Fluorescent Lamps

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Fluorescent Lamps: Visual and Thermal Comfort in Modern Interiors

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Abstract

Air conditioning's impact on the modern office interior was immediate and profound but lost in historical concentrations on thermal comfort has been the importance of fluorescent lighting. Fluorescent lamps and fixtures were key components of what Reyner Banham called "power-membrane ceilings," key counterparts to the glass curtain walls of the 1950s and 1960s. Fluorescent lamps relied on 19th century advances, but they were spurred on by the expiration of incandescent patents in the 1930s. Keen to find new markets to corner, General Electric and Westinghouse developed commercially viable lamps that offered greater electrical and thermal efficiency. Avoiding the heat gain of incandescent lamps, however, was only part of fluorescent lamps' impact on thermal comfort. Their cool operating temperatures allowed the use of easily-formed plastics to house them, leading to reflectors and diffusers that distributed or focused their light with precision. Fluorescent lighting's success can be measured by the evolving standards for light levels—which leapt from 3-4 foot-candles (32-40 lux) for clerical work in 1918 to 100 foot-candles (1,000 lux) in 1960. This matched air conditioning's influence on comfort standards as well as its ability to homogenise office floor plates, tuning light levels to tasks below and adding regimented, gridded order to open plan office floors.

Keywords

Lighting, Office Planning, Interior Design, Fluorescent, Air Conditioning.

Introduction

"The desideratum in illumination, except for a small group of scenic effects, is the possession of cheap and fairly powerful radiants of low intrinsic brilliancy, capable of modification in delicate color tones. It is doubtful whether these qualities are compatible with very high luminous efficiency in a flame or incandescent radiant … the best chance for obtaining sources of low intrinsic brilliancy seems to be by chemical processes analogous to those carried on by photogenic bacteria and perhaps the fireflies. Nothing practical has yet appeared in this particular field."

Louis Bell, Chief Electrical Engineer, General Electric,
"The Illumination of the Future," in The Art of Illumination, 1912.[1]

Writing in 1912, Louis Bell stood at a turning point in architectural lighting. Carbon-filament electric lamps, which produced faltering light of around 16 candlepower and burned out after a few hundred hours of use, had been the industry's standard for over a generation. Tungsten filaments, which had debuted in 1907, offered brighter, longer lives, "driving out" carbon filaments from the market despite their greater cost.[2] Bell's employer, General Electric, had established a near-monopoly on tungsten lamp production in 1911, absorbing the National Electric Lighting Association and taking over its research and industrial center, Nela Park, outside of Cleveland.

Even with improvements brought about with tungsten filaments, however, incandescent fixtures had intractable visual and thermal problems. To heat tungsten to the 2300°C necessary to achieve incandescence, a filament had to be subjected to high electrical resistance. Resistance requires a narrow *cross-section,* but brightness relies on the physical *quantity* of tungsten. Filaments must, therefore, be long and thin, and engineers settled on a long, coiled tungsten wire within a protective spherical bulb that was evacuated or filled with a neutral gas to prevent the filament from evaporating.[3] This turned long, linear filaments into intense point light sources that could reach 1000fc. Such powerful sources were uncomfortable to view directly. They had to be shaded from direct sight by diffusers, louvers, or reflectors, which decreased the lamps effectiveness. Worse than glare, however, energy radiated from an incandescent filament was mostly heat—less than 5% of the electricity that went into a typical tungsten lamp emerged as visible light.[4] At their maximum theoretical efficiency, at tungsten's melting point of 6100°F, incandescent lamps produced just 53 lumens per watt. In practice, lamps had to operate at much lower, less efficient temperatures, since the melting point of the solder that held their components together was just 345°F, at which, tungsten filaments produced just 16 lumens per watt.[5] The remaining energy from a filament would be transmitted, along with visible light, to surrounding materials, room fixtures, and occupants. This added to the surrounding rooms' temperature and restricted manufacturers' options for lamp holders and shades; any material that intercepted and absorbed visible radiation also absorbed radiant heat which could cause scorching, melting, or even ignition close to hot bulbs and filaments.

General Electric and their closest competitor, Westinghouse, responded to these problems by matching modest improvements in efficiency with silvered caps or frosted bulbs that reduced direct glare. Their fixtures paired lamps with metal or glass enclosures that diffused or reflected the filaments' piercing brightness, but with marginal success. By 1939, *Architectural Record* expressed frustration, shared by illuminating engineers and architects alike, with incandescent lighting's limitations. "Efficiency of the tungsten-filament lamp," it noted, "is now approaching its practical limits."[6] The spectacular debut of new, "firefly-like," lamps at the New York World's Fair and the Golden Gate International Exposition San Francisco that same year, however, held out new promise for better lighting.[7]

Fluorescent Lamp History and Principles

Since the 1860s, scientists had known that certain gases—neon, helium, and sodium vapor—emit visible radiation when energized.[8] Electric discharge lamps such as the Cooper-Hewitt, which debuted in 1901, relied on this effect, as did sodium-vapor lamps, which appeared in commercial form in 1931.[9] These were difficult to operate, however, and the light they produced was limited in color. They were appealing since they contained no fragile filaments, but they saw little use outside of advertising and industrial applications. French scientist Alexandre Edmond Becquerel noted in 1859, however, that adding 'luminescent solids' to discharge lamps added impressive candlepower, and he proposed spreading a paste of such materials on the interior surface of glass bulbs to boost their output.[10] Edison himself experimented with this technique in 1896, using bulbs coated with a tungsten oxide that gave off visible light when bombarded by energized gas particles.[11] This produced light levels on par with incandescent or electric discharge lamps, but at lower wattage—and thus cooler temperatures. Such coatings proved difficult to produce and apply; however, and Edison soon abandoned the project.

Fluorescent lamps rely on similar principles to those explored by Edison: glass tubes lined with phosphor-rich powder and filled with a low-pressure inert gas and a small quantity of mercury, which vaporizes in the tube's near-vacuum. Electrodes pass an arc through this gaseous mixture, which causes the mercury to emit radiation across the spectrum. While this alone produces some visible light—the electric discharge effect—it is the invisible, ultraviolet radiation accompanying this that excites phosphors in the tube's coating, which in turn produce visible light.[12] By adjusting the phosphors' chemistry, engineers could adjust the emitted light's color and intensity.[13] Electric discharge lamps required several ounces of mercury to produce adequate light, but fluorescents required only a few milligrams to energize their phosphorescent coatings. While fluorescents were simple and efficient in principle, making a viable lamp from these delicate chemical and electrical reactions required technical innovation and engineering finesse. Among other issues, fluorescent lamps become more efficient conductors as they energize. As a result, they require electric ballasts to prevent runaway electric currents. Starting also requires a precise mixture of argon and mercury vapor, and fluorescent lamps are sensitive to temperature—mercury emits radiation most efficiently at 45°C (113°F).

Despite the painstaking engineering required, researchers remained interested in fluorescents during the incandescent era for three reasons. First, by spreading their output over a bulb's broad surfaces instead of concentrating it in a single point-source filament, fluorescent lamps addressed incandescents' persistent glare and brightness problems—the "low intrinsic brilliancy" suggested by Bell in 1912. Second, whereas an incandescent lamp's maximum life was around 1000 hours, fluorescent lamps averaged 2500-5000 hours.[14] Finally, fluorescent lamps offered improved thermal efficiency. By 1943, despite constant improvements, 100-watt tungsten filaments still converted less than 7% of their electricity consumption into useful light.[15] A 40-watt fluorescent lamp converted more than 18% of its energy into visible light, providing as much illumination but at less than half the incandescents' wattage.[16] This reduced the electricity needed to illuminate a given space, and with this came a direct reduction in heat—3.415 British Thermal Units for every watt-hour of energy consumed.[17] 40-watt fluorescent lamps had bulb surface temperatures of 100°F to 120°F, compared to 250°F for 100-watt incandescent lamps, yet both produced the same amount of visible light. As air conditioning encouraged more scientific attention to thermal comfort in the 1930s, the heat produced by incandescent lighting proved a troublesome factor; *Progressive Architecture* estimated that each incandescent lamp in a building required an additional $14 to $23 of increased air conditioning capacity.[18]

The advantages of fluorescent lamps only reached the market, however, with dedicated engineering and experimentation. GE and Westinghouse had enjoyed a near-corner on the incandescent market, producing 78% of the nearly 700,000,000 lamps sold in the United States. This had discouraged research into alternative lighting technologies, but the two companies had mounting concerns. The American patent on tungsten filaments—filed by two Austrian citizens, purchased by General Electric, and granted in February 1912—was set to expire in 1929.[19] Agreements with glass suppliers such as Corning kept the two companies ahead of their competitors, but independent manufacturers such as Hygrade, which merged with radio manufacturer Sylvania in 1931, posed a growing threat and General Electric looked for a new strategic, competitive edge.

