greater concentration to areas of less concentration
B.less concentration to areas of greater concentration
C.greater concentration to areas of equal concentration

Q.55) **Thermal classification of materials can be placed into 2 types**

A.insulators and conductors
B.insulators and exsulators
C.conductors and envelopes

Q.56) **insulators are broken into 3 different groups**

A.organic, inorganic, metallic(metalized)
B.organic, inorganic, steel
C.natural, inorganic, metallic(metalized)

Q.57) **name a form of insulation**

(3 words **or** 2 words **or** 4 words)

Q.58) **Conductors are**

A.dense, durable, and diffuse heat rapidly
B.dense, durable, and compact heat rapidly
C.open, durable, and diffuse heat rapidly

Q.59) the U-factor is

A.an overall property that expresses the rate at which heat exits through a building envelope assembly
B.an overall property that expresses the rate at which heat is loss through a building envelope assembly
C.an overall property that expresses the rate at which heat transfers through a building envelope assembly
D.an overall property that expresses the rate at which heat flows through a building envelope assembly

Q.60) Many building codes require a minimum outdoor air flow rate based upon

A.building occupation
B.floor area
C.either building occupation or floor area

Q.61) Estimated numbers of air changes per hour (ACH) are function of

A.construction type
B.climate
C.bother construction type and climate

Q.62) Estimated numbers of air changes per hour (ACH)

A.can be converted to airflow rate
B.cannot be converted to airflow rate
C.are equivalent to airflow rates

Q.63) Symptoms associated with poor indoor air quality are often

A.headaches
B.irritation of the eyes and upper respiratory system
C.all of the previous

Q.64) In the Imperial System, airflow rate is measured generally using this unit

Q.65) The most rational IAQ strategy is to

A.choose materials and equipment with care and isolate pollutants
B.increase outdoor air flow rates
C.provide for filtering of fresh air

Q.66) **Often a simple measurement is used as a first indicator of potential IAQ problems related to occupancy. This is**

A.a measurement of carbon dioxide (CO2)
B.a measurement of radon
C.a measurement of formaldehyde

Q.67) **Volatile organic compounds or (VOCs) are**

A.chemicals containing carbon molecules that are volatile or evaporate from material surfaces at room temperature
B.hydrofluorocarbons, formaldehyde and hydrocarbons that are found frequently in new buildings
C.irritants connected to pesticides

Q.68) **New and newly renovated buildings are prone to problems from outgassing of**

A.paints
B.adhesive and sealants
C.carpeting and vinyl wall coverings
D.all of the previous

Q.69) **What does IAQ stand for**

A.Indoor adhesive quality
B.Indoor air quality
C.Interior air quality
D.interior air quantity

Q.70) **Sick Building Syndrome symptoms are**

A.headaches
B.upper respiratory irritation
C.irritation of the ears
D.headaches and upper respiratory irritation
E.all of the answers

Q.71) **Indoor air pollution can be described both in terms of the types of**

A.contaminants and odors
B.effects and contaminants

C.effects and liquids

D.contaminants and irritants

Q.72) **One of the most immediate indicators of IAQ problems is**

A.effects

B.odor

C.irritants

D.noise

E.contaminants

Q.73) **Irritants are often imperceptible at first but cause increasing distress**

A.over time

B.in a day

C.in an hour

D.over months

E.over years

Q.74) **some symptoms of irritants**

A.burning of eyes, sneezing, coughing, dry nose and throat, sore throat and tightening of the chest

B.shining of eyes, sneezing, coughing, dry nose and throat, sore throat and tightening of the chest

C.burning of eyes, sneezing, laughing, dry nose and throat, sore throat and tightening of the chest

D.burning of eyes, sneezing, need to use bathroom, excessive gas, sore throat and tightening of the chest

Q.75) **most irritants are in the form of**

A.particles

B.gas

C.liquids

D.solids

E.particles or gases

Q.76) **what does VOC stand for**

(3 words)

Q.77) **what toxic particulate substance was used up until the 1970's**

A.plastic
B.asbestos
C.hair insulation
D.carbon fiber

Q.78) **Biological contaminants are**

A.contaminants that can biologically grow over time and cause more damage
B.contaminants that can evaporate into the air
C.contaminants that cause an odor in the air that encourages the flow of air

Q.79) **radon is**

A.a toxic gas that causes color blindness
B.a random gas that brings odor and biological contaminants to the area
C.a radioactive gas that decays rapidly

Q.80) **radon when inhaled can cause**

A.kidney failure
B.lung cancer
C.gum diseases

Q.81) **ventilation rates are calculated by**

A.occupancy of a building
B.square footage of building
C.envelope type
D.both occupancy and square footage of building

Q.82) **the olf is a unit of**

A.operable living fenestration
B.occupancy
C.pollution

Q.83) **the decipol is a unit of**

A. perceived air quality

B. outdoor air quality

C. air flow through envelope

Building Systems 5 Midterm

69 Questions | 17 Attempts | Created By tonybc2888 910 days ago

Building Systems 5 Midterm Study Guide

Name

Start

Embed

Remove Question Excerpt

Question Excerpt From Building Systems 5 Midterm

Q.1) **Choose the correct factors to consider when selecting a structural system for a building (select all that apply)**

A. Length of Span
B. Client Attitude
C. Purpose/Function
D. Size of Occupants
E. Permanence

Q.2) **What is the most appropriate steel structural system to use in order to economically frame a regular size building with regular spans?**

(2 words)

Q.3) **Using a well-known rule of thumb, what is the approximate depth of a steel beam that spans 24 ft?**

A. 8in
B. 10in
C. 12in

D. 14in

Q.4) A king-post truss spans 64ft, the most economical depth for this truss is

A. 8ft
B. 10ft
C. 16ft
D. 20ft

Q.5) A steel parallel-chord truss is to span 100ft, the most appropriate and economical depth range is

A. 8.5ft to 12.5ft
B. 12ft to 15ft
C. 16ft to 20ft

Q.6) a steel rigid frame system is to span 120ft, the most appropriate and economical spacing range is

A. 10ft to 16ft
B. 16ft to 20ft
C. 20ft to 24ft

Q.7) W-shapes used as column sections general range in depth:

A. between 8 and 14in
B. between 16 and 20in
C. between 20 and 24in

Q.8) A typical spacing of steel beams in a skeleton framing is

A. 2 to 4ft
B. 6 to 10ft
C. 14 to 16 ft
D. more than 15ft

Q.9) Typical steel lintels are made of

A. steel angles placed back to back
B. steel channels
C. structural tees

Q.10) The open-web steel joists system is generally used for

A. light uniform loads and long spans
B. heavy concentrated loads and long spans
C. heavy concentrated loads and shorts spans

Q.11) Open-web steel joists of the K-series could span up to

A.60ft
B.80ft
C.100ft
D.120ft

Q.12) **Open-web steel joists of the DLH series could span up to**

A.60ft
B.96ft
C.144ft
D.200ft

Q.13) **Open-web steel joists of the DLH series have depths of up to**

A.4ft
B.6ft
C.8ft
D.10ft

Q.14) **The perimeter bottom ring in a steel dome is normally stressed in**

A.compression
B.tension
C.bending

Q.15) **A perimeter ring in a cable-roof structure is normally stressed in**

A.compression
B.tension
C.bending

Q.16) **In wood frame construction, a crawl space should have a minimum clearance of**

