CHAPTER 11

INDUSTRIAL AIR CONDITIONING

INDUSTRIAL plants, warehouses, laboratories, nuclear power plants and facilities, and data processing rooms are designed for specific processes and environmental conditions that include proper temperature, humidity, air motion, air quality, and cleanliness. Airborne contaminants generated must be collected and treated before being discharged from the building or returned to the area.

Many industrial buildings require large quantities of energy, both in manufacturing and in the maintenance of building environmental conditions. Energy can be saved by the proper use of insulation, ventilation, and solar energy and by the recovery of waste heat and cooling.

For worker efficiency, the environment should be comfortable, minimize fatigue, facilitate communication, and not be harmful to health. Equipment should (1) control temperature and humidity or provide spot cooling to prevent heat stress, (2) have low noise levels, and (3) control health-threatening fumes.

GENERAL REQUIREMENTS

Typical temperatures, relative humidities, and specific filtration requirements for the storage, manufacture, and processing of various commodities are listed in Table 1. Requirements for a specific application may differ from those in the table. Improvements in processes and increased knowledge may cause further variation; thus, systems should be flexible to meet future requirements.

Inside temperature, humidity, filtration levels, and allowable variations should be established by agreement with the owner. A compromise between the requirements for product or process conditions and those for comfort may optimize quality and production costs.

A work environment that allows a worker to perform assigned duties without fatigue caused by temperatures that are too high or too low and without exposure to harmful airborne contaminants results in better, continued performance. It may also improve worker morale and reduce absenteeism.

PROCESS AND PRODUCT REQUIREMENTS

A process or product may require control of one or more of the following: (1) moisture regain; (2) rates of chemical reactions; (3) rates of biochemical reactions; (4) rate of crystallization; (5) product accuracy and uniformity; (6) corrosion, rust, and abrasion; (7) static electricity; (8) air cleanliness; and (9) product formability. Discussion of each of these factors follows.

Moisture Regain

In the manufacture or processing of hygroscopic materials such as textiles, paper, wood, leather, and tobacco, the air temperature and relative humidity have a marked influence on the production rate and on product mass, strength, appearance, and quality.

Moisture in vegetable or animal materials (and some minerals) reaches equilibrium with the moisture of the surrounding air by **regain**. Regain is defined as the percentage of absorbed moisture in a material compared to its bone-dry mass. If a material sample with a mass of 110 g has a mass of 100 g after a thorough drying under standard conditions of 220 to 230°F, the mass of absorbed moisture is 10 g—10% of the sample's bone-dry mass. The regain, therefore, is 10%.

Table 2 lists typical values of regain for materials at 75°F in equilibrium at various relative humidities. Temperature change affects the rate of absorption or drying, which generally varies with the nature of the material, its thickness, and its density. Sudden temperature changes cause a slight regain change, even with fixed relative humidity; but the effect of temperature on regain is small compared to the effect of relative humidity.

Hygroscopic Materials. In absorbing moisture from the air, hygroscopic materials deliver sensible heat to the air in an amount equal to that of the latent heat of the absorbed moisture. Moisture gains or losses by materials in processes are usually quite small, but if they are significant, the amount of heat liberated should be included in the load estimate. Actual values of regain should be obtained for a particular application. Manufacturing economy requires regain to be maintained at a level suitable for rapid and satisfactory manipulation. Uniform humidity allows high-speed machinery to operate efficiently.

Conditioning and Drying. Materials may be exposed to the required humidity during manufacturing or processing, or they may be treated separately after conditioning and drying. Conditioning removes or adds hygroscopic moisture. Drying removes both hygroscopic moisture and free moisture in excess of that in equilibrium. Free moisture may be removed by evaporation, physically blowing it off, or other means.

Drying and conditioning may be combined to remove moisture and accurately regulate final moisture content in, for example, tobacco and some textile products. Conditioning or drying is frequently a continuous process in which the material is conveyed through a tunnel and subjected to controlled atmospheric conditions. Chapter 22 of the *ASHRAE Handbook—Systems and Equipment* describes dehumidification and pressure-drying equipment.

Rates of Chemical Reactions

Some processes require temperature and humidity control to regulate chemical reactions. For example, in rayon manufacture, pulp sheets are conditioned, cut to size, and passed through a mercerizing process. The temperature directly controls the rate of the reaction, while the relative humidity maintains a solution of constant strength and a constant rate of surface evaporation.

