latter two may be in small quantities but still injurious, particularly to copper and brass. Extensive tests were carried to establish the harm done, particularly to books, by sulfur dioxide.[2,3,4] Water sprays, with the *pH* value maintained between 8.5 and 9.0, should be incorporated into the conditioning apparatus to neutralize the sulfur dioxide.

Sound and Vibration

Air conditioning should be augmented by sound and vibration *conditioning, not only to provide comfort and quiet for* the visitor, student and staff, but also to avoid transmitting or setting up resonant vibration to and in the objects on exhibit which may be damaged by such motion. Sound level should be low, but not so low as to produce an environment where normal sounds will be objectionable. It should be noted that the exhibit spaces tend to be acoustically reverberant. For further information on sound and vibration control, see Chapter 14 of the 1961 Guide And Data Book.

BENEFITS TO EXHIBITS

This section will discuss the specific benefits of air conditioning on the various objects and materials being exhibited in a controlled atmosphere.

The benefits are enumerated for each of the following objects and materials:

1. *Paper, papyrus, parchment, and vellum.*
   a. Retards brittling, caused by dry air.
   b. Eliminates brown splotches known as *foxing*, caused by dampness.
   c. Tends to prevent paper becoming soft and *fuzzy*, caused by dampness.
   d. Reduces prevalence of molds, fungus and mildew, caused by dampness and lack of air motion.
   e. Prevents bookworms, caused by temperatures above 70–74 F.
   f. Eliminates abrasive action and moisture attraction of dust.
   g. Retards discoloration of paper.
   h. Stabilizes the pliability of glue, starch and casein.
   i. Reduces susceptibility to decay.
   j. Increases the life of adhesives, thread, paper, cloth and leather by stabilization of ambient conditions.
   k. Eliminates damage due to sulfur dioxide when sprays maintained at proper *pH* value are included in the system.
2. *Paintings.*
   a. Reduces expensive maintenance and rehabilitation made necessary by appearance of bubbles and blisters in the paint.
   b. Lengthens the intervals of time between the necessary restorations, which are costly and impair the subtle quality, tone brilliancy and original *touch* of the artist.
   c. Eliminates from the surface of oil paintings the bluish film of moisture, known as *bloom*, that will show up in damp places.
   d. Reduces the depositions of fine soot along the edges of glass-framed paintings and on etchings under glass.
   e. Increases life by stabilization of moisture content in wood and canvas, and by protection against acidic atmosphere. Mediums on which paintings are done include canvas, gypsum, paper, papyrus, plaster or fresco painting, stone and wood. Canvas, paper and papyrus are subject to attacks by mildew if damp.
3. *Tapestries, rugs, and fabrics.*
   a. Eliminates the presence of harmful and abrasive dusts.
   b. Guards against mold and mildew.
   c. Lengthens the intervals between the necessary cleanings that are costly, impairs the tone and brilliancy and result in eventual wear and tear.
   d. Increases the life by minimizing the *brittling* of fibre through changes in moisture content.
   e. Eliminates damage due to sulfur dioxide.
4. *Furniture and woodwork.*
   a. Eliminates changes in moisture regain caused by either too dry or too humid atmosphere, thus preventing loosening of joints, warping, buckling, bulging and splitting.
   b. Reduces greatly the need for refinishing made necessary by dust and grime.
   c. Increases life by stabilization of temperature and humidity.
   d. Reduces the need for daily dusting.
5. *Metallic exhibits.*
   a. Reduces greatly the need for refinishing due to elimination of acid-forming gases that usually attack and tarnish in one or another way the metals.
   b. Reduces need for daily dusting where required.
6. *China and porcelain.*
   a. Minimizes discoloration due to elimination of ravages of object humidity and microscopic dust.
   b. Reduces dusting.
7. *Egyptology.*
   a. Benefits through constant dry bulb temperature and lower humidity.
   b. Reduces dusting.
8. *Natural history exhibits.*
   a. Eliminates changes in moisture regain of hygroscopic materials.
   b. Guards against mold, mildew and moth.
   c. Eliminates the presence of harmful and abrasive dusts.
   d. Eliminates attack by acid forming gases.
   e. Increases the life of exhibits.
   f. Reduces maintenance.
9. *Exhibit materials.*
   a. *Horn* is subject to the attacks of insects. Even ivory and bone are not exempt, though less liable than horn to be attacked.
   b. *Leather* is subject to deterioration and to attacks of various insects, particularly cockroaches and silver fish. Well fitted cases ventilated as suggested above, and regular museum object maintenance practices, are the solutions.
   c. *Iron is more readily corroded than the majority of metals.* The principal agents are moisture, impurities that set up electrolytic action, oxygen and carbon dioxide, and common salt from the ground in which the iron was buried.
   d. *Zinc* is acted upon readily by most acids, and is subject to corrosion similar to iron.
   e. *Lead* oxidizes quickly in moist air, resulting in only superficial tarnish.
   f. *Aluminum* is unaffected by corrosion.
   g. *Stone* (*porous kind, such as limestone and sandstone*) may contain salt and therefore be subject to attack in damp atmospheres.