A.18in
B.2ft
C.4ft
D.6ft

Q.17) **Compared to platform framing, the main advantage of ballon framing is**

A.ease of construction
B.a lower cost
C.smaller vertical shrinkage

Q.18) **In ordinary wood construction walls are required to be**

(or 2 words)

Q.19) **in heavy timber construction the minimum column size by code is**

A.6x6
B.8x8
C.10x10
D.12x12

Q.20) **in heavy timber construction, the minimum code size for beams and girders is**

A.2x14
B.4x8
C.3x8
D.6x10

Q.21) **wood I-joists could be used to span**

A.up to 25ft
B.up to 45ft
C.up to 60ft
D.more than 70ft

Q.22) **Glulam beams could span up to**

A.30ft
B.50ft
C.70ft
D.100ft and more

Q.23) **Sawn lumber beams generally span up to**

A.10 to 12ft
B.15 to 20ft
C.25 to 30ft
D.40ft and more

Q.24) **Structural insulated panels (SIPs) generally have panels that are made of __________ and a core that consists of ____________.**
(put a comma between your answer so your answer should look like this : blank 1, blank 2

(3 words)

Q.25) **In light wood framing, rows of bridging are provided at the joist mid-pan or on rows spaced apart not more than**

A.6ft

B.8ft
C.10ft
D.12ft

Q.26) **Wood I-joists could be spaced at (select all that apply)**

A.12in o.c.
B.19.2in o.c.
C.24in o.c.
D.3ft o.c.
E.4ft o.c.

Q.27) **Wood stud walls are built using wood studs of these sizes**

A.2x4 or 2x6
B.3x4 or 3x6
C.1x2 or 1x4

Q.28) **In wood stud walls , the general spacing of studs is**

A.12in o.c.
B.16in o.c.
C.20in o.c.
D.22in o.c.

Q.29) **A system of I-wood joists is used with a span of 35ft, the most appropriate way to support these joists is to use**

A.2x10 lumber joists
B.LVL-beams
C.a typical wood stud wall topped by a double-plate

Q.30) **Choose the correct traditional reinforced concrete building systems (choose all that apply)**

A.flat shearhead plate
B.pan joists
C.one-way slab
D.waffle plate
E.flat plate

Q.31) **Which Concrete Systems are two way systems (choose all that apply)**

A.Flat Slab

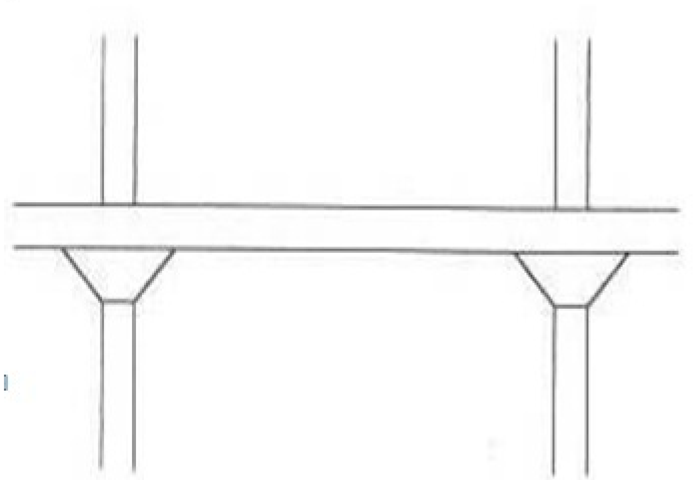
B.Pan Joists
C.One way Slab
D.Waffle slab
E.Flat Slab w/shear head and w/beam

Q.32) **Which Concrete Systems are one way systems (choose all that apply)**

A.Flat Slab
B.Pan Joists
C.One way Slab
D.Waffle slab
E.Flat Slab w/shear head and w/beam

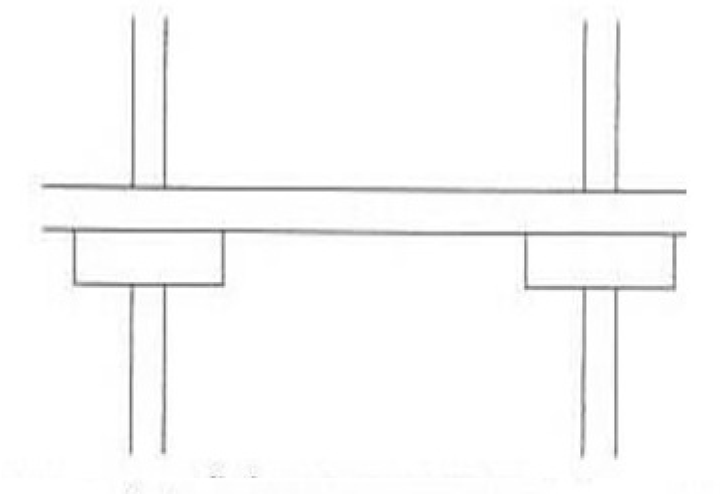
Q.33) **A Flat Plate Concrete system used for a residential building with a span of 15ft should have a minimum thickness of**

A.4in
B.5in
C.6in
D.7in
E.8in

Q.34) 

name this shearhead

(2 words)

Q.35) 

name this shearhead

(2 words)

Q.36) a flat slab concrete system with shearheads is used for what type of loads

A. light loads
B. heavier loads
C. dead loads
D. live loads
E. really tiny loads

Q.37) a Flat slab concrete system with shearheads has a span of 20ft and a slab thickness of 8in. needs a minimal panel thickness of

A. 8in
B. 11in
C. 14in
D. 17in

Q.38) a Flat slab concrete system with shearheads has a span of 28ft and total panel thickness of 17in has a slab thickness of

A. 6in
B. 8in
C. 10in

D.12in

Q.39)

Flat Slab with Shearheads Thicknesses

Span (ft)	Slab Thickness (in.)	Total Panel thickness (in.)
16	6	
20	8	
24	10	
28	12	

8

Fill in the Blanks
(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(**or** 4 words)

Q.40) **a Flat slab concrete system with beams has a span of 20ft and beam depth of 16in. what should the slab thickness be?**

A. 7in.
B. 9in.
C. 11in.
D. 13in.

Q.41)

Flat Slab with Beams Thicknesses

Span (ft)	Slab Thickness (in.)	Beam Depth (in.)
20		16
24		20
28		25
30		28

10

fill in the blanks

(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(**or** 4 words)

Q.42)

Waffle Slab Thicknesses

Span (ft)	Slab Thick. (in.)	Total Thick. (in.)
25	3	
30	3	
35	4	
40	5	

13

fill in the blanks

(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(**or** 4 words)

Q.43) **The typical column spacing of a one-way slab concrete system is**

A. flat plate
B. pan joists
C. one-way slab
D. waffle slab
E. flat slab with beams

Q.44) **typical one-way slab concrete systems span (select all that apply)**

A. 10-15ft
B. 15-25ft
C. 26-30ft
D. 30-45ft

Q.45) **In a Pan joist concrete system the joists typically span (select all that apply)**

A. 10-12ft
B. 10-20ft
C. 15-20ft
D. 14-16ft
E. 10-15ft

Q.46)

