

THE EVOLUTION OF THE RELATIONSHIP BETWEEN ENERGY
CONSUMPTION AND THE ARCHITECTURE OF THE HIGHRISE OFFICE BUILDING

by

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B.A., University of California, Berkeley 1980

Submitted to the Department of Architecture
in partial fulfillment of the requirements for the degree of
Master of Architecture

at the

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ABSTRACT

With the growing awareness of the rapid disappearance of the global fuel resources, energy conservation became an issue of general concern. Prompted by the results of studies done in the 1970's--which show a marked increase of energy consumption per square foot of office space over the years, as well as differences in consumption between buildings of different periods -- this thesis looks at the features that determine the considerable variation in energy consumption in office buildings from the beginning of the century to our days. An overview of the historic evolution of the highrise offices presents the events that influenced the change in energy performance. The elements that determine the energy use in a building, like its orientation, exterior envelope, interior design, and mechanical systems, are individually analysed to present a detailed picture of their role. Their characteristics in the periods before and after the second world war are then compared, showing how they determined the energy performance of buildings of the respective periods.

Thesis supervisor: Harvey J. Bryan
Assistant Professor of Building Technology

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Muh-ching Yee for putting my work into real English and for typing my thesis.

This work is dedicated to my father.

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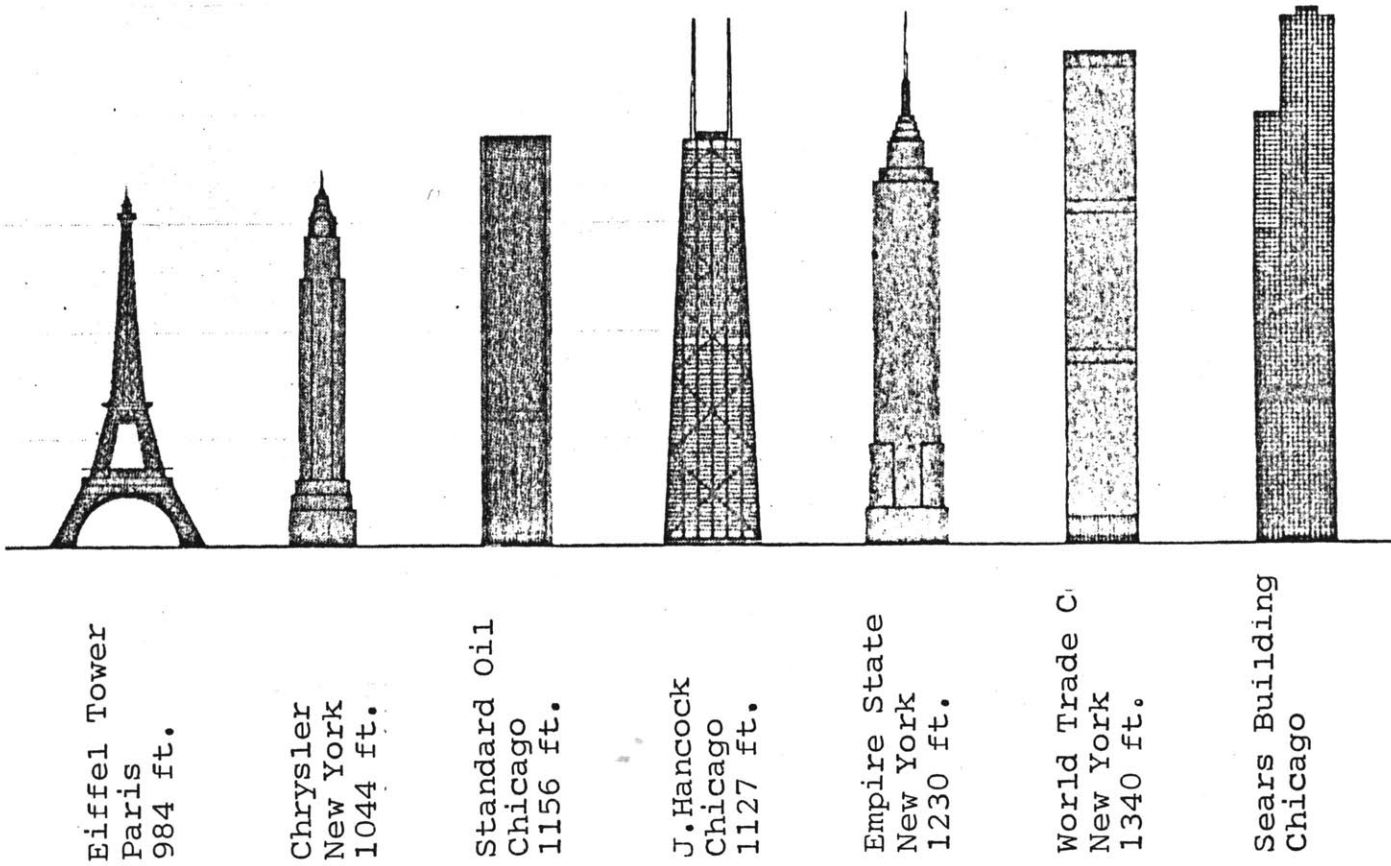
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INTRODUCTION

In the past hundred years, office buildings have been the most dynamic architectural program. In many ways, they were the habitrails where new theories regarding the work environment as well as new technologies were being tested. The most important element of the dynamics has been the office building's role as a symbol of power and position. In terms of image and significance, it has replaced the cathedrals of the Middle Ages and the palaces of the Renaissance. They are also important elements in the shaping of some of the most admired cities: Paris, Milano, Dusseldorf, Tokyo. The entire city of New York can be considered a monument for office buildings; its streets are shaped by them, its skyline changes with them. The World Trade Center towers have become one of its major attractions. The Transamerica and Bank of America buildings are now the landmarks of San Francisco, its Tours Eiffel.

Highrise offices are more than buildings, they are huge exhibition stands for the success and power of their owners; Guinness Books of Records for the Highest Building, the Most Glass, the Biggest Canteliver, the

Least Millions and so on. This race for records has left aside the concern for other issues. Energy consumption was, for a long time, one of the forgotten problems. Yet, due to the role that office buildings have in our society, their efficient use of energy would provide examples with wide consequences.



Since money for office building construction is more readily available than for other programs, and owners are willing to accept extravagances in order to insure the originality of their building, office design became an unparalleled field for architectural exploration. Office buildings are therefore important in the promotion of novel attitudes and technologies as well as in setting aesthetic and functional standards. This is helped by the fact that the office building is today the most ubiquitous construction, the one most advertized and most consequential for the image of the urbanscape.

The downtowns of American cities are office citadels whose vitality depends on the success of office activities and whose life rhythms reflect the nine to five schedule. The suburban office parks are a more striking and memorable image to the highway traveler than any settlement. Their elaborate skyline marks the landscape with the force with which European towns impact the landscape. The downtown office building promotes the new ideas incorporated in its design to the general public. New materials and styles have thus the opportunity to test the public taste and acceptance or to impose them when necessary.

It is interesting to compare the contents of architectural magazines of today and of the early part of this century. The latter were dominated by discussions of residential architecture, and decoration, other architectural programs and issues having only occasional entries. Today, office buildings occupy most pages of a magazine. The interest in construction materials and their advertizing also finds favorable ground in examples of office building design.

Most recently, competitions have brought energy related issues into the spotlight. Also, in some of the most publicized office buildings, like the T.V.A. offices, the concern for energy is emphasized as the determinant factor of the design solution. Other buildings, as for instance Philip Johnson's towers in Houston, Texas, stress the architect's attention to energy issues (daylighting and the use of low transmittance dark colored glass) without really solving the problems, sometimes still perpetuating the mistakes that made the buildings of the last decades so poor in terms of energy conservation.

A better understanding of the factors that determine energy performance and the knowledge of examples of

previous good design would lead to more energy efficient new office buildings, which in their turn would positively affect the national energy use.

As an important part of the built stock, office buildings have a significant contribution to the amount of energy used for the operation and maintenance of buildings, which approaches 40% of all the energy consumed in the United States. Before the 1973 oil embargo, the commercial sector's share in the national energy use was 15%.

The energy profile of the highrise office building is particularly interesting since it combines the disadvantages of excessive internal consumption with the advantages resulting from high density.

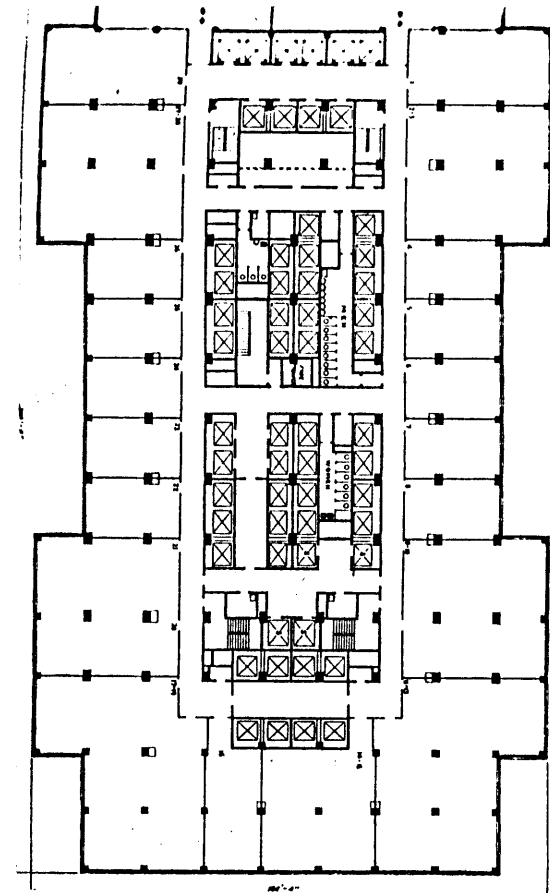
In contrast to individual structures in rural areas, highrises make use of an existing infrastructure, water supplies, sewage systems, electrical distribution and roads. In "Energy and Urban Form," Y.H. Chibuk notes that

"as density increased from the urban

fringe towards the urban center, energy consumption per capita decreased until it reached the central area where density was the highest and energy consumption again increased."

It appears that density at an urban scale offers advantages only under a certain limit beyond which the impact of the highrises in terms of economics and energy is questionable as problems of power generation and traffic become acute.

At the building's level, the density of the units, because of shared walls and utilities, also has a positive influence on energy conservation. Studies done by the New York Regional Planning Association in 1974 show that buildings with heights over 15 floors are slightly more energy conserving. Buildings with areas between 51,000 square feet and 100,000 square feet seem to perform the best. Increasing the height beyond a certain limit, though, results in progressively higher energy loads; this could be explained by the burden introduced by larger vertical circulation systems for people and air.