SYSTEM DESIGN

The architecture and space arrangements used for libraries, art, historical, natural history, and industrial museums vary greatly. It is absolutely essential to conduct a thorough survey to provide information on: (1) the details of building affecting the heat gain or loss calculations; (2) the availability of space or spaces for air handling, refrigeration and heat rejection equipment; (3) the availability of various services that might condition the selection of the various elements of equipment; and (4) the architectural peculiarities for working out a design to conceal as much as possible the air transmission ducts and distribution outlets.

Design Conditions

The design conditions for temperature and humidity are: in winter, 72 F dry-bulb and 35–40 percent relative humidity, and, in summer, 78 F dry-bulb and 45–50 percent relative humidity. Because of the importance of constant conditions, any change in ambient conditions should be limited to once a season. The storage rooms and vaults for manuscripts, rare editions and other rare objects are maintained at 70–72 F and

45 percent relative humidity year-round. This is done particularly to discourage the propagation of bookworms, which will occur at temperatures above 72 F.

The *museum* perhaps would thrive with year-round 76 F dry-bulb and 45–50 percent relative humidity. Some museums have designed air conditioning to maintain 70–72 F dry-bulb and 50–55 percent relative humidity year-round.

To maintain constant conditions, the operation of air conditioning 24 hr a day year-round is common in the leading libraries and museums of the United States to prolong the life of collections. While the operating expense may increase as compared to the plants operated only for human comfort for 8 or 10 hr per day, it may be offset by a reduction in maintenance expense of the buildings and exhibits. In addition, the plant carefully designed for 24 hr operation is smaller, and the equipment is operated more nearly at its peak efficiency.

Load Calculations

The heating and cooling loads are calculated in accordance with the methods discussed in Chapters 25 and 26 of the 1961 Guide And Data Book. However, some of the specific factors of particular importance will be discussed in this section. These include:

1. *Sun gain.* Windows, at times of stained glass, and skylights are in evidence in libraries and museums. Windows are more in evidence in traffic areas rather than in book stacks or storage areas. Care must be exercised to minimize sun effects, unwelcome either as light or as heat source. The short wave (actinic) rays are particularly injurious. Heat gain from skylights, often over artificially lighted frosted glass ceilings, can be reduced by use of a separate forced ventilation system.
2. *Transmission* is usually of small significance because of massive construction. In winter, however, evaluation must be made of effects on the objects located close to outside walls, and possible condensation of moisture on the objects and surface of outside walls. In summer possible radiant effects from the west exposure should be considered.
3. *People.* Analysis should be made of various areas and possible occupancies of reading, study and seminar rooms which may have concentrations as high as 10 sq ft per person, while office and book-stack space will have closer to 100 or 120 sq ft per person. The museum exhibit rooms and galleries must be analyzed on the basis of popularity with the public or student, and the population density varys from 50 to 300 sq ft per person.