Pan Joist Thicknesses

Span (ft) JoistxBeam	Joist Depth (in.)	Beam Depth (in.)
18x28	9	
20x32	11	
24x36	14	
28x40	17	

fill in the blanks
(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(**or** 4 words)

Q.47) **For a building with normal spans, the cost of the above-grade structure is about _________ of the total construction cost**

A. 5% to 10%
B. 10% to 15%
C. 10% to 20%
D. 15% to 20%
E. 15% to 25%

Q.48) **Name a concrete Shell Structure**

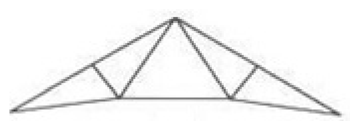
(2 words **or** 3 words)

Q.49) **What are the advantages of Precast Concrete?**
(select all that apply)

A. lightweight
B. very heavy
C. low heat insulation value
D. high heat insulation value
E. low cost

Q.50) **prestressing concrete is used for _____ spans and _____ loads**
seperate your answers with commas. Your answer should look like this: blank 1, blank 2)

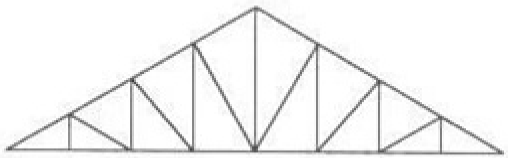
(2 words)

Q.51) 

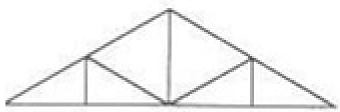
name the truss system

(2 words)

Q.52)



name the truss system

Q.53) 

name the truss system

(**or** 2 words)

Q.54) **Rigid frames in a steel structural system generally span**

A.20 to 50ft
B.30 to 100ft
C.40 to 100ft
D.50 to 100ft
E.75 to 100ft

Q.55)

Spacing

	Span	Spacing
30’-40’		
40’-60’		
60’-100’		
More than 100’		1/5 to 1/6 of span

19

fill in the blanks
(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(**or** 3 words)

Q.56) **The only Damaging effects of earthquake that is covered in the IBC is**

A.vibration or earth shaking
B.death
C.injury
D.shifting of plates
E.global warming

Q.57) **The 2 components of vibration in an earthquake are the _________ and ________ movements**
(seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)

(2 words)

Q.58) **Where is the base shear of a building calculated from**

A.the top of the building
B.the center point of the building
C.the base of the building
D.the face in the direction of the sun

Q.59) **The Richter Scale measures the __________ of an earthquake**

Q.60) **The Modified Mercalli scale measures the _________ of an earthquake**

Q.61) **Largest Earthquake ever recorded on the richter scale was**

A.7 to 8
B.8 to 9.5
C.9 to 9.5
D.9 to 10

Q.62) **The point on the earths surface that is hit by an earthquake is called the**

A.hypocenter
B.epicenter
C.megacenter
D.shakocenter
E.verticenter

Q.63) **The point underneaths the earths surface where a earthquake begins is called the**

A.hypocenter

B.epicenter
C.megacenter
D.shakocenter
E.verticenter

Q.64) **The most vulnerable areas for earthquakes in America are (select all that apply)**

A.New York
B.California
C.Utah
D.Alaska
E.Main

Q.65) **Name the factors affecting earthquake design not including geographic location and soil type. (seperate your answers with commas. Your answer should look like this: blank 1, blank 2, blank 3, blank 4)**

(11 words **or** 10 words)

Q.66) **The period of vibration depends on**

A.mass of pendulum and stiffness of rod
B.mass of pendulum and length of rod
C.mass of pendulum and mass of rod
D.radius of pendulum and stiffness of rod

Q.67) **The _______ is the ability of material to absorb energy without collapse**

Q.68) **All systems resist forces in 3 ways. (select all that apply)**

A.by bending
B.by jumping
C.by shear
D.by temperature
E.by axial tension and compression

Q.69) **Movement of resisting frames can be constructed using**

(2 words)

Take this quiz by clicking Start button on top.

Question Excerpt From Building Systems 3 final review

Q.1) **The altitude angle is**

A.the angle between the horizon and the sun's position above the horizon
B.the angle along the horizon between the projected position of the sun and the solar south
C.the angle between the horizon and true south

Q.2) **the azimuth angle is**

A.the angle between the horizon and the sun's position above the horizon
B.the angle along the horizon between the projected position of the sun and the solar south
C.the angle between the horizon and true south

Q.3) **the altitude of the sun is highest in**

A.summer
B.winter
C.spring
D.fall

Q.4) **the azimuth angle is also called the**

(2 words)

Q.5) **the daily maximum altitude of the sun**

A.decreases as a location approaches the equator
B.increases as a location approaches the equator
C.is not related to the distance between the location and the equator

Q.6) **sunpath projections can be used to**

A.assess site conditions and orient a building
B.provide information critical for passive solar design
C.do all of the previous

Q.7) **a sunpeg chart**

A. shows the exact position of sun penetration and shadow on a model of any scale, on any date, and at any time of the day between shortly after sunrise and shortly before sunset

B. shows the exact position of sun penetration and shadow on a model of a particular scale, on any date, and at any time of the day between shortly after sunrise and shortly before sunset.

C. shows the exact position of sun penetration and shadow on a model of any scale, in the summer only, and at any time of the day between shortly after sunrise and shortly before sunset.

Q.8) **the Pilkington calculator diagrams are based on**

A. the horizontal or equidistant sunpath projections
B. the vertical sunpath projections
C. the sunpeg charts

Q.9) **South orientation receives**

A. more sun in the winter and less sun in the summer than any other orientation
B. more sun in the winter and in the summer than any other orientation
C. less sun in the winter and more sun in the summer than any other orientation

Q.10) **For south facing windows the most effective shading device is**

A. the horizontal overhang
B. vertical fins
C. either a horizontal overhang or vertical fins

Q.11) **on east and west facing windows a horizontal overhang is effective when**

A. the sun is at high positions in the sky
B. the sun is at lows altitude angles
C. the sun is at high positions in the sky or at low altitude angles

Q.12) **Shading devices made of a combination overhangs and vertical fins are called**

Q.13) **In early design stages, it is advisable to orient spaces to face**

A. north or south
B. east or west
C. east

Q.14) the overheated period of the year is a function of

A.climate
B.building type
C.both climate and building type

Q.15) envelope-dominated buildings have a

A.large surface-to-volume ratio
B.small surface-to-volume ratio
C.large internal heat gains

Q.16) Internally dominated buildings have a

A.large surface-area-to-volume ratio
B.small surface-area-to-volume ratio
C.modest internal heat gains

Q.17) The Balance Point Temperature (BPT) is

A.the outdoor temperature below which heating is required
B.the outdoor temperature above which cooling is required
C.the optimal indoor temperature

Q.18) a key design strategy for passive cooling and to reduce cooling loads on active HVAC systems is

A.to shade windows from solar heat gain
B.to shade windows from solar heat lose
C.to open windows to solar heat gain

Q.19) It is important but less important than shading glazing to

A.shade the opaque envelope
B.shade the dominate envelope
C.shade the transparent envelope

Q.20) For _______ -facing windows, in the summer and due to high sun altitude the most effective shading device is the horizontal overhang.

