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New design opportunities afforded by modern high-intensity light sources, and the many ways of integrating package air-conditioners with the design of buildings, are discussed. A guide to unitary air-conditioners and heat pumps is included. (RK)

NECA
ELECTRICAL DESIGN
GUIDELINES

VISUAL ASPECTS OF THE ELECTRIC ENVIRONMENT

☐ **How modern high-intensity light sources offer new opportunities in design**

☐ **The many ways of integrating package air conditioners with the design of buildings**

Number 2

NEW LIGHTING LETS CEILINGS ASSUME NEW FORMS

Lighting has always played an important role in architecture, and for the last 75 years much of this lighting has been electric. Moreover, for the last 10 years or so architects have turned almost completely to electric light, rather than daylight, to provide illumination for both functional and aesthetic purposes. Windows are being used mainly to give a sense of the outdoors; a view; a change of pace; a place to rest the eye.

With almost entire dependence on electric light in buildings for the assimilation of visual tasks and with lighting levels increasing because of the availability of new light sources and the establishment of new lighting standards, electrical loads for lighting have increased greatly. At high lighting levels, heat must be removed from fluorescent lamps for them to operate at optimum efficiency; also, opportunities for obtaining higher-grade (i.e., higher-temperature) exhaust heat from lamps present themselves through new lighting design and equipment approaches, as well as the new high-intensity lamps.

What this means to architects and engineers is that even now they can take advantage of some fairly sophisticated techniques for re-using the heat from lighting: for example, the tempering of air for zoned temperature control, or reclaim of heat by a

Renewed interest in the ceiling as a three-dimensional element of design—with lighting playing the key role—is demonstrated in this elegant office space. Quartz-tube lamps in the column-mounted indirect reflectors wash the ceiling vaults with light. Recessed lamps in the ceiling provide an additional downward component for desk work. The quartz-tube lamps (tungsten-iodide cycle) are a new light source that packs high wattage in a small envelope.

heat pump system. But shortly, they will be able to avail themselves of new techniques that represent not only more sophisticated engineering but new architectural design approaches.

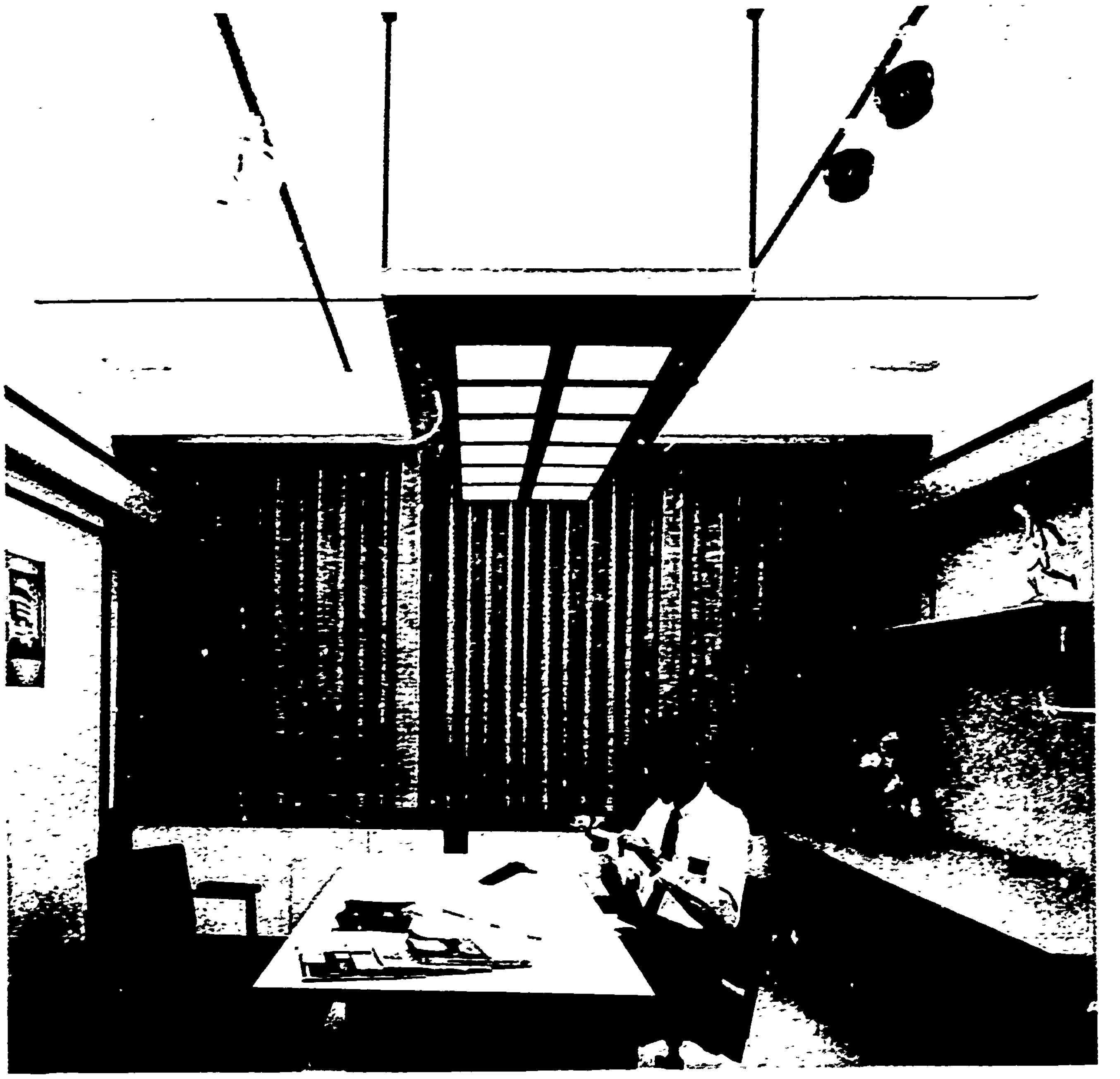
While lighting has always played an important part in architecture, this lighting was never quite as "organic" as it has become of late. "Engineered" lighting has been practiced for close to 50 years; and "decorative" lighting (which used to be called "architectural lighting") has been practiced for even longer. Much of this lighting was expertly done, technically, and much of it was both effective and stimulating. But this lighting was more "applied" than it was "integrated." Indirect lighting, using a wide variety of techniques was employed for many years, with equipment specially designed for placement in coves, cornices, niches, and ceiling domes; or sometimes it was located in wall boxes, on brackets, on posts, or in bowls, urns, or vases on floor pedestals. So while the light sources themselves were concealed, the "architectural lighting" techniques were actually decorative in nature.

Control more critical with higher lighting levels

There are several reasons lighting now is more "organic." For one thing, higher lighting levels require a new discipline in terms of control of light for proper utilization and prevention of direct and reflected glare. At higher lighting levels, the brightness of the light sources has to be controlled by such devices as louvers, lenses, or parabolic reflectors, or recessing of the equipment. Diffusing media such as translucent plastics and glass need supplementary control devices—baffles or louvers—to keep light sources from being uncomfortably bright at higher lighting levels. At the same time, within reasonable limits, the reflectances of room finishes need to be controlled to avoid excessive brightness contrasts within the room. The guidelines on room finishes, while fairly specific in nature, are, nonetheless, not restrictive on the architect if he applies the rules with good sense.

Another reason that lighting is more "organic" is that with so much going on at the ceiling plane and above it (lighting, air conditioning, acoustical treatment), all of the components have to work together in coordinated fashion in order to fit dimensionally and operate functionally. Architects and lighting engineers certainly have become conscious of the interaction among lighting, the ceiling assembly, and the air-conditioning system, and they are much more aware of what constitutes good seeing conditions in terms of quantity and quality of lighting. Even more than this, they have come to realize that the design of interior spaces—and even exterior spaces—may indeed succeed or fail

Another lighting trend is to provide a room with a series of points of focal interest—getting away from the bland, uninteresting appearance that results from a completely uniform lighting treatment. The ceiling here is indirectly lighted by 400-watt metal halide (color-improved mercury vapor) lamps in specular reflectors set in the coves. The desk is illuminated by square fluorescent lamps in the floating panel. Mounted in ceiling tracks, 12-volt spotlights accent various room objects.



visually, depending upon how carefully the lighting design has been worked out.

One important reason some lighting has failed to work as conceived in the architect's mind's eye is that lighting fixtures sometimes are selected as if they were hardware, with their operation and performance not being entirely understood. While design of a fixture *per se* and finesse in its design details may in many cases be an important factor, it does not necessarily follow that the fixture's lighting effect is what is wanted.

It is encouraging, however, that architects and other designers are growing more conscious of how various light control devices work and of what their potentialities are in terms of an integrated design solution. They also have become interested in the growing body of lighting research, particularly when it has a direct bearing on a lighting-architectural concept. An example is research in England by Hopkinson and Waldram. These scientists emphasize that it is the subjective impression that determines the visual impact of a task (in offices, classrooms, etc.) and the idea of a space. For this reason they recommend the use of a local light source to create focus on a task in addition to the overall general illumination. Hopkinson stresses that he is not suggesting the greater use of "untidy" lamps placed on the desk or bench, but built-in preferential work lighting. The reason for the local light source is primarily psychological: it helps shut out distracting elements in the visual environment.

The ceiling's established role as a light source

As light and lighting have always been important to architectural design, so has the ceiling performed significantly in serving as a light source: a "device" for controlling light, a screen for concealing lamps and fixtures, and, more recently, an integrated element in the structural-electrical-mechanical complex. In ancient times, a hole in the roof (ceiling) let daylight in. During the incandescent lamp era, the ceiling reflected light, serving as an indirect source and as a screen for recessed fixtures. With the development of fluorescent lamps (circa 1938), the ceiling was sometimes used as an indirect source for direct-indirect suspended fixtures, later becoming a direct source with the introduction of recessed troffers and luminous ceilings. At present, with growing interest in exposed structural elements in the ceiling, both incandescent and fluorescent systems have used structural elements for controlling light rays and shielding lamp sources. But as lighting levels have continued to increase, new glare control media have had to be developed.

The use of a continuous expanse of translucent plastic or glass in the ceiling plane is quite limited in terms of maximum footcandle level that can be provided without excessive brightness in the field of view. The use of shielding baffles or replacement of the diffuse material with light control panels of the prismatic lens type can considerably increase the application of the luminous ceiling for higher footcandle levels. As the modular shielding is decreased in size one reaches the point where the shielding becomes essentially an eggcrate type louver—used for many years, almost as long as the fluorescent lamp has been available. By increasing the shielding angle of louvers or baffles, lighting levels can be raised to several hundred footcandles.

Two techniques that have been particularly successful in controlling direct glare are the use of parabolic-shaped elements for fixtures and prismatic lenses. The lenses have an additional advantage in that they can be designed not only to keep light out of the glare zone but to direct light to the viewing plane, whether it be horizontal (a desk) or vertical (lenses fixture working as a wall washer). The parabolic shape shows up in a wide variety of applications. One of the first was for an open-bottom fluorescent fixture—directing light to the work plane and reducing fixture brightness. In one particular fixture design, louvers were developed for controlling brightness in the longitudinal direction, the louvers having a series of horizontal lines which themselves were small parabolas, helping to reduce louver surface brightness.

More recently, parabolic-shaped cones have made possible incandescent downlights, which, when the reflectors have a dark, specular finish, make the light source practically invisible. A room lighted with a ceiling of these downlights seems almost to have no direct light sources at all.

As fluorescent lamps were improved and new ones developed, permitting higher and higher footcandle levels for general illumination, the need grew for better devices to control direct glare. One answer to this problem is the recently developed "miniature"-scaled (on the order of one-half inch) multi-celled louvers in which square or hexagonal cells have parabolic-shaped sides. This type of louver can allow footcandle levels in the 400 range without any discomfort from glare. It can be made to appear colored if the louver or lamp source is colored.

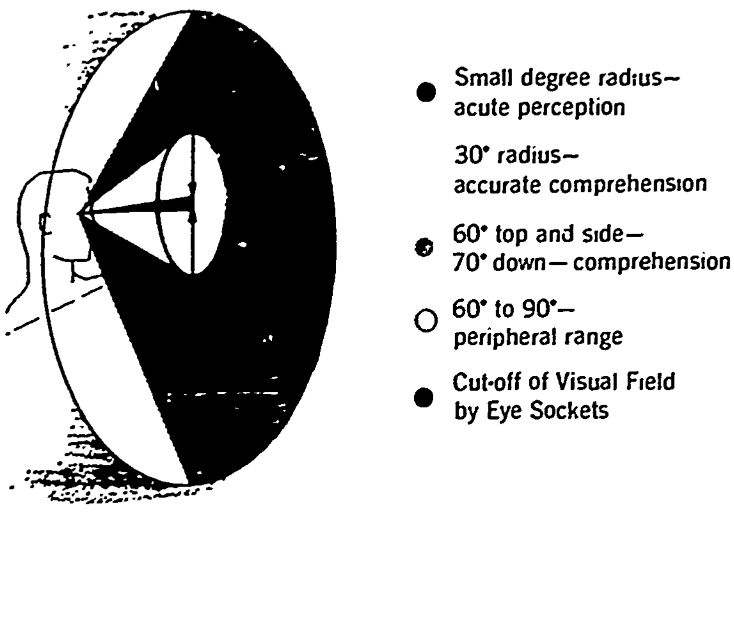
Some pertinent history and observations

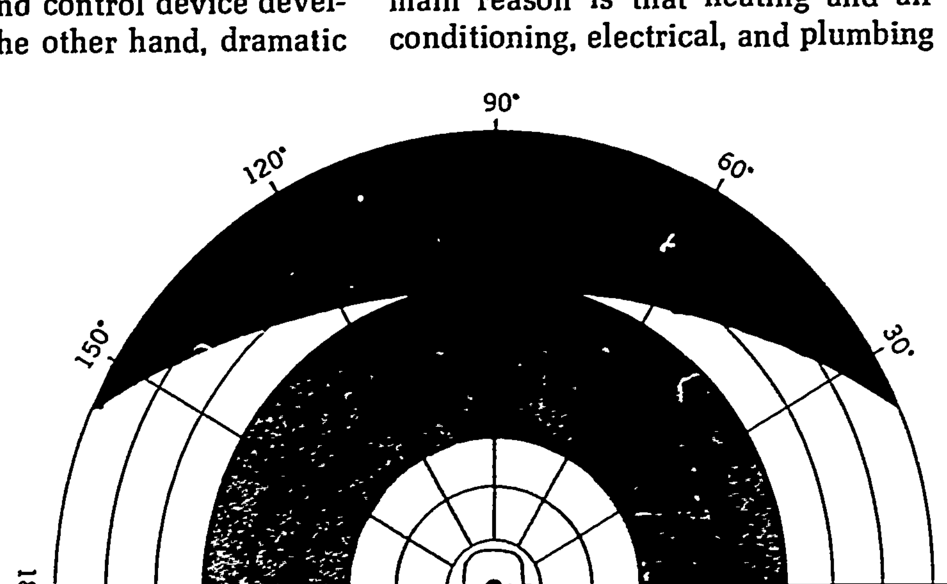
It is both interesting and instructive to note ways in which new control devices were engineered to prevent glare and widen lamp applications as sources were improved and new ones developed. By and large, much of lighting design, and, consequently, room appearance pretty closely followed lamp and control device development. On the other hand, dramatic and special lighting effects for auditoriums, stores, churches, and restaurants were derived largely from the techniques and know-how of manufacturers of theatrical and ecclesiastical lighting. In fact, these special demands encouraged modifications of lamps and the development of new ones. The expertise responsible for today's special-effect lighting—incandescent downlights, wall washers, etc. came from the organizations just mentioned.

A different technical development, which has had considerable impact not only on ceiling appearance but the nature of lighting equipment as well, is the suspended ceiling of modular tile and panels. Originally developed as a method for providing sound absorption, it later became the means for recessing lighting troffers and for concealing ducts, air control devices, piping, and wiring.