The oxidizing process in drying varnish depends on temperature. Desirable temperatures vary with the type of varnish. High relative humidity retards surface oxidation and allows internal gases to escape as chemical oxidizers cure the varnish from within. Thus, a bubble-free surface is maintained with a homogeneous film throughout.

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

Table 1 Temperatures and Humidities for Industrial Air Conditioning

Process	Dry Bulb, °F	rh, %
ABRASIVE		
Manufacture	79	50
CERAMICS		
Refractory	110 to 150	50 to 90
Molding room	80	60 to 70
Clay storage	60 to 80	35 to 65
Decalcomania production	75 to 80	48
Decorating room	75 to 80	48

Use high-efficiency filtration in decorating room. To minimize the danger of silicosis in other areas, a dust-collecting system or medium-efficiency particulate air filtration may be required.

Process	Dry Bulb, °F	rh, %
DISTILLING		
General manufacturing	60 to 75	45 to 60
Aging	65 to 72	50 to 60

Low humidity and dust control are important where grains are ground. Use high-efficiency filtration for all areas to prevent mold spore and bacteria growth. Use ultrahigh-efficiency filtration where bulk flash pasteurization is performed.

Process	Dry Bulb, °F	rh, %
ELECTRICAL PRODUCTS		
Electronics and X-ray		
Coil and transformer winding	72	15
Semiconductor assembly	68	40 to 50
Electrical instruments		
Manufacture and laboratory	70	50 to 55
Thermostat assembly and calibration	75	50 to 55
Humidistat assembly and calibration	75	50 to 55
Small mechanisms		
Close tolerance assembly	72*	40 to 45
Meter assembly and test	75	60 to 63
Switchgear		
Fuse and cutout assembly	73	50
Capacitor winding	73	50
Paper storage	73	50
Conductor wrapping with yarn	75	65 to 70
Lightning arrester assembly	68	20 to 40
Thermal circuit breakers assembly and test	75	30 to 60
High-voltage transformer repair	79	5
Water wheel generators		
Thrust runner lapping	70	30 to 50
Rectifiers		
Processing selenium and copper oxide plates	73	30 to 40

*Temperature to be held constant.

Dust control is essential in these processes. Minimum control requires medium-efficiency filters. Degree of filtration depends on the type of function in the area. Smaller tolerances and miniature components suggest high-efficiency particulate air (HEPA) filters.

Process	Dry Bulb, °F	rh, %
FLOOR COVERING		
Linoleum		
Mechanical oxidizing of linseed oil*	90 to 100	
Printing	80	
Stoving process	160 to 250	

*Precise temperature control required.

Medium-efficiency particulate air filtration is recommended for the stoving process.

Process	Dry Bulb, °F	rh, %
FOUNDRIES*		
Core making	60 to 70	
Mold making		
Bench work	60 to 70	
Floor work	55 to 65	
Pouring	40	
Shakeout	40 to 50	
Cleaning room	55 to 65	

*Winter dressing room temperatures. Spot coolers are sometimes used in larger installations.

In mold making, provide exhaust hoods at transfer points with wet-collector dust removal system. Use 600 to 800 cfm per hood.

In shakeout room, provide exhaust hoods with wet-collector dust removal system. Exhaust 400 to 500 cfm in grate area. Room ventilators are generally not effective.

In cleaning room, provide exhaust hoods for grinders and cleaning equipment with dry cyclones or bag-type collectors. In core making, oven and adjacent cooling areas require fume exhaust hoods. Pouring rooms require two-speed powered roof ventilators. Design for minimum of 2 cfm per square foot of floor area at low speed. Shielding is required to control radiation from hot surfaces. Proper introduction of air minimizes preheat requirements.

Process	Dry Bulb, °F	rh, %
FUR		
Drying	110	
Shock treatment	18 to 20	
Storage	40 to 50	55 to 65

Shock treatment or eradication of any insect infestations requires lowering the temperature to 18 to 20°F for 3 to 4 days, then raising it to 60 to 70°F for 2 days, then lowering it again for 2 days and raising it to the storage temperature.

Furs remain pliable, oxidation is reduced, and color and luster are preserved when stored at 40 to 50°F.