A.north
B.south
C.east
D.west

Q.21) **on the ___________-facing windows a horizontal overhang is effective when the sun is at high positions in teh sky but not at low altitude angles**

A.north and south
B.east and west
C.north
D.south
E.north and east

Q.22) **Direct solar gain through east- and west-facing windows can be a great**

A.heat gain liability and can produce thermal and visual discomfort
B.heat loss liability and can produce thermal and visual pleasure
C.heat gain liability and can produce thermal and visual pleasure
D.heat loss liability and can produce thermal and visual discomfort

Q.23) **in the early design stages, orient spaces to face __________ to avoid the east/west sun's low angle**

A.north or south
B.east or west
C.north
D.south
E.east and north

Q.24) **Eggcrate shading devices are**

A.combination of overhangs and movable fins
B.combination of overhangs and vertical fins
C.combination of horizontal and vertical fins

Q.25) **_________-facing windows receive direct solar radiation in the summer in the early morning and near sunset when the sun's altitude is very low**

A.north
B.south
C.east
D.west

Q.26) **Operable shading devices are useful because**

A.they respond to daily and seasonal variations in solar and weather patterns.
B.they respond to daily and hourly variations in solar and weather patterns
C.they respond to daily and seasonal variation in cooling and heat patterns

Q.27) **horizontal movable fins are very effective at blocking low sun angles from**

A.north and south
B.west
C.east and west
D.south

Q.28) **From an energy point of view buildings can be divided into 2 types**

A.envelope- internally- dominated
B.envelope and dominated
C.envelope- externally- dominated

Q.29) **Envelope-dominated buildings are**

A.very much affected by the climate
B.have large surface-area-to-volume ratio
C.have modest internal heat sources
D.all the answer

Q.30) **What are natural shading devices**

(**or** 3 words **or** 2 words)

Q.31) **Internally dominated buildings have**

A.a small surface-area-to-volume ratio
B.large internal heat gains from machines, lights, people, etc.

C.a large surface-area-to-volume ratio

D.a small surface-area-to-volume ratio and large internal heat gains from machines, lights, people, etc.

Q.32) **the BPT for internally dominated bulidings is**

A.60 degrees Fahrenheit

B.70 degrees Fahrenheit

C.65 degrees Fahrenheit

D.80 degrees Fahrenheit

Q.33) **the BPT for envelope-dominated buildings is**

A.65 degrees Fahrenheit

B.50 degrees Fahrenheit

C.55 degrees Fahrenheit

D.70 degrees Fahrenheit

Q.34) **the overheated period of the year starts when the BPT of a building increases**

A.10 degrees Fahrenheit

B.15 degrees Fahrenheit

C.20 degrees Fahrenheit

D.25 degrees Fahrenheit

E.30 degrees Fahrenheit

Q.35) **The comfort zone is generally from**

A.50 to 70 degrees Fahrenheit

B.58 to 78 degrees Fahrenheit

C.65 to 85 degrees Fahrenheit

D.68 to 78 degrees Fahrenheit

Q.36) **designing tighter building envelopes in the 1970's helped conserve energy but also resulted in decreased air leakagfe leading to indoor air quality concerns and the syndrome known as**

(3 words)

Q.37) **Wall U-factors are somewhat complicated by framing members interrupting insulation. This is known as**

(2 words)

Q.38) Thermal Conductance (C) is

A. the heat transferred by conduction through a non-homogeneous material of a particular thickness per unit of time when a given temperature difference is applied to a unit area

B. the heat transferred by conduction through a homogeneous material of a particular thickness per unit of time when a given temperature difference is applied to a unit area

C. the heat transferred by conduction through a substance of a particular thickness per unit of time when a given temperature difference is applied to a unit area

Q.39) the reciprocal of the thermal conductance (C) is known as

A. the R-value or Thermal Resistance

B. the U-factor

C. the Thermal conductivity

Q.40) Thermal Resistance is

A. directly proportional to the density of the material

B. inversely proportional to the density of the material

C. is not related to the density of the material

Q.41) the best resistor of heat flow in buildings is

A. a layer of still air

B. water

C. masonry

Q.42) In an effort to increase the resistance of double-glazing, manufacturers tried increasing the air thickness between panes. they discovered that thermal resistance increases slightly as the layer is thickened to about ________ in. and then stops to increase with further increase in air thickness because ____________. separate answer by comma

(**or** 2 words)

Q.43) a layer of metal foil or aluminum foil within or on either side of the airspace can eliminate most of

A. conductive transfer

B. radiative transfer

C.convectional transfers

Q.44) Specific heat is

A.a measure of the amount of heat required to raise the temperature of a given mass of material by 1 degree

B.an indicator of the ability of a material to store heat

C.the thermal resistance of material

Q.45) Thermal Capacity is

A.a measure of the amount of heat required to raise the temperature of a given mass of material by 1 degree

B.an indicator of the ability of a material to store heat

C.the thermal resistance of a material

Q.46) the difference in temperature through a cross-section of a construction assembly is known as

(2 words)

Q.47) according to a rule of thumb, areas that have long cold winters have more than

A.5,500 HDDs per year

B.4,000 HDDs per year

C.2,000 HDDs per year

Q.48) The initials HDDs stand for

(3 words)

Q.49) the initials CDDs stand for

(3 words)

Q.50) In order to consider heat loss by air movement, calculation methods

A.assume only one condition: infiltration or ventilation

B.add heat losses from infiltration and ventilation

C.consider only heat loss by ventilation and the effect of infiltration is ignored

Q.51) Heat flows are of 2 types

A.sensible and latent heat

B.sensible and low heat

C.latent and stupid heat

Q.52) sensible heat is

A.results in a change in temp
B.results in a change in moisture content of the air
C.results in a change of the heat loss of a structure

Q.53) Latent heat is

A.results in a change in temp.
B.results in a change in moisture content of the air
C.results in a change in heat lose of a structure

Q.54) Heat flows from areas of

A.greater concentration to areas of less concentration
B.less concentration to areas of greater concentration
C.greater concentration to areas of equal concentration

Q.55) Thermal classification of materials can be placed into 2 types

A.insulators and conductors
B.insulators and exsulators
C.conductors and envelopes

Q.56) insulators are broken into 3 different groups

A.organic, inorganic, metallic(metalized)
B.organic, inorganic, steel
C.natural, inorganic, metallic(metalized)

Q.57) name a form of insulation

(3 words **or** 2 words **or** 4 words)

Q.58) Conductors are

A.dense, durable, and diffuse heat rapidly
B.dense, durable, and compact heat rapidly

C.open, durable, and diffuse heat rapidly

Q.59) **the U-factor is**

A.an overall property that expresses the rate at which heat exits through a building envelope assembly
B.an overall property that expresses the rate at which heat is loss through a building envelope assembly
C.an overall property that expresses the rate at which heat transfers through a building envelope assembly
D.an overall property that expresses the rate at which heat flows through a building envelope assembly

Q.60) **Many building codes require a minimum outdoor air flow rate based upon**

A.building occupation
B.floor area
C.either building occupation or floor area

Q.61) **Estimated numbers of air changes per hour (ACH) are function of**

A.construction type
B.climate
C.bother construction type and climate

Q.62) **Estimated numbers of air changes per hour (ACH)**

A.can be converted to airflow rate
B.cannot be converted to airflow rate
C.are equivalent to airflow rates