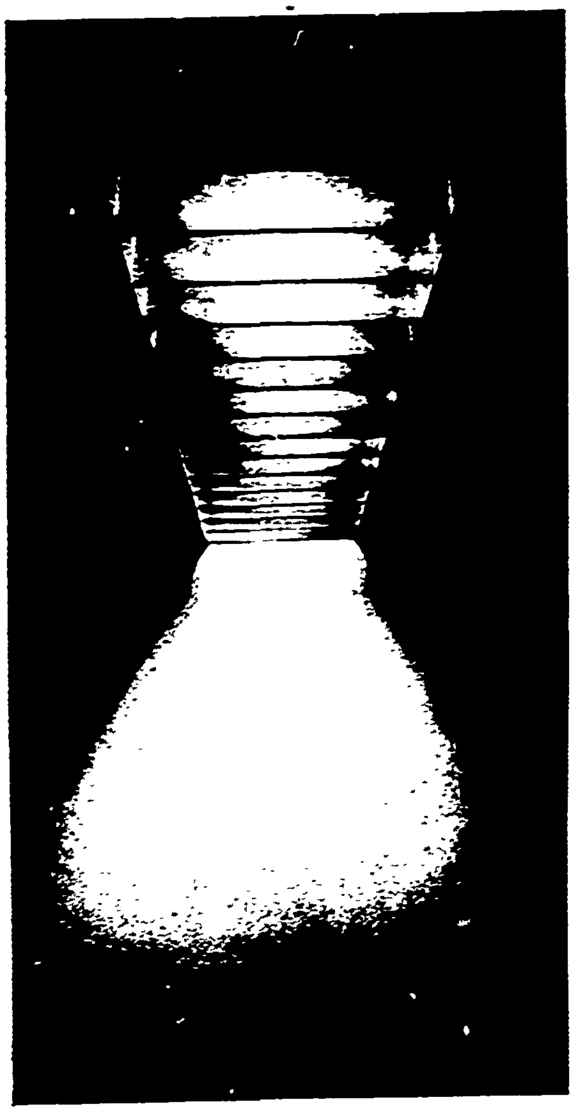
The suspended ceiling now has become an *electric ceiling* as the lighting system continues to be improved through higher lighting levels and recovery of lighting heat.

The suspended, non-structural ceiling plane will continue to be used for a large part of office, institutional, and commercial building construction. The main reason is that heating and air conditioning, electrical, and plumbing





These diagrams, which represent the binocular field of vision (all within the outer limit of the middle-gray area), are useful in understanding potential glare sources and problems.



Decorative baffles shield lamps producing 400 footcandles, above; dark, thin strips are diffusers for air. Contoured, specular reflector and specular crossbaffles produce low brightness for an air-handling library-stack luminaire, right.

services require concealment; physical and spatial integration of their components is difficult functionally, even in the most favorable situation. A visually coherent integrated system with exposed ceiling structure frequently turns out to be integrated more in name than in function. The difficulties arise from the fact that the separate spatial, functional, and economic requirements of structure, lighting, and air conditioning components often are not compatible. It is probable that such disciplines as visual efficiency and comfort, thermal comfort, and the economics of increasingly industrialized components will be the controlling factors in the ceiling design of most of our buildings in the foreseeable future.

The suspended ceiling sometimes has been criticized by architects for a lack of "organic" quality—that is, the modular discipline itself is thought not to be significant enough to create meaningful architecture. The real aesthetic discipline in this case is to provide organized, pleasant patterns with the luminous areas and the opaque panels. It is true, of course, that a three-dimensional ceiling, coffered, troughed, etc., can be visually interesting and can enhance the sense of height.

Lighting levels increase as efficiencies improve

Higher lighting levels have been justified mainly on the technical basis of the improved visual acuity people experience. (At the same time, it is recognized that the value of higher levels of illumination can be considerably diminished by reflected glare, which means that lighting equipment must be carefully designed, the proper type selected for the purpose, and located correctly in relation to objects being viewed.) Strangely enough, many fewer people appreciate the fact that high levels of light bring out the detail, the color in everything—people's faces, furniture, flooring, wall paneling, etc. If it were only the desk tasks that counted, then it would seem logical to have the most light on the desk, yet without too much brightness contrast between the task and the room surround. Obviously, there has to be much more to the visual environment than this. For example, in a large office space there ought to be other places in the room for people's eyes to rest, to experience a fresh visual sensation. If all the rest of the room except for the desk tops is dully lighted, the visual environment will not only be dull but, most likely, enervating.

The high lighting levels we have today are made possible by the ever-increasing efficiencies of light sources, the new techniques for utilizing them, and the lower cost of electrical energy. Incandescent lamps, for example, have efficiencies of around 15 lumens per watt (efficiency in 1905 was three lumens per watt); fluorescent lamps from 30 lumens per watt in 1940 to 60 today; mercury lamps are now around 80 lumens per watt; and the new sodium, high-intensity discharge lamp (Lucalox, for example) has an initial efficiency of 105 lumens per watt.

The new high-intensity discharge lamps (color-improved mercury and Lucalox) as well as the new quartz-tube lamps (tungsten-iodide cycle) pack a lot more light in small glass envelopes—which means that, again, new control media must be developed so that the brilliance of the sources is shielded from view.

Each lamp type has gone through a somewhat similar cycle as its light output and efficiency were increased. At first the light source itself was made less by diffusing media or merely shielded to cut out the brightness. Also, equipment was developed to control the light so that the light rays were directed to point or area of use

Small-cell (½-inch) gray-colored louvers in a floating panel glow from the light of high-output fluorescent lamps spaced on one-foot centers. Drapes are lighted by 150-watt PAR spots, bringing out their color and texture for room interest.

and kept out of the direct glare zone and, if possible, the reflected glare zone.

The first incandescent lamps were of such low brilliancy that they were not bothersome to the eye; hence, many of them were used unshaded. The day of the exposed light source (except now when dimmed, operated at a fraction of usual voltage, or coated or colored for decorative purposes) passed with the introduction of the gas-filled incandescent lamp in 1913.

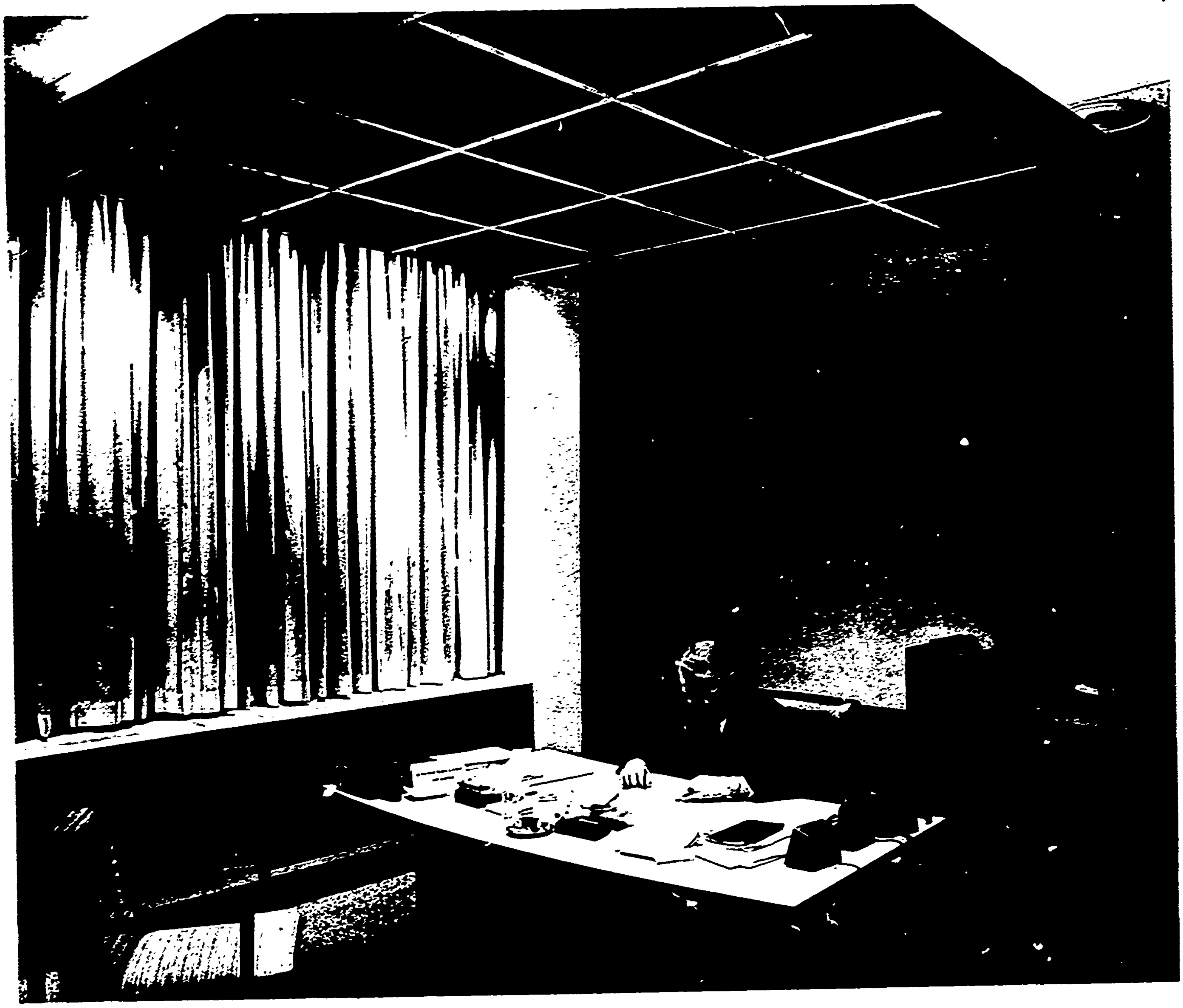
The metal conical shade was probably the first device used for reflecting light from incandescent lamps downward. (When did the green eye shade emerge, then disappear?) Then followed a succession of mirrored glass, prismatic glass, polished or plated metal, porcelain enameled steel, and opalescent glass. With the first two, light rays could be controlled with considerable accuracy The light could be concentrated into a narrow beam, or spread over a wide area, or shaped to a desired non-symmetrical pattern for particular applications such as store windows.

The first indirect lighting was tried out in 1908 in the home of Augustus Curtis, a Chicago lighting fixture manufacturer. Light from the source was directed to the ceiling by a mirrored reflector, causing the ceiling to become a large source of low brightness. After this followed numerous types of indirect and semi-indirect fixtures utilizing glass and metal bowls. Not too long following the inception of indirect lighting, extensive applications of cove lighting and similar forms were made; various architectural elements concealed the light sources. Equipment was specially designed for placement in coves, cornices, niches, and ceiling domes. Sometimes the light was projected a considerable distance beyond the source; other times the light was fanned out over adjacent areas. The architect provided not only space for lighting equipment but chose contours of architectural elements to give proper cut-off angles.

The highest levels of incandescent-lamp lighting were ordinarily achieved by means of direct-indirect techniques, i.e., louvered or lensed fixtures for the down component plus a reflector for indirect lighting, or, occasionally, by indirect or downlighting techniques separately. An example of the first method is the S.H. Kress variety store in New York City. Opened in 1936, it was designed, according to an article in *Illuminating Engineering*, for 65 foot-candles of general illumination through use of recessed downlights (silvered-glass reflectors shielded by decorative louvers) and large-scale, flat suspended luminaires providing a direct component (similar to recessed ceiling downlights) and an indirect component through use of reflectors (same type as in the downlights) aimed at the ceiling. A 1954 down-lighting installation using 750-watt reflector lamps in Bettendorf's St. Louis supermarket is said to provide 110 footcandles in the high-ceiling central area. Preceding the fluorescent lamp era, a very popular indirect lighting technique for offices and especially schools was the concentric ring fixture and silver-bowl incandescent lamp.

Heat removal studied in 1938

Just prior to introduction of the fluorescent lamp at the 1939 New York World's Fair, lighting application research was becoming concerned with the more effective utilization of incandescent light, particularly because of the anticipated growth of air-conditioned buildings. For instance, in a 1938 technical paper by Walter Sturrock of General Electric's Nela Park,



an office was shown which had a ceiling consisting of large parabolic vaults of aluminum reflectors. This installation was said to provide one-third higher utilization than ordinary indirect lighting. In this same technical paper, Sturrock discussed the effect of lighting heat on room temperatures and the implications of heat removal by natural ventilation and forced ventilation. He concluded that up to one-third of the lamp heat could be removed by forced ventilation. He recommended that a separate ventilating system should be considered for the lighting fixtures when the watts per square foot reached fairly high values. Along with the forced ventilation, Sturrock suggested the use of heat-resisting glass to "intercept a considerable portion of the radiant energy."

When the fluorescent lamp arrived, it meant that twice as much illumina-

(Text continued on Page 12)

A high level of illumination at desk level is obvious in the top photo, but the floating panel source is of low brightness because of the use of specular, small-scale parabolic wedge louvers. The same type of louver was used above by lighting consultant Sylvan Shemitz to conceal lamps but let them light the ceiling.

LIGHTING AS A FUNDAMENTAL ELEMENT OF DESIGN

'Details must follow design'—Lam

When all buildings were designed around a single, fixed light source, the sun, the difference between great architecture and mere building could be measured to a great degree by the skill with which that source was used.... Now, finally, we have artificial sources which are not only easier to control than daylight, but can also light interior spaces far more brightly. Theoretically, our ability to create great architecture should have increased in proportion to the availability of more, and more versatile, artificial sources.

To get the full potential from artificial lighting in a building, decisions must first be made on the desired patterns of light and on schematic ways of achieving them. Then decisions can be made on actual equipment and other design details. But the details must follow the design, just as in any other phase of architecture.

Although the lighting designer's first goal is to provide enough light to see by, he must also provide it in such a way that the light as it is encourages the occupants of a room to use the space as intended.

One of the more important psychological aspects of lighting is the establishment of a mood appropriate to the purpose for which a space is to be used. Because "mood" is the result of a subjective response, it is difficult to define in how-to-do-it terms. It can, however, be planned within fairly close limits if it is consciously considered as one of the lighting objectives.

Almost as widely applicable as light's ability to define the character of a space is its ability to direct attention, and thus, if movement is called for, to guide that movement.

If the architect's objective is to express the relationship between the appearance of a room and its intended uses, he may approach that end by relating the lighting to the specific activities which will be carried on within the space. Merely providing appropriate lighting for both the physical and psychological requirements of a space will usually produce such a lighting-activity relationship, for when lighting is properly related to intended uses it also tends to reinforce their inherent character. No tricks are necessary, just a logical analysis of needs and confident provision for those needs.

If an interesting structure is important in the design concept, the architect can enlist light to define and reinforce it, by silhouetting major structural members or washing its surfaces with light.

In addition to expressing use and emphasizing structural features, lighting can also be used to alter the way in which the light is introduced and by the colors of the reflecting surfaces. Designers have long used color to modify the apparent shape of a room, but the space can also be modified visually by the planned introduction of light, with the advantage of fluidity in design. One can hardly repaint a room every time a change in spatial effect is desired, but lights can easily be turned on or off.

Excerpts from "Lighting: Design or Accident," William M. C. Lam, consultant: coordination of lighting and architecture, *Architectural Record*, June, 1960.

'Uniformity is undesirable'—Birren, Logan

The functions of light and color are mainly these:
1. to aid visibility and manual skills
2. to increase efficiency
3. to promote good morale
4. to enhance the appearance of rooms and their furnishings
5. to put man at ease in his interior environment
6. to help assure safety

Light level is the simplest of all problems to deal with as far as the agreeable environment is concerned (excluding the technical engineering of a lighting installation). But for a given task the level must not only be high enough to make the task visible, but the light must have such quality as to permit the task to be easily and efficiently done. Some of the important considerations related to light levels and light quality are:
1. The surround of the task shouldn't be too dark or too bright in relation to the task.
2. Glare, prolonged convergence, constant shifts in accommodation, constant adjustments to

brightness differences, all of these involve wearisome muscular chores.

