CHAPTER 25

POWER PLANTS

THIS chapter discusses HVAC systems for industrial facilities for the production of process heat and power and for electrical generating stations. Not every type of power plant is specifically covered, but the process areas addressed normally correspond to similar process areas in any plant. For example, wood-fired boilers are not specifically discussed, but the requirements for coal-fired boilers generally apply.

Aspects of HVAC system design unique to nuclear power plants are covered in Chapter 26.

GENERAL DESIGN CRITERIA

Space-conditioning systems in power plant buildings are designed to maintain an environment for reliable operation of power generation systems and equipment and for the convenience and safety of plant personnel. A balance is achieved between the cost of the process systems designed to operate in an environment and the cost of providing that environment.

Environmental criteria for personnel safety and comfort are governed by several sources. The U.S. Occupational Safety and Health Administration (OSHA) defines noise, thermal environment, and air contaminant exposure limits. Chapters 12 and 29 of this volume and *Industrial Ventilation* by the American Conference of Governmental Industrial Hygienists (ACGIH 2004) also provide guidance for safety in work spaces, primarily in the areas of industrial ventilation and worker-related heat stress. The degree of worker comfort is somewhat subjective and more difficult to quantify. The plant owner or operator ordinarily establishes the balance between cost and worker comfort.

Exhaust vents are subject to regulation of the plant's air quality permit and local air pollution control board's requirements. For this reason, all exhaust vent locations should be properly identified and classified, and coordinated with the plant's environmental compliance department. Treatment of exhaust streams is discussed in Chapter 25 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.

Criteria should be clearly defined at the start of design, because they document an understanding between the process designer and the HVAC system engineer that is fundamental to achieving the environment required for the various process areas. Typical criteria for a coal-fired power plant are outlined in Table 1. They should be reviewed for compliance with local codes, the plant operator's experience and preferences, and the overall financial objectives of the facility. Additional discussion of criteria may be found in the sections on specific areas.

Temperature and Humidity

Selection of outdoor design temperatures is based on the operating expectations of the plant. If the power production facility is critical and must operate during severe conditions, then the effect of local extreme high and low temperatures on the systems should be evaluated. Electrical power consumption is usually highest under extreme outdoor conditions, so the plant should be designed to operate when needed the most. Other temperature ranges, indicated in Table 1, may be more appropriate for less-critical applications.

Indoor temperatures should match the specified operating temperatures of the equipment. Electrical equipment, such as switchgear, motor control centers, and motors, typically determines the design temperature limits in the plant; common temperature ratings are 104 or 122°F. Other areas such as elevator machine rooms may include electronic equipment with temperature restrictions.

In plant areas where compressed-gas containers are stored, the design temperature is according to the gas supplier. Typically, the minimum temperature should be high enough that the gas volume can be effectively released from the containers. If the gas is hazardous (e.g., chlorine), the minimum temperature does not apply during personnel occupancy periods, when high dilution ventilation rates are needed.

Practical ventilation rates for fuel-fired power plants provide indoor conditions 10 to 20°F above the outdoor ambient. Therefore, ventilation design criteria establish a temperature rise above the design outdoor temperature to produce an expected indoor temperature that matches the electrical equipment ratings. For example, an outdoor extreme design temperature of 112°F with a ventilation system designed for a 10°F rise would meet the requirements of 122°F-rated plant equipment unless a new record temperature occurred. However, the environment for workers should also be considered. Velocity (spot) cooling may be necessary in some areas to support work activities.

Low temperatures may affect plant reliability because of the potential for freezing. The selection of the low design temperature should be balanced by the selection of the heating design margin. If the record low temperature is used in the design, indoor design temperatures of 35 to 40°F may be used. In the heating system design, credit is generally not taken for heat generated from operating equipment.

The selection of outdoor design humidity levels affects the selection of cooling towers and evaporative cooling processes and the sizing of air-conditioning coils for outdoor air loads. When values from Chapter 28 of the 2005 *ASHRAE Handbook—Fundamentals* are used for design, the mean coincident wet bulb is appropriate. If extreme dry-bulb temperatures are selected for the design basis, the use of extreme wet bulbs is too restrictive because the extremes are not coincident. It is prudent to use the wet bulb associated with the 1% dry bulb when extreme dry-bulb temperatures are used for the design.

The preparation of this chapter is assigned to TC 9.2, Industrial Air Conditioning.

Table 1 Design Criteria for Fuel-Fired Power Plant

Building/Area	Design Outdoor Cooling/ Heating Dry-Bulb[a]	Indoor Temperature, °F		Relative Humidity, %	Room Ventilation Rate, ach*	Filtration Efficiency, %	Pressurization	Redundancy[b]	Noise Criterion
		Maximum	Minimum						
Steam Turbine Area									
Suboperating level	0.4%/99.6%	Design outdoor + 10	45	None	30	None	None	Multiplicity	Background
Above operating floor	0.4%/99.6%	Design outdoor + 10	45	None	10	None	None	Multiplicity	Background
Combustion Turbine Area	0.4%/99.6%	Design outdoor + 18	45	None	20	None	None	Multiplicity	Background
Steam Generator Area									
Below burner elevation	0.4%/99.6%	Design outdoor + 10	45	None	30	None	None	Multiplicity	Background
Above operating floor	0.4%/99.6%	Design outdoor + 10	45	None	15	None	None	Multiplicity	Background
Air-Conditioned Areas[d]									
Control rooms and control equipment rooms containing instruments and electronics	Extreme (see text)	75 ± 2	72 ± 2	30 to 65	ASHRAE *Std.* 62.1	85 to 90 (see text)	Positive	100%	NC-40[c]
Offices	1%/99%	78	70	30 to 65	ASHRAE *Std.* 62.1	ASHRAE *Std.* 62.1	Positive	None	See text
Laboratories	1%/99%	78	70	30 to 65	ASHRAE *Std.* 62.1	High	Positive	None	See text
Locker rooms and toilets	1%/99%	78	70	None	ASHRAE *Std.* 62.1	ASHRAE *Std.* 62.1	Negative	None	See text
Shops (not air-conditioned)	1%/99%	Design outdoor + 10	65	None	15	None	None	None	85 dBA
Mechanical Equipment									
Pumps, large power	0.4%/99.6%	Design outdoor + 10	45	None	30	None	None	Multiplicity	Background
Valve stations, miscellaneous	0.4%/99.6%	Design outdoor + 10	45	None	15	None	None	None	85 dBA
Elevator machine rooms	0.4%/99.6%	90	45	None	None	Low	Positive	None	85 dBA
Fire pump area	0.4%/99.6%	NFPA *Std.* 20	NFPA *Std.* 20	None	NFPA *Std.* 20	None	None	None	85 dBA
Diesel generator area	0.4%/99.6%	Design outdoor + 10	45	None	30	None	None	None	Background
Electrical Equipment[d]									
Enclosed transformer equipment areas	0.4%/99.6%	Design outdoor + 10	45	None	60	Low	Positive	100%	85 dBA
Critical equipment	Extreme (see text)	Design outdoor + 10	45	None	30	None	None	100%	85 dBA
Miscellaneous electrical equipment	0.4%/99.6%	Design outdoor + 10	45	None	20	None	None	Multiplicity	85 dBA
Water Treatment									
Chlorine equipment rooms									
When temporarily occupied	0.4%/99.6%	Design outdoor + 10	None	None	60	None	Negative	None	85 dBA
When unoccupied	0.4%/99.6%	Design outdoor + 10	60	None	15	None	Negative	None	85 dBA
Chemical treatment	0.4%/99.6%	Design outdoor + 10	60	None	10	None	None	None	85 dBA
Battery Rooms	0.4%/99.6%	77	77	None	As required for hydrogen dilution	None	Negative or neutral	50%	85 dBA

*Listed numbers are for estimating purposes only. When heat gain data are available, use Equation (1) to calculate required ventilation rate.