In October, 1934, physicist Arthur Compton saw an experimental fluorescent lamp in an English laboratory and, as a technical consultant on retainer to GE, he urged executives at Nela Park to pursue the idea as a potential new market to dominate.[20] Researchers led by George Inman began work that November, building on tentative but fruitless experiments with fluorescence in electric discharge lamps done by GE engineers in Schenectady, by those that Compton had seen in England, and by French scientists who employed luminescent solids to correct the mercury discharge lamps' green color.[21] Within a few weeks, the GE team developed a working 10-inch lamp that proved fluorescent's feasibility. They launched parallel initiatives to develop ballasts and manufacturing tools. Westinghouse and Sylvania followed GE's lead, as did Dutch manufacturer Philips. Three years of fine-tuning followed GE's prototype; internal correspondence revealed that the prodigious performance promised by fluorescent technology only occurred with a delicate balance:

> "Within the range of acceptable bulb sizes, the designer (of fluorescent lamps) must compose the electrical characteristics to produce the desired lumens per foot, brightness per square inch of tube, and over-all efficiency. He must adjust the electrical relationship of current, voltage, lamp loading (which is the wattage-diameter-length relationship), and related gas pressures so as to provide reliable starting and satisfactory regulation under operating conditions as to temperature and humidity."[22]

General Electric demonstrated prototype fluorescent lamps at the Illuminating Engineering Society's annual meeting in Cincinnati in September, 1935, at a dinner celebrating the U.S. Patent Office's centenary in Washington, D.C., that November, and at the American Institute of Electrical Engineering's annual meeting in 1936. (Figure 1) The company's publicists described progress in restrained terms, however, as merely "a laboratory development of great promise."[23] After work by Philip Pritchard and his team on the precision manufacturing necessary to produce thin, coated, tubular bulbs and to fill these with argon and mercury vapor, GE announced in April, 1938, that fluorescent lighting's "efficiencies heretofore unobtainable" would reach the market that spring. Along with Westinghouse, they offered three lamp sizes—18, 24, and 36 inches—ranging from 15 to 30 watts. The new lamps' debuts at the World's Fairs in 1939 were sensational; the *New York Times* reported that thirty percent of the New York fairgrounds were illuminated by fluorescents offering a visual 'softness' and nuance that contributed to the Fair's signature 'Wellsian fantasy of color' in a precise realization of Bell's prediction of phosphorescent light similar to that of 'photogenic bacteria and perhaps the fireflies.'[24] (Figure 2) Much of the Golden Gate Exposition's billion-and-a-half candlepower came from fluorescent lamps as well, in particular the soft pink light that bathed the 'Court of Reflections.'[25] Public response was enthusiastic and GE, along with its prime licensee, Westinghouse, scrambled to increase production. Having manufactured 200,000 units in 1938, the companies manufactured 1.6 million lamps in 1939, 7.1 million in 1940, and 21 million in 1941, when their key patents were finally granted.[26] Upstart manufacturer Hygrade/Sylvania pursued parallel patents, spurring competition that reduced prices by 2/3, raised average lumens-per-watt across the industry from 35 to 50, and increased options in color and size, all by 1942.[27] While GE and Westinghouse concentrated on the lamps themselves, Hygrade/Sylvania offered "complete units of light" to their customers, matching their lamps with fixtures that could manipulate, direct, or diffuse their output.[28]

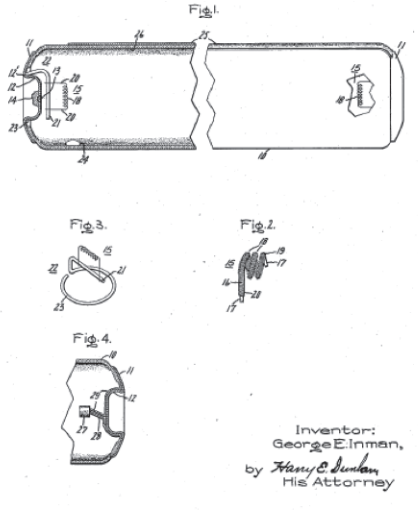


Figure 1. George E. Inman (General Electric). U.S. Patent #2,259,040 for "Electric Discharge Lamp." Filed 22 Apr 1936, granted Oct. 14, 1941.

Figure 2. Fluorescent lighting's public debut at the New York World's Fair, 1939. Manuscripts and Archives Division, The New York Public Library. "General Motors - Building - Aerial view at night with Trylon and Perisphere in background" The New York Public Library Digital Collections. 1935 - 1945. http://digitalcollections.nypl.org/items/5e66b3e8-e3e4-d471-e040-e00a180654d7

World War II accelerated the fluorescent lamps development and production. Wartime restrictions on metal limited manufacturers' ability to supply fixtures, forcing them to look for alternative materials. At the same time, the war effort itself increased industrial demand for illumination. Here, fluorescent lighting proved itself. Large, open factory floors could take the best advantage of its improved efficiency. Its diffuse light meant that it required less elaborate fixtures to cast an even illumination over work areas and plant designers also recognized that the fluorescent lamps cool operation matched the sophisticated climate control systems needed for precision manufacturing. (Figure 3) In 1940, engineers for the Austin Company paired one of the country's largest and most complex air conditioning systems with 40-watt, three-lamp fluorescent fixtures throughout General Motors' Allison aircraft engine plant in Speedway, Indiana, citing lighting load as a major factor in their design and calculations. The factory's ambient temperature—held between 70°F and 78°F throughout the year—and the even, reliable illumination offered by cooler, efficient fluorescent fixtures enabled "high-speed quantity production methods to the manufacture of airplane engines."[29] A contemporaneous factory, also designed by the Austin Company, for Simonds Saw in Fitchburg, Massachusetts, matched fluorescent lighting with 400,000 cfm of precision air conditioning.[30] (Figure 4) When first planned in 1931, designers had specified 650-watt incandescent fixtures, but depression-related delays in construction until 1939 made fluorescent lighting's efficiencies available and the factory was ultimately outfitted with 1400 100-watt fluorescent tubes that provided 20 foot-candles on work surfaces throughout the plant.[31] This "manufactured north light," a reference to the desirable, glare-free daylight that factory skylights are designed to maximize, worked well enough that the entire Simonds complex was designed without windows.[32] "The scientific superiority of artificially controlled environment furnished the basis for designing this completely windowless plant," reported *Architectural Record*. "Air, light, heat, humidity, and sound are all regulated to provide the best attainable working conditions for employees, and a maximum of efficiency in manufacturing processes."[33] Simonds estimated that air conditioning and fluorescent lighting, along with improvements in acoustics, increased worker efficiency by 35%.

Figure 3. The Western Aircraft Plant in Fort Worth in 1942, "a plant equipped with one of the best air conditioning and fluorescent lighting systems in the country" that produced B-24 and C-87 aircraft for the American war effort. United States Office of War Information, Hollem, Howard R, photographer. Fort Worth Fort Worth. Tarrant County Texas United States, 1942. Oct. https://www.loc.gov/item/2017694769/.

Figure 4. The Simonds Saw Factory, Fitchburg, MA (1931, 1939) exemplified the trend toward "Controlled Conditioning" for lighting and climate. Advertisement, Carrier Air Conditioning Company. Architectural Record, February, 1940. p. 117.

Cooler operation, diffuse illumination, and lower electricity consumption all made fluorescent lighting the preferred system for wartime factories. The Simonds example showed, too, that enclosed, windowless factories were feasible, an important design aspect as fears of Axis bombing raids led to blackout conditions at night. "One of the recent romances of American Industry is the development of fluorescent lighting," wrote Lester Smith in the *Wall Street Journal* in 1942. "Not since Thomas A. Edison invented the incandescent lamp has the art of lighting undergone as radical a change as that which has occurred in the past few years."[34] Workers in factories during WWII enjoyed more than double the illumination on their tasks as had those in WWI and the new fixtures provided up to twenty times previous installations' candlepower. Ford's plant at Willow Run used more than 100,000 fluorescent lamps, allowing greater precision and faster production on bombers manufactured there. "The brightest lights today aren't found on dimmed-out Broadway," noted the *Journal*. "They are in the arms factories where vastly improved illumination is helping war workers chalk up impressive production records."[35]

Postwar introduction

Fluorescent lamps were limited to industrial production through the war, but their benefits were anticipated for residential and commercial use. When the war ended, the lighting industry had a tremendous overcapacity, bringing costs down and forcing GE, Westinghouse, Sylvania, and other competing manufacturers to find new markets for lamps and fixtures. Manufacturers saw limitless potential in the energized postwar economy; industry produced nearly 41 million fluorescent lamps in 1945, but it still manufactured nearly 800 million incandescent lamps.[36] Department stores were quick to take advantage of fluorescent fixtures' soft, soothing light and enthusiastic designers foresaw "handfuls" of fluorescent lamps replacing the "dozens" of incandescent lamps in a typical American home. Residential adoption proved slower, in large part because of their poor color rendition; Bell's recognition of the need for 'delicate color tones' proved nearly impossible with fluorescent's overwhelmingly blue output. The new lamps' linear geometry, though, offered a powerful new approach to office lighting, matching radical changes in the way offices were being organized. While the "fireless light" made inroads in homes and stores throughout America in the 1950s, it was in offices, and especially high-rise offices, where it found its most robust market and its ideal architectural application.