3. High-level light may aid visual acuity, but not if it involves glare.
4. Bright walls may be a handicap if the task happens to be work at a desk, since the eye cannot help but focus upon the brightest area in its field of view.
5. Shadows should give form and depth to lighted spaces. They should be light enough to see into, yet not so light as to create flatness.
6. Although a monotonous task may require little light, the worker may be kept more alert if he is stimulated by brightness.
7. The total effect must be pleasing, and, in addition, the appearance of the worker should be acceptable and sometimes flattering.
8. What is familiar and easily recognized will not require as much light as that which is strange.
9. Uniformity is undesirable and debilitating. If monotony is long continued, the ability of a person to respond to a stimulus will deteriorate. People, therefore, require varying, cycling stimuli to remain sensitive and alert to their environments. If overstimulation may cause distress, so may severe monotony.

There is a wide latitude possible in the use of color, but if average people are to be pleased, it may be best to feature simple colors such as greens, blues, pinks, yellows, grays; few people like yellow-green and purple. If human appearance is important, the light source should be warm and background colors should not exceed approximately 50-55 per cent reflectance—otherwise the phenomenon of brightness contrast may cause the skin to look unattractive (dark pallor) by direct visual comparison.

In low levels of light (under 30 footcandles) object colors will look normal to the viewer if the light source is slightly tinted with pink, orange, and yellow. At higher light levels, normal appearance for object colors will be obtained with cooler light, more like sunlight and noon.

Adapted from "The Agreeable Environment,"
Faber Birren, color consultant, and
Henry L. Logan, illuminating engineer,
Progressive Architecture, August, 1960.

'Identify the main focal points'—Hopkinson

1. We see better if the main visual task is distinguished from its surroundings by being brighter or more contrasting, or more colourful, or all three. It is therefore important to identify the main focal points and build up the lighting from their requirements.

2. We see better if the things we have to look at are seen in an unobstrusive and unconfusing setting, neither so bright nor so colourful that it attracts the attention away, nor so dark that work appears excessively bright with the result that the eyes are riveted on to the visual task. Good lighting therefore provides a moderate and comfortable level of general lighting, with preferential lighting on the work. This can be called *focal lighting*.

3. The surroundings should be moderately bright, and this should be achieved by combination of lighting and decoration.

4. No source of light should be a source of glare discomfort. Excessively bright areas should never be visible. Windows should be provided with curtains, blinds, or louvres to be brought into use when the sky is very bright.

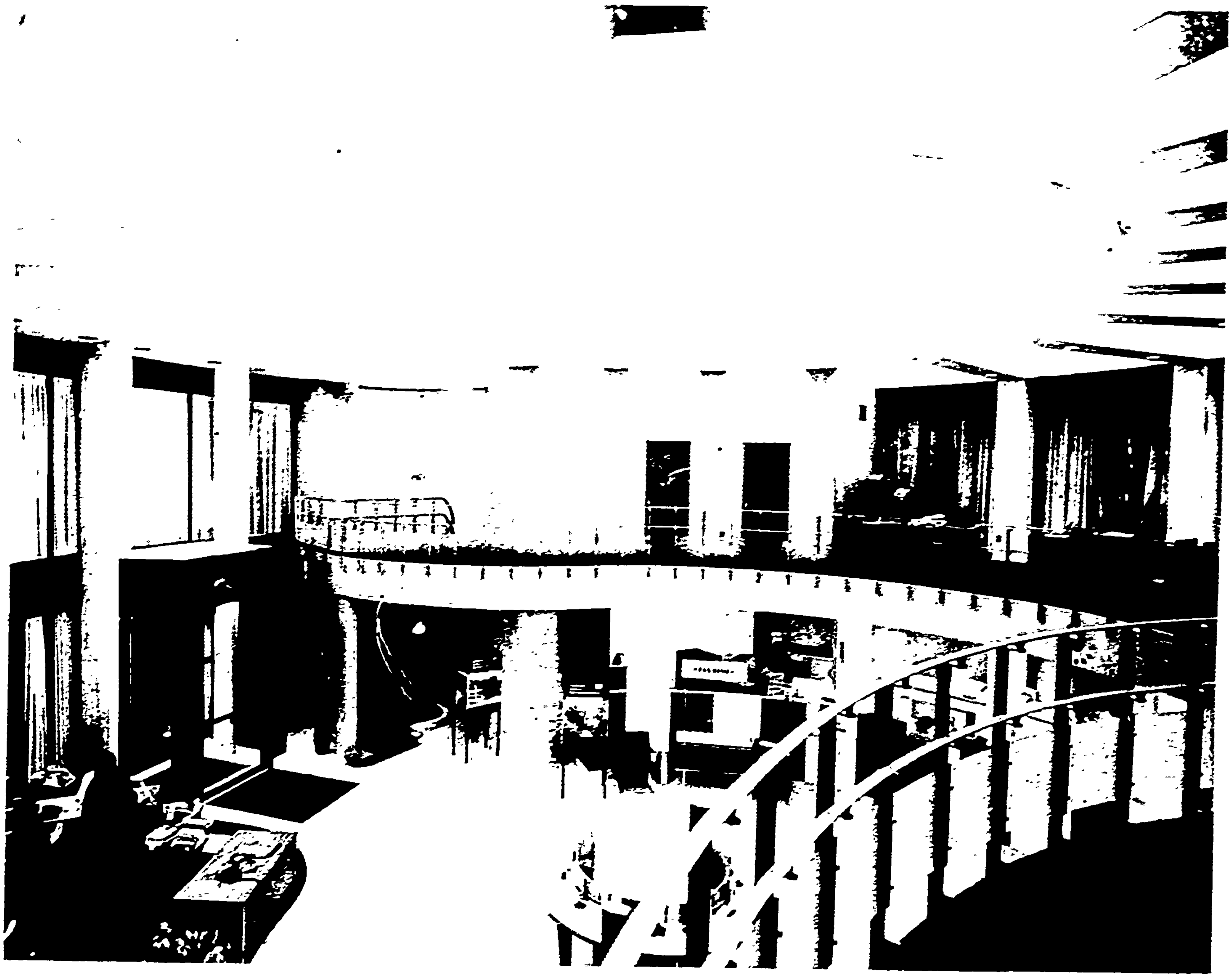
5. Plenty of light should reach the ceiling, in order to dispel any feeling of gloom, and to reduce glare.

6. Care should be taken to eliminate any discomfort from flickering light sources.

7. A dull uniformity should at all costs be avoided. Small brilliant points of light can give sparkle to a scene without causing glare.

Excerpts from "Some Principles of Good Lighting,"
R. G. Hopkinson, *Architectural Physics: Lighting*,
Her Majesty's Stationery Office, London, 1963.

The crenellated ceiling shows up in both modern and traditional versions, working for both functional and decorative purposes. In the top photo, phosphor-coated mercury lamps, mounted in reflector boxes, direct light to experimental, stepped-pyramid ceiling reflectors of aluminum. The steps have parabolic curves to reduce brightness. The example shows how a small number of high-intensity sources can give high lighting levels. In the example at left, lamps in the chandeliers light the ceiling and quartz-tube lamps recessed in the ceiling light the working zone below.



The higher-wattage, small-envelope incandescent lamps, made possible by the quartz-iodide principle, are particularly suited to giving a greater punch to ceiling lighting. In the top example, a total of fifty-three 400-watt quartz-iodide lamps illuminate the spokes of the wheel. In the store at right, the dome ceiling is illuminated by quartz-iodide lamps placed in four urns near the counters.

(Continued from Page 7)

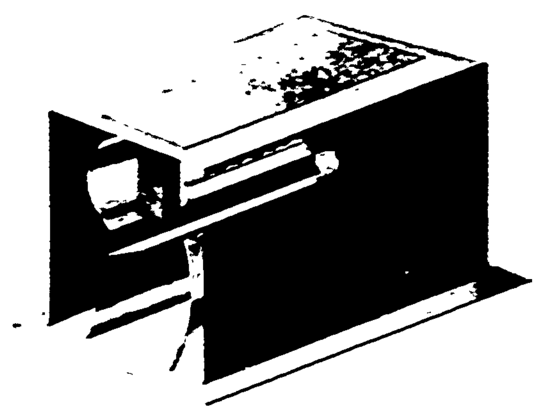
tion could be provided for the same wattage. Also, since the lamp was much larger in area and generally of lower brightness than the incandescent lamp, early fixtures were designed mainly to control light distribution and only partially shield the lamp. Very shortly thereafter, longitudinal and crosswise louvers were added to luminaires — to minimize brightness as the output of lamps was increased and as the fluorescent fixtures began to populate the ceiling more densely.

The troffer came on the scene quite early, and it was improved from a glare standpoint when the egg-crate grid was added. It was only a short step from the fixtured ceiling to a fully luminous ceiling, especially as plastics became more readily available and accepted. But it was soon learned that the fully luminous ceiling should be subdivided visually with louvers or baffles to minimize glare and to avoid a monotonous appearance. Plastic prismatic lenses were an early development for recessed and surface-mounted fluorescent fixtures. These controlled light rays for both light distribution and apparent surface brightness. The geometry of the parabola played an important role in fixture shape of the unenclosed fluorescent troffer and the geometry of the prism for the enclosed, lensed unit. All the while, footcandle levels kept increasing. With the techniques outlined above, lighting levels seldom exceeded 100-150 footcandles.

For critical seeing, such as desk work, it is a good idea for the lamps themselves to be behind translucent diffusing media or lenses to help reduce or avoid reflected glare. The small-scale parabolic-shaped louver grid not only permits much higher levels (250-350 footcandles), but, architecturally, an uninterrupted smooth-plane ceiling.

It is obvious that the matter of light control is now highly sophisticated. At this point it also should be mentioned that fixture design is also highly developed technically for downlights and wall washers and for illuminating ceiling coffers and large-scale structural elements, as well as for floodlighting.

Heat-recovery techniques, while significantly reducing the air conditioning loads of rooms, still have thermodynamic limitations. For instance, where



Even when a wall is to be lighted, the light source usually is part of the electric ceiling. Here is a wall-washer employing a quartz-iodide lamp and special Alzak reflectors for even illumination of a wall up to 14 feet high.

fluorescent lamps are used, 85 F air is about the maximum practicable temperature recoverable from a ceiling plenum. This is used more flexibly in the overall system if it is raised in temperature through use of a heat pump instead of by direct re-use for air tempering or heating. However, if the recovered air had temperatures of, say, 100 F or higher, different and more economical system combinations would be possible. Investigation of various heat recovery approaches can be expected in the future.

The implication is clear: more investigation should be made of the possibilities of heat recovery from higher-wattage lamps—the high-intensity discharge lamps and quartz-tube lamps. Already these lamps are being used in downlights for such high-ceilinged space as sports arenas, and they are beginning to find their way into stores. Also there are experimental installations of improved-color mercury vapor lamps for the indirect lighting of office areas and corridors. And the highly efficient (105 lumens per watt), color-improved, high-intensity, sodium discharge light is being tried out in combination with deluxe cool-white fluorescent — the system being shielded by parabolic wedge louvers —to yield 350 footcandles of illumination from the electric ceiling.

Consideration of color in selecting light sources

Color in lighting has become much more important as the catalogue of electric lamps grows in diversity at an increasingly rapid pace. It has been said that color's significance is comparable with that of lighting levels, brightness contrasts and glare, and other technical matters. The two color considerations that must be dealt with by the architect are: (1) psychological comfort for building occupants (or providing a desired psychological stimulus), and (2) accuracy of color rendition. The latter is of especial importance in connection with viewing complexions, foods, natural objects such as flowers, etc. Psychological comfort is more related to whether room-use calls for warm, exciting colors or cool, restful ones.

A particular light source might very well provide the desired psychological luminous environment, depending upon both the color of the light source and the colors of room surfaces and furnishings. But this same light source might not offer good color rendition of certain objects.

It is interesting to consider the fact that even though the color "output" of sunlight varies during the day, the colors of different objects as we see them not surprisingly seem natural, no matter what the hour is. This phenomenon is known as "color constancy," which means that when we are given sufficient clues we make automatic adjustment for variations in color of the illumination source and perceive objects in their "true" colors. An example of this is light under the shade of a tree, which is both dimmer and greener than the sunlight. Even though this condition makes the grass under the tree dimmer and greener than the rest of the lawn, we perceive that the grass is of the same color throughout.[1]

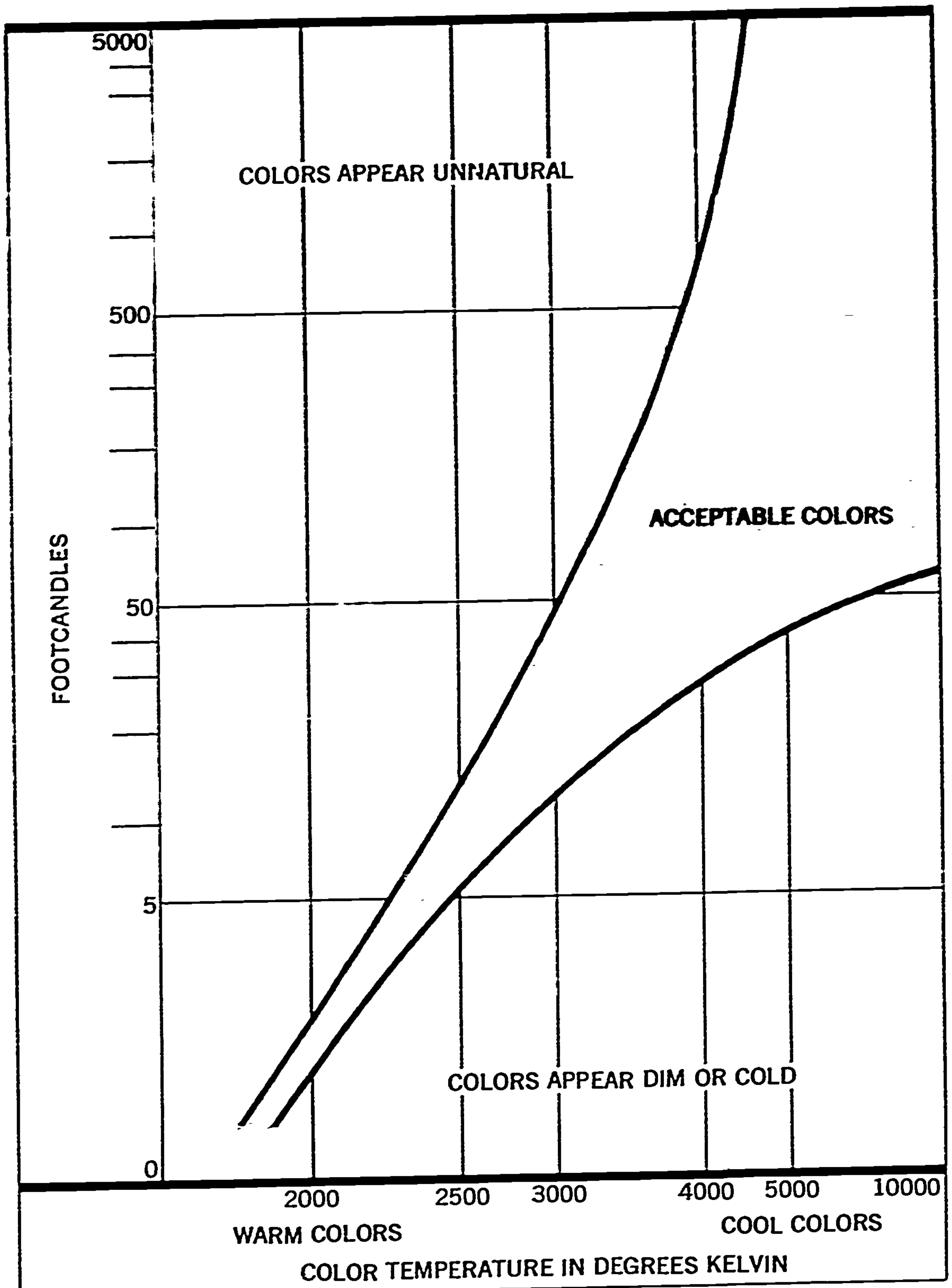
It is thought, since visual processes evolved under daylight and flame sources, that our sensory system can more easily compensate for variations in the color of sources of illumination if these sources have spectral distributions corresponding to that of a black body—which is true of sunlight, flame, and incandescent lamp sources. (A black body is a theoretical object, with a mathematical basis only, that radiates the maximum possible energy in all parts of the spectrum of any incandescent radiator at the same temperature. As the temperature of a

[1]Much of the information on color constancy has been adapted from, "Artificial Lighting," *The Architects' Journal* (London) Jan 4, 1967.

black body changes, its color changes uniformly from red and yellow at low temperatures to blue at high temperature. This property is used to describe the apparent color of light sources. If an incandescent lamp has a color temperature of 2800 deg. K, the color of the filament would appear to be the same as that of a black body heated to this same temperature. Fluorescent and high-intensity discharge lamps differ from black-body-type distribution because of certain spectral peaks. For these lamps, the term used is "correlated color temperature." When a fluorescent lamp has a correlated color temperature of 4200 deg. K, the lamp is said to look to the human eye like a theoretical black body heated to this temperature.)