Q.63) **Symptoms associated with poor indoor air quality are often**

A.headaches
B.irritation of the eyes and upper respiratory system
C.all of the previous

Q.64) **In the Imperial System, airflow rate is measured generally using this unit**

Q.65) **The most rational IAQ strategy is to**

A.choose materials and equipment with care and isolate pollutants
B.increase outdoor air flow rates

C.provide for filtering of fresh air

Q.66) **Often a simple measurement is used as a first indicator of potential IAQ problems related to occupancy. This is**

A.a measurement of carbon dioxide (CO2)
B.a measurement of radon
C.a measurement of formaldehyde

Q.67) **Volatile organic compounds or (VOCs) are**

A.chemicals containing carbon molecules that are volatile or evaporate from material surfaces at room temperature
B.hydrofluorocarbons, formaldehyde and hydrocarbons that are found frequently in new buildings
C.irritants connected to pesticides

Q.68) **New and newly renovated buildings are prone to problems from outgassing of**

A.paints
B.adhesive and sealants
C.carpeting and vinyl wall coverings
D.all of the previous

Q.69) **What does IAQ stand for**

A.Indoor adhesive quality
B.Indoor air quality
C.Interior air quality
D.interior air quantity

Q.70) **Sick Building Syndrome symptoms are**

A.headaches
B.upper respiratory irritation
C.irritation of the ears
D.headaches and upper respiratory irritation
E.all of the answers

Q.71) **Indoor air pollution can be described both in terms of the types of**

A.contaminants and odors

B.effects and contaminants

C.effects and liquids

D.contaminants and irritants

Q.72) **One of the most immediate indicators of IAQ problems is**

A.effects

B.odor

C.irritants

D.noise

E.contaminants

Q.73) **Irritants are often imperceptible at first but cause increasing distress**

A.over time

B.in a day

C.in an hour

D.over months

E.over years

Q.74) **some symptoms of irritants**

A.burning of eyes, sneezing, coughing, dry nose and throat, sore throat and tightening of the chest

B.shining of eyes, sneezing, coughing, dry nose and throat, sore throat and tightening of the chest

C.burning of eyes, sneezing, laughing, dry nose and throat, sore throat and tightening of the chest

D.burning of eyes, sneezing, need to use bathroom, excessive gas, sore throat and tightening of the chest

Q.75) **most irritants are in the form of**

A.particles

B.gas

C.liquids

D.solids

E.particles or gases

Q.76) **what does VOC stand for**

(3 words)

Q.77) what toxic particulate substance was used up until the 1970's

A.plastic
B.asbestos
C.hair insulation
D.carbon fiber

Q.78) Biological contaminants are

A.contaminants that can biologically grow over time and cause more damage
B.contaminants that can evaporate into the air
C.contaminants that cause an odor in the air that encourages the flow of air

Q.79) radon is

A.a toxic gas that causes color blindness
B.a random gas that brings odor and biological contaminants to the area
C.a radioactive gas that decays rapidly

Q.80) radon when inhaled can cause

A.kidney failure
B.lung cancer
C.gum diseases

Q.81) ventilation rates are calculated by

A.occupancy of a building
B.square footage of building
C.envelope type
D.both occupancy and square footage of building

Q.82) the olf is a unit of

A.operable living fenestration
B.occupancy
C.pollution

Q.83) the decipol is a unit of

A.perceived air quality
B.outdoor air quality
C.air flow through envelope

Question Excerpt From bs 6

Q.1) **define travel distance**

(9 words)

Q.2) **deluge system**

(14 words)

Q.3) **name and define 3 types of sprinkler heads**

(18 words)

Q.4) **define stand pipe systems**

(14 words)

Q.5) **name and define 4 basic stand pipe systems**

(36 words)

Q.6) **Name 3 types of Containment Systems**

(7 words)

Q.7) **Containment Systems Fire Seperation define Firewalls FireSeperation Barriers Sharft Walls Fire Stopping Fire Proofing**

(75 words)

Q.8) **Redundancy**

(14 words)

Q.9) **Containment Systems Smoke Management**

(16 words)

Q.10) **Containment systems Compartmentalization**

(16 words)

Q.11) **Ductility**

(12 words)

Q.12) **Water systems must be hydrolically tested to ensure**

(9 words)

Q.13) **Suppression Systems**

(45 words)

Q.14) **7 Components of Spinkler Systems**

(18 words)

Q.15) **Sprinkler Systems**

(59 words)

Take this quiz b

Building Systems 3 the search for a better teacher

31 Questions | 16 Attempts | Created By tonybc2888 1146 days ago

congrats you found a study guide

Question Excerpt From Building Systems 3 the search for a better teacher

Q.1) **porThe humidity ratio is**

A.the ratio of weight of moisture to the weight of dry air in the air vapor mixture
B.the ratio of the weight of moisture to the weight of moist air in the air-vapor mixture
C.the relative humidity of the air

Q.2) **When the air is saturated**

A.the wet-bulb temperature is larger than the dry-bulb temperature
B.the wet-bulb temperature is lower than the dry-bulb temperature
C.the wet-bulb temperature is equal to the dry-bulb temperature

Q.3) **The difference between dry-bulb temperature and wet-bulb temperature is called**

A.wet-bulb depression
B.total heat
C.enthalpy

Q.4) **According to some studies, the percentage of people expressing discomfort or dissatisfaction due to "asymmetric radiation" is the greatest in the case of a**

A.warm wall
B.cool wall

C.warm ceiling

Q.5) **The transfer of energy between adjacent molecules from the warmer region to the cooler region is called**

Q.6) **The humidity ratio at the saturation point**

A.increases when the dry-bulb temperature increases
B.decreases when the dry-bulb temperature increases
C.the same regardless of the air temperature

Q.7) **High-Mass Cooling with Night Ventilation is best suited to**

A.large concrete buildings
B.wood-framed small buildings
C.steel-framed medium size buildings

Q.8) **Sensible heat is**

A.wet heat released into the air as water changes from liquid to vapor
B.dry heat in the air related to dry-bulb temperature
C.dry heat in the air related to wet-bulb temperature

Q.9) **Enthalpy is**

A.the same as latent heat
B.the sum of sensible and latent heat in the air
C.the measure of tthe effect of moisture in air-vapor mixture

Q.10) **The "Direct Gain" passive heating strategy is compatible with the following passive cooling strategy**

A.Evaporative Cooling
B.Natural Ventilation Cooling
C.High-Mass Cooling with Night Ventilation

Q.11) **The unit used to measure heat production in a human body is called**

Q.12) **The transfer of heat by a moving fluid medium is called**

Q.13) **The unit used to measure the insulating value of clothing is called**

Q.14) **The passive cooling strategy known as "High-Mass Cooling" is best suited to**

A.humid, hot climates where night temperatures are only slightly lower than day temperatures
B.warm, dry summers where night temperatures are cooler than day temperatures
C.conditions that are more uncomfortably dry than uncomfortably hot and when higher humidity is welcome

Q.15) **In providing thermal comfort to building occupants some upper humidity levels are set in order to avoid**