Open-plan offices had lighting needs analogous to the Allison or Simonds plants' factory floors. Office planners, architects, and illuminating engineers thus matched technical developments in fluorescent lighting to office layouts; a new, integrated approach to lighting and thermal control. The incandescent lamps high bulb temperatures had limited the materials that could be used to shade, focus, or diffuse their intense output; a glass globe could diffuse an incandescent lamp's brightness, but glass was heavy and expensive and a globe trapped and converted more of the lamp's luminous energy into heat. More efficient louvers or baffles had to be fabricated from materials that could handle constant high temperatures. Glass and metal had thus formed the basic material vocabulary for luminaires throughout the early 20th century, but material science in the 1930s offered new possibilities, in particular plastics. Here, the heat from incandescent lamps had proved limiting. Thermoplastic resins such as Bakelite, acetate, and polystyrene soften and deform at temperatures ranging from 127°F to 212°F—polystyrene's *melting* point is 248°F, just below a tungsten filament lamp's bulb temperature. Thermo*setting* plastics such as melamine and acrylic can withstand higher temperatures without softening, but here incandescent lamps' high heat created issues such as discoloration and brittleness; even acrylic has a service temperature of just 195°F, making it unsuitable for incandescent luminaires.[37]

Architectural Record recognized the potential for plastics within cooler fluorescent luminaires, however, as early as 1939:

> "Plastics are lighter in weight than glass or metal, permitting savings in structural details, and greater safety in the use of overhead fixtures. They are less breakable than glass and less likely to crack from sudden temperature changes. Thickness, color, and shape can be controlled with precision, and optical characteristics can be varied to suit requirements as to transmission, reflection, and diffusion; but they are not practical for control by refraction. Some plastics can transfer light by internal reflection, like diffused quartz. The use of plastics with the larger filament lamps and with electric discharge sources is still limited because of its inability to withstand the temperatures developed. They will probably be used more widely with the cooler fluorescent lamps."[38]

In 1946, Underwriters Laboratories determined that "polystyrene and…other slow-burning plastics" were suitable for use in fluorescent lamp fixtures, and by the next year exhibitors at the International Lighting Exposition in Chicago told the *Chicago Tribune* that "plastics have largely replaced glass in fluorescent fixtures."[39] Thermoplastic materials could be produced in a range of opacities and could be molded or extruded into more precise, complex shapes than glass. This presented opportunities not only for shades and louvers but also for lenses and diffusers that could replace the heavy glass globes that had surrounded incandescent lamps. Acrylic louvers and diffusers were matched by aluminum louvers and reflectors. Both materials were lighter and, after the war, less expensive than glass or steel.[40] *Scientific American* predicted that plastics would "guide, blend, transport, and control light" in ways that would "be a stimulus to production, worker morale, and safety."[41] (Figure 5)

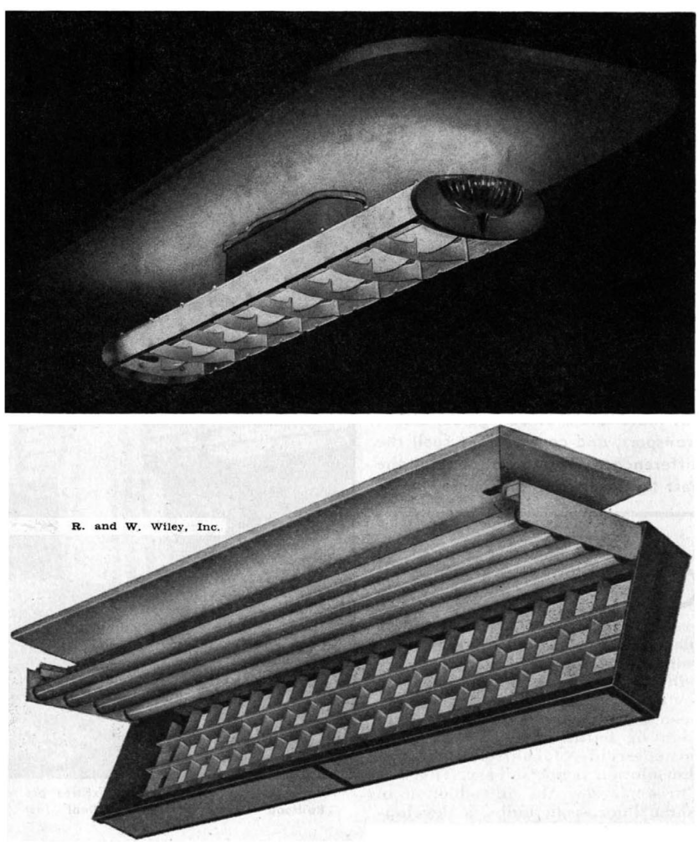
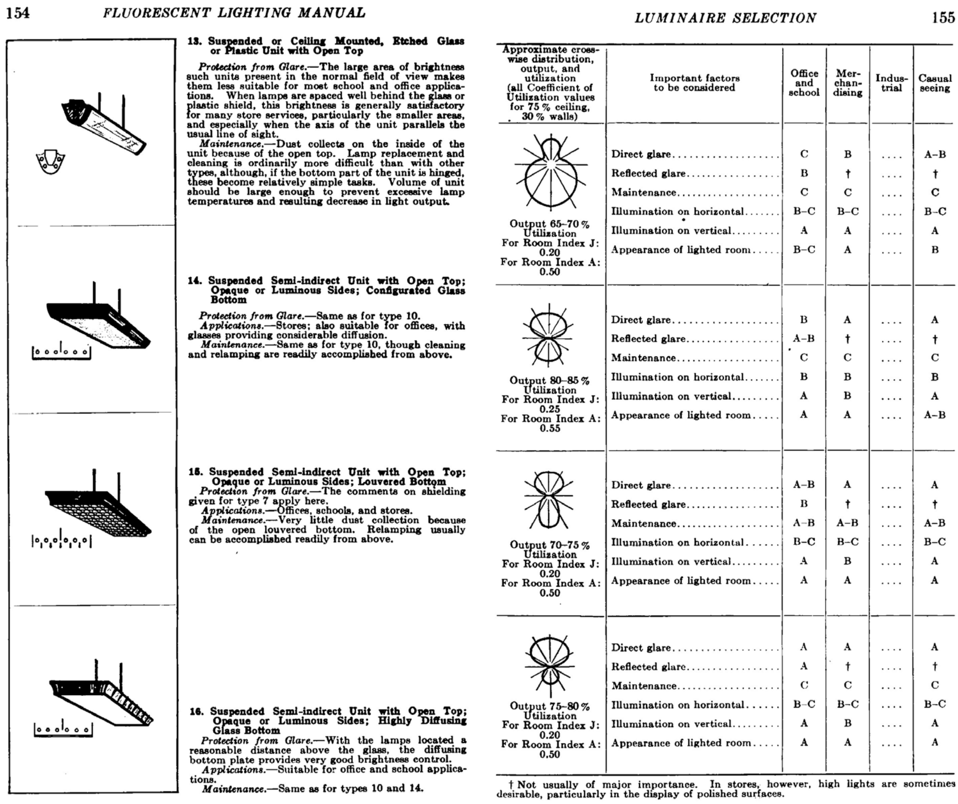


Figure 5. Two early uses of plastic diffusers in fluorescent fixtures that took advantage of the new lamps' cool operating temperatures to provide precise distribution on work surfaces and ceilings. "Partners in Light," Scientific American, May, 1946. p. 200.

Plastics were critical in developing strategies for visual comfort in open work areas because of the lingering problem with glare from exposed lamps. While fluorescent lamps spread their light output over a greater area than incandescent lamps—a reduction of almost 98% in direct foot-candles, according to one source—they were still too bright to be fully exposed in office environments. Such "light out of place" had been acceptable in factory installations where workers moved around but for continuous visual tasks even minimal glare was distracting and inefficient.[42] Lighting designers addressed this by manipulating fixture locations relative to the ceiling, tuning fixtures to distribute some lamp light upward and using bright white ceiling surfaces as giant reflectors. This indirect approach could be supplemented by louvers that shielded views of the lamp itself, but that still permitted light to illuminate work surfaces below. This worked well in theory since diffuse background lighting reduced eyestrain for more intensely-illuminated visual tasks, but in practice it proved difficult to balance light emerging from the fixtures' tops with that directed downward. Suspended fixtures needed to be placed well above head height, however. In typical offices with ceiling heights less than 10'-0", a light located at the accepted minimum for headroom, 6'-8", would be closer to the ceiling than to a 29" high desk. Research in the late 1930s suggested that a ceiling half as bright as the work surface would be most comfortable but illuminating ceilings from suspended fixtures produced ceilings that were up to fifteen times brighter than desks below.[43] This imbalance was worsened if ceiling heights were lower, and high-rise construction, where every inch of building height is critical, placed particular pressure on these dimensions. Fixtures set into ceilings, with light reflected into the room from within, emerged as a more effective arrangement.