Humidity control is required to prevent mold growth (which is prevalent with humidities above 80%) and hair splitting (which is common with humidities lower than 55%).

Process	Dry Bulb, °F	rh, %
GUM		
Manufacturing	77	33
Rolling	68	63
Stripping	72	53
Breaking	73	47
Wrapping	73	58
LEATHER		
Drying	68 to 125	75
Storage, winter room temperature	50 to 60	40 to 60

After leather is moistened in preparation for rolling and stretching, it is placed in an atmosphere of room temperature and 95% relative humidity.

Leather is usually stored in warehouses without temperature and humidity control. However, it is necessary to keep humidity sufficiently low to prevent mildew. Medium-efficiency particulate air filtration is recommended for fine finish.

Process	Dry Bulb, °F	rh, %
LENSES (OPTICAL)		
Fusing	75	45
Grinding	80	80

Table 1 Temperatures and Humidities for Industrial Air Conditioning (*Concluded*)

Process	Dry Bulb, °F	rh, %
MATCHES		
Manufacture	72 to 73	50
Drying	70 to 75	60
Storage	60 to 63	50

Water evaporates with the setting of the glue. The amount of water evaporated is 18 to 20 lb per million matches. The match machine turns out about 750,000 matches per hour.

Process	Dry Bulb, °F	rh, %
PAINT APPLICATION		
Lacquers: Baking	300 to 360	
Oil paints: Paint spraying	60 to 90	80

The required air filtration efficiency depends on the painting process. On fine finishes, such as car bodies, high-efficiency particulate air filters are required for the outdoor air supply. Other products may require only low- or medium-efficiency filters.

Makeup air must be preheated. Spray booths must have 100 fpm face velocity if spraying is performed by humans; lower air quantities can be used if robots perform spraying. Ovens must have air exhausted to maintain fumes below explosive concentration. Equipment must be explosion-proof. Exhaust must be cleaned by filtration and solvents reclaimed or scrubbed.

Process	Dry Bulb, °F	rh, %
PHOTO STUDIO		
Dressing room	72 to 74	40 to 50
Studio (camera room)	72 to 74	40 to 50
Film darkroom	70 to 72	45 to 55
Print darkroom	70 to 72	45 to 55
Drying room	90 to 100	35 to 45
Finishing room	72 to 75	40 to 55
Storage room (b/w film and paper)	72 to 75	40 to 60
Storage room (color film and paper)	40 to 50	40 to 50
Motion picture studio	72	40 to 55

The above data pertain to average conditions. In some color processes, elevated temperatures as high as 105°F are used, and a higher room temperature is required.

Conversely, ideal storage conditions for color materials necessitate refrigerated or deep-freeze temperatures to ensure quality and color balance when long storage times are anticipated.

Heat liberated during printing, enlarging, and drying processes is removed through an independent exhaust system, which also serves the lamp houses and dryer hoods. All areas except finished film storage require a minimum of medium-efficiency particulate air filters.

Process	Dry Bulb, °F	rh, %
PLASTICS		
Manufacturing areas		
Thermosetting molding compounds	80	25 to 30
Cellophane wrapping	75 to 80	45 to 65

In manufacturing areas where plastic is exposed in the liquid state or molded, high-efficiency particulate air filters may be required. Dust collection and fume control are essential.

Process	Dry Bulb, °F	rh, %
PLYWOOD		
Hot pressing (resin)	90	60
Cold pressing	90	15 to 25
RUBBER-DIPPED GOODS		
Manufacture	90	
Cementing	80	25 to 30*
Dipping surgical articles	75 to 80	25 to 30*
Storage prior to manufacture	60 to 75	40 to 50*
Testing laboratory	73	50*

*Dew point of air must be below evaporation temperature of solvent.

Solvents used in manufacturing processes are often explosive and toxic, requiring positive ventilation. Volume manufacturers usually install a solvent-recovery system for area exhaust systems.

Process	Dry Bulb, °F	rh, %
TEA		
Packaging	65	65

Ideal moisture content is 5 to 6% for quality and mass. Low-limit moisture content for quality is 4%.