The color of light from clear incandescent lamps is strictly a function of the filament temperature — the hotter the filament, the greater the proportion of blue light in relation to yellow and red. In any case, the spectral distribution is always close to that of a black body. The color of light from fluorescent lamps depends upon the mixture of phosphors. The phosphors convert the ultraviolet to visible light most efficiently at the blue end of the spectrum and least efficiently at the red; yet the eye is most sensitive to yellow. Since there is a conflict between optimum efficiency and optimum color rendering, no one lamp is best from all viewpoints. Also, since the spectral distribution differs from that of a black body, the apparent color of a lighted lamp will not necessarily give a correct impression of how an illuminated object will look.

Color preference studies are now underway on rooms lighted with high-intensity discharge sources, which provide many more lumens in small glass envelopes. Such studies are important to the hopes for widening the applications of these high-efficiency sources (80 lumens per watt to 105 lumens per watt). More care must be exercised in using them because of their strong spectral characteristics. Mercury vapor lamps have a characteristic blue color, and the new high-intensity ceramic discharge lamp (Lucalox) produces a "golden" light. Suggested combinations of metal halide lamps (improved mercury) and ceramic discharge lamps have been offered: (1) equal levels of illumination from metal halide mercury, Lucalox, and incandescent; (2) equal levels of Lucalox and deluxe cool white fluorescent, and (3) equal levels of metal halide mercury, and deluxe warm white fluorescent lamps or incandescent lamps.[2]



Apparently, because of human development under natural sources of light, i.e., the sun and flame, people seem to prefer warm colors at lower intensities and cooler colors at higher intensities. Graph gives an idea of relationship between color and intensity of light.

[2]*Light*, Vol. 35, No. 4, 1966, published by the Large Lamp Department of General Electric.

PICTURE SOURCES: pp. 2, 3, 4, General Electric Co.; p. 5 (left), *Illuminating Engineering*; p. 5 (right), Columbia Lighting; pp. 6, 7 (top), General Electric Co.; p. 7 (bot.), Sylvan R. Shemitz and Associates; p. 10, General Electric Co.; p. 11 (top), *Illuminating Engineering*; p. 11 (bot.), Sylvania Electric Products, Inc.; p. 12, Century Lighting, Inc.; p. 14 (left), Singer Co.; p. 16 (bot.), Westinghouse Electric Corp.; pp. 18, 19 (exc. top), 21, Herman Nelson Div., American Air Filter Co. (from a booklet, "Architects Are Ingenious People"); p. 19 (top), Giffels & Rossetti, Inc.; p. 20 (top), *Building Construction*: p. 20 (middle), Electric Heating Association; p. 20 (bot.), Lennox Industries, Inc.

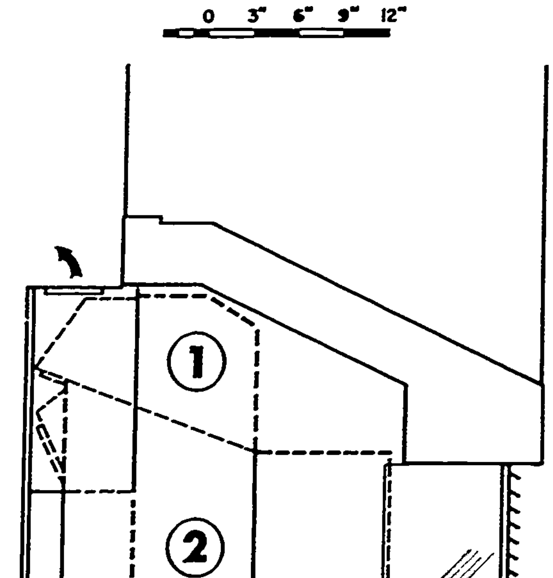
APPROACHES TO INTEGRATING UNITARY AIR CONDITIONERS

Architec s and engineers are using unitary package air-conditioning equipment more frequently than in the past for a wider variety of buildings. But occasionally an architect does not consider package equipment in a particular case because of his concern about integrating it into the overall design of both exterior and interior. This consideration is particularly true concerning the smaller local package units containing air-cooled condensers. The architect has to work out means to: (1) make exterior wall air openings compatible with the facade design, and (2) incorporate the casing of the unit into the interior design.

However, since this equipment is particularly suitable for a number of different building types, many architects have applied their imaginations to developing techniques for concealing air openings, blending air openings with the facade, or even making a design feature of air openings. The openings demand special attention because they need to be larger than openings used strictly for ventilation air—for instance, where room fan-coil units with a central chilled water system are employed or unit ventilators are used in a school. (The use of "through-the-wall" unitary air-conditioning or heat-pump equipment implies that an integral air-cooled condenser is part of the package, requiring an outside air opening.) The fact that these openings will occur on a repetitive, modular basis can, nonetheless, be turned into an advantage by the architect in his design of the exterior wall.

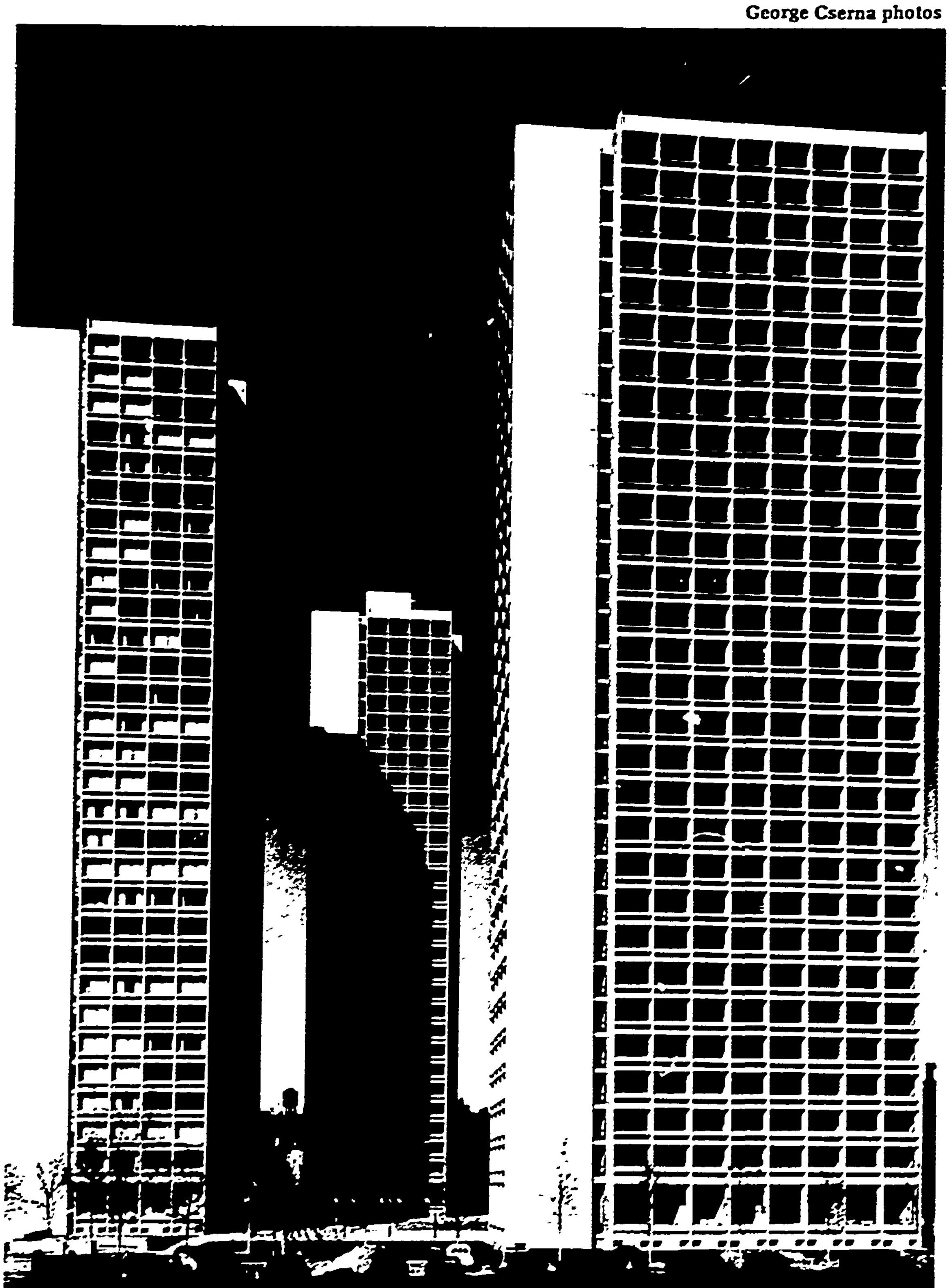
The casings of through-the-wall package units have been made amenable to interior design in several ways. First, the manufacturers have designed room enclosures with cleaner lines and, generally, a more "architectural" appearance. Second, in order to get lower and thinner unit profiles, architects have asked manufacturers to produce custom enclosures–with equipment components being slightly rearranged to yield the lower and narrower dimensions. Third, even when it is necessary for the unit to project slightly outside, particularly with curtain wall application, the projection can be made inconspicuous by architectural treatment (e.g., over the door in balconied apartments).

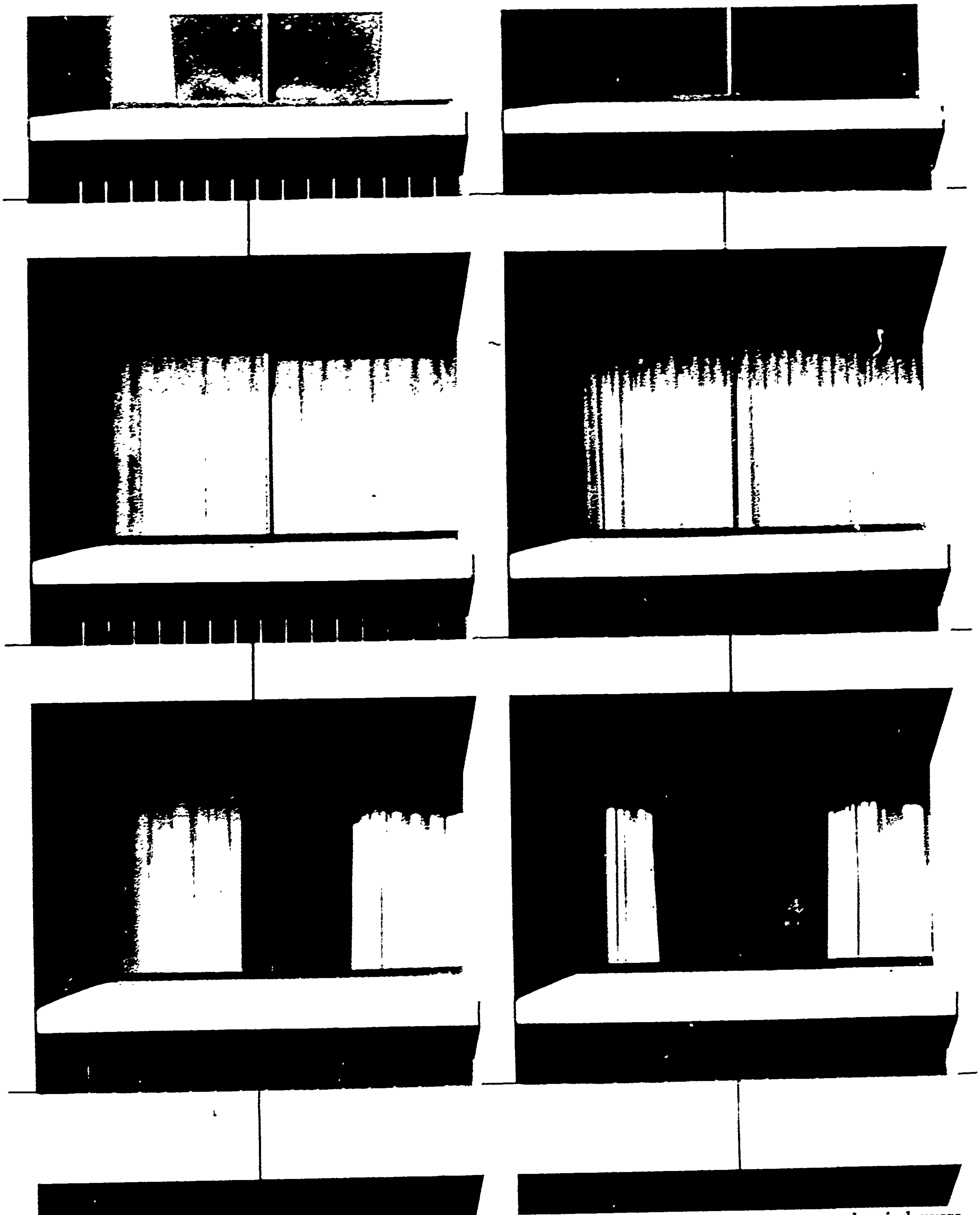
While, in using room-by-room package equipment, the architect must take time and apply his ingenuity to work out suitable design treatment of the



Equipment is low-profile modification of standard unit. No. 1 marks heating section, and No. 2 cooling chassis.

George Cserna photos





The strong lines of exterior columns and beams of University Plaza Apartments by I. M. Pei & Partners make air louvers unnoticeable. Louvers fit between concrete sills and spandrel beams. Opening provides ventilation air plus cooling air for the self-contained condenser of the room heating-cooling unit.

peripheral area, this requirement is somewhat balanced by the simpler design possible for the interior area, resulting mainly from reduction or elimination of machine rooms, shafts, and large trunk ducts. Also, some perimeter spaces having large ventilation and cooling loads due to high occupancies, and perhaps relatively large glass areas, can very appropriately be served by perimeter unit ventilators. Since economics would dictate the use of outside air for cooling in these situations whenever outdoor temperatures permit, large exterior wall openings would be required in any event. Thus, if a unitary through-the-wall air-conditioning package were included in a perimeter unit ventilator, the somewhat larger wall opening required for the air conditioning cycle of operation normally would present no problem.