Luminaire design thus balanced several factors: preventing direct glare, balancing direct and indirect illumination, distributing light over work surfaces, and limiting impact on room cooling loads. Manufacturers responded with new fixtures that worked with the fluorescent lamps narrow, tubular geometry. While consumers had "become…accustomed to circular-shaped lighting equipment," the new lamps' long, narrow proportions determined by the need to limit the distance from activating mercury vapor to fluorescing phosphorescent coating, created "more dominantly linear" solutions that suggested "lines of light," rather than points.[44] Fixtures incorporated reflecting and diffusing elements along these lamps' lengths, matching plastic's extrusion processes to the linear nature of the tubes themselves. Distributing light became a geometrical exercise in cross section, while louvering or shielding was handled along the lamps' long dimensions. Aluminum provided a lightweight, thin reflective surface that could be bent into precise parabolic shapes to focus light or cut into blades to baffle or shade it, while plastics were molded or extruded into lens-like or prismatic patterns that could diffuse a tube's light over a flat surface. Manufacturers began producing fixtures tuned to mounting locations within ceilings that diffused or concentrated light in reliable patterns along their axes. Standardized light distribution charts and tables for fixtures enabled designers to assess how many foot-candles could be thrown onto work surfaces or ceilings at varying angles, and lighting design became more science than art, with predictable effects obtained through aluminum and plastic fixtures that focused, diffused, baffled, or concentrated light from fluorescent tubes.[45] (Figure 6)

The resulting precision was matched by architectural possibilities. Linear fixtures could be arrayed in coves or cornices, for instance, providing even lighting over ceiling and wall planes. Attention focused, however, on "troffers," flush-mounted ceiling units that combined a "trough" fixture with "coffer" lighting to provide an illuminating ceiling. Troffers could be arrayed in ranks across open offices and tuned, with lenses, reflectors, or adjustments in how many lamps each contained, to provide continuous, consistent background and task lighting along work surfaces and surrounding walls. The regular "lines of light" provided ceilings that were bright but comfortable.[46] One study showed that fluorescent troffers could, if placed adjacent to one another, throw up to 375 foot-candles over a whole office, far exceeding recommended levels—levels that were changing as the fluorescent lighting's efficiencies became commonplace.



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13. Suspended or Ceiling Mounted, Etched Glass or Plastic Unit with Open Top

Protection from Glare.—The large area of brightness such units present in the normal field of view makes them less suitable for most school and office applications. When lamps are spaced well behind the glass or plastic shield, this brightness is generally satisfactory for many store services, particularly the smaller areas, and especially when the axis of the unit parallels the usual line of sight.

Maintenance.—Dust collects on the inside of the unit because of the open top. Lamp replacement and cleaning is ordinarily more difficult than with other types, although, if the bottom part of the unit is hinged, these become relatively simple tasks. Volume of unit should be large enough to prevent excessive lamp temperatures and resulting decrease in light output.

14. Suspended Semi-indirect Unit with Open Top; Opaque or Luminous Sides; Configurated Glass Bottom

Protection from Glare.—Same as for type 10.

Applications.—Stores; also suitable for offices, with glasses providing considerable diffusion.

Maintenance.—Same as for type 10, though cleaning and relamping are readily accomplished from above.

15. Suspended Semi-indirect Unit with Open Top; Opaque or Luminous Sides; Louvered Bottom

Protection from Glare.—The comments on shielding given for type 7 apply here.

Applications.—Offices, schools, and stores.

Maintenance.—Very little dust collection because of the open louvered bottom. Relamping usually can be accomplished readily from above.

16. Suspended Semi-indirect Unit with Open Top; Opaque or Luminous Sides; Highly Diffusing Glass Bottom

Protection from Glare.—With the lamps located a reasonable distance above the glass, the diffusing bottom plate provides very good brightness control.

Applications.—Suitable for office and school applications.

Maintenance.—Same as for types 10 and 14.

LUMINAIRE SELECTION 155

Approximate crosswise distribution, output, and utilization (all Coefficient of Utilization values for 75% ceiling, 30% walls)	Important factors to be considered	Office and school	Merchandising	Industrial	Casual seeing
Output 65–70% Utilization For Room Index J: 0.20 For Room Index A: 0.50	Direct glare	C	B	....	A–B
	Reflected glare	B	†	....	†
	Maintenance	C	C	....	C
	Illumination on horizontal	B–C	B–C	....	B–C
	Illumination on vertical	A	A	....	A
	Appearance of lighted room	B–C	A	....	B
Output 80–85% Utilization For Room Index J: 0.25 For Room Index A: 0.55	Direct glare	B	A	....	A
	Reflected glare	A–B	†	....	†
	Maintenance	C	C	....	C
	Illumination on horizontal	B	B	....	B
	Illumination on vertical	A	B	....	A
	Appearance of lighted room	A	A	....	A–B
Output 70–75% Utilization For Room Index J: 0.20 For Room Index A: 0.50	Direct glare	A–B	A	....	A
	Reflected glare	B	†	....	†
	Maintenance	A–B	A–B	....	A–B
	Illumination on horizontal	B–C	B–C	....	B–C
	Illumination on vertical	A	B	....	A
	Appearance of lighted room	A	A	....	A
Output 75–80% Utilization For Room Index J: 0.20 For Room Index A: 0.50	Direct glare	A	A	....	A
	Reflected glare	A	†	....	†
	Maintenance	C	C	....	C
	Illumination on horizontal	B–C	B–C	....	B–C
	Illumination on vertical	A	B	....	A
	Appearance of lighted room	A	A	....	A

† Not usually of major importance. In stores, however, high lights are sometimes desirable, particularly in the display of polished surfaces.

Figure 6. Early charts showing light distribution from fluorescent fixtures using plastic diffusers and lenses. From Charles L. Amick, General Electric, Fluorescent Lighting Manual. (New York: McGraw-Hill, 1942). pp. 154-155.

Integration with Air Conditioning

Fluorescent's advances in cost and energy efficiency influenced the very definitions of visual comfort. In 1912, Louis Bell suggested that "nearly all classes of clerical and office work can be performed easily under an illumination of 3 to 4 foot-candles."[47] As more powerful tungsten filaments became available, however, this standard changed with the easy availability of brighter, more efficient sources.[48] By 1938 experts recommended 10-30 foot-candles for "general office" tasks, with a distinction between background lighting and task lighting to reduce visual fatigue and a special emphasis on eliminating glare from exposed filaments and in 1942 GE engineer Charles Amick reported that "modern fluorescent office illumination is being installed at 50 foot-candles or more"[49] In 1957, the Illuminating Engineering Society doubled its recommended lighting levels for offices. Based on work done by University of Michigan research scientist H. Richard Blackwell, it suggested that 100 foot-candles should be provided in office settings-*thirty times* the standard levels just forty years earlier.[50] While the new levels were praised for their scientific derivation and greater worker productivity, air conditioning engineers reacted to these new provisions with alarm, since doubled lighting levels doubled the number of fluorescent lamps which would produce twice as much heat for their systems to handle. W.S. Fisher and J.E. Flynn, two engineers with General Electric, argued in 1959 that "the effect of lighting on air conditioning" was, with the new recommendations, "even more serious…when conventional methods of cooling are employed."[51] (Figure 7)

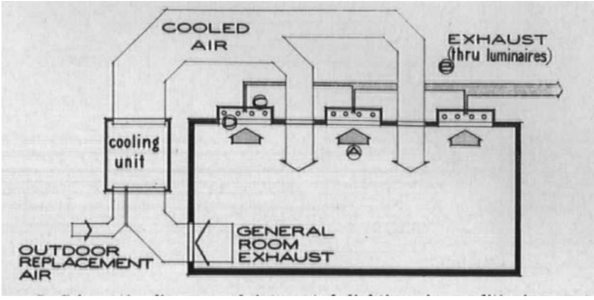

Figure 7. W.S. Fisher and J.E. Flynn's scheme for using fluorescent fixtures to remove fixture and room heat. "Air Conditioning for Higher Lighting Levels." Architectural Record, November, 1959. p. 230.

Given these higher standards, fluorescent light's thermal efficiency made it the only possible solution for office lighting from an air-conditioning standpoint. Samuel Adams Bogen, writing in *Progressive Architecture* in 1950, made the case that incandescent lighting, despite lower installation costs, was "a luxury that few jobs these days can afford in any quantity" because of its higher heat output[52] A 40-watt fluorescent lamp, even with a 10-watt ballast attached, saved more than just 100 watts of power over a 150-watt filament lamp. Bogen estimated that it also saved an additional 37 watts of cooling load. Fisher and Flynn, however, noted an additional distinction between the two lighting types. Because the optical geometries of the incandescent lamps' point sources and the linear bulbs of the fluorescents were so different, luminaire designs for the two had very different goals; simply dispersing light in the first instance, and baffling and focusing it in the second. Fluorescent luminaires thus have more surfaces that absorb longwave radiation than incandescent fixtures, and while the heat emitted from incandescent lamps tends to be transmitted into rooms, it tends to build up within luminaires.[53] Ballasts on fluorescent fixtures further this distinction; Fisher and Flynn figured that 40-watt fluorescent fixtures absorbed more than 60% of the heat that would otherwise be introduced to rooms below by 150-watt incandescent lamps.[54] The room cooling needed to counteract such heat gain could be eliminated with dedicated extraction to remove heat from fluorescent luminaires themselves. H.L. Logan, an engineer for lighting manufacturer Holophane, suggested in 1939 that using ceiling space to exhaust heat from fluorescent fixtures would align lighting's needs with other systems, reducing refrigeration loads and making a dedicated service space between ceilings and floors above a viable proposition.[55] Fisher and Flynn's article, which appeared in *Architectural Record* twenty years later, reported on research at Nela Park that tested three variations on this idea: ventilated ceiling-mounted fixtures that used heat absorbed by luminaires and ballasts to draw exhaust air from the room into a ceiling plenum, and two configurations of bare lamps mounted *above* a 'luminous ceiling' composed of either open or closed plastic surfaces that baffled and focused their light.[56] These all exhausted around 40% of the total heat generated by each fixture directly, without ever entering the room, leading to substantial savings in room cooling capacity. An integrated system that tied luminaire design and exhaust strategies together, Fisher and Flynn predicted, would save 2/3 the cost of a typical air conditioning system for an office building, making the new, higher foot-candle standards more achievable.[57]

This integration was not only mechanical, however, it was also architectural. If luminaires were to serve as key exhaust elements in mechanical systems, they had to be located in conjunction with supply outlets to avoid short-circuiting and to maximize airflow efficiency. Standard ceiling modules had already emerged that integrated office planning with fluorescent lighting's linear geometry, air conditioning supply and exhaust patterns.[58] In particular, the lamps themselves generated key ceiling dimensions. The narrow diameter of bulbs, between ¾ and 1-1/2 inches, meant that the parabolic geometry for reflectors was most effective around 6" wide, which became a standard module for fixtures that could be multiplied to hold additional lamps.[59] A quirk of efficiency also influenced fluorescent fixtures' linear dimensions. The electrical arcs that generated the initial luminosity from mercury vapor were most effective between forty and fifty inches. Lamps shorter than this wasted generating voltage, while longer lamps produced fewer gains in efficiency.[60] While lamps in standard sizes from 10 to 60 inches were produced throughout the era, the 48-inch long 40W T-12 lamp became the most popular, matching the efficiency that came with length with relatively easy handling.