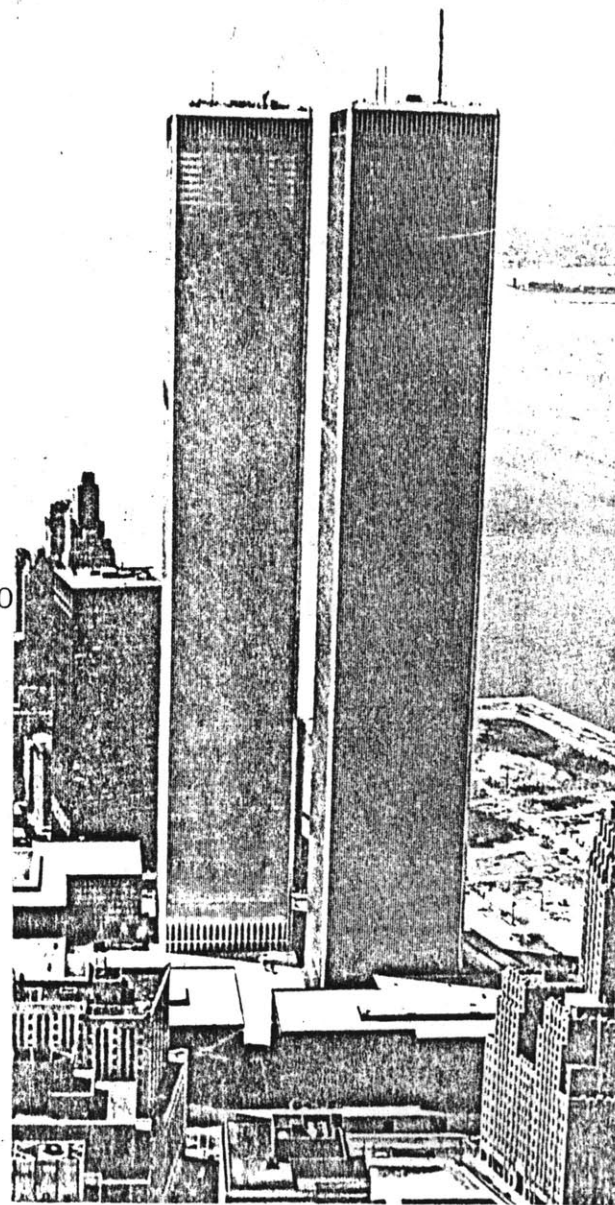


Plan of the Empire State Shows area occupied by elevators relative to total area.

Therefore, one cannot equate a 100-story building with two 50-story ones; the former results in an inefficient ratio of built and useable areas. Since elevator shafts have to be carried through the whole building, ducts are larger and service floors have to be provided to house the necessary mechanical equipment. Even relatively short skyscrapers, around 30 stories, can use up to 60 elevators.

The World Trade Center offers a suggestive example of the energy consumption excesses of record breaking high buildings; its two towers use approximately the same amount of energy as Schenectady, a city of 100,000 inhabitants.

The excessive energy consumption of highly dense urban areas affects the weather conditions of the city. In New York, for example, the increased combustion and moisture released from air conditioning changed the temperature and humidity of the outdoor environment. The buildings in general and highrises in particular changed the wind pattern and annulled the beneficial presence of breezes coming from the nearby ocean. The dominance of paved surfaces raised the reflectivity of the ground while also reducing



the ability of the soil to absorb water. All this altered the natural weather pattern, replacing it with conditions whose amelioration depends increasingly on human intervention, and, implicitly, more energy consumption. By limiting the use of air conditioning and the burning of fuels, energy efficient design can contribute to the slowdown or even stop of further climatic deterioration.

An important factor in the rate of energy consumption in office buildings appears to be their age. Two studies done in the 1970's show a direct relationship between energy consumption and the age of the buildings.

One of these studies, done by Dr. Charles Lawrence, a Public Utilities specialist in New York, analyzed 80 buildings. He reported a marked increase in the energy use per square foot from decade to decade with changes in the services rendered to the tenants insignificant changes in the services rendered for the tenants. On the contrary, the work environment became more monotonous, less individualized and with a greater disconnection between the environment and the people who work in it. Among the factors that led to this, he mentions:

- higher buildings requiring more expensive and higher performance elevators.
- higher light levels
- more interior space requiring cooling and lighting more of the time
- more high level lobby and facade lighting.

The consulting firm of Syska and Hennessy conducted a survey of office buildings in New York. Their findings, based on the results of questionnaires sent to owners of office buildings, dating from the early part of this century to today, confirm the proportional relationship between age and energy consumption. A look at the historic evolution of the office building would help us understand the events that led to the change in energy performance.

CHAPTER I

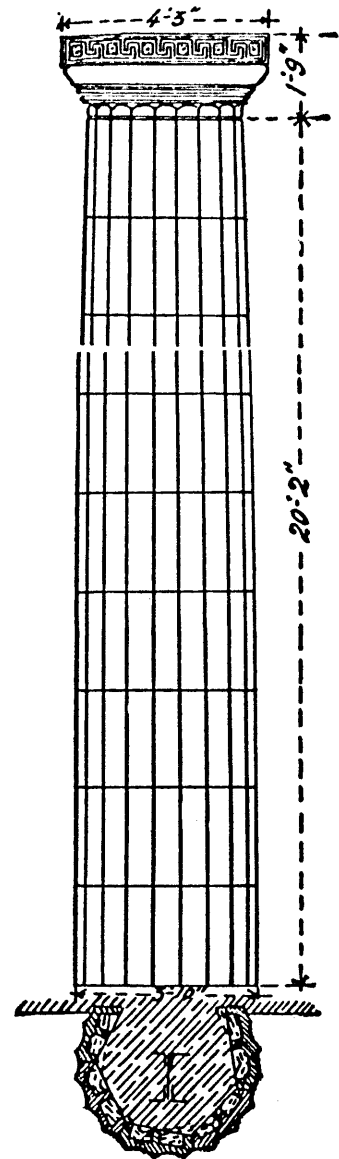


HISTORY

The history of the highrise office building began in Chicago at the end of the 19th century. After the 1871 fire which destroyed most of the city, Chicago went through an unprecedented construction boom. The fervor of the reconstruction continued for decades, triggering a rapid development of the city, which grew from 300,000 inhabitants in 1870 to 2 million in 1900. The need to rebuild the city in a short period of time encouraged innovative design and construction techniques.

One such revolutionary construction method in commercial building was introduced by William Le Baron Jenny. In his Home Insurance Building of 1885 and later in the Leiter Building of 1889, he used for the first time a steel skeleton based on the principle of the balloon frame, another indigenous technique that set a precedent in construction which led to the amazing development of the American housing industry in the 19th century.

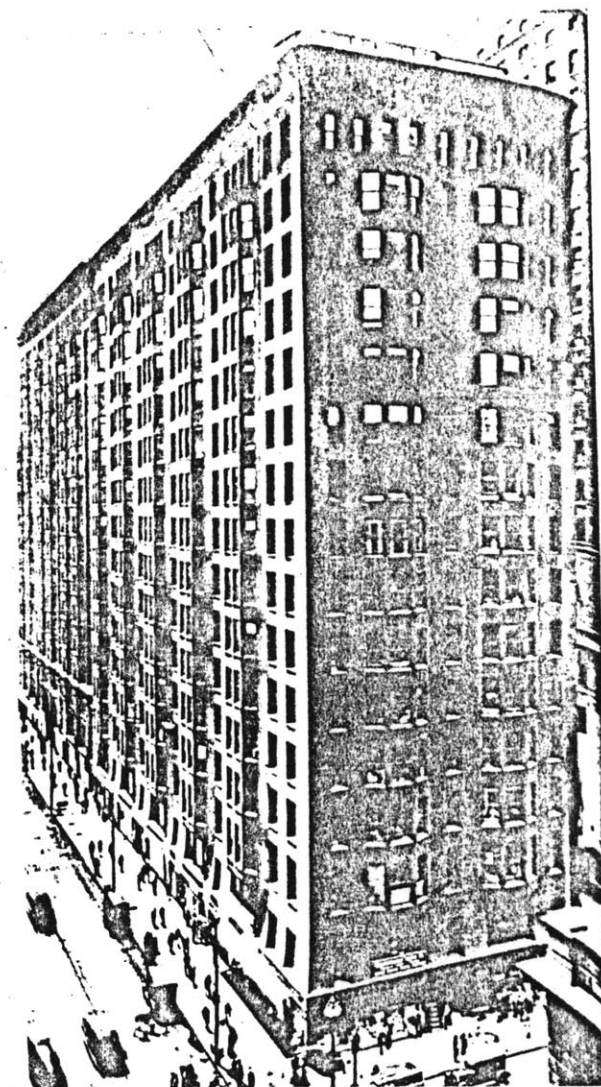
The steel frame allowed the height to exceed limits previously imposed by the bearing wall construction which reached a maximum of 17 stories in Burnham and Root's Monadnock Building, 1891. Yet, masonry continued to



Steel and terra-cotta column

be used both for walls and for the fireproof cladding of the metal structure, a fact which led to the massive appearance of the buildings of that period and the possibility of continuing the classicist stylistic preferences of the public. The masonry also provided the thermal mass which would significantly affect the energy performance.

A movement towards a new formal expression, which would later be called the First Chicago School, was initiated in the 1880's by D. Adler, L. Sullivan, Burnham and Root, Holabird and Roche. Their efforts to give the office building a new image reflecting the new construction system was to have a great influence on modern architecture in general and especially on the office buildings after World War II. But at the turn



Monadnock Building, 1981

of the century, their ideas had only been accepted locally; New York was still populated with Neo-Gothic or Classicist towers. The 1922 competition for the Chicago Tribune Tower temporarily pushed aside the new movement and reestablished the supremacy of the eclectic styles in Chicago.

The limits to vertical expansion were pushed further by the invention of the escalator in 1870. The increased availability of electric power helped spread the use of the new mode of vertical transportation. Concrete began to be used more frequently and in 1902 the first concrete skyscraper, the Ingalls Building in Cincinnati, demonstrated the potentials of that material in highrise construction.



William Le Baron Jenney
(1832-1907)

Daniel H. Burnham
(1846-1912)



Dankmar Adler (1844-1900)



Louis Sullivan (1856-1924)



Two major changes in the urban structure, that is, the concentration of the commercial activities in the centers of the cities and the move of the residential areas into the suburbs, contributed to a general atmosphere of mobility and acceptance of the new, and also determined the future character of the American cities. Advances in the construction field, together with the necessity of providing more buildings for industrial and commercial activities concurred in creating the basis for the accelerated building development.

The role of promoter of progressive construction shifted from Chicago to New York, which was soon to become the symbol of highrise architecture and of office activity. Its rapid general growth was echoed, between the first World War and 1929, by an intense building production; in that period in New York, more money was spent yearly on construction than on food. Thus, by 1929, of the 377 skyscrapers in the United States, 88 were in New York City, 15 being over 500 feet tall.