A question of what small-size equipment to use

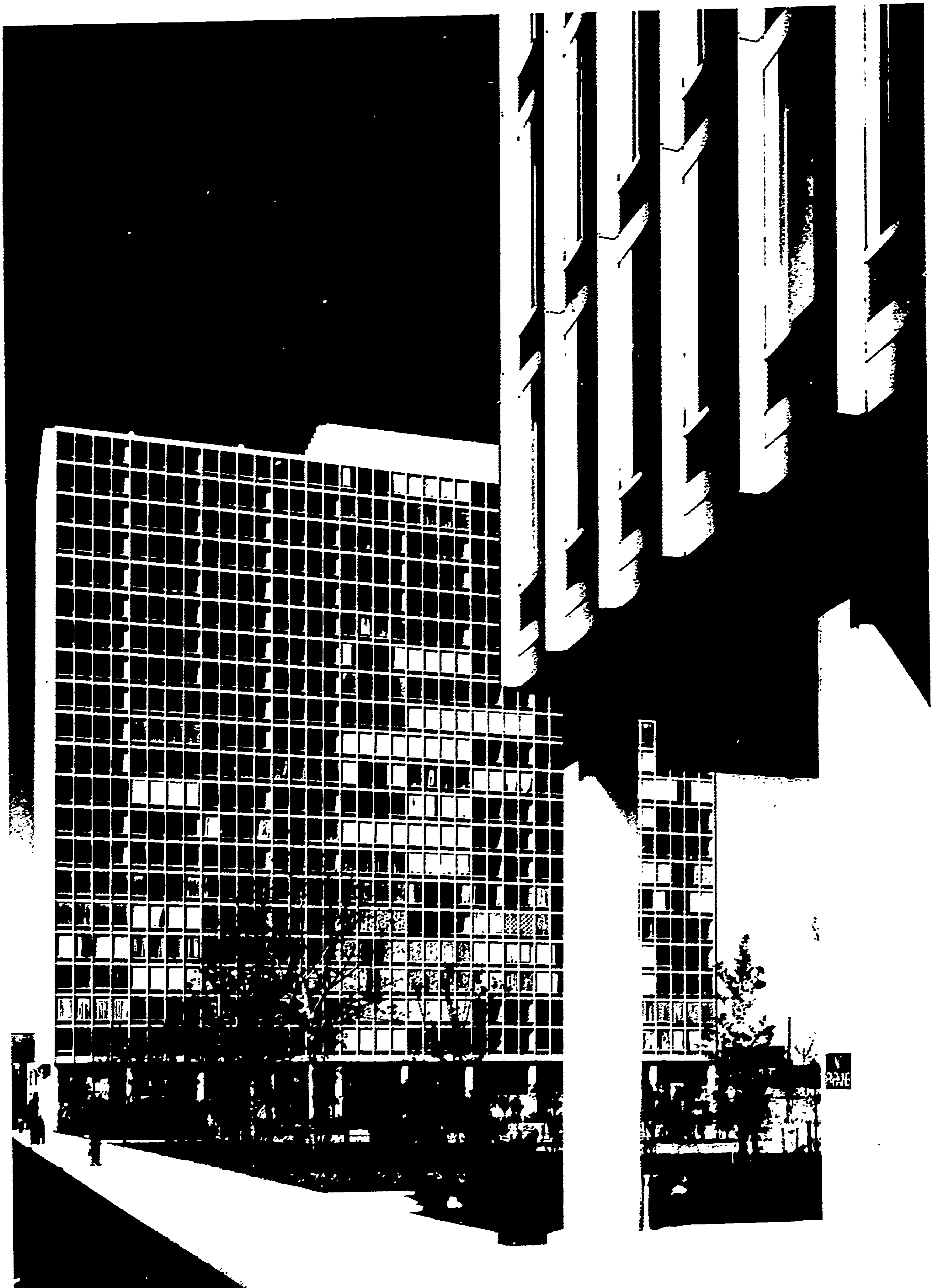
Because through-the-wall room air conditioners frequently are sold as appliances, detailed product information is not always readily available. For this reason, the architect, and even his engineering consultants, may find it difficult to keep up with product design changes and improvements relating to application and performance—styling changes, the range of sizes in a particular type of unit, etc. This is particularly so for the through-the-wall package air conditioners up to about two tons, which are designed for "at-sill" location.

Terminology used to describe this type of equipment is not standardized. However, it is possible to identify equipment variations in meaningful terms. For example, the larger at-sill equipment of about four to five tons (e.g., a modification of the largest classroom unit ventilator) would be classified as a side-by-side, split-system package air conditioner. This equipment and other related types are described and categorized in the application guide which is included in this monograph.

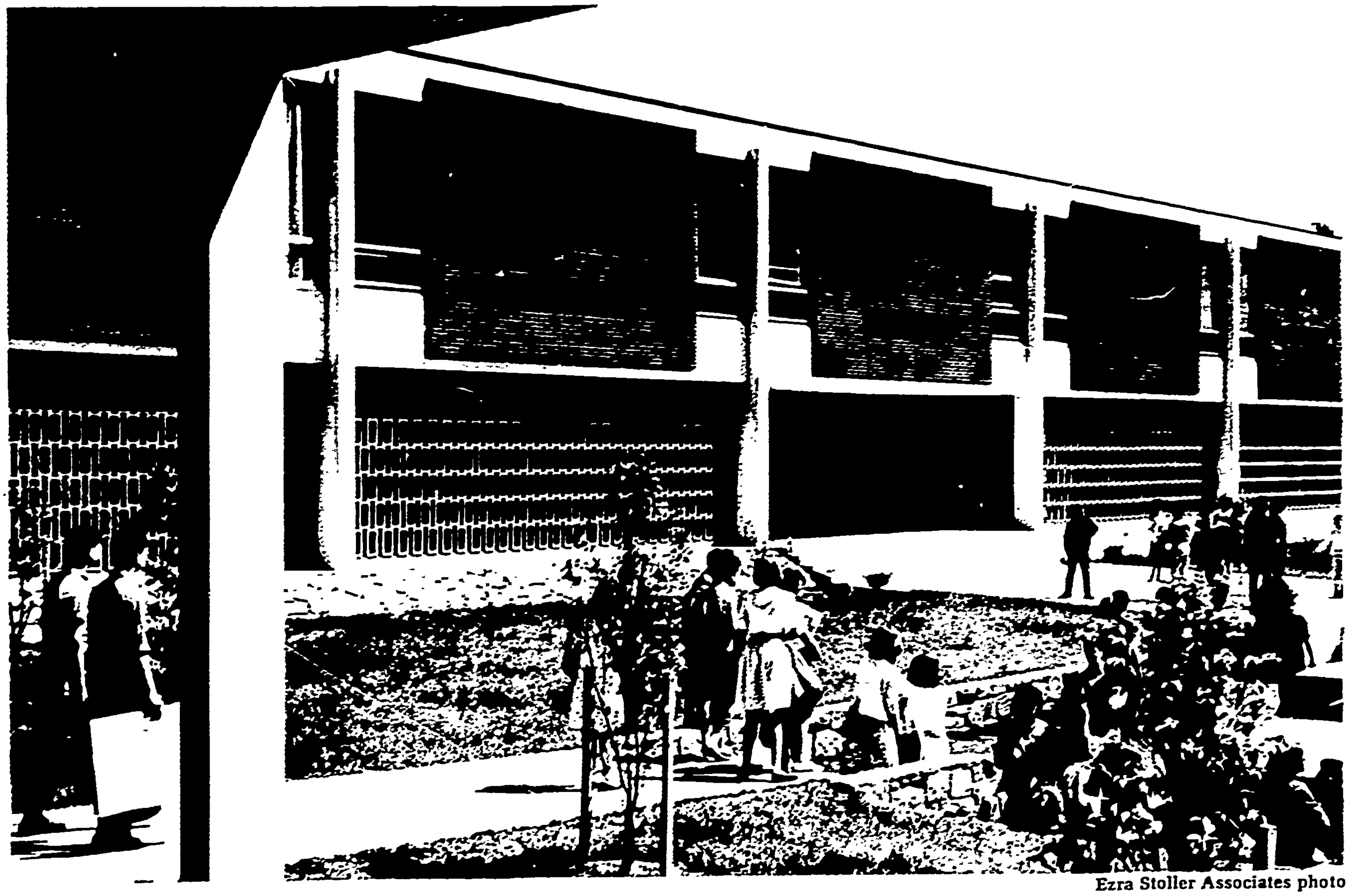
Architects' preference for making through-the-wall units inconspicuous has encouraged manufacturers—often with the architect's help—to develop equipment with low-sill height. With enough lead time, the manufacturer can work with the architect to develop special configurations. Modifications in cabinets of standard equipment can be made at low cost; rearrangement of components to achieve low profiles is costlier, requiring a large order to justify the manufacturer's development costs. Example at top is a motel designed by architect George Yurchison. Above is interior of apartment building across page by architect Mies van der Rohe.

What's new in larger unitary package equipment?

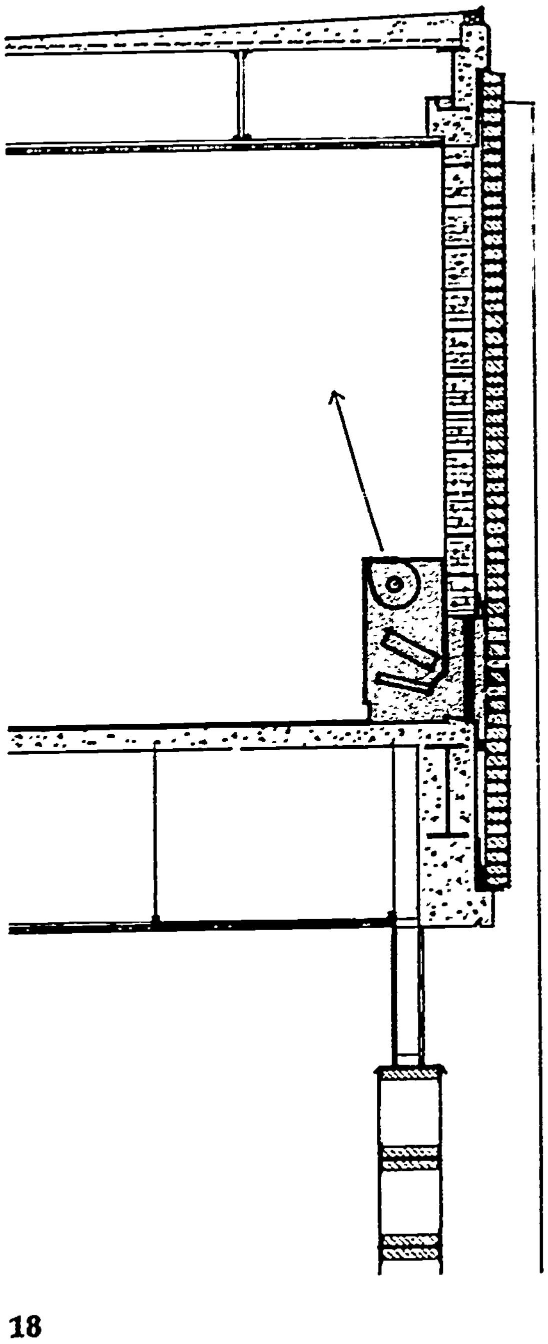
Architects and engineers are perhaps more familiar with the application of free-standing package air conditioners or heat pumps in sizes starting at five or seven-and-one-half tons, than in the equipment just described. (Free-standing and roof-top equipment may be found in sizes up to 100 tons or more.) While larger zone-by-zone package units are basically unchanged from those of ten years ago, the use of "split-system" combinations is increasingly required to allow for a remotely installed air-cooled condenser (roof-, basement-, or ground-mounted). The reasons for this are that: (1) water conservation has become increasingly important, even mandatory, in many cities, and (2) the



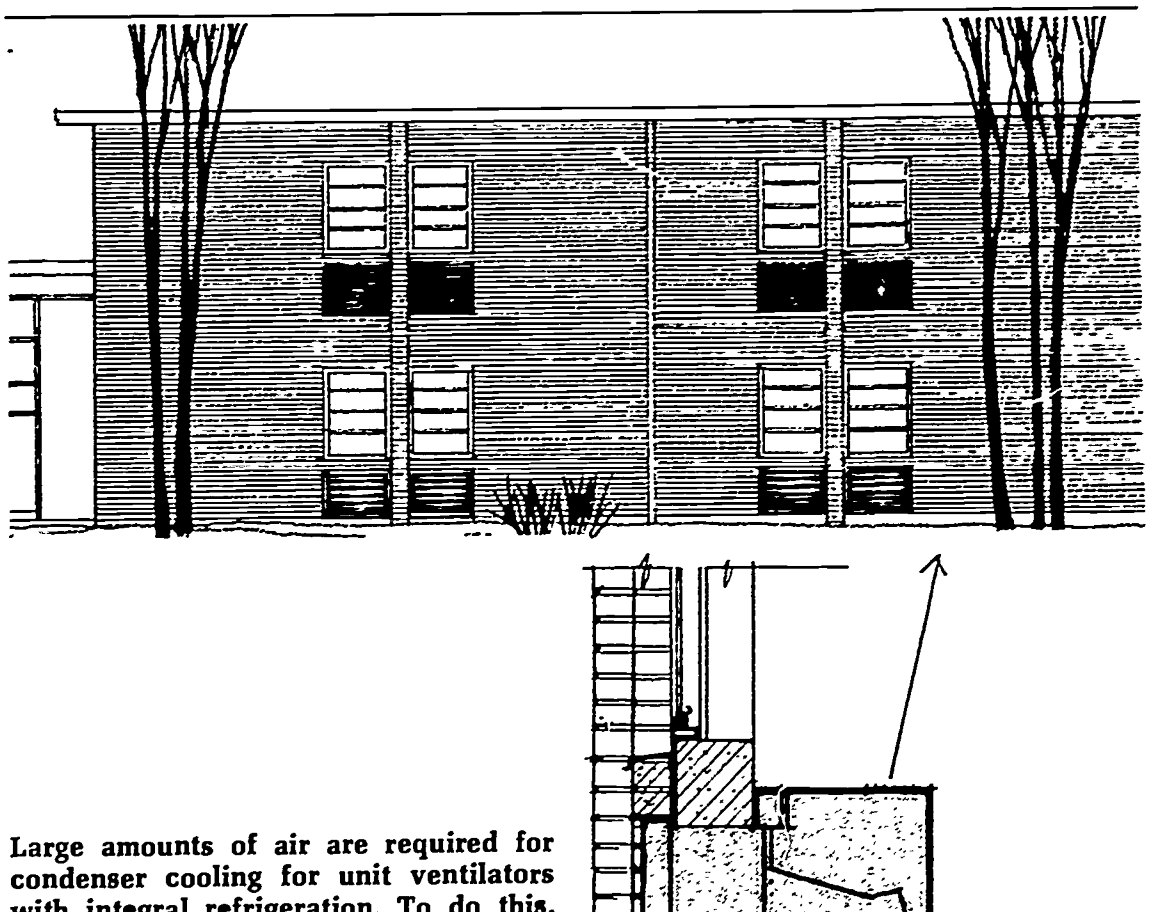
Modularity of facade of Colonnade Park Apartments makes the specially designed grilles for room units blend with design. Intakes for fresh air are under one window, for condenser cooling under next.