As larger, more open, offices became corporate standards, fluorescent lighting proved responsive to their need for flexibility. The desire for efficiency was matched by the need for even illumination over work surfaces that might be re-arranged often. Even with the best diffusers and reflectors, fixtures spaced too far apart produced a 'roller-coaster' effect of brighter and darker illumination. Amick and others thus recommended "spacing distances which do not substantially exceed the mounting height," between 9' and 11', with 1/3 room height suggested between fixtures and walls to prevent distracting scalloping patterns.[61] These dimensions, combined with structural bays in high-rise buildings that were most efficient at spans between twenty-five and forty feet, contributed to ceiling modules of around ten feet, often split in two with every other panel centered on fluorescent fixtures. These incorporated exhausts within the fixture itself, using the lamp's heat to encourage airflow, and with supply registers located at each modules' edges to maximize the ventilation circuit's length. Once established, these modules were most efficient when they could be deployed in uninterrupted ranks; walls were not only impediments to the workflow of the offices, they were also barriers to effective illumination and ventilation. This modular approach was aided by a new generation of adaptable luminaires, which could hold up to six lamps or as few as one, allowing the same ceiling module to serve diverse needs, from reception areas to high-intensity drafting or production rooms.[62] Louvers and prismatic lenses diffused light over modules that could be partitioned at various heights without interrupting even illumination over work surfaces. (Figure 8) In some cases, fixtures were incorporated within the ceiling itself; egg-crate louvers or plastic diffusers obscured the lamps, forming 'glowing ceilings' that offered an even background while casting diffuse working light on desks below. Plexiglas manufactured a perforated plastic sheet for such ceilings by 1960, while Westinghouse and Sylvania experimented with phosphor-coated glass panels to provide ceiling that, themselves, illuminated rooms below.[63] Well-illuminated spaces also brought with them changes in finishes and fixture design. "Office lighting today has revolutionized the entire office scene," noted one planning expert. "In today's office, the wall and ceiling colors, as well as the floor and office equipment, are all coordinated with the desired lighting intensities. Dark walls, floors, and furniture are out of harmony" with cool, diffuse, fluorescent lighting.[64] (Figure 9)

Just how well-aligned fluorescent lighting, visual and thermal comfort, and the trend toward open, flexible office spaces all were can be seen by comparing two editions of the field's primary reference source, the *Fluorescent Lighting Manual* by lighting engineer Charles Amick. (Figure 10) First published by McGraw-Hill in 1942 (cited above), a second edition was published in 1947 and a third in 1961, each updated to reflect changes in standards (including the IES' raised foot-candle recommendations in the third edition), available technology, and the latest thinking among designers and engineers regarding placement and configuration.[65] A chapter titled "Fluorescent Applications" shows typical installations for commercial, industrial, and residential spaces. While industrial applications dominated the first edition, by the third edition these were relegated to the end of the photographic essay; offices took the lead in 1961. The first edition included just one open office space and two drafting rooms, illuminated by individual troffers mounted within hard ceilings; the third edition, in contrast, showed four open spaces and four drafting rooms, featuring parabolic troffers with aluminum louvers, acrylic plastic lenses deployed in glowing ceilings, and well-tuned side and upward-casting fixtures in reading and drafting areas. Whereas the 1942 examples treat fixtures as isolated objects—mounted to or

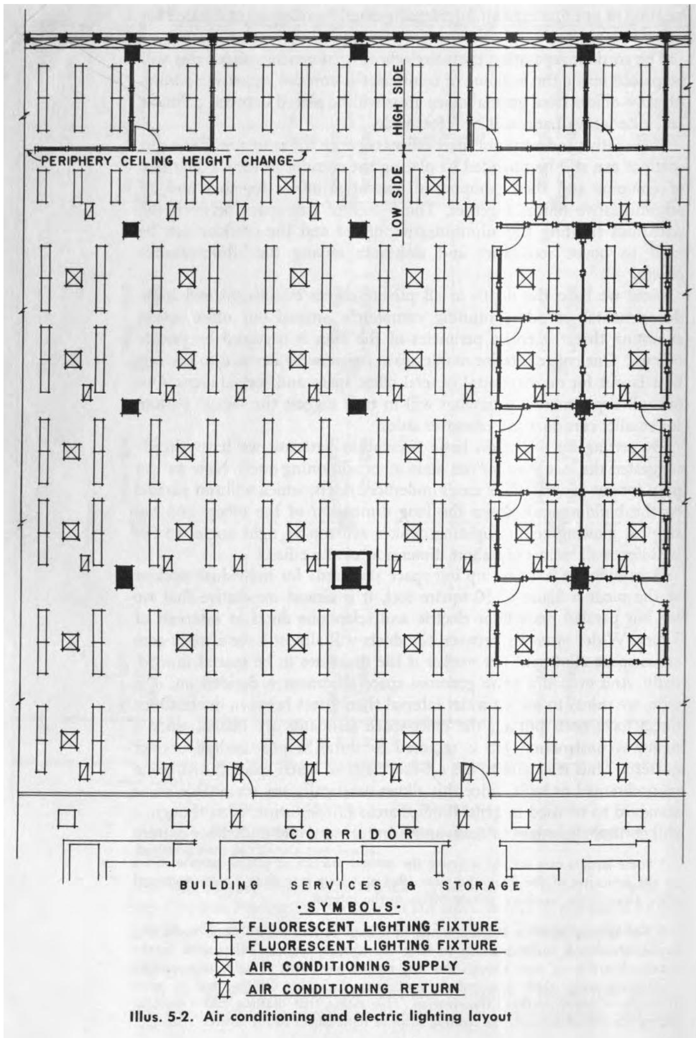

Figure 8. Office planning expert Kenneth Ripnen summarized the resonance between spatial patterns of office work and the illuminatory rhythms of fluorescent fixtures in prototype ceiling plans in his 1960 manual. Kenneth H. Ripnen, RA, AIA. Office Building and Office Layout Planning. (New York: McGraw-Hill, 1960). p. 53.

suspended from the ceiling and serving enclosed, cellular office spaces, later images show fluorescent lighting as one of several integrated systems in modular, expandable work environments. These positions and rhythms of the fixtures varied according to tasks and architectural preferences—office desks were served by longitudinally-arranged fixtures to illuminate desk surfaces and drafting rooms often had fixtures aligned parallel to the desks to reduce glare, for instance. But the effects that Ripnen and others had noted—lighter colors, modular furniture placement, and a ceiling transformed from a hard plaster surface to a lightweight, accessible modular plane that supported and concealed environmental services—became consistent office features after the 1958 change in recommended lighting levels and the impetus these provided toward integrated systems.

Figure 9. IBM Manufacturing and Administrative Center, Rochester, Minnesota, 1956-58. Office interior with fluorescent fixtures and coordinated finishes. Balthazar Korab collection of photographs showing Eero Saarinen architecture, Library of Congress, Prints and Photographs Division.

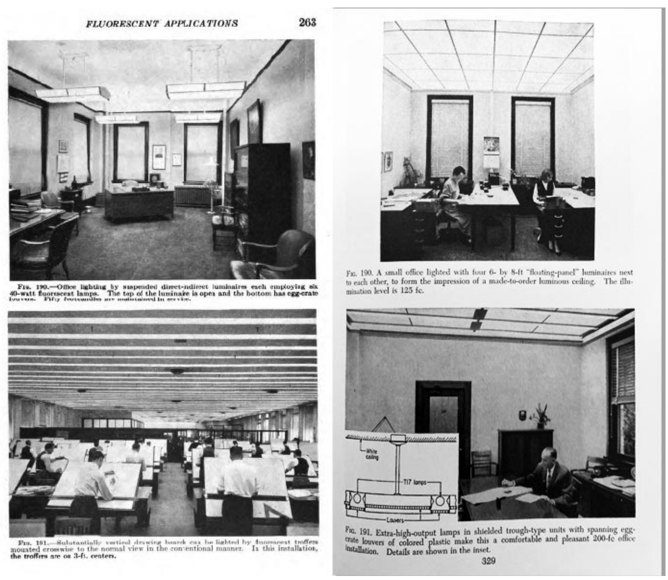

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FIG. 190.—Office lighting by suspended direct-indirect luminaires each employing six 40-watt fluorescent lamps. The top of the luminaire is open and the bottom has egg-crate louvers. Fifty footcandles are maintained in service.