[a] See Chapter 28 of the 2005 *ASHRAE Handbook—Fundamentals* for design dry-bulb temperature data corresponding to given annual cumulative frequency of occurrence and specific geographic location of plant.

[b] Multiplicity indicates that the HVAC system should have multiple units.

[c] See Figure 6 in Chapter 7 of the 2005 *ASHRAE Handbook—Fundamentals* for noise criterion curves.

[d] See ASHRAE Research Project RP-1104 (White 2003) for heat release values.

Indoor design humidity is not a factor in ventilated areas unless the plant is in a harsh, corrosive environment. In this case, lower humidity reduces the potential for corrosion. In air-conditioned areas for personnel or electronic equipment, ASHRAE *Standard* 62.1, Instrumentation, Systems, and Automation Society (ISA) *Standard* S71-04, and manufacturers' recommendations dictate the humidity criteria.

Ventilation Rates

Ventilation within plant structures provides heat removal and dilution of potentially hazardous gases. Ventilation rates for heat removal are calculated during HVAC system design to meet summer indoor design temperatures.

The numbers shown in Table 1 for air change rates are for estimating approximate ventilation needs. Actual heat emission rates should be obtained from equipment manufacturers or from the engineer's experience. American Boiler Manufacturer's Association (ABMA) heat loss curves (Stultz and Kitto 1992) can be used to approximate heat loads from boiler casings if better information is not available.

The ventilation rate for room heat removal is

$$Q = \frac{q}{(t_r - t_o)(60\rho c_p)} \qquad (1)$$

where

Q = ventilation rate, cfm
q = room heat, Btu/h
t_r = allowed room temperature from Table 1, °F
t_o = outside air temperature, °F
ρ = air density, lb_m/ft^3
c_p = specific heat of air = 0.24 $Btu/lb_m \cdot °F$

Hazardous gases are mostly handled by the process system design functions. Natural gas and other combustible fuel gases are controlled by ignition safeties and may contain odorants for detection. Hydrogen and other gases used for generator and bus cooling are monitored for leakage by pressure loss or makeup rates. Escaped gases are diluted by outside air infiltration. For a building with very tight construction (i.e., very little natural infiltration), an analysis should be performed to verify that dilution rates are acceptable.

Flue gas is confined to the boiler and flue gas ductwork and generally poses no hazard. In some types of boilers and associated gas ducts, however, flue gas is at a higher pressure than the surroundings and can leak into occupied areas. Also, special treatment gases such as ammonia or sulfur compounds encountered in flue gas conditioning systems can leak into the boiler building, depending on the location of the treatment device in the flue gas stream. In these cases, gas detection monitors should be used.

Ventilation for areas with hazardous gases (e.g., chlorine) should be designed by specific gas industry standards such as *The Chlorine Manual* (CI 1997) or ACGIH (2004).

Infiltration and Exfiltration

Infiltration of outside air into boiler and power-generation structures or exfiltration of room air from these buildings is driven by thermal buoyancy of heated air. Both infiltration and exfiltration are beneficial; infiltration air dilutes fugitive fumes, whereas exfiltration air carries out excess heat during hot weather. However, infiltration adds to the cold-weather load on the heating system.

Filtration and Space Cleanliness

Filtration of ventilation air for process areas is usually not needed because some process areas are dirtier than the outdoor surroundings, and the process equipment is designed to operate in a dusty environment. However, the plant may be located in an area with sources of outdoor particulate contaminants that need to be managed to protect the process equipment. Power plants in dusty or sandy areas, or where there are seasonal nuisances such as airborne plant matter, may require filtration of ventilation air. Plants at industrial sites such as refineries and paper mills may need to address gaseous contaminants and corrosive gases, as well.

Indoor air cleanliness is a concern in control room HVAC system design. Even if the control center is in an independent building, remote from the boiler-turbine building, other operations such as coal transportation, coal crushing, fuel/air distribution and combustion, ash handling, fume heat recovery, fume/smoke exhaust diffusion, and so forth may contaminate the entire plant and its surroundings.

When potential outdoor contaminants are a factor, the quality of outdoor air may need to be evaluated. This may include collection of typical particulates and the use of corrosion coupons to quantify gaseous contaminants. The U.S. Environmental Protection Agency (EPA) is a source of data. Filtration requirements may include 30% dust-spot test efficiency prefilters, 65 to 90% efficiency final filters, and gas-phase filtration units.

Air-conditioned areas for people should meet ASHRAE *Standard* 62.1 requirements. Air-conditioned areas for control and electrical equipment should meet the requirements of the equipment manufacturer(s). Guidelines for reliability of electrical equipment are found in ISA *Standard* S71.04.

Redundancy

Maintaining design operating temperatures within the power plant is essential for reliable operation. Operating electrical equipment above its rated temperature reduces equipment life. Sensitive electronic equipment, such as in the main control center, may not function reliably at high temperatures. Low temperatures also affect plant availability; for example, low temperatures in batteries or freezing of pipes, instrument lines, or tanks could prevent normal plant operation.

The HVAC systems or components essential for plant operation should be designed with redundancy to ensure plant availability. Automatic switchover to the back-up system may be required in normally unoccupied areas. In areas where back-up systems are impractical, temperature monitoring and alarming systems should be considered to initiate temporary corrective measures.

HVAC systems that include multiple units (indicated as “multiplicity” in Table 1) also improve power plant reliability. A space ventilated by multiple fans, such as four at 1/4 capacity, may retain sufficient ventilation even if one fan is out of service.

Noise

Consideration should be given to noise levels produced by HVAC system equipment both inside and outside plant spaces. Indoor noise guidelines should be established for air-conditioned areas and ventilated areas with continuous occupancies. Outdoor noise levels are established by the environmental noise pollution concerns of adjacent areas.

Air-conditioned indoor spaces should meet the normal sound level guidelines for occupancies (such as offices) listed in Chapter 47. Special occupancies such as control rooms should follow the guidelines in Table 1.

Ventilated areas of the plant should be treated as other industrial areas following OSHA regulations. Sound levels indicated in Table 1 are suggested guidelines that may be appropriate in the absence of a specific engineered solution to meet the OSHA requirements. Where “background” is indicated in Table 1, noise generated by HVAC equipment is usually not a major noise source in comparison to the noise from processes or equipment such as turbine generators, motors, pumps, and relieving of process steam. In these areas, overall noise level criteria are established by the process equipment requirements.