The chaotic placement of skyscrapers in the city fabric aroused a consequential concern from the public. With the

new construction, the streetscape acquired an unfamiliar image which at once fascinated and frightened the passersby. The spectacular heights were exciting, and they also responded to the 20th century man's admiration of achievements and technological progress. On the other hand, the canyon-like spaces and the overwhelming volumes provoked the distrust in the environment and the longing for the familiar images of common cities, or even of New York only a couple of decades before. The change of downtown Manhattan is suggestive; from the patriarchal, almost rural environment of the late nineteenth-hundreds, it became by 1930 a showcase of vertical expansion. After a period of uncontrolled and chaotic building of skyscrapers, the public concern for the bad effects this had on the quality of life in the city echoed in the Zoning Resolution of 1916. The official motive for the law's issuance was that of maintaining the street quality and safeguarding the interest of the citizens and of the adjacent property owners.

The resolution established districts classified into types according to the physical as well as social characteristics of the area. The district system took into account both local aspects and factors related to

the city as a whole. The categories of districts were determined by height, use, and area. The height of the buildings depended on the width of the street and it varied between 1-1/4 to 2-1/2, height to width ratio; where streets were narrower than 50 feet, the regulations applied were those of 50-foot streets, while on streets wider than 100 feet or in front of parks, the heights allowed were the same as for 100-foot streets. The relationship with adjacent lots was also considered: "on a wide street, the building robs the neighbor at the rear of light and air as much as it would if it were located on a narrow street." The buildings designed according to the setback requirements of the law resulted in the stepped volumes characteristic for the prewar period. This appearance, generated by the need to secure light and air in the buildings and in the streets was considered by some a promising improvement of the aesthetics of the skyscraper. The new buildings were seen as:

"different from the crude cubical masses that poke their harsh, gaunt outlines into the sky...blunt angular objects that no skill in design or in details can redeem or else conceal."⁴



Others fantasized about the possibilities of change in the urban image:

"Forming thus a vast terrace above which would rise a wonderful array of minor terraces, pavillions, loggias, roofs, dormers, turrets, towers all pyramiding into the sky. New York might vie with ancient Rome of the seven hills but in a different way in a character entirely its own."²

New York never became the idyllic place described above, but the zoning resolution did help maintain a certain degree of humanism in the developing concrete jungle.

Prefabrication and industrialization, characteristics of the steel frame, were necessary factors not only in the rate of construction, but also in securing the adequate production in the restrictive conditions of a minimal site in an area crowded with traffic and people.

The erection of the Empire State Building in 1930 illustrates the unparalleled advantages of the industrialized construction and demonstrated the impressive, and

STARRETT BROTHERS BUILDERS 30 PARK AVENUE NEW YORK		PROGRESS SCHEDULE EMPIRE STATE BUILDING												EMPIRE STATE INC. OWNER				
DATE FEBRUARY 5 th 1930		LOCATION 33 rd , 34 th STREETS AND FIFTH AVE. N.Y.												SHREVE, LAMB & HARMON ARCHITECTS				
TRADES	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY
1 GENERAL CONDITIONS CONTRACT																		
2 FOUNDATIONS & WRECKING																		
3 EXCAVATION																		
4 CONCRETE FOOTINGS																		
5 FORMS OR CASING																		
6 STRUCTURAL STEEL																		
7 STRUCTURAL CONCRETE																		
8 UNCLE																		
9 HANDWORK - EXTERIOR WALLS																		
10 INTERIOR PARTITIONS																		
11 EXT. STONE & GRANITE																		
12 LIMESTONE OR MARBLE																		
13 CARING & MODEL																		
14 ARCHT. TRUSS COPY																		
15 ROOFING																		
16 SHEET METAL																		
17 METAL WINDOWS																		
18 ROUGH CARPENTRY																		
19 LATHING & PLASTERING																		
20 FLOOR FILL & FINISH																		
21 FIN. CARP. & MILLWORK - MILLWORK																		
22 FIN. CARP. & MILLWORK - FIN. CARP.																		
23 MET. CAS. & TRIM - MET. CAS.																		
24 DOORS & TRIM																		
25 ELEVATOR ENCLOSURES																		
26 GLASS & GLAZING																		
27 HARDWARE																		
28 ORN. IRON & BRONZE - STAIRS																		
29 CASTING - ORN. IRON																		
30 BRONZE																		
31 MISCELLANEOUS IRON																		
32 BRICK SHUTE																		
33 INTERIOR MARBLE																		
34 TILE																		
35 TERRAZZO																		
36 PLATE & COMPOSITION FLOOR																		
37 PAINTING & DECORATING																		
38 ELEVATOR MACHINES																		
39 MACHINES & PLATFORMS																		
40 GEAR AND FINISH																		
41 SUBMITTERS																		
42 PLUMBING - ROUGHING																		
43 FIXTURES AND FITTINGS																		
44 PUMPS AND TANKS																		
45 HEAT & VENT. - PIPING																		
46 BOILERS																		
47 PUMPS AND WASH																		
48 RISE AND FINISH																		
49 ELECTRICAL WIRE - CONDUITS																		
50 PANELS & WIRING																		
51 ELECTRIC FIXTURES																		
52 SPRINKLER SYSTEM																		
53 REFRIGERATION																		
54 VACUUM CLEANING SYSTEM																		

PROGRESS SCHEDULE SHOWING PROGRAM OF CONSTRUCTION
EMPIRE STATE BUILDING, NEW YORK CITY

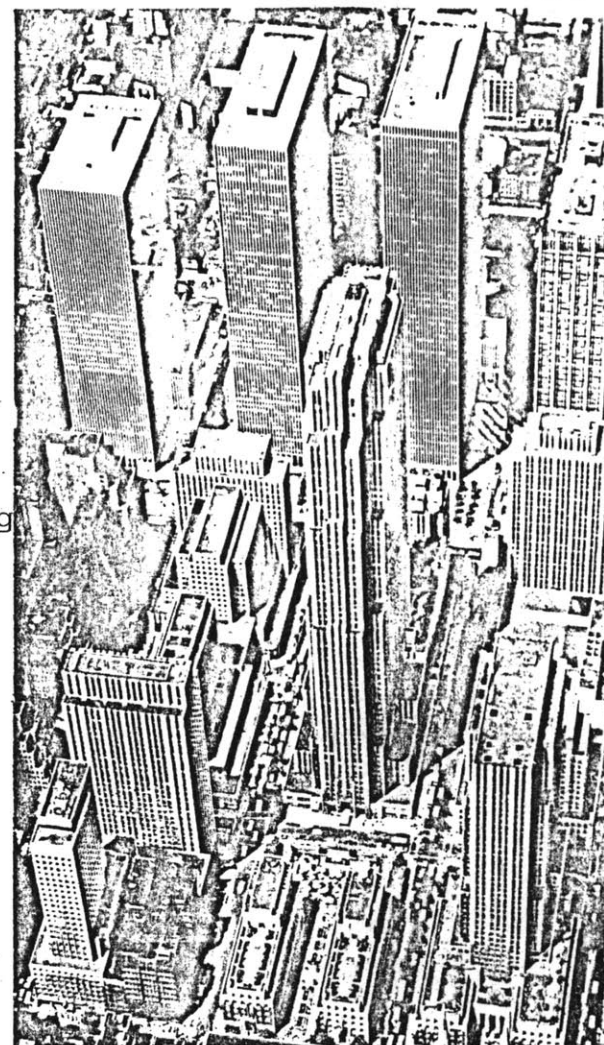
SHREVE, LAMB AND HARMON, ARCHITECTS

A chart of this nature shows how carefully the many processes that go into the building of a modern office structure are timed and controlled. "The plaster may appear in the lower floors before the roof, many stories above, has been made tight."

Item (4) fixes the time within which the steel is to be erected. This item by itself is shown on page 346 carried into greater detail.

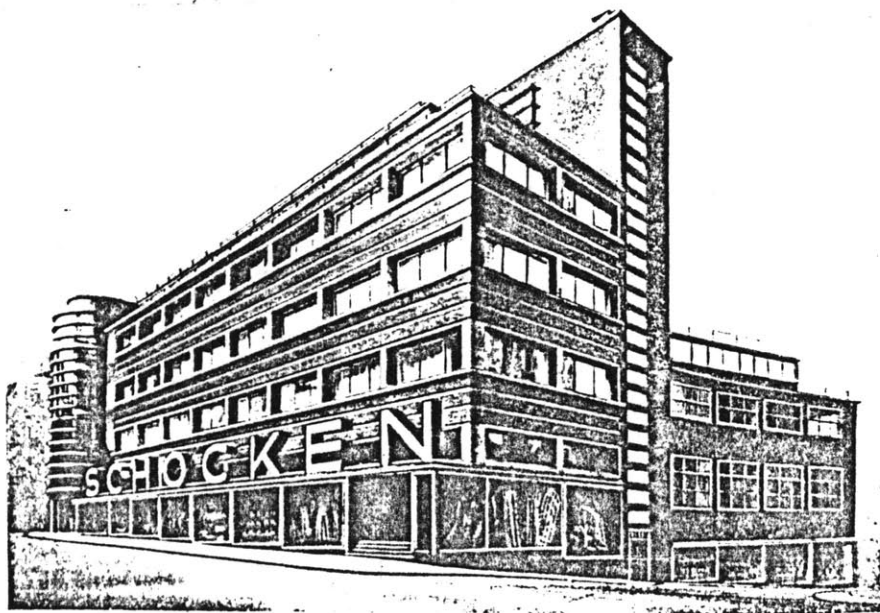
at the same time alarming, speed with which the metal colossus could fill the landscape. It took only one year and a half to pass from the working drawing stage to the completion of what was to be, for decades, the tallest building in the world. Its 50,000 ton steel structure was erected in only 5 months, during which the prefabricated steel structural elements were continuously brought to the site by trucks from a plant in New Jersey.

The height record set by the Empire State Building being so hard to exceed, the race for excesses was stopped for a while and architects' concern shifted to other issues related to highrise design. Thus, the idea of designing an ensemble of tall buildings was introduced by the Rockefeller Center, which proved that highrise buildings can define pleasant sequences of urban space. It also marked a change in the architectural style. Although not welcomed at the beginning -- Pencil Points wrote in 1931 "the functionalist design of Radio City Hall aroused public indignation" -- the new design attracted the architectural community and accelerated the acceptance of the International Style which just took the shape of a skyscraper in the Philadelphia Savings Fund by W. Lascaze and George Howe in 1932.