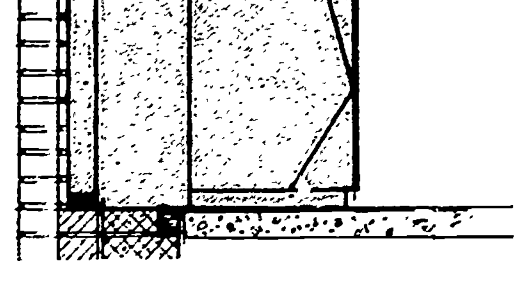


Ezra Stoller Associates photo

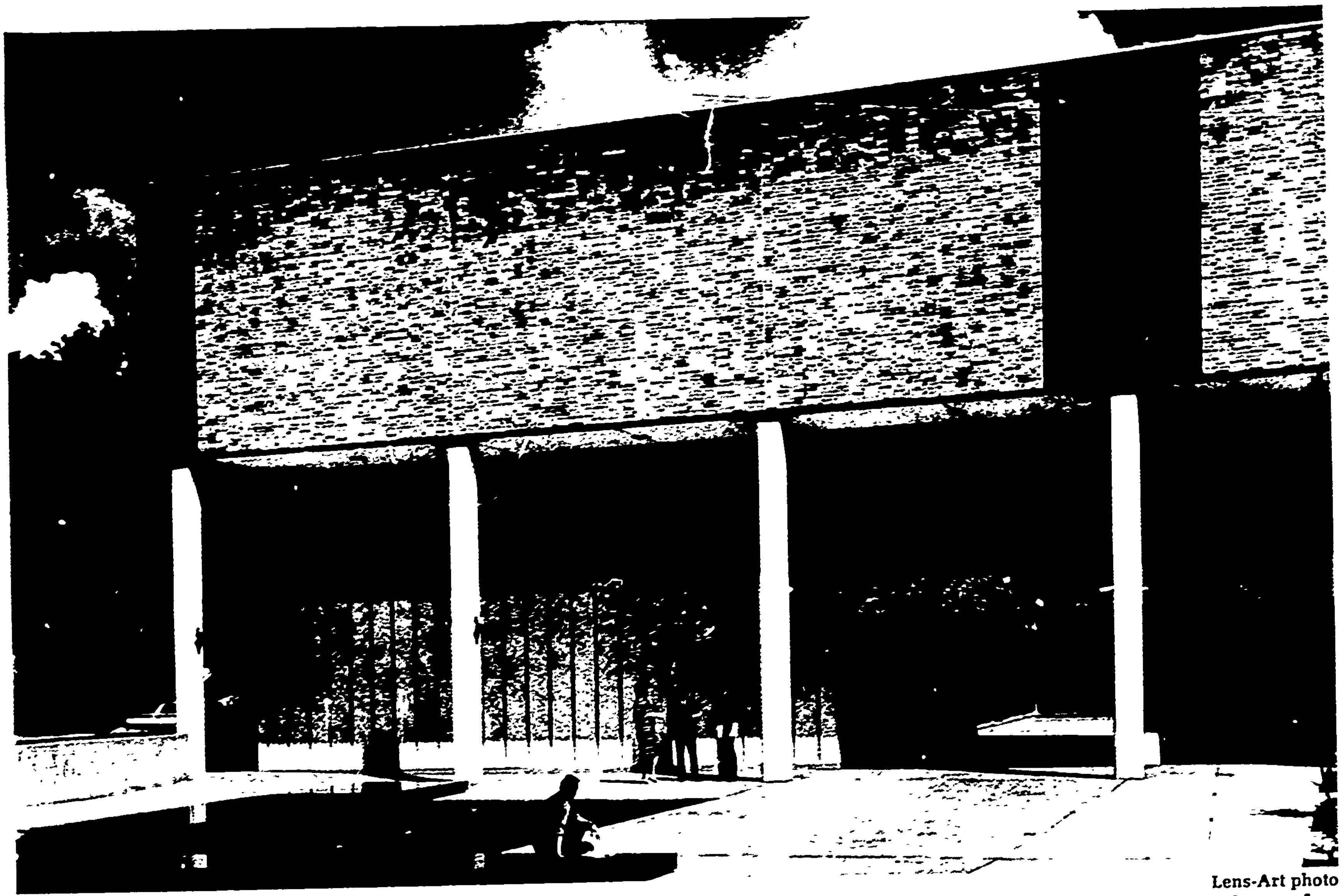


△ Small area of brick cavity wall is perforated to provide air opening for unit ventilators. The technique relates well to use of clay tile at first floor level for sun ◁ screening. Brick wall is carried by spandrel beam. Turn of River Junior High School, Stamford, Conn., designed by architects Sherwood, Mills and Smith.



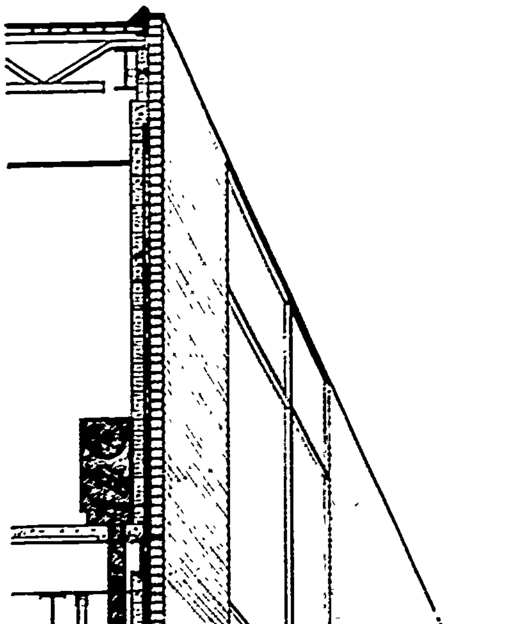


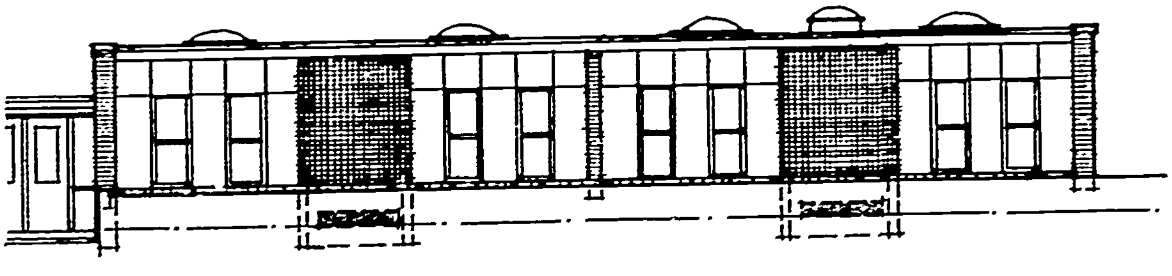
Large amounts of air are required for condenser cooling for unit ventilators with integral refrigeration. To do this, yet minimize the visual impact of the outdoor openings, architects Walton and Madden divided the openings with brick piers and placed them under the windows, the whole pattern being neatly organized. The building is Bowie (Md.) Senior High School.

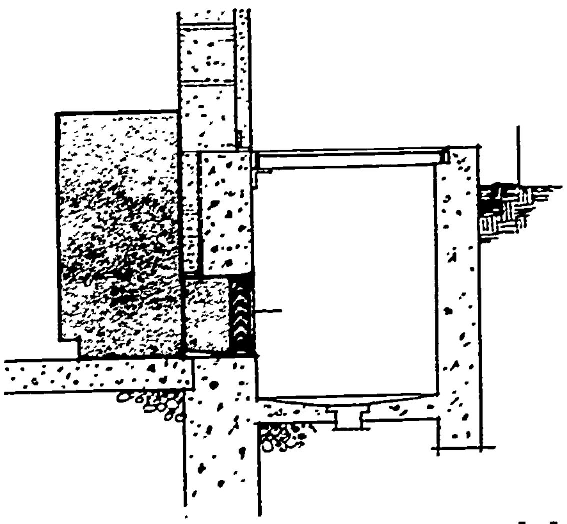


Lens-Art photo

△ Underside of projecting floor as a location for unit ventilator air openings takes grillework away from the facade. Refrigeration is located remotely in this case. St. John Fisher's College, Rochester, N.Y., Giffels & Rosetti, Inc., architects-engineers. ◁ When units have self-contained refrigeration, space should be left between air intake and condenser cooling air outlet, and the grille should direct air away from the building. Precautions should prevent mixing of the two air streams.





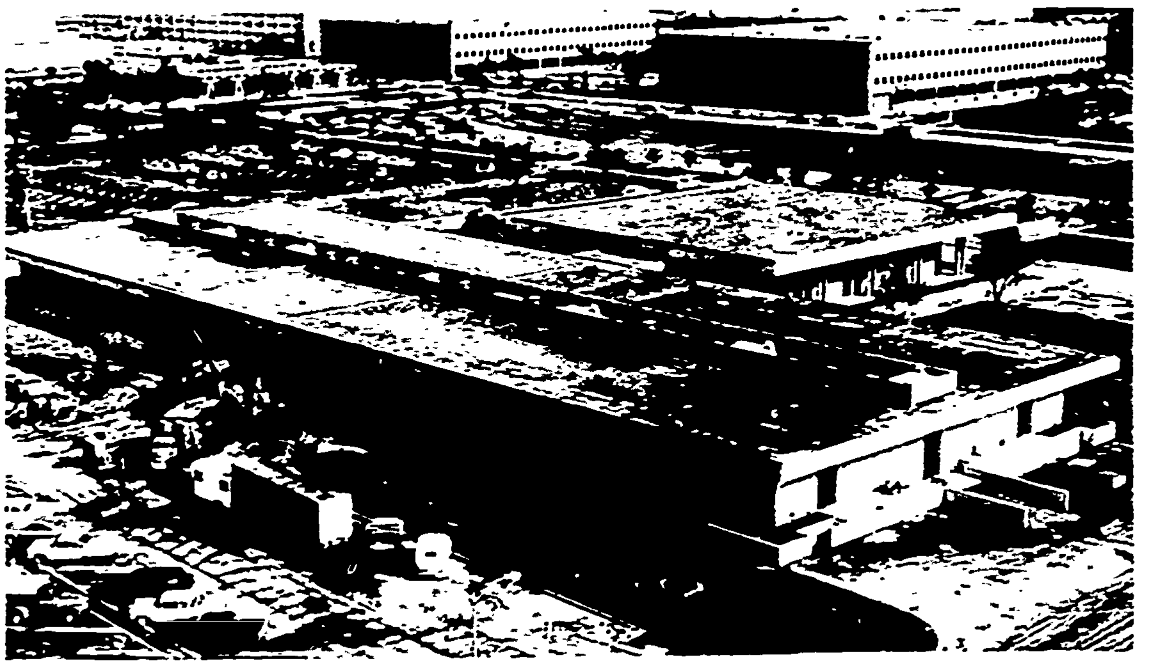


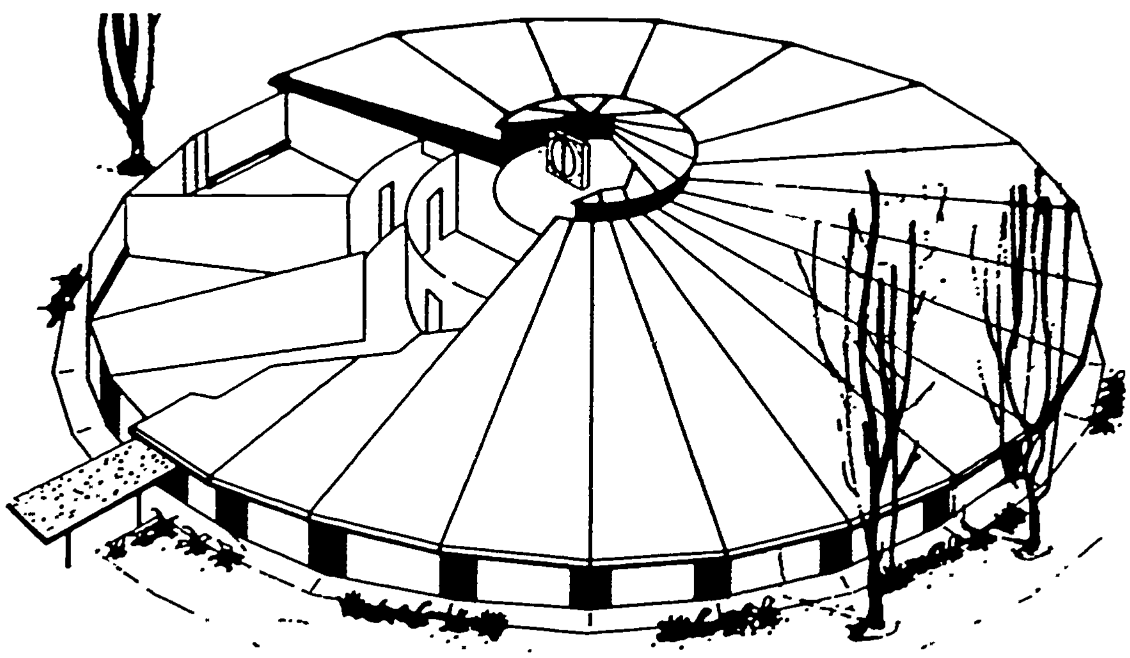
Unit-ventilator air opening is concealed by using an areaway for air access. Brentwood Elementary school, St. Louis County, Mo., Hellmuth, Obata & Kassabaum, Inc., architects. Opening must be baffled for package air conditioning.

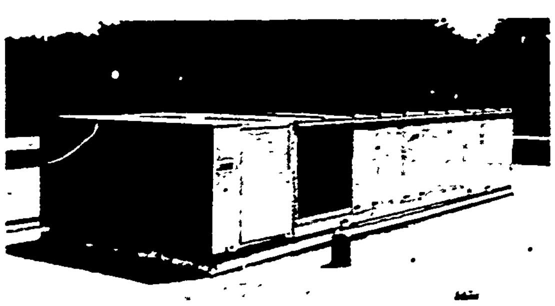
owner may wish to avoid having to provide for chemical treatment of condenser cooling water (rust inhibitors, pH treatment, fungicides, etc.).

Another recent development in the larger package equipment is the multizone unit, which permits individual temperature control for a large number of spaces. While this equipment usually is designed for roof-top installation, some types can be installed within the building (ducted air may be required for condenser cooling).

Architects and engineers who want to use these products of today's technology to produce high-quality buildings will need to think about where to put equipment rooms and about pro-







Three different techniques are shown here to let the architect use roof or below-roof space for larger-size package air-conditioning equipment, while eliminating distracting elements. At top is the familiar technique of screening the equipment (Douglas Space System Center, Daniel, Mann, Johnson & Mendenhall, architects & engineers). The drawing shows a "dropped" equipment room, called a pod, at the apex of the sloped roof for Douglas MacArthur School by Joseph St Cyr, architect. The manufacturer's contribution can be slimmed-down, rooftop equipment with attractively painted cabinets rather than standard unpainted galvanized steel. This is the rooftop multi-zone unit first used in the California School Construction Systems Development project.

visions for heat-rejection equipment such as air-cooled condensers or cooling towers. The architect, if he wants to, can use relatively expensive floor space within the building for all of the equipment (even the cooling tower). The equipment will then be concealed, and integration of air louvers can readily be accommodated.

When the architect thinks in terms of placing air-conditioning equipment on the roof, he has a greater problem of concealment, even if only a cooling tower is involved. This requires special architectural treatment. However, it simplifies the problem of dealing with air supply and discharge from heat-rejection and ventilation systems. Cooling towers or air-cooled condensers always require large quantities of outside air; central fan systems for buildings also require large quantities during intermediate seasons. Equipment rooms to house the fans must have large exterior wall louvers, or shafts up to the roof, and, because of possible layout difficulties, may require much more space than would be needed if the equipment were located in a roof-top enclosure. Also, interior space is much more costly (in rental terms) than roof space.

Architectural treatments for roof-top equipment

As roof-top equipment continues to grow in importance, architects must give much more thought to its architectural treatment. Several possibilities exist. The least expensive is to use an attractive low-outline cabinet designed by the equipment manufacturer. Use of multiple units makes possible application of low-outline equipment as well as savings in structural costs (as opposed to a larger, concentrated unit). Still, a large number of small units would be less preferable and economic that somewhat larger multi-zone equipment. A maximum size of an aesthetically pleasing, low-outline unit appears to be in the order of 25 tons.