HVAC system components contribute to the overall noise level outside the plant buildings either by generating noise or by having ventilation openings. HVAC designs for power plants in urban areas can be significantly influenced by outdoor noise level requirements. Equipment may have to include sound-absorbing materials or be located indoors in sound attenuation enclosures. Openings may require acoustical louvers.

VENTILATION APPROACH

Summer ventilation can be achieved by natural draft, forced mechanical supply and exhaust, or natural and mechanical combined systems. **Natural-draft systems** use a combination of adjustable inlet louvers and open doors or windows and relieve warmed air through roof or high side-wall openings. **Mechanical systems** use fans, power roof ventilators (PRVs), or air-handling units to move air. A **combined system** typically uses lower and upper wall and roof openings for natural ventilation while using mechanical ventilation as a supplement. With any ventilation arrangement, consideration should be given to physical separation of inlet and outlet openings to minimize recirculation, as discussed in Chapter 16 of the 2005 *ASHRAE Handbook—Fundamentals*.

APPLICATIONS

Large plants or units with layouts containing large ducts and equipment in the ventilation airflow path, possibly with limited separation between pieces of major equipment and/or exterior walls, imposing a pressure drop exceeding the capability of gravity ventilation systems, require mechanical assistance. The plant design may have cavities, such as the area under the boiler arch and between the casing and flue gas duct (see Figures 1 and 2), which require mechanical ventilation. Areas of the plant such as the conveyor gallery usually require mechanical assistance in the makeup air system to ensure pressurization control and proper functioning of dust collectors and associated equipment.

Natural or gravity systems are appropriate for facilities without basements and with relatively open airflow paths. The pressure drop of intake louvers, control dampers, powerhouse airflow path, and exhaust louvers/gravity vents should not exceed the minimum expected buoyancy forces. Care should also be taken to configure the system so as not to interfere with mechanical dust collection equipment.

In any system configuration, the engineer should ensure all areas of the plant are provided airflow. Air intakes and supply ducts/fans should be located to prevent short-circuiting with relief openings. Ventilation air should be supplied to electrical boards and other equipment located in upper elevations of the plant, because these areas are usually significantly hotter than the lower elevations.

Driving Forces

Natural ventilation systems use the thermal buoyancy of the air as the motive force for air movement through a building. Equations for determining differential pressures for natural ventilation are found in Chapter 27 of the 2005 *ASHRAE Handbook—Fundamentals*. With natural ventilation, air enters the enclosed space and is heated by the plant equipment. The difference in density between the inside air and the outside air causes air to be drawn into the building at low elevations and relieved at high elevations.

Mechanical ventilation depends on fans (or fans and buoyancy forces) to provide required ventilation regardless of the building configuration or the temperature difference.

Air Distribution

With natural ventilation, small differential pressures drive air movement. Accordingly, air is drawn into the building at low velocities; it penetrates a short distance into the building and then disperses.

Mechanical ventilation supplied from the walls or roof can distribute air more effectively throughout the structure.

A combined system uses both natural and mechanical ventilation to achieve effective air distribution and prevent air stagnation A typical combined system uses lower-level sidewall openings as the primary natural air intake and roof or upper-level sidewall openings for hot air relief. The location and size of openings can prevent hot air accumulation under the roof naturally. Mechanical ventilation should be provided where sufficient airflow cannot be established.

Inlet and Exhaust Areas

Because of the low differential pressure driving the air, natural ventilation requires numerous large inlet louver and exhaust relief areas. Mechanical ventilation requires fewer openings.

Noise

Openings required for natural ventilation allow noise generated by inside plant equipment to pass more easily to the outside.

Mechanical equipment such as fans and PRVs generate noise directly, but the noise level can be managed by fan selection and acoustical treatment.

Impact on Plant Cleanliness

Natural ventilation creates negative pressure in the lower portions of the building, which may draw dust and fumes into the building through openings near ground level.

Mechanical ventilation can pressurize the building and can draw air from relatively clean sources at higher elevations.

Economics

The primary advantage to natural ventilation is that there are no operating costs for fan power. Because natural ventilation is passive, it is more reliable and has lower maintenance costs than a mechanical system. However, natural ventilation may not always be the most economical selection. The cost of louvers and inlet openings, architectural features, and gravity relief openings to achieve an acceptable ventilation rate may be higher than the first cost for mechanical ventilation.

Another consideration is the average building temperature. Because internal heat is the driving force, the naturally ventilated building is normally warmer than the power-ventilated building. This warmer average temperature may shorten the life of plant equipment such as expansion joints, seals, motors, electrical switchgear, and instrumentation. Warmer temperatures may also affect operator performance.

The large louver areas associated with natural ventilation may allow greater infiltration, thereby increasing the winter heating load. This additional heating cost may offset some of the summer energy savings of natural ventilation.

A combined system takes on the strengths of both natural and mechanical ventilation and can offer the advantages of reduced capital and operating costs.

STEAM GENERATOR BUILDINGS: INDUSTRIAL AND POWER FACILITIES

A steam generator is a device that uses heat energy to convert water to steam. The two basic subsystems of a steam generator are the heat energy system and the steam process system.

The heat energy system for a fueled (oil, gas, coal, etc.) steam generator includes fuel distribution piping or conveyors, preparation subsystems, and supply rate and ignition controls. Provision to supply and regulate combustion air is required at the combustion chamber; flue gas is handled downstream of the combustion area. With ash-producing fuels, bottom ash below the steam generator and fly ash entrained in the flue gas must be processed. Figure 1 shows a steam generator building with typical components.

Steam process components typically found in the steam generator building include an enclosure for the fire and heat transfer surfaces and feedwater equipment such as pumps, piping, and controls. Steam lines for primary and reheat steam are typically routed from the steam drum and reheat sections of the steam generator to the steam turbine or process systems.

The heat energy and steam process systems impose requirements on the HVAC systems for specific areas of the steam generator building.

Burner Areas

Fuel (gas, oil, coal, etc.) is transferred to the furnace, mixed with combustion air, and ignited in the burner area of the steam generator. Instrumentation must modulate the fuel in response to combustion needs. Viewports typically allow operators to monitor combustion. In many cases, these viewports are equipped with aspirating air systems to limit the amount of flue gas and heat escaping the boiler and entering the boiler room.