Rockefeller Center
the R.C.A. Building

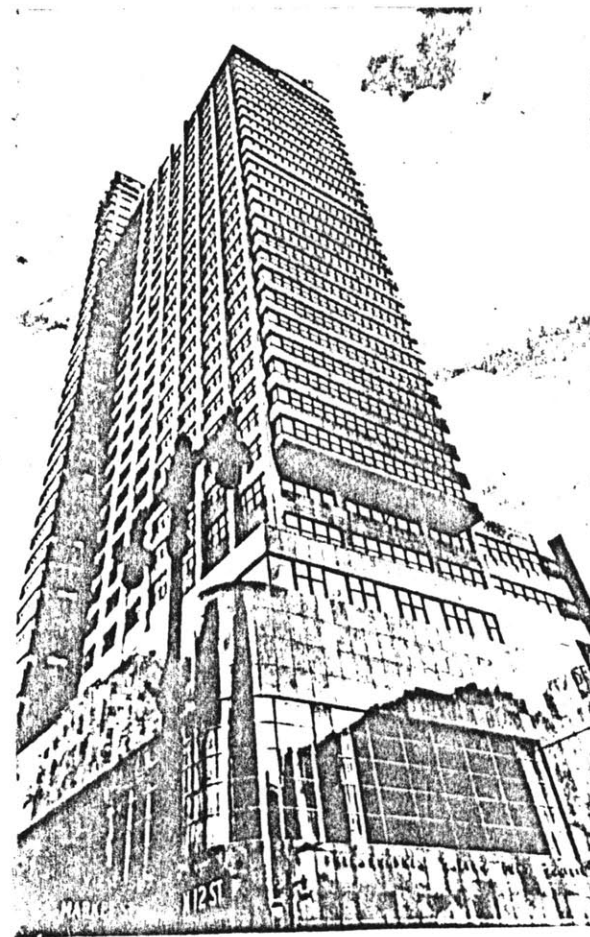
The ideas of the International Style had been infiltrating into American architectural thought for more than a decade, but it was not until the exhibition of European modern architecture organized by the Museum of Modern Art in 1932 that it officially entered the American scene. In 1933, the association with the new style received another impetus from the arrival of



SCHOCKEN DEPARTMENT STORE, STUTTART, GERMANY

ERICH MENDELSON, ARCHITECT

Note the glass tower at the further end. The lettering is an integral part of the architectural design



Beginnings of the International Style in America

above: Philadelphia Savings Fund

left : an influential European model

several masters of the Bauhaus who were fleeing unsympathetic working conditions in Germany, and who had come to teach at American universities. Walter Gropius and Marcel Breuer were invited by Harvard, Mies van der Rohe settled in Chicago. Their influence would determine the drastic changes in the world architecture and in a large measure the image of our cities today. The appearance of the office buildings of the postwar period is one of the most ubiquitous results of their impact.

The typical prewar office building was a steel skeleton clad in brick or concrete and usually faced with terracotta or sandstone. Its floor plan reflected the nec-

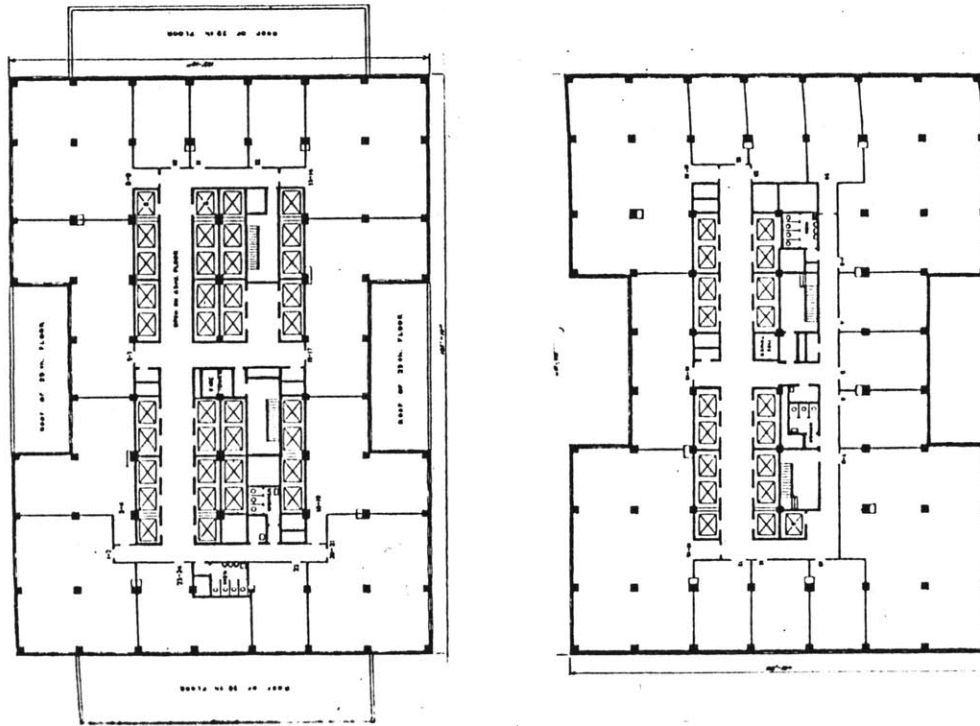


Walter Gropius
(1883-1969)

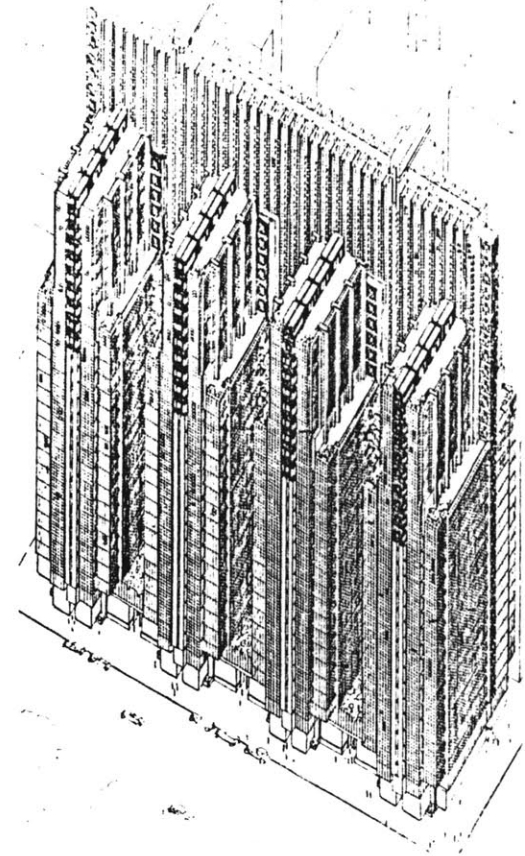


Ludwig Mies van der Rohe
(1886-1969)

essity to naturally light and ventilate the working spaces, the building thus resulting in a U or H shape, or, as in F. L. Wright's project for the Life Insurance Company (1920), in a comb-like plan with light courts open on one side separating five building wings.



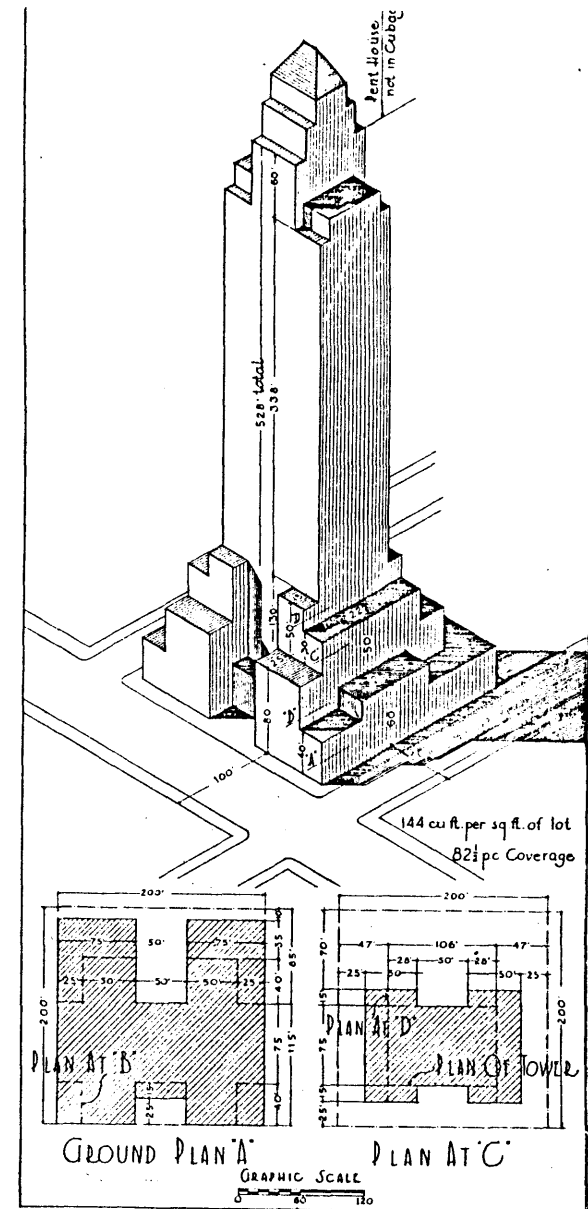
Plans of the Empire State Building



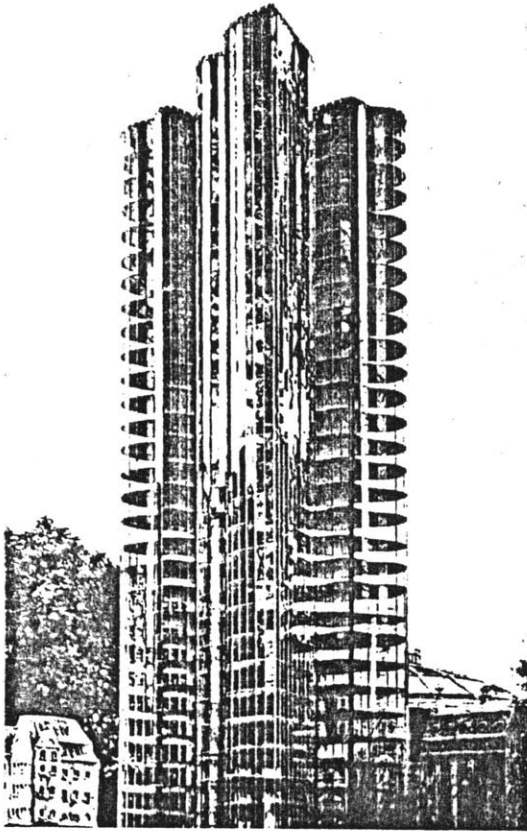
F.L.Wright's project for Life Insurance Company

The "wedding cake" building, called so because of its successive setbacks, dominated the period between the 1916 Zoning Resolution and the zoning law of 1961. The "wedding cake" shape resulted from the requirement to limit the height at street line according to the ratio of height to street width allowed in the area, and the possibility of going to an unlimited height with a tower that would not have a typical floor area larger than 25% of the lot area. The usual building shape was that of a main body, with a height that harmonized with the surroundings, resting usually on a three-story base and supporting a slim, mostly square tower whose height was determined only by the ambitions and financial capabilities of the owner. The RCA slab building in Rockefeller Center made an unusual departure from both the multi-winged building and from the square tower, securing the necessary daylight with its long and narrow plan.