(**or** 2 words)

Q.16) **There are 2 different concepts of ventilation used in the passive cooling strategy known as Natural Ventilation Cooling:**

(2 words)

Q.17) **The type of heat transfer by electromagnetic waves that pass through space or air from a warmer object to a cooler one is called**

Q.18) **In the passive heating strategy known as "Direct Gain", and in order to avoid overheating in sunny hours, the area of the thermal mass surfaces should be at least _____ times the area of south-facing glass**

Q.19) **The passive solar approach encountered least often is**

A. Direct Gain
B. Indirect Gain
C. Isolated Gain

Q.20) **List 2 disadvantages of the passive heating strategy known as "Direct Gain".**

(**or** 3 words **or** 9 words)

Q.21) **The value of daylight to buildings has long been recognized in zoning laws. According to these laws, and as a building rises, the maximum buildable volume**

A. becomes narrower
B. becomes wider
C. remains the same

Q.22) **The passive cooling strategy that relies on adding moisture to air and increasing relative humidity while dry-bulb temperature decreases is called**

(2 words)

Q.23) **Wind forces**

A. increase with increased building height
B. decrease with increased building height
C. are not related to building height

Q.24) **Windbreaks are used to protect some outdoor areas from wind. A very dense windbreak compared to a less dense one, produces**

A. a greater reduction in wind speed behind it, but the wind recovers its full velocity closer to the barrier
B. an increase in wind velocity right behind the barrier
C. a smaller reduction in wind speed behind it

Q.25) **The passive heating strategy known as "Isolated Gain" relies on a _____________ heated greatly by the sun that then passes some of its heat to the space behind.**

(2 words)

Q.26) **The initials in the LEED system stand for**

(6 words **or** 4 words)

Q.27) **Buildings and plants are major contributors to**

A.the greenhouse effect

B.causes of acid rain and smog

C.all of the previous effects

Q.28) **List 2 examples of how building designers could help reduce air pollution caused by burning fuel in buildings**

(5 words)

Q.29) **The passive heating strategy of "Indirect Gain" relies on using a mass wall of highly conductive material behind a glass layer to transfer and reradiate heat to the internal space. This wall is Called**

(2 words)

Q.30) **Operative temperature is**

A.the average of the dry-bulb temperature and the mean radiant temperature

B.the average of the dry-bulb temperature and the mean radiant temperature

C.the same as the mean radiant temperature

Q.31) **What are the 4 levels of LEED v2.2**

Emergency power

Select the systems for which emergency power is NOT always provided:

A. Egress lighting
B. Escalator
C. Fire alarms
D. Sewage ejector pump
E. Elevator
F. Horizontal sliding doors

Answer

ARE 4.0 exam prep: BS
Email ThisBlogThis!Share to TwitterShare to Facebook
TUESDAY, JANUARY 24, 2012

Daylight calculation

Which calculation method can be used to calculate daylight at any location in a room?

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
TUESDAY, DECEMBER 27, 2011

Photovoltaics

What type of electricity do PV cells convert sunlight into initially? (choose 2)

A. alternating current
B. galvanic current
C. direct current
D. pulsating current
E. variable current

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook

TUESDAY, DECEMBER 20, 2011

Noise transmission

Which of the following is true?
A. The level of **airborne noise** that passes through either a floor/ceiling or wall assembly at a specific location is tested giving an IIC rating.
B. The level of **airborne noise** that passes through either a floor/ceiling or wall assembly at a specific location is tested giving an STC rating.
C. Sound transmission occurring due to **impact noise** transferring through a floor-ceiling assembly is tested producing an IIC rating.
D. Sound transmission occurring due to **impact noise** transferring through a floor-ceiling assembly is tested producing an STC rating.

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook

WEDNESDAY, DECEMBER 14, 2011

All-air systems

Which of the following is NOT a basic type of all-air systems that would be used for larger buildings? Choose 2

A. VAV
B. Reheat system
C. Electric resistance
D. Dual-duct
E. Multizone
F. Hydronic Radiant

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
WEDNESDAY, DECEMBER 7, 2011

VOCs: architectural coatings

The following standards set limitations on source emissions (volatile organic compounds) from paints and coatings. Which is a more restrictive standard?

A. EPA 40 CFR Part 59
B. SCAQMD rule 1113

Answer

ARE 4.0 exam prep: BS

Resource Tip: Here's a description, table of standards, and link to the text of SCAQMD Rule 1113.
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
THURSDAY, DECEMBER 1, 2011

Sprinkler Systems

Which type of fire sprinkler system is used where damage from water to the contents or finishes of a building is a significant concern:

A. wet-pipe
B. dry-pipe
C. pre-action
D. deluge

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
THURSDAY, NOVEMBER 17, 2011

Automatic heat/smoke ventilating hatches

What is a standard temperature for fusible link activation?

A. 155 degrees F
B. 165 degrees F
C. 185 degrees F
D. 200 degrees F

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
TUESDAY, NOVEMBER 15, 2011

Energy Policy Act of 1992

The deregulation of the electric utility industry commenced with the signing of the National Energy Policy Act of 1992 (EPACT 92), which additionally set minimum efficacy standards for many PAR and R incandescent lamps, and prohibited the manufacture of certain types of fluorescent lamps. One such fluorescent lamp type that is no longer manufactured is the 40W F40T12 (CW and WW). Which of the following are available alternatives? Choose 4

A. F40T10 lamps
B. 40W and 34W triphosphor F40T12 lamps (69+ CRI)
C. 60W halophosphor F96T12 CW or WW
D. 95W halophosphor F96T12/HO CW or WW
E. F32T8 lamps (requiring a compatible ballast)
F. F96T8/HO lamps (requiring a compatible ballast)
G. 34W halophosphor F40T12/ES CW or WW lamps
H. 75W and 60W triphosphor F96T12 (69+ CRI)

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
TUESDAY, NOVEMBER 1, 2011

Power generation

What type of solar system relies on the natural convective circulation of water?

A. concentrated solar
B. thermosyphon
C. active closed loop
D. amorphous silicon cell

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
SUNDAY, OCTOBER 23, 2011

Oil grades

Which is the most refined and most expensive grade of oil for heating use?
A. No. 2
B. No. 5 heavy
C. No. 4
D. No. 5 light
E. No. 6

Answer

ARE 4.0 exam study: BS

Resource tip: read about heating oil changes in NYC
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
THURSDAY, OCTOBER 6, 2011

Sprinkler system types

A large warehouse facility in Oregon stores paper products. Which of the following fire sprinkler systems should be installed?

A. Pre-action system
B. Wet pipe system
C. Deluge system
D. Dry pipe system

Answer

ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
WEDNESDAY, SEPTEMBER 28, 2011

Ohm's Law

If a wall clock is connected to a 9 volt battery that passes a 0.06A current, then what is the resistance (R)?
A. 100 ohms
B. 125 ohms
C. 150 ohms
D. 0.1 ohms
E. 0.125 ohms
F. 0.15 ohms

Answer
ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
MONDAY, SEPTEMBER 19, 2011

Fluorescent lamp output

What percentage of light output is lost when a bare fluorescent lamp is exposed to a temperature of 32deg Fahrenheit (0 Celsius)?