The burner area requires special attention for the steam generator building ventilation system. This area is often occupied by plant operators who monitor and inspect the controls and the combustion process. Heat is radiated and conducted to the adjacent spaces from

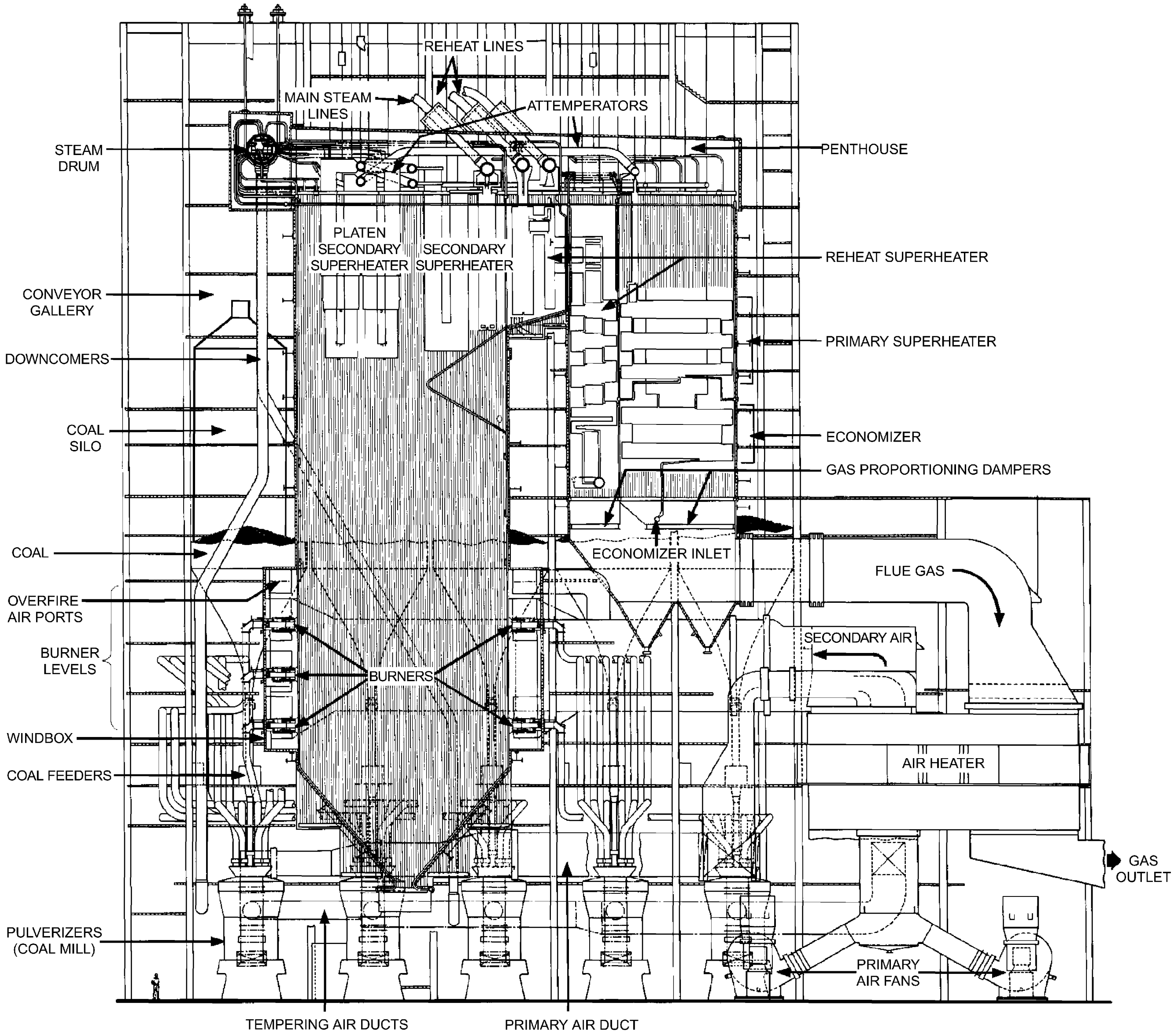

Fig. 1 Steam Generator Building
(Courtesy The Babcock & Wilcox Company)

inspection ports, penetrations, and the steam generator. Leakage of fumes and combustion gases is also possible.

Both the burner area operator and the controls require ventilation with outdoor air. Outdoor air also provides dilution for fugitive fumes. Outdoor air can be ducted to burner areas and discharged by supply registers or blown directly into the area with wall-mounted fans, depending on the building arrangement. The flow rate is difficult to quantify; generally, 60 air changes per hour supplied to an area 15 to 20 ft around the steam generator provide adequate ventilation. Consider providing velocity cooling of personnel workstations. In cold climates, outdoor air may need to be tempered with indoor air.

Steam Drum Instrumentation Area

A typical steam generator has a steam drum at the top of the boiler that provides the water-to-steam interface. The water level in the drum is monitored to regulate the flow of steam and feedwater. This is a critical steam generator control function, so accurate and reliable process flow measurement is important.

The steam drum instrumentation area may include sections of uninsulated furnace surface, which conducts and radiates heat to the surrounding area. The ventilation system should remove this heat to ensure that area temperatures are within instrumentation temperature limits. Instrumentation may need to be shielded from hot surfaces. Velocity cooling may be needed at operator workstations.

Wall-mounted panel fans in the outside walls are an option for providing ventilation air during warm weather. Heating is generally not a concern unless the steam generator is expected to be out of service during cold weather.

Local Control and Instrumentation Areas

In addition to the drum and burners, the steam generator building may house local control areas for functions such as fuel supply, draft fans, or ash handling. Because areas around a steam generator may be hot and dirty, the location and selection of the control equipment should be coordinated between the electrical system engineer and the HVAC system engineer.

The alternatives are to (1) locate the control equipment remotely from the steam generator, (2) use electrical components that can withstand the environment, or (3) provide a local environmentally controlled enclosure. The first alternative requires additional cable and raceway and perhaps additional signal boosters and conditioners. The second alternative requires more robust electrical equipment that can tolerate extremely hot or dirty areas.

When the electrical and control system design dictates that the equipment be located near the steam generator, a dedicated enclosure with a supporting environmental control system may be necessary. A typical environmental control system may control an air-handling unit capable of providing adequate filtration, pressurization, and temperature control. The temperature control may be obtained with a chilled-water or direct-expansion (DX) coil with a remote condensing unit. An air-cooled condensing unit may be used if it is rated to match the surroundings.

Coal- and Ash-Handling Areas

Coal is typically stored on site, either in piles or in storage structures. Material-handling equipment moves the coal to conveyors for transportation to preconditioning equipment (e.g., a crusher). Processed coal is conveyed to steam generator building storage silos. Coal feed equipment regulates the supply of coal from the silos either to the burner or to final processing equipment such as pulverizing mills.

Many new power plants are designed to burn low-cost coals from Wyoming’s Powder River Basin and other similar coal seams. Many of these coals are extremely friable when dry, creating significant amounts of dust during handling. During new plant design, the material handling and ventilation systems should be designed to control dusting, preferably by using modern chutework and coal-handling machinery design to reduce or control dust emissions during fuel handling. This can reduce the effects of mechanical dust collectors and associated makeup air on plant HVAC systems.

Some coals spontaneously begin to burn during normal outdoor ambient weather and normal powerhouse interior conditions. Under some conditions, accumulated coal dust spontaneously smolders, then suddenly flashes if the surface crust of the pile is broken, exposing the smoldering coal to oxygen. It is important that equipment in areas subject to dust accumulation be designed to reduce dust accumulation with sloped or curved surfaces, and designed to facilitate manual cleaning and washdown. Spontaneous combustion must be addressed in ventilation and dust collector design and installation to facilitate emptying dust out of the collector without exposing plant personnel to fire and explosion hazards.