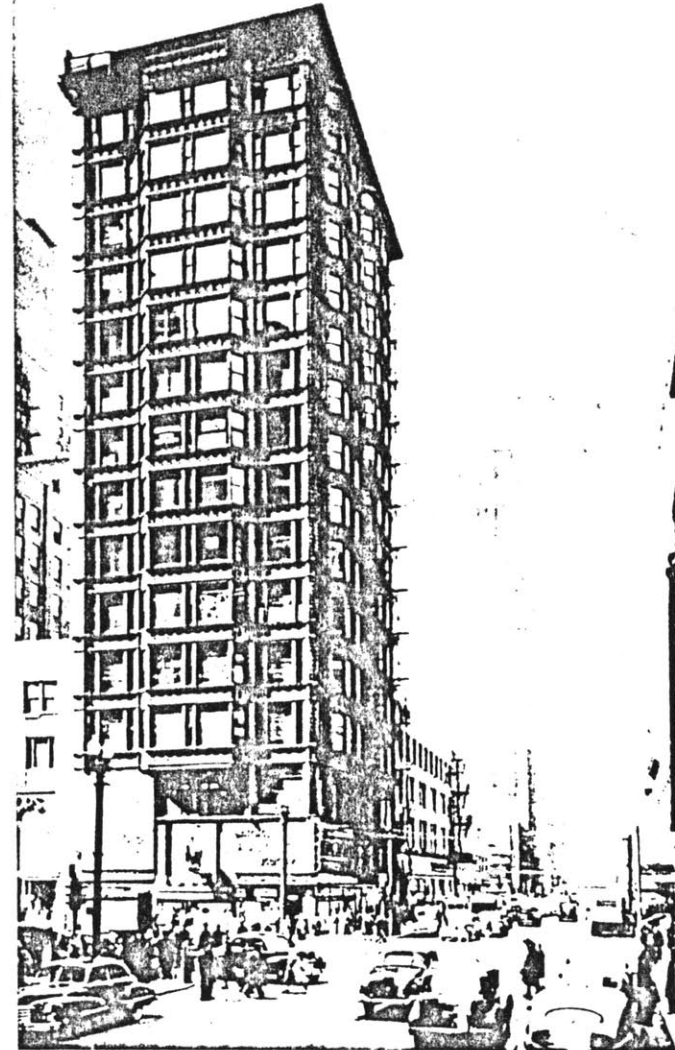
No matter what the building configuration was, the common feature of all prewar office buildings was the massiveness of the exterior envelope. In the post-war period, this image would be replaced by that of the lightweight curtain walled and extensively glazed boxes.



First only an idea on paper, the glass tower became during the 1950's and 60's one of the most common images of our cities. Gropius's sketch of an all-glass skyscraper in 1909 and Mies van der Rohe's Glass Tower Project of 1919 were at that time only the dreams of their architects. Although Burnham and Root's Reliance Building in Chicago (1890-1894)

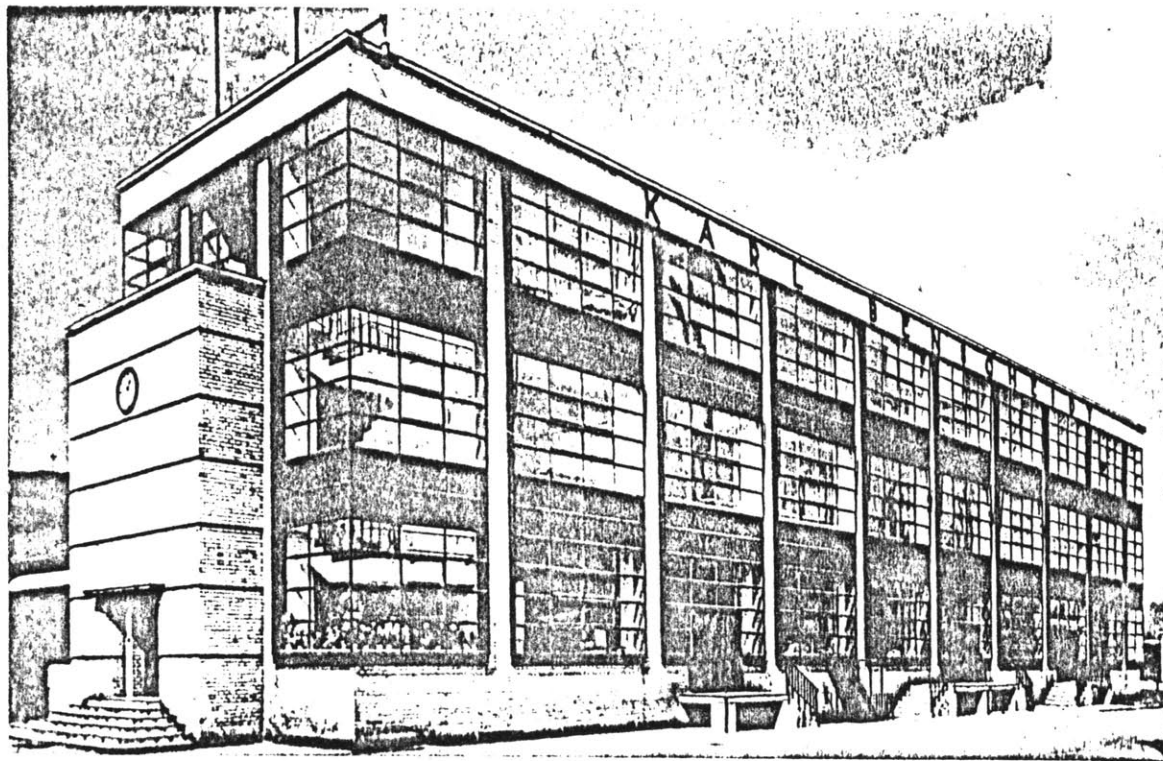
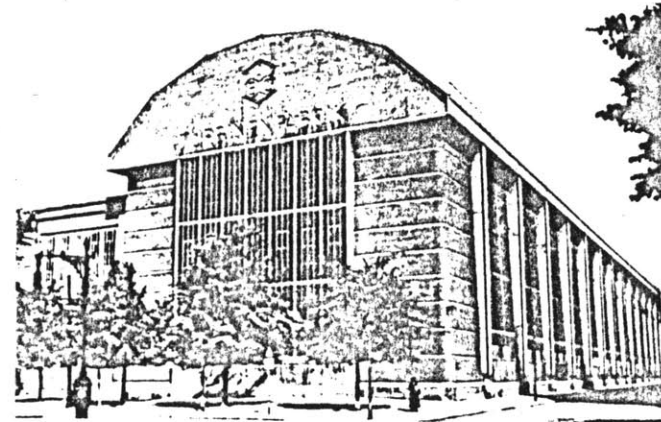


Mies van der Rohe's
Glass Tower Project



Reliance Building

featured for the first time the window-wall, in America the all glass wall did not have the theoretical importance it later had in Europe. Therefore, it was via Europe that the glass architecture returned to the United States, after the European architects had transformed it into a symbol of progress and well being.



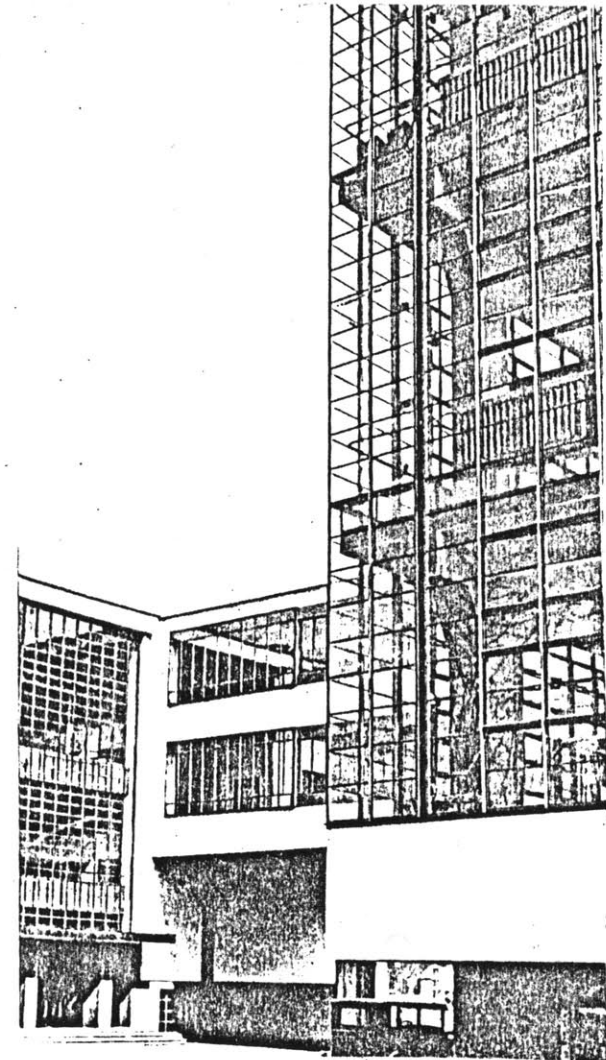
Initial phases of the
curtain wall;

above: the Turbine Plant
by P. Behrens

left : the Fagus Factory
by W. Gropius

Through innovative design and due to technological advancements, glass gradually became the dominant element of the facade. The Turbine Plant designed for A.E.G. by P. Behrens in 1908 had a several story high glass wall. In his Fagus Factory (1911), Gropius demonstrated new possibilities in glass joinery; in the Bauhaus Building in Dessau (1925) he again joins on a corner, with no structural support, two three-story high glass walls.

The near obsession of the European avant-garde architects with large expanses of glass and with daylight indoors has its roots in the situation of the European cities at the end of the 19th century, especially in countries where sun is not a frequent amenity, like Germany, the North of France, and the mountainous regions of Switzerland. In his writings, Le Corbusier often refers to light as an "essential joy" of life. Yet, European interiors often lacked sufficient lighting. Energy considerations, since windows increase heat losses, technological restrictions as well as stylistic preferences, promoted for centuries small size windows. On the other hand, the crowded built stock did not allow light and sunshine to reach most of the windows of regular tenement houses and office



The Bauhaus Building
by W.Gropius, Dessau

The emergence of a socially oriented architecture was a determinant factor in the architects' crusade for a universal enjoyment of light and sunshine. The traditional fascination with and longing for the sun, that drove the great German Romantics to Italy, continued to be nourished by the modern architects who were trying to trap as much of the ungenerous sun of their countries as possible through their large windows. Thus, they conceived a future architecture of light and openness. Their idealism and, maybe, the climatic conditions of their country, where solar gains are not feared, hindered them from foreseeing the eventual problems caused by excessive glazing.