A. 10%
B. 25%
C. 35%
D. 50%

Answer
ARE 4.0 exam prep: BS

Related reading: the Precast Concrete Institute publishes several resources for parking facility lighting and recommended practices for exterior applications.
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
TUESDAY, SEPTEMBER 6, 2011

Group replacement

Select the most correct statement for
Group Replacement System
A. Used in stadium installation
B. Desirable for lower installation costs
C. Following burnout, system is used when lamps are replaced
D. Extends lamp life by operating under voltage

Answer
ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
FRIDAY, SEPTEMBER 2, 2011

Pipe joining methods

The process of joining two pieces of piping that requires the material to be heated occurs with which of the following?

A. plastic
B. copper
C. iron
D. steel

Answer
ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook
FRIDAY, AUGUST 26, 2011

Heating systems

Which of the following systems is a more expensive type of heating system?

A. electric resistance
B. small space heating
C. wood & pellet fuel

D. hydronic radiant

Answer

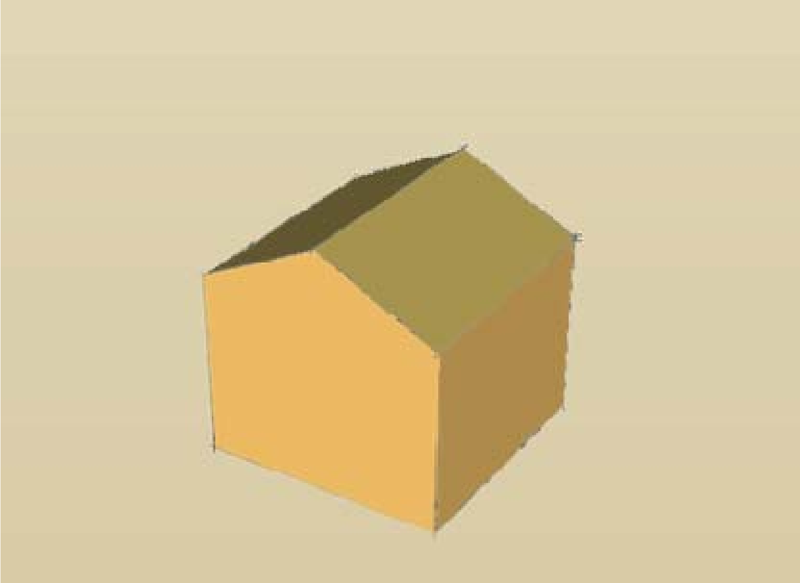
ARE 4.0 exam prep: BS

0 comments

Email ThisBlogThis!Share to TwitterShare to Facebook

SUNDAY, AUGUST 21, 2011

Building shapes



Which of the four US climatic regions is most suitable for an external load dominated building that is square in shape?

I. hot-humid

II. hot-arid

III. cool

IV. temperate

Answer

ARE 4.0 exam prep: BS

0 comments

Email ThisBlogThis!Share to TwitterShare to Facebook

THURSDAY, AUGUST 11, 2011

Heat transfer

Tracey Saxby,
IAN Image Library
(ian.umces.edu/imagelibrary/)

What is the most efficient conveyor of heat? Choose the best answer from one of the following:

A. thermal mass
B. water
C. air
D. infra-red

Answer
ARE 4.0 exam prep: BS
0 comments
Email ThisBlogThis!Share to TwitterShare to Facebook

FRIDAY, AUGUST 5, 2011

Calculate Luminance

A typical 60-watt standard frosted incandescent bulb outputs 890 lumens for an efficacy ratio of about 15 lumens per watt. As an A19, its shape is spherical. What is the its calculated luminance?

A. 25,115 cd/in^2
B. 25.115 cd/ft^2

C. 25,115 cd/m²
D. Indeterminate, missing variable.

Answer

ARE 4.0 exam prep: BS

For your reference, here are the primary content areas that will be covered on the BS exam and practice exams.

- Acoustics
- Codes and Regulations
- Electrical Systems
- Environmental Issues
- HVAC
- Lighting
- Plumbing
- Specialties

he schematic design division in the examination consists of two graphic vignettes: interior layout and building layout. The structural systems division consists of 125 multiple-choice questions and one graphic vignette. It covers the following topics: general structures, seismic forces, wind forces, and general lateral forces. The vignette for this section has to do with structural layout. The building systems division of the ARE consists of 95 multiple-choice questions and one graphic vignette. The topics covered in this division are codes and regulations, environmental issues, plumbing, HVAC, electrical, lighting, and specialties. The vignette is the development of a mechanical and electrical plan. The construction documents and services division of the ARE consists of 100 multiple-choice questions and one graphic vignette. The topics covered in this division include codes and regulations, environmental issues, construction drawings and project manuals, and project and practice management. The vignette in this section relates to a building section. The ARE was developed by the National Council of Architectural Registration Boards.

ARE Practice Questions

1. A foundation is being built in clay soil. If the area of a correctly designed footing has an area of 12 square feet and the applied load is 24,000 pounds, then what is the bearing capacity of this soil?

a. 500 pounds per square foot
b. 2000 pounds per square foot
c. 288 kips per square foot
d. 2 kips per square foot

2. What advantage is gained by adding calcium chloride to concrete as an admixture?

a. It accelerates the hydration rate.
b. It allows a lower water-cement ratio in the concrete.
c. It decreases the likelihood of corrosion of reinforcing steel in the future.
d. It increases the final strength of the concrete after it has cured fully.

3. A slump test is performed on concrete used in a building slab. The concrete slumps one inch during the test. What conclusions can be drawn about the concrete that this sample is from?

a. This concrete is rigid and may not be very workable.
b. This concrete slumps within the tolerable range and should have good stiffness and workability.
c. This concrete is not rigid enough and may be too soft to be properly workable.
d. The slump test is no longer used to gauge the stiffness and workability of concrete.

4. Where should the vapor barrier be placed in the wall construction in a cooling climate such as Phoenix, Arizona?

a. On the exterior side of the thermal envelope
b. On the interior side of the thermal envelope
c. A vapor barrier is not needed
d. On both the interior and exterior side of the thermal envelope

5. Which of the following is a disadvantage of pursuing a design/bid/build method of project delivery?

a. A firm price is not known until the construction documents are mostly completed.
b. Competitive bidding typically will result in a lower cost than if a contractor is selected earlier in the design process
c. The contractor will not be present to act in the best interest of the owner during design.
d. There is a risk that design changes will cause significant issues because construction begins before the documents are finished.

6. Why is an additive alternate to a bid preferable to a deductive alternate to a bid?

a. Because the contractor will usually deduct less than the actual value of the work installed when putting together a deductive alternate.
b. Because a bid with additive alternates has a lower base price.
c. Because the bid can be put together in less time if additive alternates are used.
d. Because it is easier for the subcontractors to price additive alternates.

7. Which of the following materials has the highest shading coefficient (SC)?

a. One-eighth of an inch of clear glass
b. Half-inch clear glass
c. Quarter-inch heat absorbing glass
d. One-inch insulated glass

8. Which of the following is NOT a characteristic of a ramp that is handicapped accessible?

a. It has a minimum five-foot-long landing ramp at the top and the bottom.
b. It has a maximum length of 30 feet.
c. It has a maximum rise of 24 inches before a landing is required.
d. It has a minimum width of 36 inches.