Coal-handling areas in the steam generator building that require special ventilation system consideration are the conveyor, silo, feeder, mill, and their transition areas, and ash-handling areas.

Conveyor Areas. Primary concerns are dust control, outgassing from the coal, freezing of the coal and personnel access areas, and fire protection. Dust can be a concern because of the potential for environmental emission and also as a personnel and/or explosive hazard. Dust may be controlled by water-based spray systems or by air induction pickups at the point of generation. Some types of coal may outgas small quantities of methane, which could accumulate in the conveyor and storage structures. See the section on Coal Crusher and Coal Transportation System Buildings for a discussion of ventilation of methane fumes.

Natural or forced ventilation must remove heat from conveyor motors, other equipment, and envelope loads. Ventilation air can also remove outgassed fumes. Generally, ventilation requirements can be as low as 2 to 5 air changes per hour. If air entrainment dust collection equipment is used, provisions for makeup should be included in the design. If natural openings are not sufficient for makeup air, supply ventilation fans may need to be electrically interlocked to operate with the dust suppression/collection equipment. Makeup air may have to be heated if freeze protection is a design criterion. Unit heaters are generally used for spot heating. The unit heater should be specified to the hazard classification for the area it serves. Because coal dust can produce acids when wet, consideration should be given to specifying noncorrosive materials and coatings.

NFPA *Standard* 120 and the U.S. Bureau of Mines (1978) provide other safety considerations for coal handling and preparation areas.

Silo and Feeder Areas. Coal is generally fully contained by feeders and silos, so no special ventilation is needed. Occasionally, coal systems include an inert gas purge system for fire prevention. Ventilation may be needed for life safety dilution ventilation of purge gases.

Coal Mill Areas. Coal mills require large power motors for the grinding process. These motors may have their own ventilation system, or the motor heat may be rejected directly to the surrounding space.

The challenge for the ventilation system is to provide enough ventilation to remove heat without creating high air velocities that disturb accumulated dust. Blowing dust can pose health risks to operators and create a dust ignition hazard. Although occurrence of dust ignition air-to-dust ratios is possible, this area is generally not classified as hazardous. The dust ignition risk is managed by housekeeping, maintenance of seals on the mill equipment, and other dust-control measures.

Forced supply ventilation is generally required for equipment cooling. Sidewall propeller fans work well if the mills are arranged near outside walls. Mills located in the interior of the building may require ducted supply air. Supply air velocities at the coal-handling equipment must be lower than the particulate entrainment velocity for the expected dust size. The maximum air velocity is established using the particle size distribution spectrum and the associated air settling velocities indicated in Figure 3 and Table 1 in Chapter 12 of the 2005 *ASHRAE Handbook—Fundamentals*.

Many utilities use carbon monoxide (CO) monitoring/trending to detect fires in coal bunkers, silos, and other areas. These systems are sometimes integrated with dust collector and other exhaust streams in these areas. Specification and design of the CO monitoring should be the responsibility of a special hazards fire protection engineer and coordinated with the industrial ventilation and HVAC design.

The National Fire Protection Association (NFPA) does not differentiate between coal types/seams in the codes and standards. The utility industry, however, has accumulated experience and established best practices in handling these fuels. This information is shared between member utilities through groups such as Edison Electric Institute and Electric Power Research Institute. Other sources of specific requirements include local fire code authorities and the plant’s insurance carrier.

Ash-Handling Areas. Ash is generated when coal or heavy fuel oil is burned. Fine ash particles carried by the flue gas from the top of the steam generator are called **fly ash**. Ash that accumulates as slag in the bottom of the steam generator is called **bottom ash**.

Ash-handling equipment generally demands no special HVAC system consideration. Although fly ash is captured in the flue gas stream by a baghouse or electrostatic precipitator, uncaptured (fugitive) fly ash can create problems in equipment mechanisms because of its abrasiveness. If fugitive fly ash is expected to be in the air, HVAC equipment in the ash-handling areas should include filters to capture the ash before it enters building areas.

Stack Effect

One consideration in HVAC system design for a steam generator building is the stack effect caused by buoyancy of heated air. A 300 ft tall steam generator building with 0°F outdoor air temperature and 100°F indoor air temperature may have 0.5 in. of water negative internal pressure at ground level. This high level of negative pressure

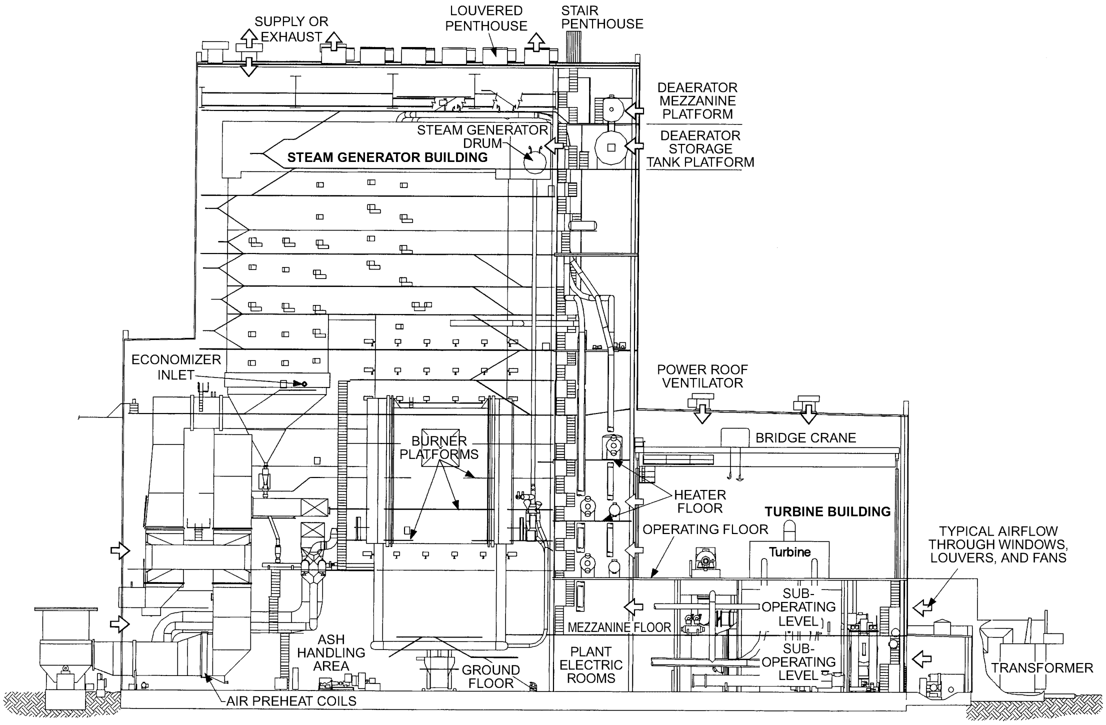

Fig. 2 Generation Building Arrangement
(Courtesy Black & Veatch LLP)

causes abnormally large forces on doors, creating a hazard for operators.