   The galleries devoted to active exhibitions should be evaluated on the basis of much heavier population and permissible temperature swing during the possible coincidence of design conditions. Loads during day visiting hours, including sun and lighting effects, should be compared with the loads for evening hours, considering population and possibly increased lights.
4. *Lights.* A detailed examination should be made of wattage provided in various rooms and the length of operation of the lights. In the book stacks, various storage rooms, and vaults, lights may be discounted completely because of occasional use. On the other hand the main reading rooms may be open as long as 16 hr.
5. *Infiltration* should generally be absent or be a very insignificant load. The windows should be sealed, but some windows may remain operable for opening in case of failure of the air-conditioning system. Infiltration then should be evaluated according to the nature of the windows (see Chapter 24 of the 1961 Guide And Data Book).
6. *Ventilation* generally should be kept to a minimum (15 to 20 percent of total air circulated). The outdoor air should be taken preferably above the roof to be free of at least the street-level dust. The building should be under positive pressure. Local codes must be verified.

   Smoking as a rule is not permitted and in fact it could be damaging to the exhibits. When smoking is permitted, care must be exercised to contain the return air and to deodorize the recirculated part of the air by application of activated carbon and similar odor removals.
7. *Stratification.* The main reading rooms, large entrance halls and large art galleries often have high ceilings that may assist in application of the heat stratification principle. Hot air rises, making it possible to stratify loads such as convection from the roof (about 25 percent), convection from the lights (about 50 percent with fluorescent and 20 percent with incandescent), and convection from the upper part of walls (about 40 percent). The conditioned supply air must be at a low level, within 8–10 ft of the floor. Approximately 20 percent of stratified heat will be induced into the supply air, and allowance should be made for this in heat load calculations. The heat generated in upper strata must be exhausted without using any excess outdoor air for makeup over the normally introduced volume for ventilation use. If the air is not removed from the upper strata, the heat will build up, and there will be no load reduction.

After the individual room loads are evaluated at their optimum values to determine the air requirements, the instantaneous refrigeration load should be calculated, utilizing proper diversity and storage factors. At times the total population may be approximately 50 sq ft per person and total lighting may be approximately as low as ¼ watt per sq ft of total area.

Equipment

Usually the buildings created by the architects are of monumental beauty and utility. Existing buildings often have special situations into which the engineer must fit the equipment and air transmission and distribution system. In new buildings the architect-engineer team should create a facility that allows for particular nature of both the materials exhibited and services rendered to them, with a minimum of visible mechanical equipment.

The equipment for conditioning the air may be of any kind within the economics of the given project. Particular attention must be devoted to the treatment of the air depending on the location of the project. In the more contaminated areas, consideration should be given to removal of acidic fumes and vapors by employing direct-spray dehumidifiers or spray coils with sprays whose alkalinity is maintained at *pH* value of 8.5 to 9.0. More attention should be given to choice of filters with efficiencies of 80 to 90 percent with the ultimate aim of removal of microscopic particles and proper precautions against filter failure. Less stringent requirements may be employed in the case of smaller buildings, of mobile use rather than long time preservation, and suburban clean locations.

The ideal systems would be those that are well zoned with central dehumidifying equipment and booster stations using bypass or steam, hot water, or electric reheat control. In all cases the automatic control should incorporate a safety device to prevent overhumidification. Equipment vibration isolation and air sound attenuation must be part of the design. The economics and the architecture of the building and the layout of spaces may require heterogeneity of systems that only an ingenuity applied to a given building may resolve. The equipment must be capable of operating satisfactorily 24 hr per day year-round.

Air Transmission and Distribution

The supply of air to the spaces having high ceiling was already discussed above under stratification. In some museums with center seats, it is possible to use the spaces under the seats and behind the backs for handling the supply and return air distribution. In picture galleries the wall space below the rail height may be made available. Under some circumstances the space above and below the wall cases may be utilized. In the book stacks each tier or deck should have individual air supply and return. Newly constructed book stacks would probably be interior spaces, with air ductwork and other services worked into steel shelf supporting structure. The most important consideration in designing air distribution should be the avoiding of stagnant spaces in all exhibits and especially in storage rooms and vaults. Steam or water piping should not be run through exhibit or storage rooms, to avoid possible damage by accidental leaks, and to avoid radiation damage to exhibits.