9. Which of the following is NOT a principle that Clarence Perry championed in his "Neighborhood Theory" in 1929?

a. Arterial streets should form the boundaries of each neighborhood, but should not pass through them at all.
b. The population of the neighborhood should not be greater than can be accommodated by one elementary school.
c. Shopping areas should be located along the arterials around the edges of the neighborhood.
d. The streets inside the neighborhood should be laid out in a grid, with many connections to arterials.

10. The footprint of a building is 10,000 square feet, has eight stories, and the site is 100,000 square feet. What is the FAR for the site in this instance?

a. 0.1
b. 0.8
c. 1.25
d. 10

11. What is the definition of an arterial road?

a. A road with on/off ramps and speed limits that are usually 55 miles per hour or higher.
b. A road that runs through the residential area of a neighborhood.
c. A road that residential streets connect to in order to take traffic to a main thoroughfare.
d. A high capacity road that connects to freeways.

12. Which of the following is NOT usually true when describing the cross section of a street?

a. If there is a sidewalk, it is included in the right of way of the street.
b. The street is sloped so that the high point is in the middle and it drains to the edges.
c. The traffic lanes are typically 9-12 feet in width.
d. Roads are typically sloped one inch per foot or higher to ensure proper drainage.

Answers

1. B: The soil-bearing capacity is equal to the load divided by the area of the footing, so 24,000 pounds divided by 12 square feet equals 2000 pounds per square foot. The soil-bearing capacity is the pressure that a given soil can hold without settling enough to negatively impact a structure. Clay soil has one of the lowest bearing capacities along with sand and silt, while rock and gravel can support the highest pressures. Answers C and D are in kips per square foot, where a kip is equal to 1000 pounds of force.

2. A: Adding calcium chloride as an admixture accelerates the hydration rate, which produces more heat of hydration. This aids the concrete in curing in cold weather. An example of admixture that would allow a lower water-cement ratio is an air-entraining admixture. Option C is incorrect because a calcium chloride admixture would increase the chances of reinforcing steel corrosion in the future. Option D is incorrect because calcium chloride will accelerate the curing process and get the concrete to its ultimate compressive strength faster, but it will not change that strength.

3. A: A slump test is conducted by filling a cone that is 12 inches tall with an upper diameter of eight inches and a bottom diameter of four feet with fresh concrete. The cone is then turned upside down and removed, and the concrete is allowed to settle in a pyramid-like form. Then the new height of the slump is compared to the height of the cone. Generally, the concrete should slump two to six inches. If it slumps less than that, the concrete may be too rigid to do its job properly. If it slumps more than that, it might be too soft. Once the test is complete, the concrete mixture can be modified if necessary.

4. A: The vapor barrier should be placed on the exterior side of the thermal envelope in this climate because the vapor barrier should always be placed on the warm side of the thermal envelope. The reason for this is that warm air can hold more moisture than cold air. When warm air hits a cold surface, it cannot hold as much moisture, so some of the moisture condenses on that surface. For example, if warm air penetrates a wall and hits a cooler section of drywall on the interior of the building, moisture will condense on the drywall, which can lead to mold formation. In addition, if the insulation in the wall gets wet, it loses much of its insulating value. In a heating climate such as New England, the vapor barrier would be on the interior, because that is usually the warm side. If a vapor barrier is installed on both the interior and exterior sides, moisture that is trapped in the wall (which is inevitable), will have a difficult time escaping and will make moisture problems worse.

5. A: This method has contractors bid on the project after design has been completed. Though cost estimates will be finalized during development, a firm price is not established until a point where it is challenging to change the scope or quality of the project. Choice B is actually an advantage of design/bid/build. Choice C is incorrect because the contractor will rarely be acting in the best interest of the owner. Even in the case of design/build, the contractor and architect are working together and not necessarily doing what is best for the owner. In the case of design/bid/build, the architect is working in the best interests of the owner in design and construction. Option D is incorrect because the design is completed before construction starts.

6. A: Although option B is a true statement, it does not have anything to do with why additive alternates are preferable. Options C and D are incorrect because it does not take any less time to use additive alternates, nor is it any easier to price them. Prices must still be obtained for all components and associated labor. Option A is the correct answer because contractors tend to give less of a credit for work taken out of the project than the actual value of the work performed.

7. A: One-eighth of an inch of clear glass has a shading coefficient (SC) of 1.00. The reason that this value is equal to 1.00 is that SC is a normalized value, and one-eighth of an inch of clear glass is a baseline. The amount of solar heat gained through a particular type of glazing is compared to the amount through an eighth of an inch of clear glass to calculate a ratio. So, if one inch of insulated glass has 60 percent of the solar heat gain of an eighth of an inch of clear glass, its SC will be equal to 0.80. This value should not be confused with the actual SHGC, or solar heat gain coefficient, which is the fraction of solar radiation that is transmitted through a piece of glazing.

8. C: In actuality, the maximum rise allowed is 30 inches. The maximum slope allowed is 1:12, so a ramp that is 30 feet long can have a rise of 30 inches. Other ramp requirements are that a ramp has handrails if it is more than six feet long or if it has a rise of more than six inches. Even at these small rises, it is important to have a handrail so that people recognize that there is a change in surface planes and will not accidentally step over the edge while not prepared for the change.

9. D: Perry proposed that the street system should be laid out in order to discourage through traffic and aid circulation within the neighborhood, which would obviously minimize the presence of the automobile, except those belonging to people that lived in the neighborhood. Other principles that he espoused were: that each neighborhood should have a system of parks and recreation areas, and that the school and other public building should be grouped in the center of the neighborhood in order to facilitate use by all.

10. B: "FAR" stands for floor area ratio. This is the ratio of floor area of the building on the site to the area of the site itself. The building in the example has an area of 80,000 square feet, and the site has an area of 100,000 square feet, so 80,000 divided by 100,000 equals 0.8. Maximum or minimum FARs may be established in certain areas as a way of controlling a building's form. If a building is in a residential neighborhood, it may have a low FAR in order to limit the size and mass of the building. This would be most useful in conjunction with a height limitation as well, as a building with a small footprint could be many stories tall and stay under the maximum FAR. Similarly, a minimum FAR could be required in an urban context in order to ensure that the building mimics its surroundings in scale.

11. D: The hierarchy of streets is: residential road, collector road, arterial road, freeway. A collector road runs along the edge of a residential neighborhood and has many residential (low traffic) streets that connect to it. These collectors "collect" cars from neighborhoods and direct them to arterials, which are high capacity roads that usually have limited access except at major intersections. Arterials, in turn, connect to freeways via on/off ramps located on the highways. This system ensures that the roads are properly sized for the number of cars travelling on them and that cars move up and down the line from smallest to largest and back, which helps traffic flow smoothly.

12. D: Choices A through C are all true when describing a street. However, roads are typically sloped up to a half-inch per foot in order to provide positive drainage. This is enough to ensure that the road does not collect water on its surface, which could present a significant chance for cars to hydroplane. This is not too far off from the quarter-inch per foot that roofs are usually sloped in order to provide positive drainage. One inch per foot of slope is somewhat excessive, as it would mean that the edges of a road would be one foot below its center, if a road is 24 feet wide.