Sources of Combustion Air

Large-draft fans supply combustion air for the steam generator. A positive-pressure steam generator is supplied by forced-draft fans, and a negative-pressure steam generator uses induced-draft fans. A balanced-draft steam generator, typical for a larger unit, uses both forced- and induced-draft fans. Because the air is heated to furnace temperatures in the combustion process, part of the fuel energy is used to heat the air. Forced-draft fans on a large steam generator can supply 100,000 cfm or more to the combustion process. A significant amount of energy is needed to preheat the combustion air.

Two prevailing methods of preheating combustion air are used. One method is to draw air in from outdoors and heat it using steam or hot-water coils using energy directly from the power cycle. Another method uses heat rejected from steam generator surfaces to the building space to heat combustion air. This method provides energy savings over heating outdoor air. Temperatures in the higher levels of the generator building can be 100°F or higher. Heat recovery is accomplished by locating the draft fan intake high in the building. Although the potential for savings is large in a cold climate, the total effect on the building heating and ventilation systems should be evaluated. One effect is that drawing the air from the building makes the building pressure more negative; this increases infiltration and adds to the building heating system load, possibly offsetting the potential power cycle thermal efficiency advantage. Increased negative pressure can also contribute to stack effect problems associated with negative pressure low in the building. The draft fan can also be used to supplement ventilation during warm outdoor conditions.

TURBINE GENERATOR BUILDING

As shown in Figure 2, a turbine generator building usually includes a high-bay operating level, a deaerator mezzanine, and one or more suboperating levels. Typically, the turbines and electric generators are located along the centerline of the building between the operating level and the first suboperating level and are the major heat sources in the building. Deaerators are another significant heat contributor; the deaerator mezzanine is commonly open to the turbine operating level. Other room heat sources are steam, steam condensate and hot-water piping, heat exchangers, steam valve stations and traps, motors, electric transformers, and other electrical equipment.

Local Control and Instrumentation Areas

Some power plants include a local turbine-generator control panel on the operating floor. The local control panel area of the turbine generator may be either enclosed or open; for the enclosed arrangement, the environmental requirements are the same as those given in the Main Control Center section.

For an open arrangement, velocity cooling with conditioned air improves the operator's working environment. Because the area may be directly exposed to high-temperature surroundings, the recommended velocity of the conditioned air discharge is 300 to 600 fpm, depending on its service distance and workers' preference. The air distribution system should have manually adjustable air deflectors for operator comfort. In addition, the control panel may need a separate cooling source.

Deaerator Mezzanine

The deaerator and associated storage tank reject significant heat at the deaerator mezzanine level. This plant area also typically includes instrumentation and control equipment enclosures; accordingly, the area should have local ventilation to provide the necessary cooling.

Bridge Crane Operating Rooms

Outside air entering the building is heated by process heat, rises toward higher elevation, and is relieved through openings. The bridge crane operating room is as high as the roof beam and within the building exhaust airstream. If the outside air temperature is 95°F, the crane operating room may be surrounded by 105°F or hotter air. Hence, the bridge crane operating room is normally air conditioned.

Because the bridge crane operating room moves within the building during its operation, through-the-wall mounted air conditioners are commonly used; to simplify the electrical work, an additional power plug in the crane for the air conditioner should be provided by the crane supplier. Provisions for the cooling-coil condensate drain should be included in the design.

Suboperating Level

The turbine generator is located on the operating floor, a large deck surface open to the turbine building roof. The deck may be 70% or more of the turbine building area. Below the operating level are one or more suboperating levels. Ventilation supply air should be provided to the suboperating levels and at the lower elevations of the operating floor. Air rising through the operating levels brings room heat to the roof area, where it is relieved through high-elevation openings (gravity vents) or exhausted by roof-mounted exhaust fans or PRVs.

The major heat sources in the suboperating levels are high-temperature mechanical and piping systems. Other contributors are electric transformer room exhaust, switchgear room exhaust, electric reactor room exhaust, electric motor heat, etc. Electrical equipment exhaust heat in the turbine generator building is small compared to heat emitted from mechanical and piping systems. Accordingly, ventilation air from the plant distribution electric room can generally be exhausted directly into the turbine building without ducting to the outside. Conditioned air may be supplied to local instrumentation panel areas.

For plants in cold climates (temperatures below 32°F), consider spot heating and/or exterior door heated-air curtains. Consideration should also be given to freeze protection of piping close to building walls; stack effect and wind-driven infiltration can increase local heating requirements at the building perimeter. This problem can be addressed by adding capacity to installed heating systems or by providing mobile, temporary heating.

Electric Transformer Rooms

Transformer rooms are typically located at a suboperating level between the turbine building and steam generator buildings. For isolation of dust, the transformer rooms should not have inlet openings to the steam generator building.

The transformer room exhaust air temperature should not exceed the design limit of the transformers. Typically, air intake is from a turbine building suboperating level or from outdoors, and exhaust air discharges at the higher level of the transformer room toward the turbine building.

Plant Electrical Distribution Equipment and Switchgear/MCC Rooms

Air for the main station switchgear and motor control center (MCC) rooms should be relatively clean. Supply air from outdoors should be filtered with 30% efficiency air filters. Air can be relieved through louvers into the plant or to the outside.

A similar approach is used for the ventilation system for an electric reactor room. If the reactors have ducted connections for the exhausts, a removable section may be required so that the ducts can be disassembled when the reactor is lifted during maintenance.

Isophase Bus Duct Cooling

Power from the generator is conveyed by isophase bus ducts to the main transformer. This generates heat, which must be dissipated to a heat sink. A specialized forced-air system is used to cool the isophase bus duct. The duct cooler consists of cooling coils, fans, dampers, and filters. For a low-velocity system, air is supplied to the cooler along two phases of the bus duct and returned in the third phase. For a higher-velocity system, air is supplied and returned midway between the transformer and generator, or is supplied at the generator end along bus ducts of all three phases and returned at the transformer end. Isophase bus cooling is essential for power production and delivery, so it is important that the designer specify sufficient redundancy (in the form of dual fans, dual cooling coils and a bypass duct to provide cooling with outside air, or another source) in the system design.

COMBUSTION TURBINE AREAS

Combustion turbines are adaptable for outdoor or indoor installation. The outdoor type is usually a skid-mounted structure, with support systems typically designed and furnished by the combustion turbine vendor. The indoor type is typically enclosed in a weatherproof and acoustically treated enclosure and may have indoor support systems, designed and installed separately.

Combustion turbine installations have some or all of the following support facilities: fuel oil handling facility, natural gas pressure-reducing facility, office or administration areas, maintenance shops, battery rooms, control rooms, distributed control system (DCS) control room, communication or computer room, and a water treatment facility. Heating and ventilation design issues associated with combustion turbines include but are not limited to airflow, combustion air source, hot duct and equipment surfaces, fuel supply, turbine inlet cooling, and noise.

The turbine manufacturer typically establishes HVAC requirements and, if required by the purchaser, provides HVAC equipment for the various compartments on the turbine skid. Turbine ventilation and equipment requirements should be coordinated with the building ventilation design.

Turbine and generator casings and the surface of the exhaust duct are large contributors to the heat removal requirements. Hot surfaces should be insulated with appropriate materials as much as is practical and with the approval of the turbine manufacturer, with appropriate airflow established to eliminate hot spots.