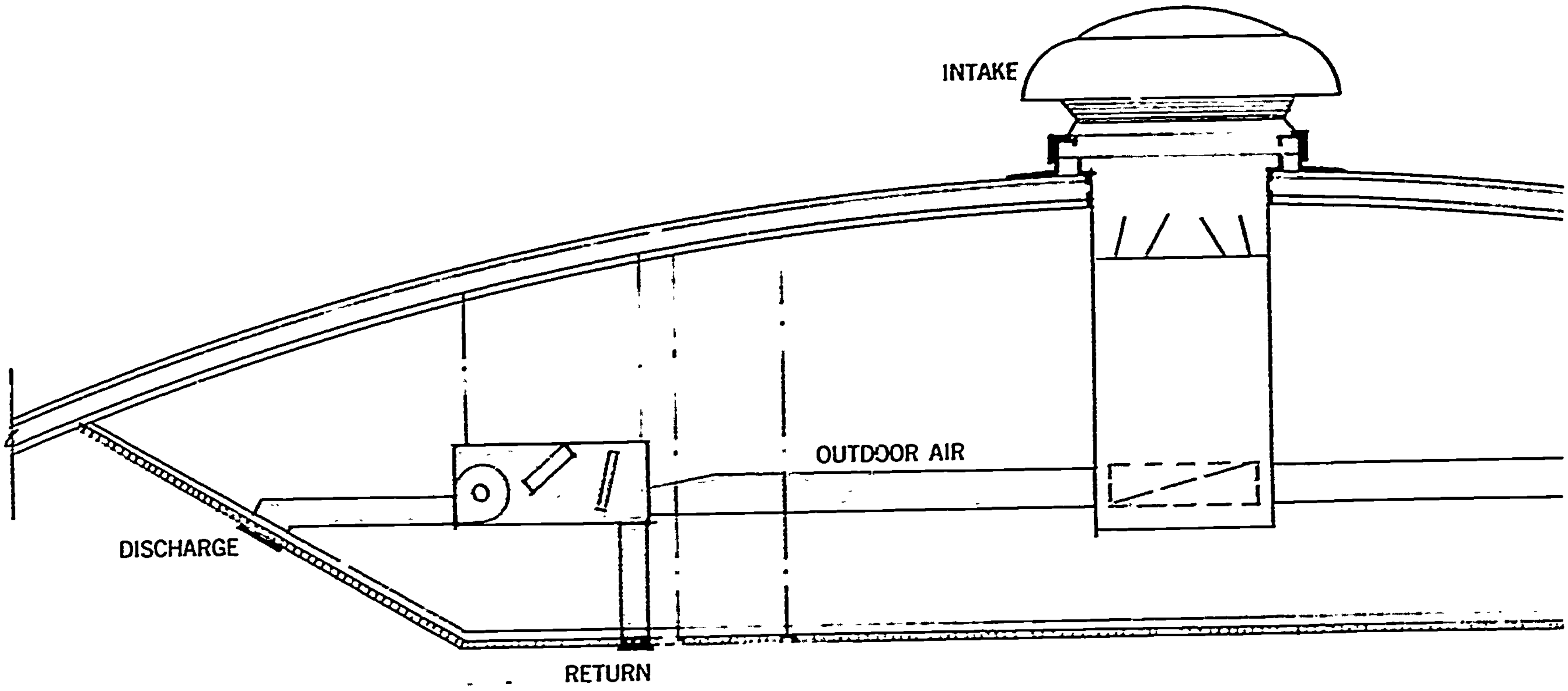
Among the more obvious techniques for concealing roof-top equipment are the edge parapet and the open enclosure immediately surrounding the equipment. The latter may be rectangular, circular, or elliptical, depending upon how the shape works with the overall architectural design.

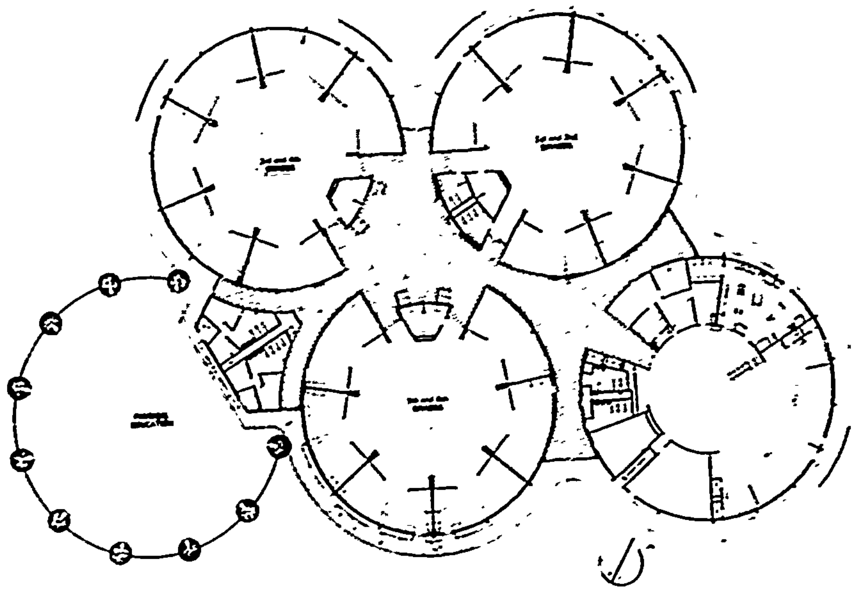
Another approach is to conceal the equipment by use of a penthouse. The penthouse may be either full-height, or it may be of the pod type with the floor of the machine room being dropped below roof level into the space over the ceiling.

Temperature control problems in spring and fall

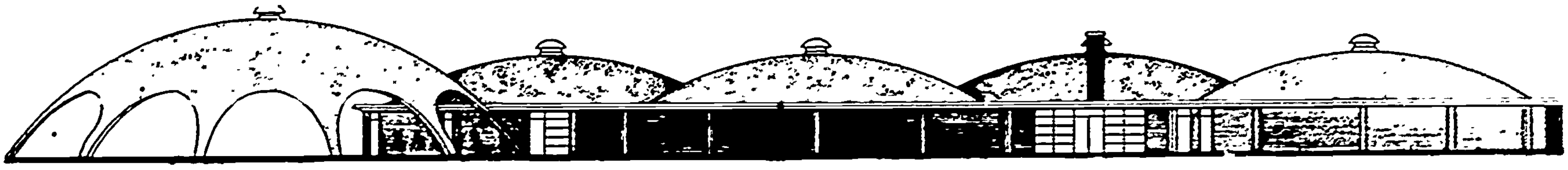
The demand for individual room temperature control of air-conditioning systems has continued to grow, and at a faster rate in the last few years. The degree of difficulty of providing this individual temperature control for perimeter spaces varies with the particular system. In the case of office buildings, perimeter areas usually will contain important offices requiring individual control. And with hotel and motel rooms, maximum flexibility of temperature control is required.

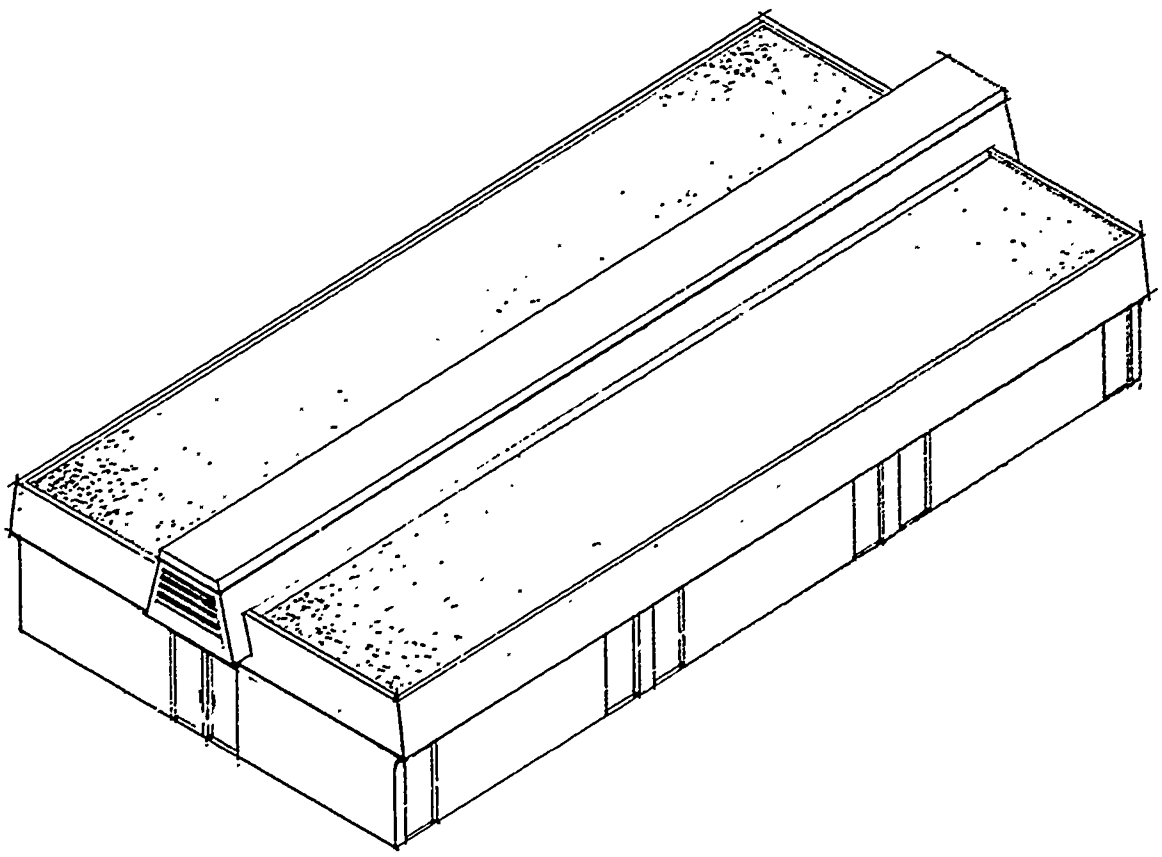
For proper performance, central systems of the all-water, all-air, and air-and-water types must be zoned by exposure and have varied temperature control of the primary heating or cooling supply ahead of the room terminal





The domed roof lends itself to easy incorporation of equipment—the unit ventilator type in this case—making it easy to provide space conditioning for the radially laid-out classrooms. Outdoor air is supplied through a low-profile unit, above. The units are grouped in a pattern around the central space of each classroom cluster. Sherwood Elementary School, Greeley, Colo., Shaver & Company architects.

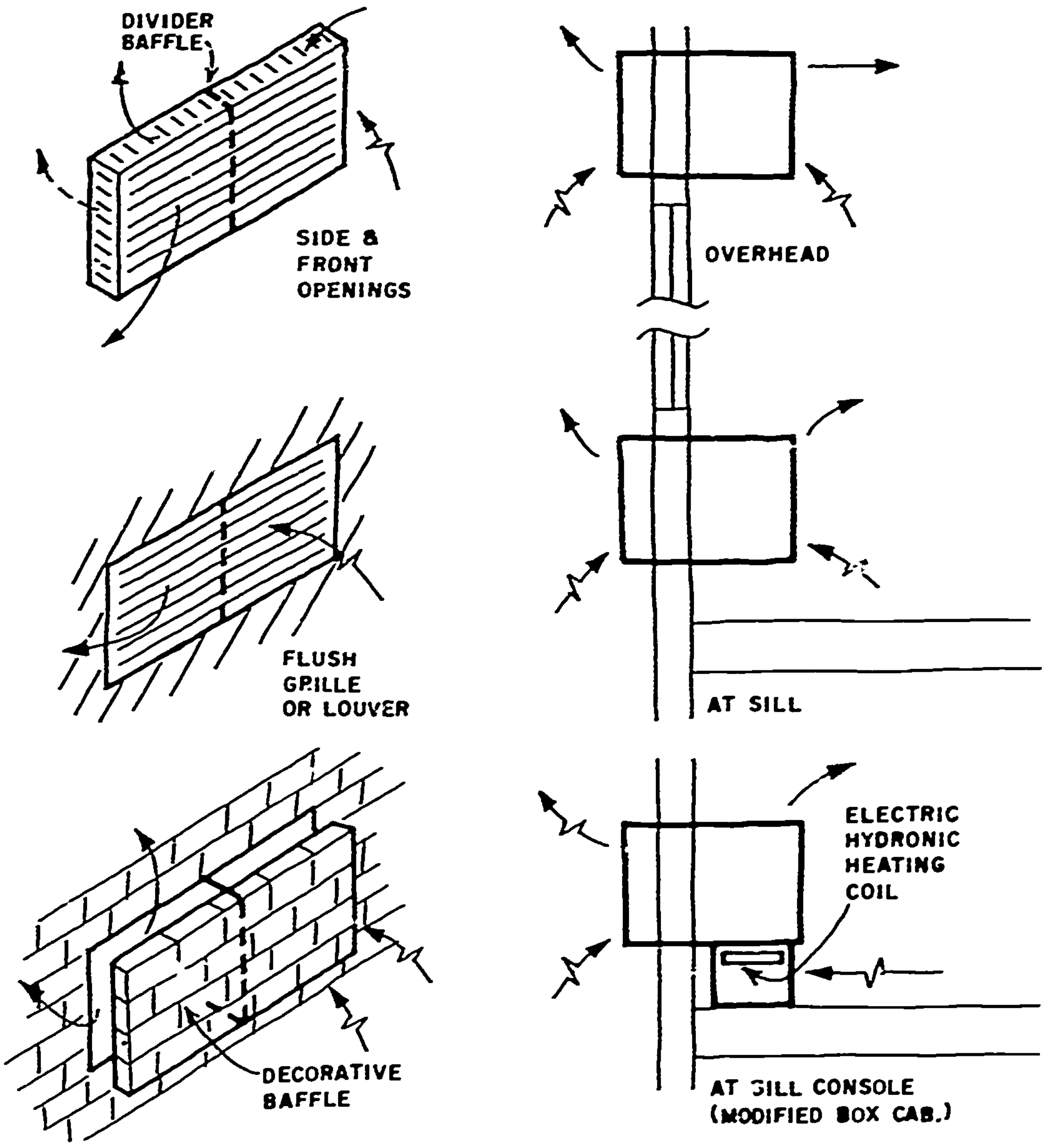




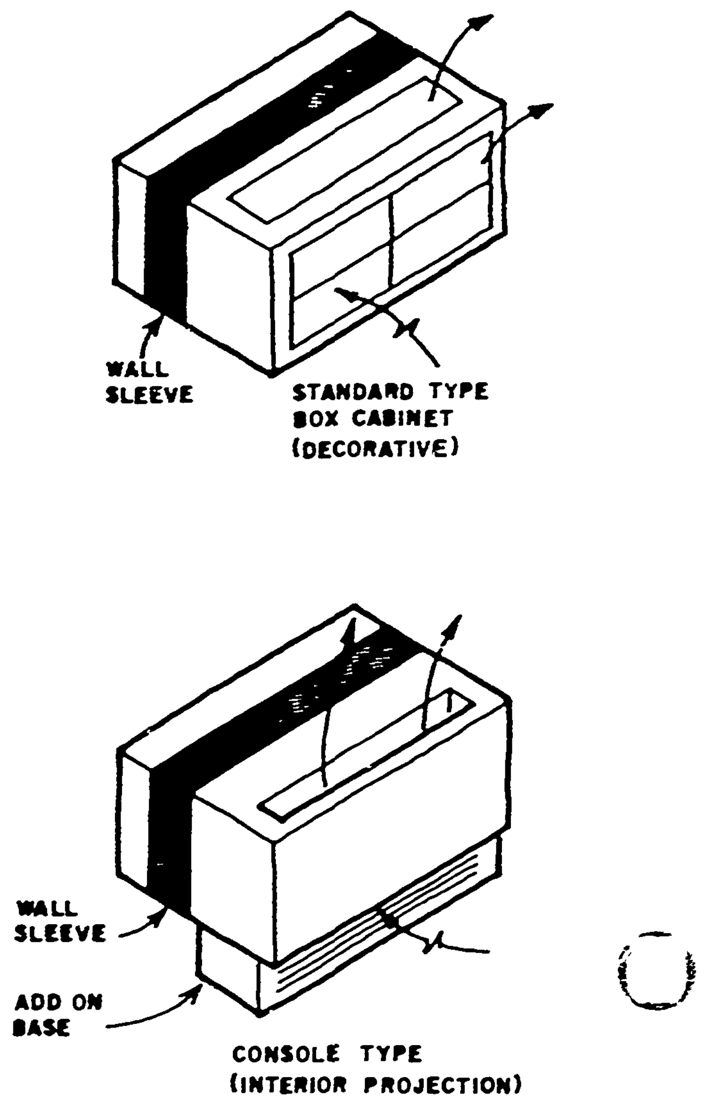
A semi-recessed roof monitor, combined with a suspended corridor ceiling, provides source for outdoor air. It is used here for unit ventilators hung from classroom ceilings at interior wall. Ortega Grade School, Sunnyvale, Cal., Kal H. Porter and Associates, architects (now Porter - Gogerty - Meston - Associates). Monitor roof could be used equally well for packaged air conditioners.