FIG. 191.—Substantially vertical drawing boards can be lighted by fluorescent troffers mounted crosswise to the normal view in the conventional manner. In this installation, the troffers are on 3-ft. centers.

FIG. 190. A small office lighted with four 6- by 8-ft "floating-panel" luminaires next to each other, to form the impression of a made-to-order luminous ceiling. The illumination level is 125 fc.

FIG. 191. Extra-high-output lamps in shielded trough-type units with spanning egg-crate louvers of colored plastic make this a comfortable and pleasant 200-fc office installation. Details are shown in the inset.

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Figure 10. Fluorescent applications in two versions of Charles L. Amick's Fluorescent Lighting Manual (op. cit.), showing presumed usage in 1942 and 1960.

Examples

What Reyner Banham called the "power-membrane" ceiling—an overhead surface combining mechanical, electrical, and lighting services—developed throughout the mid-20th century, with direct antecedents as early as the 1932 PSFS Building in Philadelphia.[66] But it was not until the late 1950s, when thermal and visual comfort standards collided, that it became systematic and ubiquitous. The economic necessity of removing heat from lighting fixtures, after the 1958 recommendations, disqualified incandescent lighting from large open office installations. It also required integrated solutions to lighting and mechanical requirements. There were two distinct stages in the integrated environmental ceiling's development. First, there was a tendency in the mid to late 1950s toward the luminous ceiling solution, with broad overhead planes dominated by plastic-lensed fixtures that provided uniform, diffuse lighting and ceiling plenums with supply and exhaust that were separate from, or only casually related to, fixture configuration and placement. Second, after 1960 designers tended toward solutions that integrated exhaust with lighting fixtures themselves, either through open troffers or dedicated exhaust boots connected to return air ductwork to evacuate heat from fixtures and ballasts.

Prime examples of the former approach can be seen in two well-known office towers by SOM—Inland Steel, Chicago, designed and built between 1954 and 1957, (Figure 11) and the Union Carbide Headquarters on Park Avenue, 1957-1960. (Figure 12) Inland Steel, while better known for its advanced structural and cladding systems, boasted a well-integrated ceiling system throughout its seventeen floors of open, flexible office space. Laid out on a 5'-2" module, its ceiling alternated perforated steel panels with recessed fluorescent fixtures enclosed by parabolic reflectors. Between these, supply and exhaust registers handled ventilation for most floor plates, with separate radiators and supply air registers at the building's perimeter. Hauserman developed a custom partition system on the building grid that enabled tenants to adjust floor layouts; the alternating lighting and ventilation bands in the ceiling assured that workspaces would have access to light, air supply, and exhaust, no matter how these were laid out. Elsewhere, Inland boasted luminous ceilings in its street entrance and each floor's elevator lobby, while its executive areas featured hard plaster ceilings with recessed incandescent downlights. Union Carbide's interiors, designed by Natalie de Blois, extended the integrated ceiling by focusing on a gridded system of supporting rails. These were designed as linear slots, made from cold-rolled stainless steel, that provided supply and exhaust air *between* ceiling panels, which each contained built-in aluminum reflectors and single fluorescent tubes, shielded by plastic diffusers. A rigorous 5'-0" x 2'-6" module organized these but permitted modular flexibility in layout. The resulting illumination levels were just 60-80 foot-candles, adequate under the old standards but not up to what the IES' recommended from 1958 on.[67] Nonetheless, Union Carbide's ceiling merited a seven-page spread in *Architectural Record*, whose editors noted its fluent ability to provide an "indoor sky—a plane of light" while providing "unlimited flexibility" and concealing lighting and mechanical systems. Hailing it as a 'fixture' ceiling that added planning flexibility to the typical 'luminous' ceiling system, *Record* noted that this represented an "unusual amount of collaboration by the building team," aided by the fact that one firm—Syska and Hennessy—provided mechanical, electrical, and lighting engineering on the project.[68]

Figure 11. Inland Steel Building, Chicago, IL. SOM, 1957. Interior view. (SOM)

Figure 12. Union Carbide Building, New York, NY. Interior view. SOM, 1960. (SOM)

The "fixture ceiling," however, underwent a key evolution after Union Carbide that followed Fisher and Flynn's proposal to directly evacuate excessive fixture heat due to the IES' mandated increases in lighting levels. SOM's design for the Crown Zellerbach Building in San Francisco (1957-59) was among the first to do this, with fixtures on a 5'-6" square module that included slots at their short ends that alternated supply and exhaust functions. Supply air was fed from ductwork through rectangular boots, while exhaust air flowed into a ceiling plenum, absorbing heat from transformers and ballasts but bypassing the lamps themselves, which were shielded by acrylic diffusers.[69] (Figure 13) Albert C. Martin and Associates' building for the Los Angeles Water and Power utilities, completed in 1961, integrated supply and exhaust slots within fixtures to "remove heat generated by the fluorescent lamps and ballasts before the heat has a chance to enter the room."[70] Martin worked with manufacturers to prototype and develop these fixtures, which included supply slots at their midpoints and apertures at their ends to draw room air across each lamp, removing heat from their entire length. Set on a 4'-2" x 2'-1" module, the ceiling provided a fixture in every other panel, on a checkerboard pattern that provided the then-requisite 100 foot-candles to office spaces below. (Figure 14) The result met, in *Record's* words, "the desire for neat appearance, the current emphasis on flexibility of space arrangement and the trend to higher lighting levels."[71] SOM's Armstrong Cork Company Building in Lancaster, PA adapted the Union Carbide ceiling system to include return air slots integrated within lighting fixtures themselves, showing the idea's evolution within that firm's general conception of the 'power-membrane' ceiling.

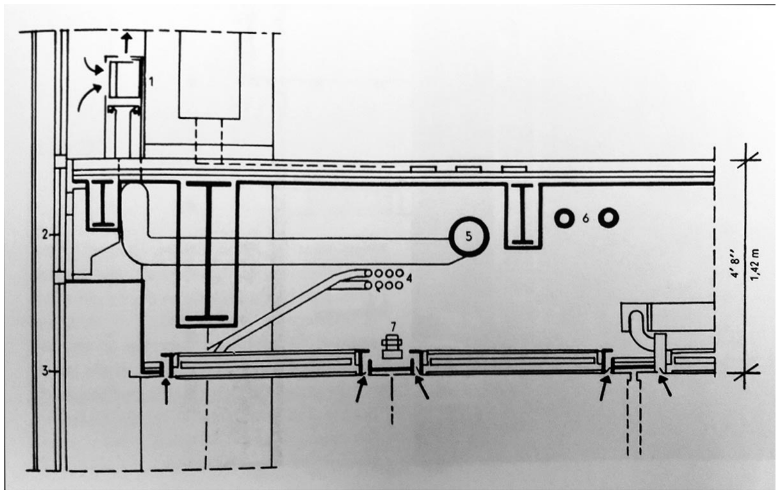

Figure 13. Crown Zellerbach Building, San Francisco, CA. Ceiling detail showing exhaust plenum in ceiling fed from fluorescent fixture. (SOM)

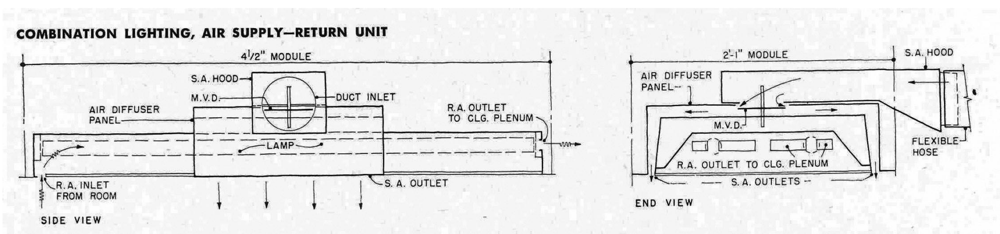

Figure 14. Water and Power Building, Los Angeles, CA. Albert C. Martin and Associates, Architects and Engineers, 1962. Detail of fluorescent fixture with integrated air supply and exhaust. Architectural Record, August, 1961. p. 143.