When heat recovery equipment is installed in the turbine exhaust, the designer must take into consideration the additional heat rejected into the building because of increased back pressure on the hot exhaust.

Airflow through the combustion turbine building should consider combustion air requirements, combustible gas dilution requirements based on design leakage rates, heat removal requirements, exhaust gas dilution, and electrical component cooling requirements. Combustion turbines draw combustion air through ducts from outside the building. The system design should ensure control of the building pressurization to keep the building under positive pressure, and building outdoor air should be filtered. This also offsets infiltration of dust, rain, snow, bugs, and other contaminants into the building. System design should address freeze protection for vulnerable components. For cold-climate applications during normal operation, mixing outdoor and building air to keep the outdoor supply air temperature above freezing is recommended. In electrically classified installations, the ventilation system must switch to 100% outdoor air during upset conditions.

Noise from combustion turbines is managed by a combination of site location considerations, acoustic enclosures; sound attenuation devices and engineered sound controls included those that are part of on HVAC Systems.

HVAC design requirements for various areas of the building or turbine skid may be obtained from Table 1. The design should use NFPA *Standards* such as 37, 70, and 90A; insurance carrier requirements; and applicable local codes and standards. HVAC system design and operation should be coordinated with the fire protection systems to ensure adequate concentration of fire suppressant and to prevent fire and smoke spread. HVAC systems also must shut down when fire or extremely high concentrations of gases are detected.

MAIN CONTROL CENTER

The main control center usually comprises a control room, a battery room, a communication equipment room, electronic and electric control panel rooms, and associated administration areas.

Because the control center usually contains temperature-sensitive electronic equipment critical to plant operation, it is generally provided with redundant air-handling units and refrigeration equipment. A back-up power supply may also be required. Passive components such as distribution ductwork and piping do not have to be duplicated. Controls should be designed so that failure of a component common to both the primary and back-up systems does not cause failure of both systems. Manual changeover is a simple solution to this problem.

Control Rooms

The control room houses the computerized microprocessor, printer, electronic and emergency response controls, fire protection controls, communication and security systems, regional system networks, accessories, and relevant wiring and tubing systems. An air-conditioning system typical for office occupancy, with features to meet overall design requirements for reliability and the specific environmental needs of the control equipment, is generally appropriate.

Battery Rooms

Battery rooms should be maintained between approximately 70 and 80°F for optimum battery capacity and service life. Temperature variations are acceptable as long as they are accounted for in battery sizing calculations. The minimum room design temperature should be taken into account in determining battery capacity. Batteries produce hydrogen gas during charging, so the HVAC system must be designed to limit the hydrogen concentration to the lowest of the levels specified by IEEE *Standard* 484, ASHRAE guidelines, OSHA, and the lower explosive limit (LEL). The recommended hydrogen concentration in the battery room is 2% or less of the room volume. If battery design information is not available, it is recommended that a five air changes per hour be provided for the exhaust system.

TURBINE LUBRICATING OIL STORAGE

A typical power plant has a turbine lubricating oil storage tank and associated filtration equipment. If this storage area is inside the building, the tank should be vented to the outdoors or ventilation rates should provide for dilution of oil fumes. The ventilation systems should be coordinated with fire protection systems to ensure adequate fire suppressant concentration and to prevent spread of fire.

OIL STORAGE AND PUMP BUILDINGS

At a power plant, fuel oil may be the main source of energy for the steam generator, combustion turbine, or diesel generator. It may also be a back-up or supplemental fuel. Coal-fueled plants usually use oil or gas as the initial light-off fuel or for operation of an auxiliary steam generator. Auxiliary steam generators provide initial plant warm-up and building heating.

Oil for combustion is generally a light oil such as No. 2 fuel oil or a heavy oil such as No. 6. Light oils can be pumped at normal temperatures, but heavy oils are highly viscous and may need to be heated for pumping. Oils are usually received by rail or truck, transported by pipeline, and stored in tanks.

Enclosures for pumps, valves, heat exchangers, and associated equipment should be heated and ventilated to remove excess heat and to dilute hydrocarbon fumes. Tank ventilation is an integral part of the tank and piping system design, which is separate from the enclosure ventilation design. Fuel oils are classified in NFPA *Standard* 30 as either combustible or flammable, depending on their vapor pressure at the indoor design temperature. Flammable liquids are hazardous; combustible liquids are not.

The design of HVAC systems for areas containing combustible fuels involves following ventilation principles for heat removal and for good air mixing. Ventilation rates should dilute fumes expected from evaporation of spilled or leaking fuel, following ACGIH (2004) guidelines and material safety data sheets (MSDSs) provided by the material manufacturer. For fuel handling confined to piping systems, the expected leakage is nearly zero, so very low fresh air rates are required for ventilation (generally less than 1 air change per hour). If fuel is handled in open containers or hoses, higher rates are prudent.

If the fuel is flammable at temperatures expected in the room, NFPA *Standard* 30 and other safety and building codes should be followed. Electrical systems may need to be classified as hazardous.

COAL CRUSHER AND COAL TRANSPORTATION SYSTEM BUILDINGS

Coal-handling facilities at a power plant receive and prepare coal and then transport it from the initial delivery point to the burners. Intermediate steps in the process may include long- or short-term storage, cleaning, and crushing. Receipt may include barge, rail car, or truck unloading. Storage may be in piles on the ground, underground, or in barns or silos. At the site, the coal is handled by mobile equipment or conveyor systems.

The following general HVAC considerations apply for the types of structures involved.

Potential for Dust Ignition Explosion

Most types of coal readily break down into dust particles when handled or conveyed. The dust can become fine enough and occur in the right particle size distribution and concentration to create a dust explosion. The design engineer should review and apply the referenced NFPA standards and guidelines to determine the dust ignition potential for each ventilation system application.

Ventilation of Conveyor and Crusher Motors in Coal Dust Environment

Heat from motors and process equipment should be removed through ventilation. The options are to use ducted, ventilated motors or to ventilate the building enclosures. Ventilation in enclosures containing coal should keep the velocity below the entrainment velocities of the expected particle sizes. Table 1 in Chapter 12 of the 2005 *ASHRAE Handbook—Fundamentals* has information on settling velocity. Generally, air should be mechanically exhausted to allow ventilation air to enter the building through louvers at low velocities.

Cooling or Ventilation of Electrical and Control Equipment

Electrical and control equipment may be located near coal piles or other coal-handling facilities. Air-conditioned control rooms should be pressurized with filtered outdoor air. Ventilated motor control or switchgear areas should also be pressurized with filtered air. Because of high dust concentrations in coal yards, ordinary filter media have a short life; a solution is to use inertial filters. For air-conditioned areas, inertial filters can be followed by higher-efficiency media filters.

For electrical equipment rooms adjacent to an area with the potential for a dust ignition explosion, NFPA *Standard* 496 should be followed. This standard recommends the flow of clean air away from electrical equipment into the dusty area.