America appeared as the perfect place for the realization of their dreams. It was a country traditionally open to inventiveness, with unprecedented technological capabilities, and, most of all, with the economic power to afford experimentation. The frame construction of the skyscrapers offered an excellent structural support for the light-weight facade promoted by the Bauhaus as well as a good formal support for the orthogonal expression of the International Style. The idea of the emphasis of the structure on the elevations,

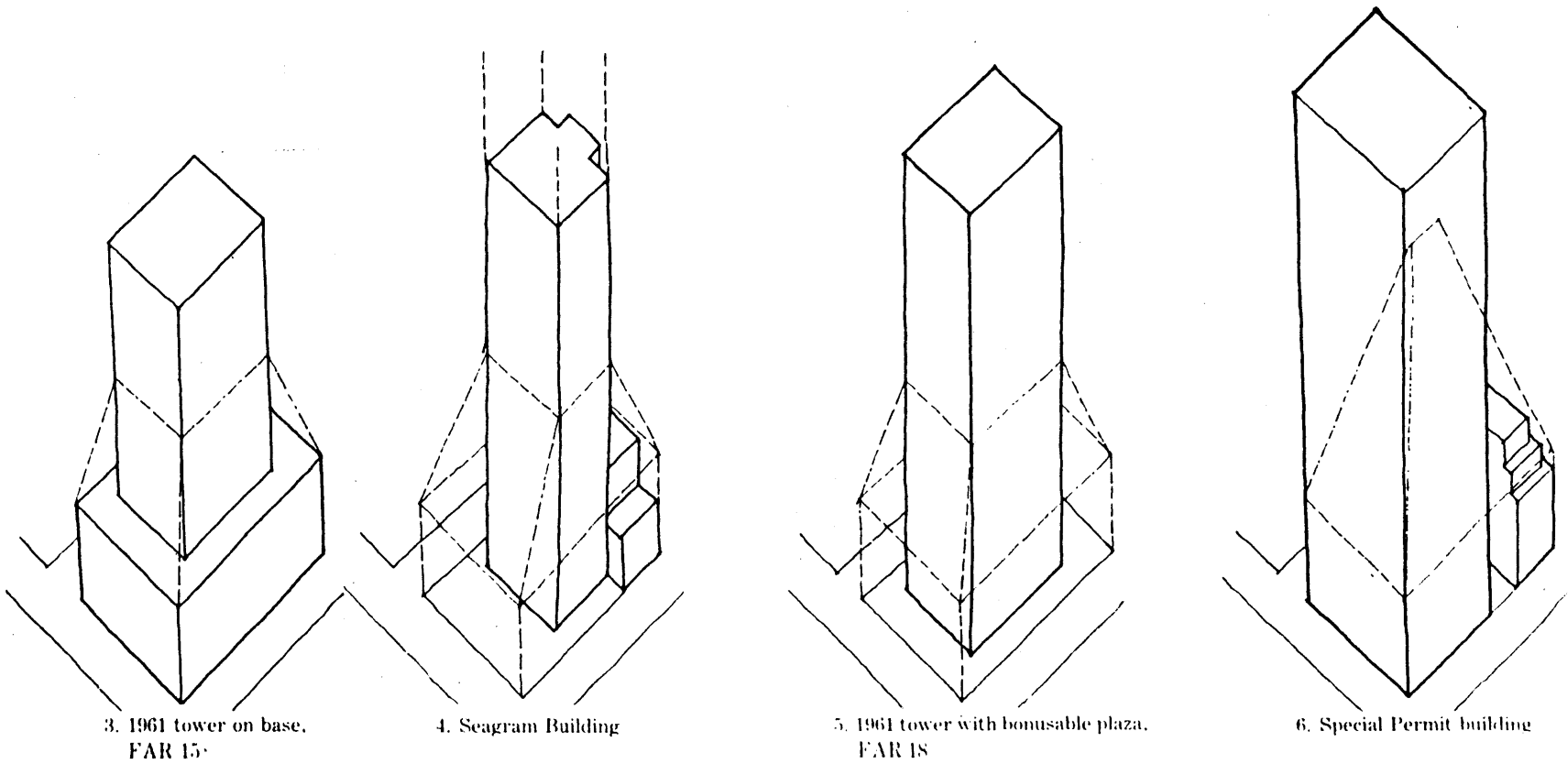
generated by the Chicago School, was thus revived a half century later.

The United Nations Building (1950) marked the birth of the new highrise office. Designed by Harrison and Abramowitz after an idea of Le Corbusier's, the building was the first skyscraper to employ the curtain wall. The energy related deficiencies of its glazed elevations facing the most unfavorable directions, East and West, were ignored in the general enthusiasm for the still novel possibility of air-conditioning, whose large-scale use was facilitated by low fuel costs.

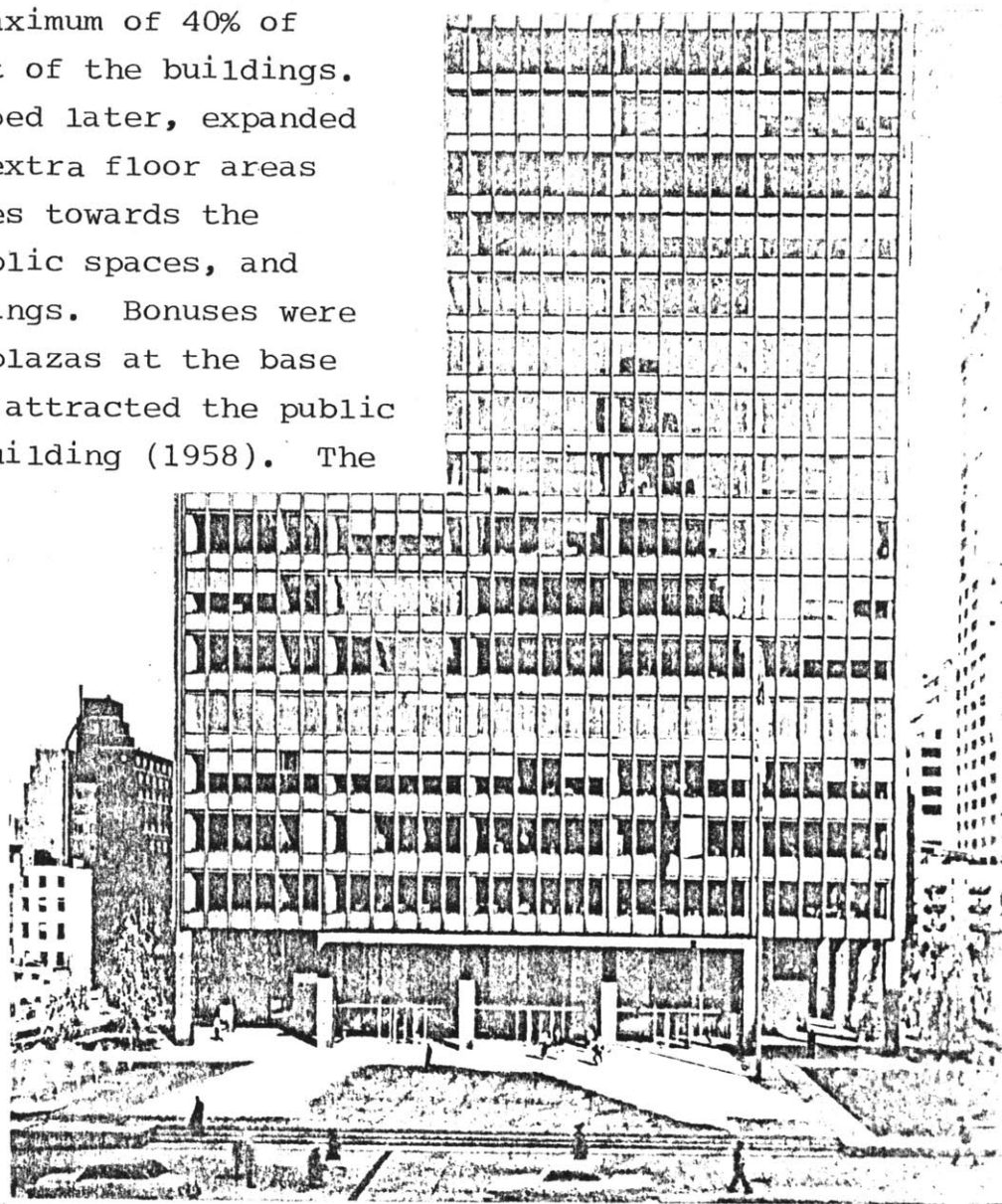
Air-conditioning, although introduced at the beginning of the century, was not extensively utilized until after the second World War. In the same period, another important amenity was made available for general use: the fluorescent tube, which became a catalog item in 1938, when Westinghouse and GEC introduced the "Lumiline" tube. The possibility of lighting efficiently and at a low cost as well as of mechanically conditioning the interior spaces determined the new configuration of the office buildings, which became large, pure volumes. This coincided with the aesthetic preference for simple volumes and was

enhanced by changes in the zoning regulations.

In 1961, the zoning law was changed to accommodate the need for larger offices. The new law stipulated that the buildings have a determined floor-to-area ratio (FAR) which, together with the requirement



that the tower area have up to a maximum of 40% of the lot area, determined the height of the buildings. The incentive system, which developed later, expanded the initial FAR of 15 by allowing extra floor areas in buildings that made some gestures towards the urban environment, for instance public spaces, and the preservation of historic buildings. Bonuses were first offered for the creation of plazas at the base of the building, a provision which attracted the public after the success of the Seagram Building (1958). The



The plaza in front of the Seagram Building

bonus system extended to include other amenities, and the FAR of some buildings was increased to 18 or even 21. Besides inspiring the "tower in a plaza," the Seagram Building also initiated the fashion of dark glassed windows.

As a result, the city began to be inhabited by the large dark boxes that robbed the environment of light. With the reduced luminosity of the urban space, daylighting was further hindered.

CHAPTER 2 _____

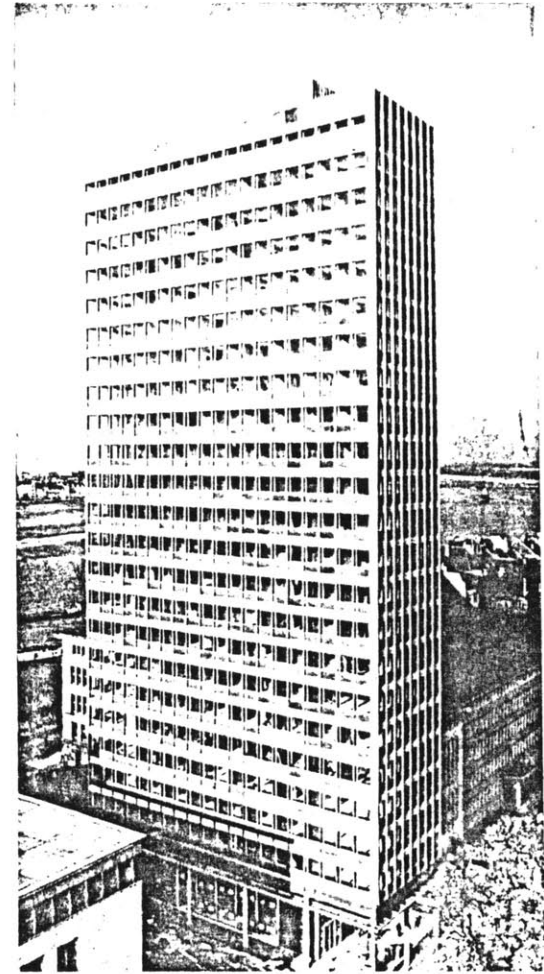
SITE & ORIENTATION

The configuration and the weather conditions of a site are the first elements to be considered in the design of an energy efficient building.