GUIDE TO UNITARY AIR CONDITIONERS AND HEAT PUMPS

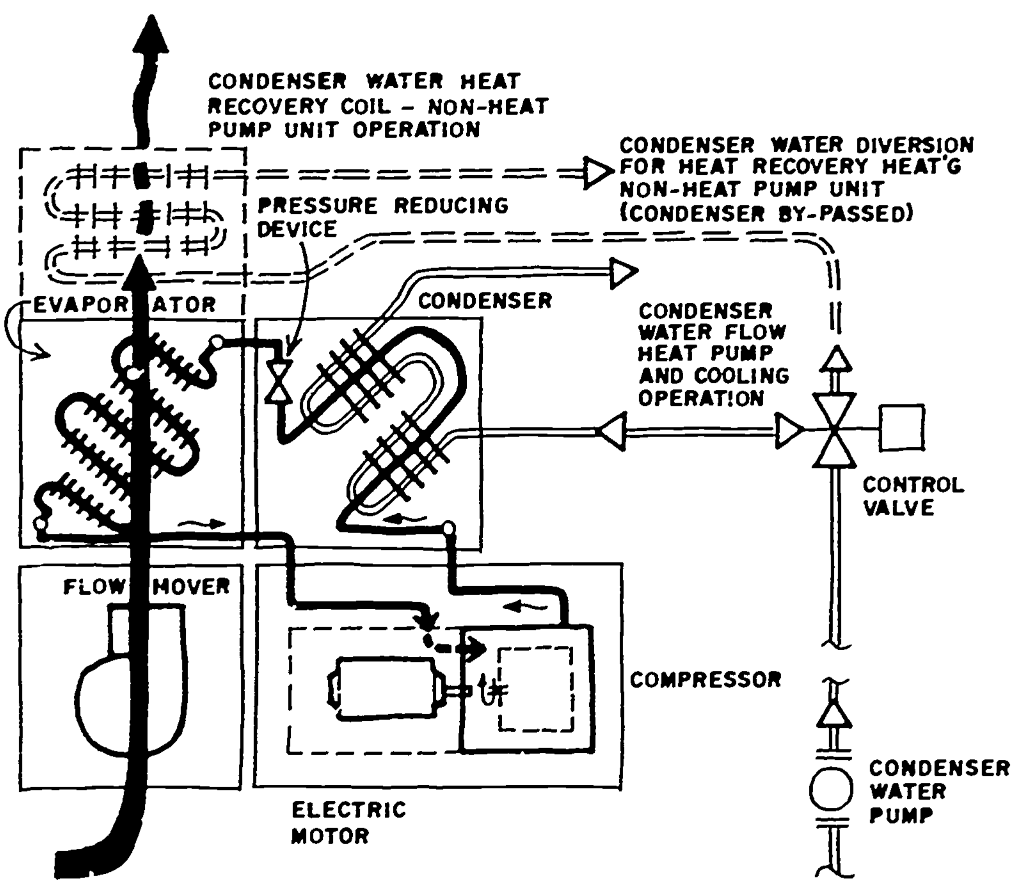
THROUGH-WALL ROOM AIR CONDITIONERS AND HEAT PUMPS (Up to 1½ tons)



Only grilles that match the air requirements of the unit should be used. They can be stock grilles or custom architectural ones. Low-sill enclosures can be custom designed.



Evaporator air-flow arrangements: All discharge and inlet grilles must allow enough air circulation. Interior low-sill enclosures can be customed designed. Some units are made to supply air to two rooms.

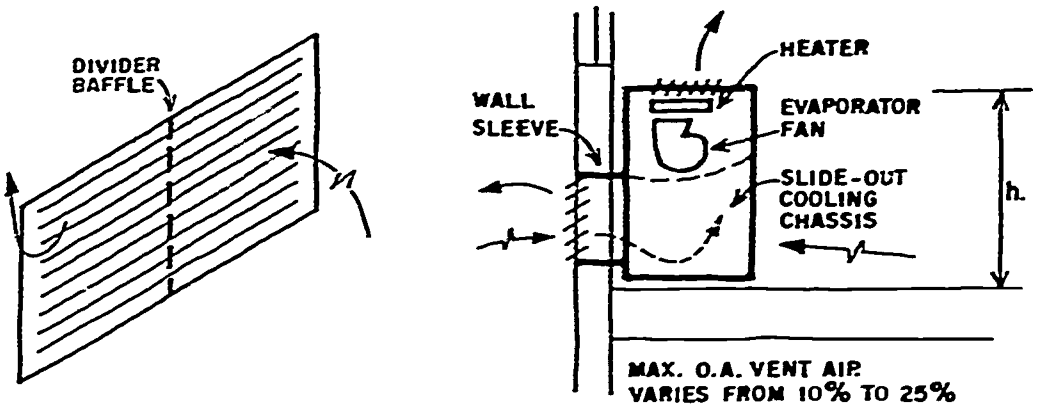


HEAT REDISTRIBUTION USING WATER-COOLED, PERIMETER, UNITARY ROOM AIR CONDITIONER OR HEAT PUMP

It is possible to remove heat from rooms requiring cooling and transfer it to rooms that need heating by connecting unitary room air conditioners or heat pumps to a condenser water loop. The solid double lines show the heat exchange arrangement for removing heat from a refrigeration condenser of a unit that is providing cooling. The dashed double lines show how condenser water can furnish heating for a room by using only the air flow of the flow mover (fan) of the unitary air conditioner (refrigeration of this unit, of course, is not operating at this time). In order to maintain the proper range of condenser water temperature when heat recovery is not sufficient, supplementary heat may be required. This type of unit includes console equipment to 1½ tons.

CONSOLE-TYPE THROUGH-WALL AIR CONDITIONERS, HEAT PUMPS
(Sizes to 2½ tons. Larger sizes can be arranged in multiple for unit ventilator application)

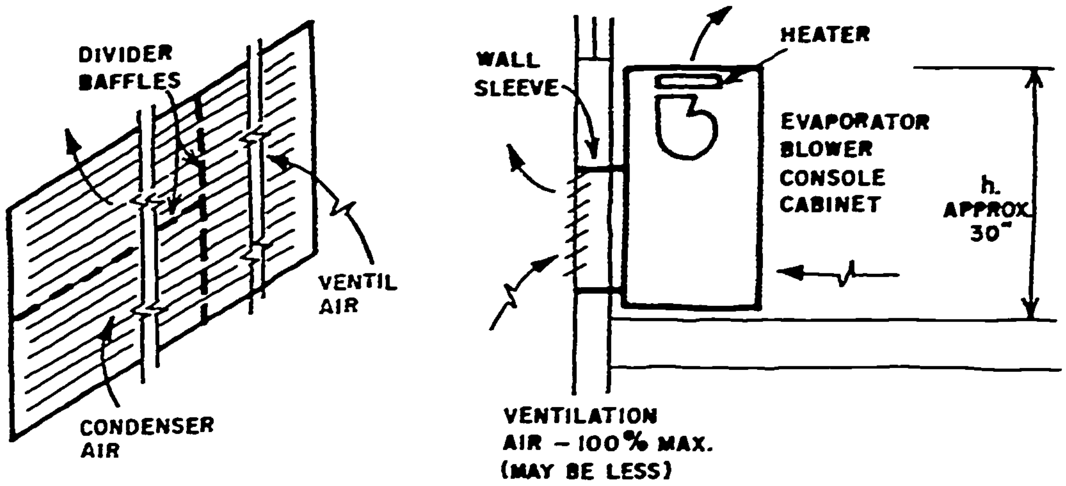
Condenser air flow possibilities: Some units utilize centrifugal fans for condenser air, allowing freedom in treating air openings.



Type variations. (1) blower-heater with add-on cooling chassis, (2) heat pump slide-out chassis (not available for classroom unit ventilator), (3) cooling/resistance electric heat (integral) slide-out chassis; (4) height (h) is usually about 24 in. Custom designs down to about 15 in. on large-volume orders.

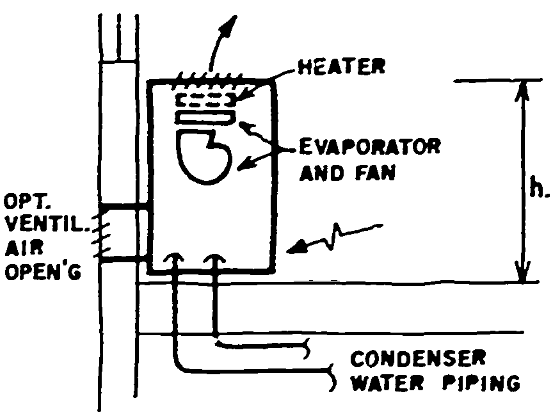
SPLIT-SYSTEM THROUGH-WALL CLASSROOM UNIT-VENTILATOR AIR CONDITIONERS
(Sizes 4 to 5 tons)

Ventilation and condenser air flow design possibilities. (1) all units utilize centrifugal fans for condenser air movement, allowing considerable freedom in treatment of air openings, (2) condensing unit section can be located 30 feet from evaporator-blower.



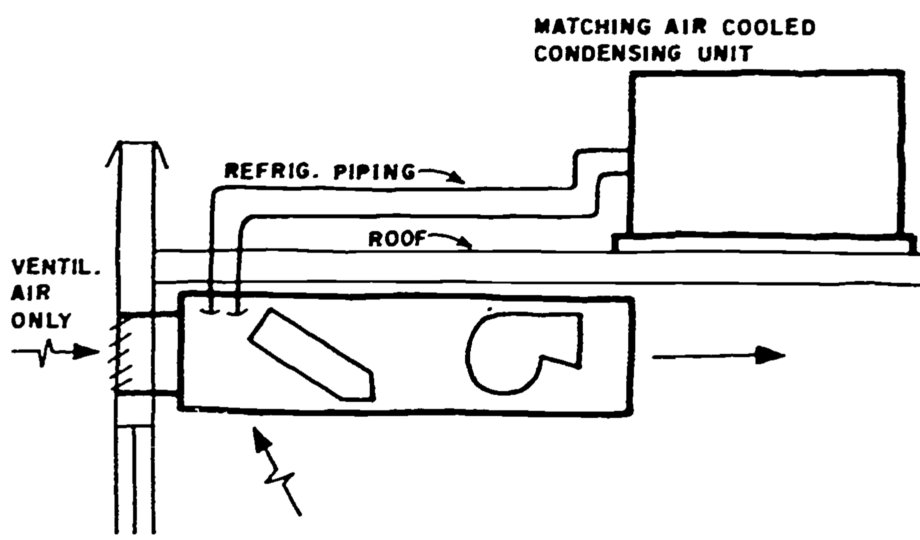
Type variations: (1) condensing unit comes in a matching add-on console cabinet that can be adjacent to ventilator unit or remote from it (30 feet maximum); (2) water-cooled condensing units can be used as well as air-cooled ones when components with matching characteristics are selected by the engineer; (3) units are joined by flexible, pre-charged refrigeration tubing.

WATER-COOLED CONSOLE AIR CONDITIONER OR HEAT PUMP
(Single-package unit at sill or interior location, to 1½ tons)



Type variations: (1) cooling only, (2) cooling/heating (heat pump, condenser water heat recovery, electric resistance), (3) height (h) usually 24 in. Custom designs down to about 15 in. on large orders.

SHALLOW OVERHEAD UNIT WITH EVAPORATOR-BLOWER
(Sizes to 10 tons)



Type variations. (1) evaporator-blower can be located in room interior, with the ventilation air being brought to the unit from a remote point, (2) a water-cooled condensing unit can be selected by the engineer for closet or other convenient location; (3) pre-charged, flexible refrigeration tubing can be used for equipment sizes up to 5 tons.

units. Architects and engineers, on the one hand, are aware of the discussions of pros and cons on three-pipe and four-pipe systems for providing individual temperature control for perimeter spaces. On the other hand, they may be much less aware of the waste of energy inherent with zone reheat systems or the wasteful mixing requirements of central all-air systems. The point is merely made here that the problem of individual temperature control with central systems is complex. Energy input requirements, particularly for the intermediate season, can hardly be predictable when peripheral areas have large amounts of glass. In downtown locations, widely variable shading effects from adjacent buildings make effective zoning an impossibility.

It should be emphasized here that one of the most favorable characteristics of the through-the-wall heat pump is its ability, in intermediate seasons, to swing from cooling to heating without any wasteful mixing of hot and cold fluid energy supplies, or without a shift from optimum range refrigeration cycle operation.

Special room-by-room air handling with heat-recovery features

If the architect does not wish to have air openings in the outside wall for air-cooled condensers of through-the-wall package equipment, the advantages of unitary equipment can be maintained by going to a water-cooled package unit of the perimeter console type. An ancillary advantage of this type of equipment (say in a motel) is its extreme quietness. This is made possible through use of today's quieter-running, extremely well balanced compressors, and the elimination of air-flow noise that is present with air-cooled condensers. These units can be in about the same noise class as the room fan-coil unit or the induction unit.

Console units for at-sill perimeter installation have cooling capacities in the range of 12,000 to 15,000 Btu per hour. Larger-capacity units for installation in closets or small equipment space can use ductwork for distributing the conditioned air. Application of these larger units must still be limited to very small perimeter zones (under five tons, maximum).

Two types of console-type, water-cooled package units are possible:

1. Room console, unitary, single-package air conditioner, having a condenser water coil in the evaporator air discharge.

Note: For units other than the console type, the coil selection and piping is a custom design. The arrangement in this unit is familiar to engineers, being similar to a "condenser water reheat" arrangement. An advantage of this system would be its ability to provide precise control of humidity under light loads if additional controls were added.

2. Room console, unitary, single-package water-to-water heat pump.

Note: Larger size units–up to about five tons–are available as a standard package for ducted installation.

Each of the two above types is illustrated and explained in the caption for the diagram on Page 22. A study of the basic refrigeration cycle diagram and the explanation of where and how heat-recovery features fit into the picture will indicate the other equipment for which space must be provided in addition to the basic package equipment. Basically these will be. (1) a closed-circuit cooling tower, and (2) condenser water circulating pumps, controls and control valving, and a supplementary electric hot-water boiler located in an equipment room. (Economical use of simple or heat-pump recovery systems should be considered to abstract heat from lights, kitchen exhaust, etc., these are not shown.)

Each type of system transfers the heat rejected from units on cooling to those on heat pump or condenser heating coil operation. Between seasons, condenser water temperatures must be kept between minimum and maximum limits for safe operation of units and high enough to allow heat abstraction where required. Where there is an imbalance between heating and cooling (which may be related to occupancy), with greater heating required, use of the supplementary heat source is increased accordingly. As with other systems (except the through-the-wall heat pump), energy usage in the between-season period can be quite inefficient. To a certain extent this can be obviated by careful selection of heat-exchange equipment and more sophisticated system analysis and control, by zoning of condenser water, by use of multiple electric booster boilers on a zoned basis, and by reset of condenser water temperatures based on outdoor ambient and/or solar conditions, etc.

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