Ventilation of Methane Fumes

Methane and other hydrocarbons are present in coal both as free gas in cracks and voids and as adsorbents within the coal. Although most of the methane is released from the interstitial coal structure during mining and handling, some methane or other potentially flammable gases may remain in the coal. Thus, flammable concentrations of methane can accumulate when large amounts of coal are stored. The design engineer should identify the potential for methane accumulation when designing for structures associated with silos or coal storage buildings. At the mine or mine mouth, methane gas emission rates as high as 5 $ft^3/ton \cdot day$ are possible; at other locations, the rate is usually less than 1 $ft^3/ton \cdot day$. Dust collection air exhaust or natural ventilation is often sufficient to prevent the methane level from reaching the 1% explosion limit. The design engineer should apply guidelines from NFPA *Standards* 120, 123, 850, 8503, 8504, and 8505.

Underground Tunnels and Conveyors

Enclosed conveyors are generally of loose construction and require no ventilation. Smoke or gases in underground conveyor tunnels, hoppers, or conveyor transfer points could cause a personnel safety hazard. Ventilation systems should be coordinated with escape route passages to move fresh air from the direction of the egress. Ventilation rates in the range of 2 to 5 air changes per hour are generally appropriate for normal system operation.

Makeup of Dust Collection Air

Coal dust can be controlled by high-velocity air pickup at locations where coal is transferred. The airflow associated with these pickup points may be sufficient to meet the ventilation requirements. Air inlets must be provided. If additional ventilation is needed, the ventilation fan must coordinate with the dust collection system. For heated structures, makeup air may need to be heated.

HEATING/COOLING SYSTEMS

Selection of the heating and cooling systems in a power plant depends on several variables, including the geographical location and orientation of the plant and the type of fuel used. Most plants are ventilated with outdoor air, but it is customary in hot climates to air-condition many plant areas. Steam, hot water, gas, and electricity are alternative heating methods to be evaluated for the most economical choice. Electricity is the primary energy source for general-purpose cooling of various areas of the plant. Areas such as the main control room, office areas, and electrical switchgear/MCC rooms are air-conditioned for continuous human occupancy or for maintaining the operability of the electrical equipment and controls.

Cooling

The cooling source may be either a centrally located system providing chilled water to various area coolers or individual direct-expansion area coolers with either air- or water-cooled condensing units. Selection depends on the layout of the areas to be cooled and the comparative costs of the two options. The condensing system of the water chiller may be cooled with either air or available water from the plant service water system. Air-cooled chillers are used when air near the proposed chiller location is moderately clean and no fly ash or coal dust problem is anticipated. For a water-cooled system, a closed-loop cooling tower is sometimes used if service water is poor or unavailable (e.g., during start-up or plant outages). To protect chillers from fouling and corrosion by the service water, a heat exchanger is sometimes used between the chiller condenser and the service water source. In a power plant with several operating units and individual self-supporting chilled-water systems, the chilled-water systems of each unit are sometimes interconnected to provide back-up and redundancy.

Heating

Heating in various areas of the power plant is usually provided by electric, steam, or hot-water unit heaters or heating coils in air-handling units. In a hot-water distribution system, glycol is usually added into the system for protection against freezing. Because the building's stack effect induces large quantities of infiltration air, heating requirements in the lower levels of the steam generator building may increase when the steam generator is operating. Pressurization fans directing cooler, outside air into the warmer upper elevations of the plant can offset this infiltration. Also, the design engineer may evaluate redistribution of hotter air from higher to lower elevations.

An alternative to heating the open areas of the plant is to use pipeline heat tracing and spot heating at personnel workstations. For this approach, the design engineer should consider all components that may require heat tracing, such as instrument lines, small and large pipes, traps, pumps, tanks, and other surfaces that may be subject to freezing temperatures. Often the large number of components and surfaces to be heat traced and insulated makes this impractical.

Hydroelectric Power Plants

Hydroelectric power plants consist of a dam structure, draft tubes with gates, and turbine generators. The facility may be arranged with the generation components within the dam structure or within structures attached to the dam. HVAC systems should be provided for reliable operation of the mechanical, electrical, and control equipment and office areas.

The system design should consider the geographical location, humidity, degree of automation needed, and potential for flooding. Dams are typically built in remote locations, so the design and arrangement of the equipment, air intakes, and exhaust ports should consider the potential for vandalism. Accordingly, intakes should include security grating or bars, should not provide a line of sight into the structure, and should be constructed of heavy-gage steel to thwart bullets. HVAC equipment should be indoors if practical, or made otherwise inaccessible.

Humidity is a major design consideration. The lake surface and outfall structure create humid outdoor conditions. Outdoor air used for ventilation may introduce humidity into indoor spaces that may cause corrosion of electrical and control equipment. In addition, dam structure and turbine components below the lake water level are usually at temperatures colder than the dew point of the outside air. Introducing unconditioned outdoor air can create a significant amount of condensation on structure and equipment surfaces.

Another consideration of the remote location of hydroelectric plants is that the HVAC systems need to be reliable and able to operate with minimum attention by operating and maintenance personnel. Thus, these systems may require seasonal changeover features and fully automatic functions. System controls should be integrated with the generation plant controls, such as communication of status and alarm of critical functions to an off-site monitoring facility.

HVAC design should consider the maximum and minimum lake water level. Intakes and exhausts should be above the maximum design flooding level. Suction points for cooling water sources should be below the minimum water level.

Because of the potential for introducing outdoor humidity, cooling of equipment areas, such as the turbine generator hall, turbine and wicker gate, and other mechanical equipment areas, should use a minimum amount of ventilation air. When practical, air should be dehumidified mechanically or with coils using cold lake water. Areas with heat-producing equipment such as for stop-log storage generally do not need ventilation air, which may introduce unwanted humidity. To minimize the effect of outdoor air humidity on electrical and control equipment areas, consideration should be given to water-cooled equipment and radiant cooling to cool structural surfaces. Battery rooms and oil storage areas should be designed for the specific hazards to minimize excessive ventilation rates.

ENERGY RECOVERY

Energy recovery should be considered in any new system design or system upgrade. Considerations in the power plant should include the following:

- **Interfaces with existing plant process systems.** Using waste steam or steam bled from a process stream must consider process system behavior during generating unit start-up, part load, full load, shutdown, and cold standby/shutdown conditions. Any water returned to the boiler steam cycle must consider effects on the generating unit boiler water chemistry/water treatment.
- **Operating environment,** including cross-contamination of clean airstreams from dirty airstreams, dusty environments, and corrosive conditions from substances such as flue gas. For details, see Chapter 44 of the 2004 *ASHRAE Handbook—HVAC Systems and Equipment*.
- **Safety,** including issues resulting from the presence of coal dust, flammable gases, etc. Fire codes and insurance underwriters should be consulted for guidance.
- **Control strategies.**
- **Constructability.**
- **Codes, standards, and local rules and regulations.**

Energy recovery systems should be evaluated by economic analysis of life-cycle costs, including

- Initial cost, including equipment and installation cost
- Fuel and station service power cost
- Operating cost savings
- Maintenance cost

Utility economic evaluations should follow the accounting guidelines and requirements as established by the Federal Energy Regulatory Commission (FERC). See Chapter 36 for further information on owing and operating costs.

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