A design that responds to the requirements resulted from the thorough analysis of the building location and the climatologic data can significantly contribute to the reduction of heating and cooling loads. A site can be looked upon at two different scales: geographic and topographic. At the geographic scale, the climatic elements are the parameters to work with. Sun, wind, temperature, and precipitations determine eventual heat gains, the rate of heat transfer between the indoors and the outdoors, and the rate of infiltration, and thus have a direct influence on the energy needs and the nature of climate control. The lot configuration and location in the urban context determine the degree by which the envelope design can positively respond to the climatic conditions, the degree by which the building can admit the beneficial natural elements and avoid the undesirable ones.

Economic parameters like land value, construction costs, investment return, pressed for architectural solutions that exploited to the maximum, within legislative and technological limits, the given lot, ignoring the local natural conditions. This, together with generalized aesthetic values, led to the worldwide uniformity of images. We see skyscrapers of similar appearances, if not identical, in cold climates like Toronto, or in hot climates like Houston, in tropical regions like Hong-Kong, or temperate like Dusseldorf.

An architecture more sensitive to the climatic conditions as well as to the location of the buildings in the specific urban microclimate, would not only benefit the energy performance, but would also contribute to the diversity and specificity of the built form.

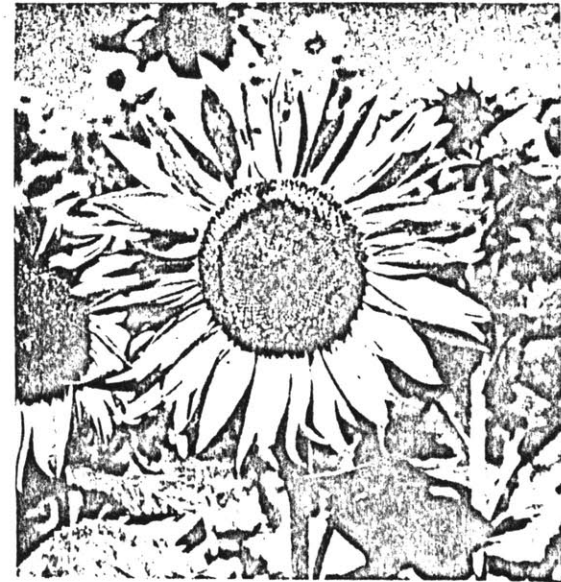


Office Building in
Dusseldorf, Germany

SUN is the most important natural element to be considered in design since it affects every stage of the process, from building orientation to exterior finishing materials.

Depending on the geographic location and the time of the year, the sun radiation is welcome and in that case the building should be able to capture as much solar heat as possible, or is undesirable and in that case the building should be able to avoid solar gains.

The first consideration in achieving a good response to the degree of solar radiation needed is the proper orientation of the building. Exposing most of the glazed areas to the South secures heat gains in winter. A Northern orientation of the windows is welcome in hot areas where sun is to be avoided all year. West and East exposure should be minimized since, unlike the case of a Southern exposure, the solar radiation is difficult to control with the elements of the envelope. The best orientation, therefore, for rectangular buildings is to place them with the long axis parallel to North-South.



The location of the buildings relative to each other and to the shadow pattern can also influence the amount of solar radiation that strikes the envelope. In very hot and dry climates, buildings are grouped together to allow for the least surface exposed to the sun, as well as to take advantage of the dense shadows thus created. The necessity of obtaining adequate natural lighting in office buildings makes it undesirable to avoid solar access by overcrowding the buildings.

WIND pattern and force have a great impact on the performance of the structure as well as on the heat transfer between the outdoors and the indoors. The concern of the designers for the vital importance of the wind action on the structure of a tall building has led to a relative neglect of the energy-related role of the wind.

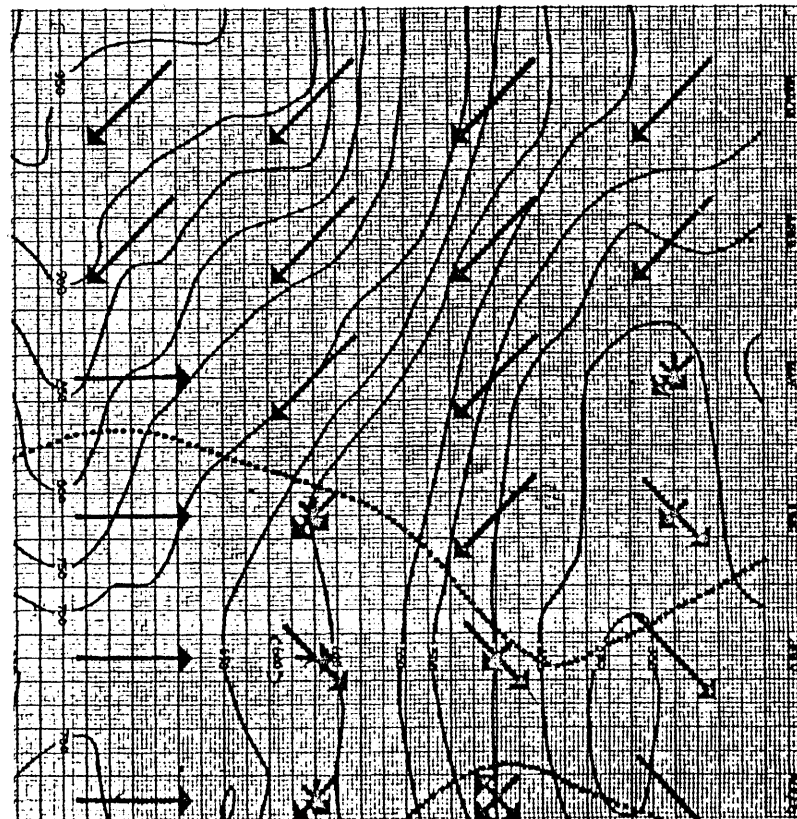
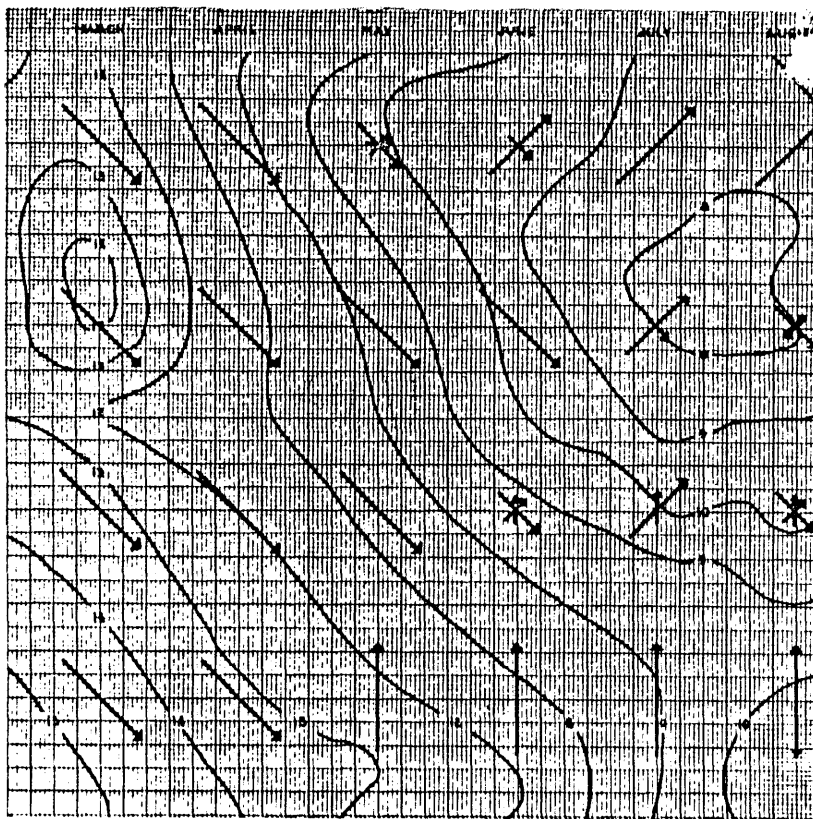
Wind has a direct impact on the quantity of the air infiltrations and thus on the building heat losses. Also by reducing the still air film on the building surface it lowers the thermal resistance of the wall, which increases the heat transfer through the envelope. Infiltrations and heat transfers influence the heating and cooling loads. Humidifying loads are increased when the wind removes the water vapors from surfaces.

Small buildings can be sheltered from adverse winds by partially burying them, or by deflecting the wind with the aid of the vegetation. Sheltering being impossible in the case of high-rise buildings, the designer has to work with the orientation and the

shape of the building in order to minimize the bad effects of the local winds. Plants on terraces can slightly affect the flow of the wind as well as increase the air film.

The placement of the building in the local wind pattern determines also the desirability of natural versus mechanical ventilation.

Wind pattern variations
in relation to height:
left: at 50 ft.
right: at 6 ft.



PREWAR PERIOD

The initial fascination with the skyscraper as a building type, as well as with its role as a symbol of the progressive age, overshadowed other concerns related to its construction. The aesthetics of the tall building has always been the issue of greatest concern. Tuning the building to the natural elements was a minor concern in all the phases of the evolution of the skyscraper design. Yet, in the first decades of this century there was a significant concern for the recognition of the points of the compass, a concern which gradually faded into the disregard of the building orientation that characterized most of the postwar architecture.

The issue of the position of the building relative to the sunpath generated a multitude of researches, discussions and disputes at the beginning of the century. The availability of sun radiation, though, was not considered from the energy point of view, but rather from that of public and personal health. Sunlight was considered to be an essential element in

the health and welfare both of individuals and of the community.

"Sunlight is an important aid in the prevention and cure of certain specific diseases; it is one of the most effective destroyers of harmful bacterins; it is the heat of the sun rather than its light that is responsible for most of the ill-effects of over-exposure, and through its direct and indirect influence as it is an important aid in developing human vitality and building bodies which can fight active diseases and disease tendencies effectively."

Around 1910, the French architect M.A. Augustin Rey wrote articles and gave lectures in the United States on the necessity of sunlight indoors. His conclusions were influenced by discussions with medical authorities on tuberculosis and other diseases affected by sunlight. Augustin Rey devised methods and schemes of planning and design that guaranteed one hour of sunlight to every window at

noon on the shortest day of the year. Another influential study on the relationship between sunlight and health, "Sunlight and Daylight in Urban Areas" by W.D. Heydecker and E.P. Goodrich appeared in the 1930 "Regional Plan of New York."