Process	Dry Bulb, °F	rh, %
TOBACCO		
Cigar and cigarette making	70 to 75	55 to 65*
Softening	90	85 to 88
Stemming and stripping	75 to 85	70 to 75
Packing and shipping	73 to 75	65
Filler tobacco casing and conditioning	75	75
Filter tobacco storage and preparation	77	70
Wrapper tobacco storage and conditioning	75	75

*Relative humidity fairly constant with range as set by cigarette machine.

Before stripping, tobacco undergoes a softening operation.

Rates of Biochemical Reactions

Fermentation requires temperature and humidity control to regulate the rate of biochemical reactions.

Rate of Crystallization

The cooling rate determines the size of crystals formed from a saturated solution. Both temperature and relative humidity affect the cooling rate and change the solution density by evaporation.

In the coating pans for pills, a heavy sugar solution is added to the tumbling mass. As the water evaporates, sugar crystals cover each pill. Blowing the proper quantity of air at the correct dry- and wet-bulb temperatures forms a smooth opaque coating. If cooling and drying are too slow, the coating is rough, translucent, and unsatisfactory in appearance; if cooling and drying are too fast, the coating chips through to the interior.

Product Accuracy and Uniformity

In the manufacture of precision instruments, tools, and lenses, air temperature and cleanliness affect the quality of work. If manufacturing tolerances are within 0.0002 in., close temperature control prevents expansion and contraction of the material. Constant temperature is more important than the temperature level; thus conditions are usually selected for personnel comfort and to prevent a film of moisture on the surface. High- or ultrahigh-efficiency particulate air filtration may be required.

Corrosion, Rust, and Abrasion

In the manufacture of metal articles, the temperature and relative humidity are kept sufficiently low to prevent hands from sweating, thus protecting the finished article from fingerprints, tarnish, and/or etching. The salt and acid in body perspiration can cause corrosion and rust within a few hours. The manufacture of polished surfaces usually requires medium- to high-efficiency particulate air filtering to prevent surface abrasion. This is also true for steel-belted radial tire manufacturing.

Static Electricity

In processing light materials such as textile fibers and paper, and where explosive atmospheres or materials are present, humidity can be used to reduce static electricity, which is often detrimental

Table 2 Regain of Hygroscopic Materials[a]

Classification	Material	Description	Relative Humidity 10	20	30	40	50	60	70	80	90
Natural textile fibers	Cotton	Sea island—roving	2.5	3.7	4.6	5.5	6.6	7.9	9.5	11.5	14.1
	Cotton	American—cloth	2.6	3.7	4.4	5.2	5.9	6.8	8.1	10.0	14.3
	Cotton	Absorbent	4.8	9.0	12.5	15.7	18.5	20.8	22.8	24.3	25.8
	Wool	Australian merino—skein	4.7	7.0	8.9	10.8	12.8	14.9	17.2	19.9	23.4
	Silk	Raw chevennes—skein	3.2	5.5	6.9	8.0	8.9	10.2	11.9	14.3	18.3
	Linen	Table cloth	1.9	2.9	3.6	4.3	5.1	6.1	7.0	8.4	10.2
	Linen	Dry spun—yarn	3.6	5.4	6.5	7.3	8.1	8.9	9.8	11.2	13.8
	Jute	Average of several grades	3.1	5.2	6.9	8.5	10.2	12.2	14.4	17.1	20.2
	Hemp	Manila and sisal rope	2.7	4.7	6.0	7.2	8.5	9.9	11.6	13.6	15.7
Rayons	Viscose nitrocellulose	Average skein	4.0	5.7	6.8	7.9	9.2	10.8	12.4	14.2	16.0
	Cuprammonium cellulose acetate		0.8	1.1	1.4	1.9	2.4	3.0	3.6	4.3	5.3
Paper	M.F. newsprint	Wood pulp—24% ash	2.1	3.2	4.0	4.7	5.3	6.1	7.2	8.7	10.6
	H.M.F. writing	Wood pulp—3% ash	3.0	4.2	5.2	6.2	7.2	8.3	9.9	11.9	14.2
	White bond	Rag—1% ash	2.4	3.7	4.7	5.5	6.5	7.5	8.8	10.8	13.2
	Comm. ledger	75% rag—1% ash	3.2	4.2	5.0	5.6	6.2	6.9	8.1	10.3	13.9
	Kraft wrapping	Coniferous	3.2	4.6	5.7	6.6	7.6	8.9	10.5	12.6	14.9
Miscellaneous organic materials	Leather	Sole oak—tanned	5.0	8.5	11.2	13.6	16.0	18.3	20.6	24.0	29.2
	Catgut	Racquet strings	4.6	7.2	8.6	10.2	12.0	14.3	17.3	19.8	21.7
	Glue	Hide	3.4	4.8	5.8	6.6	7.6	9.0	10.7	11.8	12.5
	Rubber	Solid tires	0.11	0.21	0.32	0.44	0.54	0.66	0.76	0.88	0.99
	Wood	Timber (average)	3.0	4.4	5.9	7.6	9.3	11.3	14.0	17.5	22.0
	Soap	White	1.9	3.8	5.7	7.6	10.0	12.9	16.1	19.8	23.8
	Tobacco	Cigarette	5.4	8.6	11.0	13.3	16.0	19.5	25.0	33.5	50.0
Miscellaneous inorganic materials	Asbestos fiber	Finely divided	0.16	0.24	0.26	0.32	0.41	0.51	0.62	0.73	0.84
	Silica gel		5.7	9.8	12.7	15.2	17.2	18.8	20.2	21.5	22.6
	Domestic coke		0.20	0.40	0.61	0.81	1.03	1.24	1.46	1.67	1.89
	Activated charcoal	Steam activated	7.1	14.3	22.8	26.2	28.3	29.2	30.0	31.1	32.7
	Sulfuric acid		33.0	41.0	47.5	52.5	57.0	61.5	67.0	73.5	82.5