Conclusions: Lighting and the Energy Crisis, 1973

The integrated power-membrane ceiling, in one form or another, dominated corporate office design throughout the 1960s and 1970s. Fluorescent lighting, with its cooler operating temperatures and its pairing with plastic diffusers and aluminum louvers to spread light over work surfaces below, was a key component in the era's lighting and mechanical designs. Its linear geometry proved a better formal match for the layouts and lighting needs of industrial and office work. Fluorescent lighting's higher light levels and cooler temperatures encouraged the raised standards for illumination that banished incandescent lighting from all but executive suites of office buildings in the 1960s, which in turn influenced the development of standard office modules and the integration of lighting and mechanical services in hollow ceilings. (Figure 15)

The Illuminating Engineering Society's recommended levels were eased only after the 1973 and 1979 energy crises, when heating and cooling costs jumped in response to oil embargoes and shortages. In 1983, the IES passed new standards, distinguishing between various office tasks and allowing illumination levels between 20 foot-candles for "Reading High Contrast on Well-Printed Materials" and 200 foot-candles for "Detailed Drafting, Designing, Layout Drafting."[72] These reduced levels by 20-50%

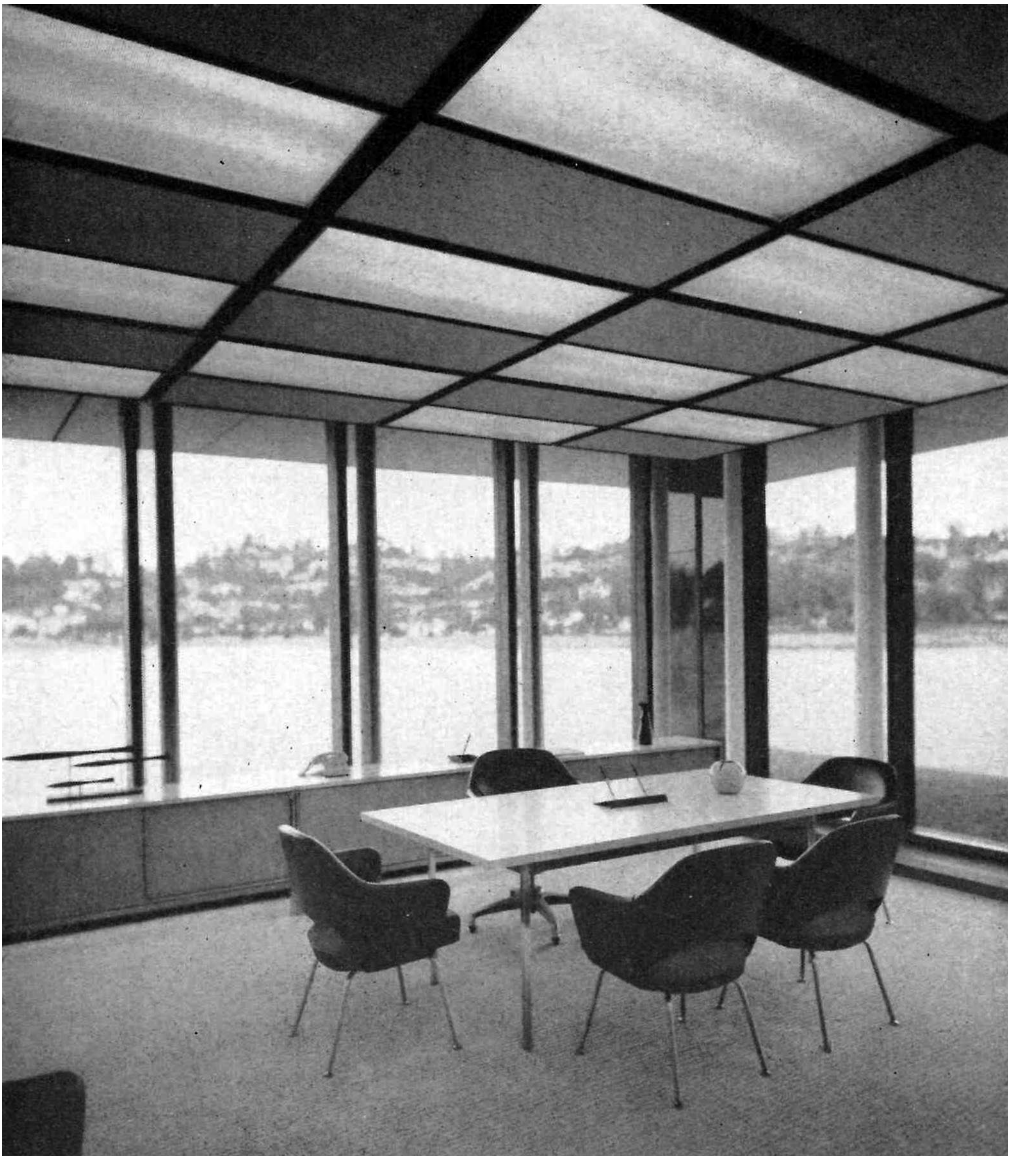

Figure 15. Water and Power Building, Los Angeles, CA. Albert C. Martin and Associates, Architects and Engineers, 1962. Ceiling mockup showing integrated lighting fixtures

on average even as systems that integrated air conditioning and lighting became more popular for their energy efficiency. In a 1980 survey on contemporary architectural engineering, *Architectural Record* devoted an entire section to "New Approaches to Integration of Lighting and Mechanical Services," showing how progressive designers in the United States and Canada had incorporated lighting into exhaust and supply strategies alongside other energy-saving techniques such as daylighting, balances between ambient and task lighting, and flexible ceiling systems.[73] (Figures 16 & 17) Bell's 'cheap and fairly powerful radiants of low intrinsic brilliancy' had, over two full generations of development and application, proven themselves an ideal match for the open-plan, mechanically conditioned spaces of the postwar era.

Figure 16. Air Products and Chemicals, Inc., Headquarters, Allentown, PA. The Eggers Group, 1978. "Not only flexible and efficient in the management of space, but also efficient in its use of energy." A notable integration of visual and thermal comfort typical of the late 1970s in its reliance on a tightly engineered power-membrane ceiling. Architectural Record, May, 1978. p. 141.

Fluorescent lighting has in recent years overtaken incandescent lighting for even residential applications, but other technologies now offer even greater efficiencies. LED fixtures today are twice as efficient as fluorescents in lighting output per watt of power. After almost a century, fluorescent lighting's dominance is being challenged for the first time. Its ninety-year run has, however, been influential on standards and the geometry and configuration of office ceilings. The power-membrane form could not have emerged with point-source incandescent fixtures, which never provided the consistency or linear modularity that matched emerging trends in layouts below. More importantly, however, incandescent fixtures could not have taken advantage of plastic's powerful optical potential. Nor could they have met emerging demands for thermal comfort and cooling while meeting higher standards for visual comfort and illumination. The geometry of fluorescent lamps, their operating temperatures, and their efficiency all made them valuable partners in refining the postwar era's climate-controlled, evenly-illuminated, deep-plan open offices. While these buildings' histories have focused on structural and cladding developments that made the towering 'glass box' ubiquitous in the postwar American city, technologies that developed from within—especially mechanical and lighting systems that defined and supported the office module itself—have received only scant attention. Fluorescent lighting has remained unexplored in architectural histories, yet its impact on the comfort and productivity of postwar workers suggests that it deserves acknowledgment as an important enabling technology in the evolution of the era's workplaces.

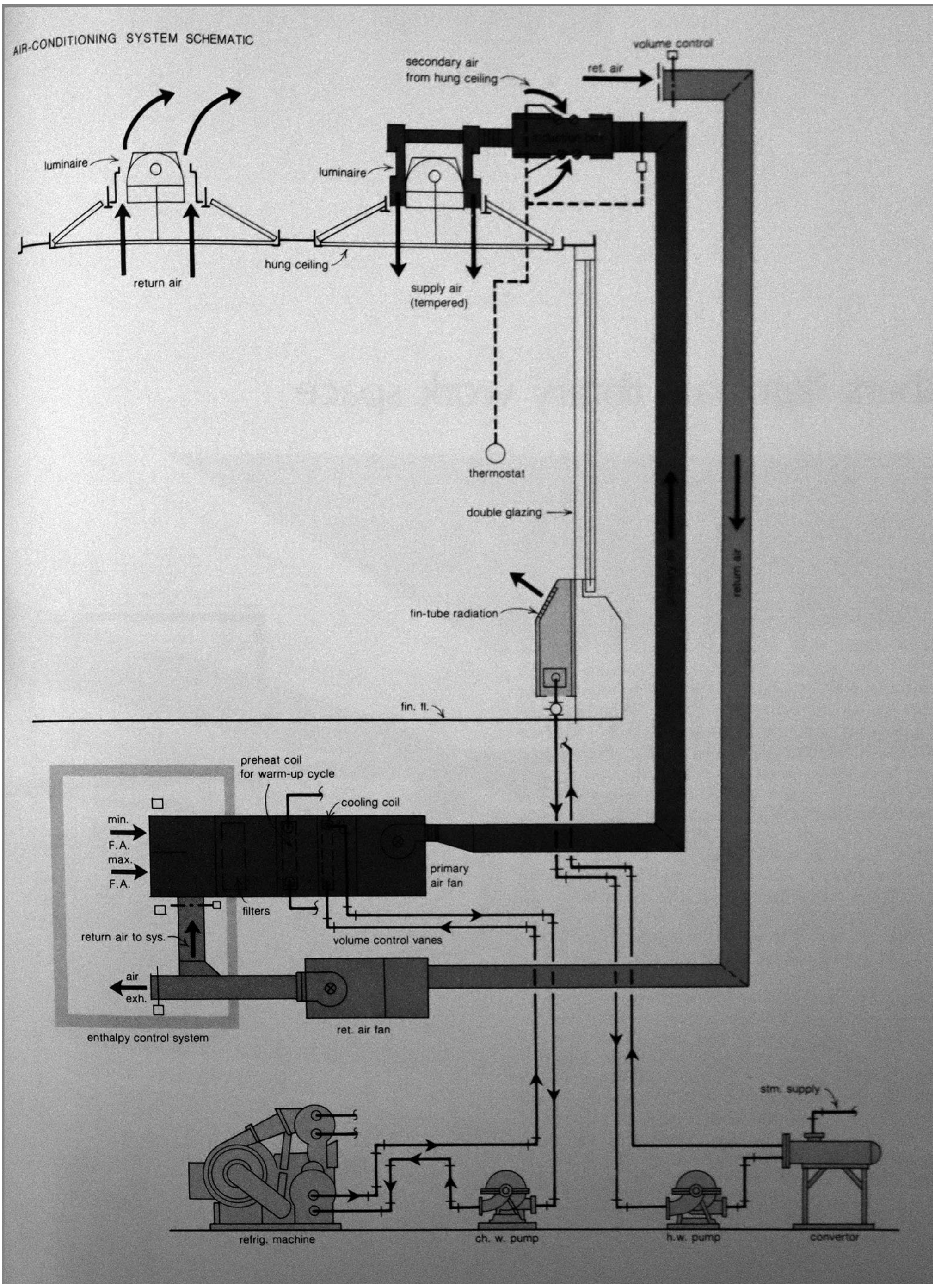

Figure 17. Air Products and Chemicals, Inc., Headquarters, Allentown, PA. The Eggers Group, 1978. Systems diagram showing the combination of air supply and exhaust with fluorescent luminaires and the power-membrane ceiling plenum. Architectural Record, May, 1978. p. 144.