[a]Moisture content expressed in percent of dry mass of the substance at various relative humidities, temperature 75°F.

to processing and extremely dangerous in explosive atmospheres. Static electricity charges are minimized when the air has a relative humidity of 35% or higher. The power driving the processing machines is converted into heat that raises the temperature of the machines above that of the adjacent air, where humidity is normally measured. Room relative humidity may need to be 65% or higher to maintain the high humidity required in the machines.

Air Cleanliness

Each application must be evaluated to determine the filtration needed to counter the adverse effects on the product or process of (1) minute dust particles, (2) airborne bacteria, and (3) other air contaminants such as smoke, radioactive particles, spores, and pollen. These effects include chemically altering production material, spoiling perishable goods, and clogging small openings in precision machinery. See Chapter 24 of the *ASHRAE Handbook—Systems and Equipment*.

Product Formability

The manufacture of pharmaceutical tablets requires close control of humidity for optimum tablet formation.

EMPLOYEE REQUIREMENTS

Space conditions required by health and safety standards to avoid excess exposure to high temperatures and airborne contaminants are often established by the American Conference of Governmental Industrial Hygienists (ACGIH). In the United States, the National Institute of Occupational Safety and Health (NIOSH) does research and recommends guidelines for workspace environmental control. The Occupational Safety and Health Administration (OSHA) sets standards from these environmental control guidelines and enforces them through compliance inspection at industrial facilities. Enforcement may be delegated to a corresponding state agency.

Standards for safe levels of contaminants in the work environment or in air exhausted from facilities do not cover all contaminants encountered. Minimum safety standards and facility design criteria are available from various U.S. Department of Health, Education, and Welfare (DHEW) agencies such as the National Cancer Institute, the National Institutes of Health, and the Public Health Service (Centers for Disease Control and Prevention). For radioactive substances, standards established by the U.S. Nuclear Regulatory Commission (NRC) should be followed.

Thermal Control Levels

In industrial plants that need no specific control for products or processes, conditions range from 68 to 100°F and 25 to 60% rh. For a more detailed analysis, the work rate, air velocity, quantity of rest, and effects of radiant heat must be considered (see Chapter 8 of the *ASHRAE Handbook—Fundamentals*). To avoid stress to workers exposed to high work rates and hot temperatures, the ACGIH established guidelines to evaluate high-temperature air velocity and humidity levels in terms of heat stress (Dukes-Dobos and Henschel 1971).

If a comfortable environment is of concern rather than the avoidance of heat stress, the thermal control range becomes more specific (McNall et al. 1967). In still air, nearly sedentary workers (410 Btu/h metabolism) prefer 72 to 75°F dry-bulb temperature with 20 to 60% rh, and they can detect a 2°F change per hour. Workers at a high rate