The Author

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2. Bell, 143. See also Cecil Elliott, *Technics and Architecture* (Cambridge: MIT Press, 1992), 259-60.
3. *IES Lighting Handbook: The Standard Light Guide*. (2d ed., New York: Illuminating Engineering Society, 1954). 8-10.
4. Arthur A. Bright, Jr. and W. Rupert Maclaurin, "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp." Journal of Political Economy, vol. 51, no. 5. October, 1943, 434-435.
5. *IES Lighting Handbook: The Standard Light Guide,* op. cit., 8-6, 8-14. For comparison, a typical LED lamp in 2019 produces a luminous efficiency of between 100 and 200 lumens per watt.
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7. "Lights Turn Fair Into a Dream City." *New York Times*, 11 Apr 1939. 1. Nearly a third of the Fair's lighting was provided by fluorescent lamps, achieving a "uniform softness" that was matched by General Electric's installation in their "House of Magic" exhibit that formally introduced the new fixtures to the public. See also Charles Macko, "World of Tomorrow: Or Man among Ramps, Atomic Fuel and Steel-Glass Houses as Predicted at Fair." *Barron's*, 29 May 1939. 20.

8. See Matthew Luckiesh, Director, Lighting Research Laboratory, General Electric Company, *Torch of Civilization* (New York: Putnam and Sons, 1940) for a contemporary history of lighting innovation that incorporates the then new technology of fluorescent lamps.
9. Peter Cooper Hewitt, U.S. Patent no. 843,534, "Method of Producing Electric Light." Filed Sept. 28, 1900, granted Feb. 5, 1907;
   Roy D. Mailey, Assignor to General Electric Vapor Lamp Company, U.S. Patent no. 1,878,502, "Gas or Vapor Discharge Device." Filed Oct. 25, 1928, granted Sept. 20, 1932.
10. Arthur A. Bright, Jr. and W. Rupert Maclaurin, "Economic Factors Influencing the Development and Introduction of the Fluorescent Lamp." Journal of Political Economy, vol. 51, no. 5. October, 1943, 436.
11. Charles L. Amick, Fluorescent Lighting Manual. (New York: McGraw-Hill, 1942). 1.
12. "The Control of Light." Architectural Record, Sept., 1939. 83.
13. While fluorescent lighting has a reputation for poor color rendition, this is the result of the relative cost of various phosphor coatings—customers have had options for redder and yellower light from particular phosphor mixes since at least 1942, but these have proven unpopular due to their cost. See Austin C. Lescarboura, "Fluorescent Lighting Stretches Out." Scientific American, October, 1942. 167-169.
14. Amick, *op. cit.,* 84.
15. "Efficiency of the tungsten-filament lamp is now approaching its practical limits." "The Control of Light." Architectural Record, Sept., 1939. 76-84.
16. Amick, *op. cit.,* 10-11.
17. W.S. Fisher and J.E. Flynn, General Electric Co. "Air Conditioning for Higher Lighting Levels." Architectural Record, November, 1959. 230.
18. For example: "The white range of fluorescent tubing is more efficient than that of incandescent lamps because the light output for the former is from two to four times greater than for the same wattage input, while the heat radiation is from 25 to 50 percent less. The latter consideration is important when dealing with showcase lighting, or in confined working quarters, or again where air conditioning is being used. Austin C. Lescarboura, "Fluorescent Lighting Stretches Out." *Scientific American*, October, 1942. 168. See, too, Samuel Adams Bogen, "Conspicuous Waste in Lighting and Air-Conditioning." Progressive Architecture, April, 1950. 83.
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21. Keating, *op. cit.,* 193-194; Bright and Maclaurin, *op. cit.,* 436-437.
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25. Tom White, "Lights For 'Dream City.'" *The New York Times*, Jan. 8, 1939: 143.
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27. Sylvania dropped "Hygrade" from its official name in 1942. See Bright and Maclaurin, *op. cit.,* 431.
28. Bright and Maclaurin, *op. cit.,* 448.
29. "Windowless-With Zoned Air Conditioning, Fluorescent Lighting: Allison Division, General Motors Corporation, Speedway, Ind." The Architectural Record, February, 1940. 91-95.
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34. Lester Smith, "Fluorescent Lighting, 4 Years Old, Aids Workers In Vital War Tasks." *The Wall Street Journal,* Apr 13, 1942. 8.
35. "Bright Lights In War Plants Increase Production and Help Cut Number of Accidents." *The Wall Street Journal,* Feb. 15, 1943. 1.
36. Keating, *op. cit.,* 216.
37. See Caleb Hornbostel, *Materials for Architecture: An Encyclopedic Guide*. (New York: Reinhold, 1961) for an unparalleled accounting of available materials.
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39. "Partners of Light." Scientific American, May, 1946. 199; and "Exhibit More Fluorescent Light Fixtures." *Chicago Daily Tribune*, Nov. 4, 1947. 30.
40. "Partners of Light." *Scientific American*, May, 1946. 197-200.
41. "Partners of Light," *op. cit.,* 197.
42. Amick, *op. cit.,* 117.
43. "The Control of Light," *op. cit.,* 79.
44. Amick, *op. cit.,* 108.
45. Amick, *op. cit.,* 186. See, for instance, David A. Loehwing, "Bright Prospects: The Makers of Lighting Fixtures Look for Continued Growth." *Barron's National Business and Financial Weekly*, Feb. 10, 1958: 38: 6. 5-6.
46. This phrase was used by both GE and Sylvania to advertise their "Slim-Line" and "Flexi-Module" fluorescent products. See, as an example, Advertisement (Sylvania Electric), *Women's Wear Daily* Vol. 80, no. 35. Feb 20, 1950. 12.
47. Louis Bell, *The Art of Illumination*, op. cit., 234.
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50. "Experts Prove Industry, Home Light Inadequate." *Chicago Daily Tribune*, 11 Feb 1960. E2.
51. W.S. Fisher and J.E. Flynn, General Electric Co. "Air Conditioning for Higher Lighting Levels." *Architectural Record*, November, 1959. 230.
52. Bogen, *op. cit.,* 84.
53. "…any reduction in light output due to luminaire absorption is accompanied by a similar reduction in invisible radiant energy, as the two 'follow each other' and have similar characteristics. When light (and invisible radiation) is intercepted and absorbed by the fixture, this loss is converted into heat within the luminaire itself. Radiant transfer, the transfer of heat directly between two objects or surfaces, is effected between the warm lamp and the cooler fixture surfaces.

    "Heat build-up within the luminaire may become substantial, with the convection-conduction heat and the ballast load initially trapped in the unit and a portion of the radiant energy absorbed by the luminaire surfaces. This confinement of heat will also increase the temperature of the ceiling and ceiling cavity (if any). If the heat is allowed to continue, the luminaires and adjacent ceiling area become 'secondary heat sources,' the heat being carried into the occupied parts of the room by convection or re-radiation to cooler objects and surfaces." Fisher and Flynn, *op. cit.,* 230-231.

54. *Ibid*., 230.
55. "The Control of Light," *op. cit.,* 81.
56. Constant air movement also helped maintain optimal temperatures within luminaires. The Illuminating Engineering Society conducted tests that showed that enclosed fixtures, or those mounted on to a solid ceiling, produced bulb-wall temperatures up to 30°F higher than the ideal 113°F. *IES Lighting Handbook: The Standard Light Guide,* op. cit., 8-49.
57. "Analysis of air conditioning costs to provide for lighting in the large office building example indicate that increasing the illumination from 50 to 100 foot-candles with conventional lighting and air conditioning systems requires an increase in initial costs of about 93 percent. This amounts to an approximate increase of 18 percent in the over-all air conditioning installation. However, if an integrated lighting-air conditioning system of the type just described is employed, the increase in cost for air conditioning is only about 57 percent (or 12-1/2 percent of the overall). This latter figure includes the cost of the extra air handling system needed to exhaust the luminaires. (Perhaps integrated systems where 20 or 30 per cent of the lighting load is removed to the outside will also prove attractive in reducing initial costs of air conditioning)." *Ibid*., 235.
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59. "The Control of Light," *op. cit*., 83.
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