The concern for sunlight, with more impact on the residential architecture of the period, is only slightly reflected in the design of the office buildings, and is illustrated by the requirements for the orientation of the light courts. Most office buildings were provided with inner courts or courts open on one side, whose role was to increase the perimeter and, with it, the availability of natural light. Since natural light was associated with the medically beneficial sunlight, the orientation of these courts sought to obtain maximal solar access. The courts were opened toward South with as much Southern facade as the lot and the design permitted. Inner courts were preferably oriented with their long axis parallel to North-South, in order to secure sunlight on both of the longer walls. Since solar gains on Western and Eastern elevations in summer are greater than on Southern elevations, and also more difficult to

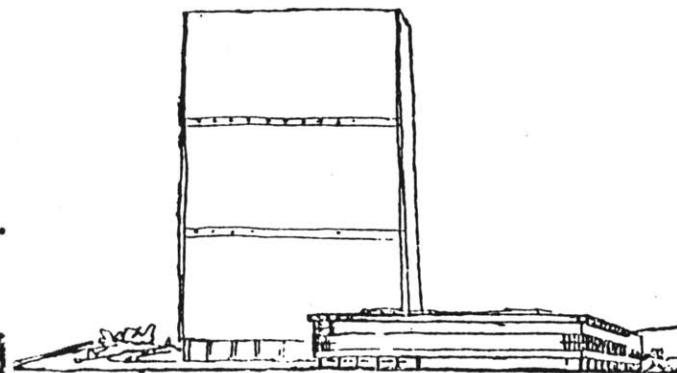
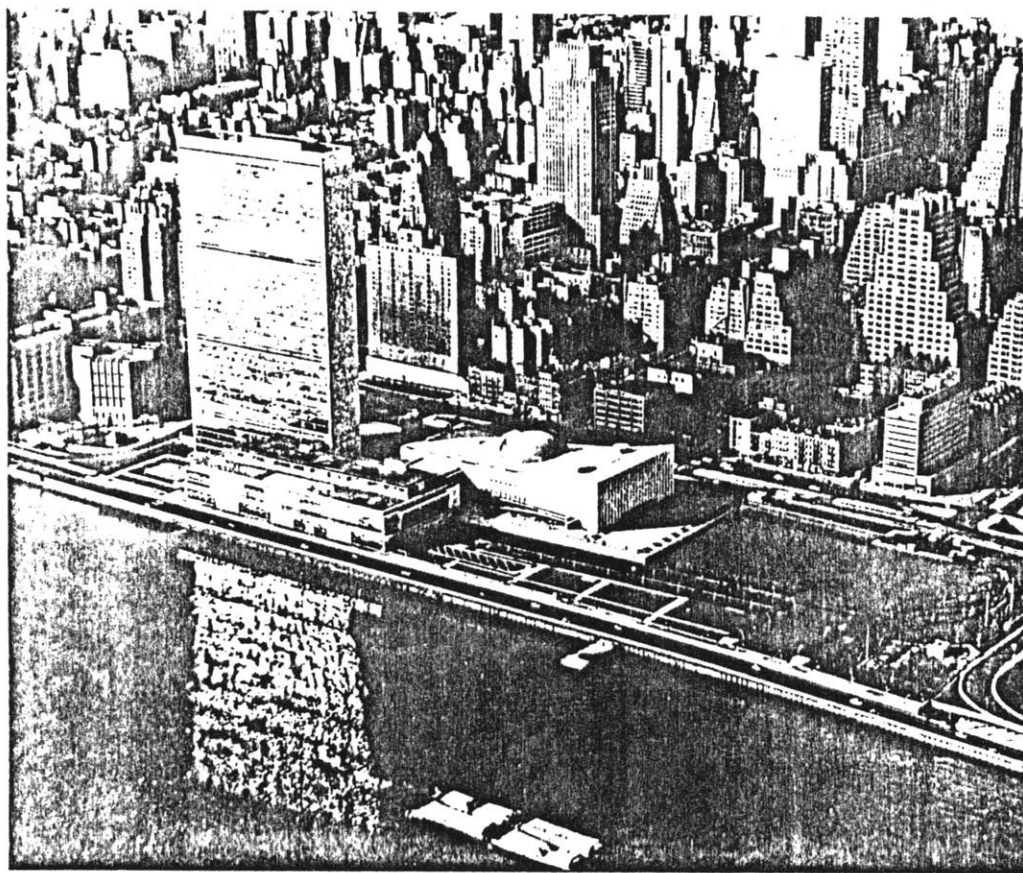
control, this example shows that the energy effects of the solar radiation were of lesser importance than its effects on health.

The impact of the local winds on the building was only considered in terms of structural issues. The shape of the prewar skyscrapers does not reflect an intent to avoid excessive exposure to cold winds.

POSTWAR PERIOD

A characteristic of the postwar skyscraper is its total independence from the natural conditions. The United Nations Headquarters in New York stands as the first manifesto of the total self-reliance of the modern office building. With its long axis oriented North-South, the U.N. Building exposes its completely glazed long elevations towards East and West, the two orientations most difficult to control. Le Corbusier's protests and insistences that shading devices be provided on the building envelope were

ignored by the designers and thus the building that set a record in heat gains was erected to serve as an unfortunate model for the decades to come. The expressive articulation of the duct floors on the elevations was yet another symbol of the building's complete dependence on mechanical space conditioning.



Le Corbusier's sketch for
the United Nations Building

The United Nations Building
as built after a design by
Harrison and Abramowitz

The total disregard of a building's orientation relative to the points of the compass developed for two reasons. With the increased use of cheap fluorescent lighting, daylighting was no longer a necessity and therefore the quality of light, mostly determined by orientation, ceased to be an issue. More of the office floor was taken by interior spaces, and the role of the window as a source of light and sunshine became minimal.

The other reason for the declining concern for orientation was new attitudes towards sunlight. The progress in medicine, pharmacology, and sanitation diminished the interest in the relationship between health and natural elements, particularly sunshine. Tuberculosis could be cured with penicillin, chemicals killed germs, mechanical devices purified the air. Men no longer needed the antiseptic role of the solar rays. The new buildings reflected this attitude. Undifferentiated elevations of equal size and treatment faced each direction. The close vicinity of several tall buildings blocked solar access, creating an environment of permanent shadow.

The effect of the wind on the heat transfer through the envelope continued to be ignored as a parameter in determining the building shape and orientation.

The rising energy consumption is only one, and by now well-documented, effect of the new architecture. The psychological effect of the lack of sunshine in work spaces is still to be studied. The movement of the sun, the variation in the intensity of its radiation, the atmospheric changes that reflect weather conditions, all contribute to the dynamic character of the environment. The latter is a recognized factor in human performance.

"Normal consciousness, perception and thought can be maintained only in a constantly changing environment; when there is no change a state of "sensory deprivation" occurs. Experiments have shown that a homogeneous and unvarying environment produces boredom, restlessness, lack of concentration and reduction in intelligence." 3.

CHAPTER 3



ENVELOPE

The exterior walls, the roof and the foundation form the protective envelope which controls the degree of contact between the outdoors and the indoors.

From its initial role of protecting men from adverse natural elements, the envelope evolved into a highly selective control device. A building skin properly designed from the point of view of energy efficiency should be able to:

- minimize the conductive heat transfer, and
- control the access of outdoor elements like solar radiation and air into the building.

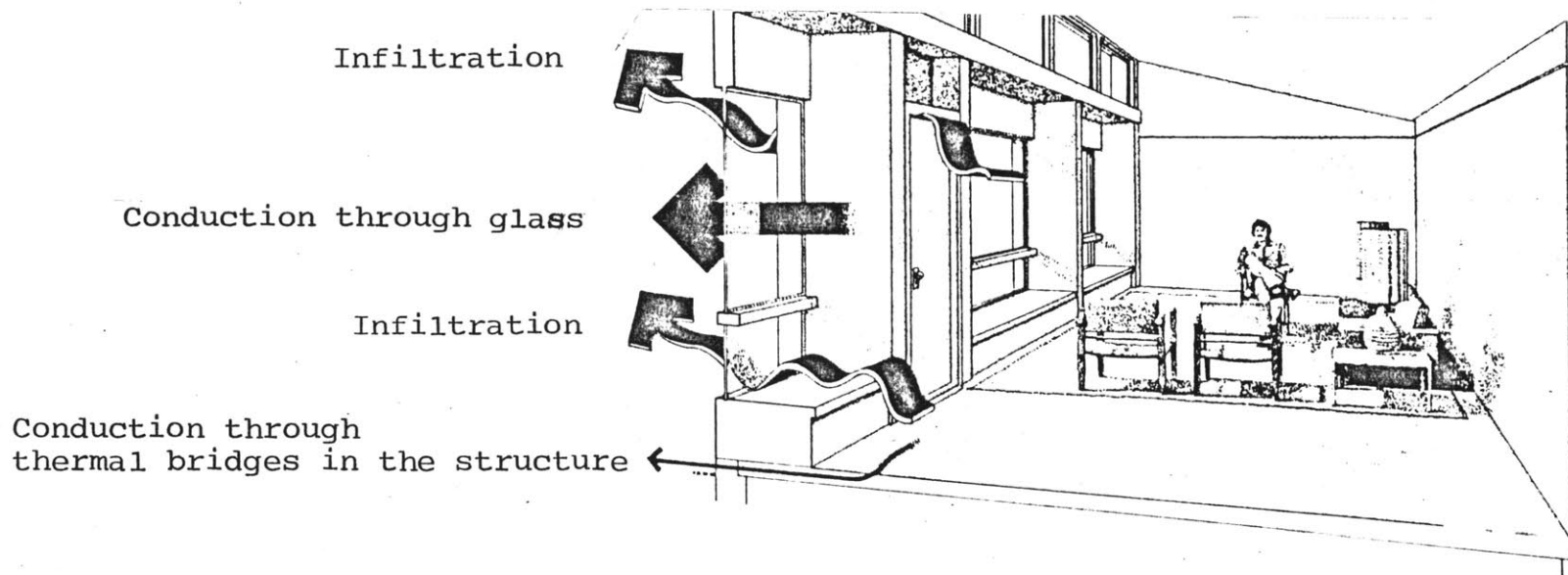
Due to the nature of the highrise building, the role of the foundation and the roof in the heat transfer is negligible compared to that of the walls. Heat transfer occurs through the wall material itself, or with the infiltrations between the different elements of a wall. In order to minimize or control the transfer, an adequate

envelope is required to:

- provide insulation against heat flow, or
- retard the heat flow in and out of the building, and
- control the heat passage in and out of the building.

Infiltration is an important factor in determining heat losses and ventilation requirements. Although, from the point of view of ventilation, infiltration could be beneficial since it provides a natural source of fresh air, its uncontrollable

Heat losses through the building



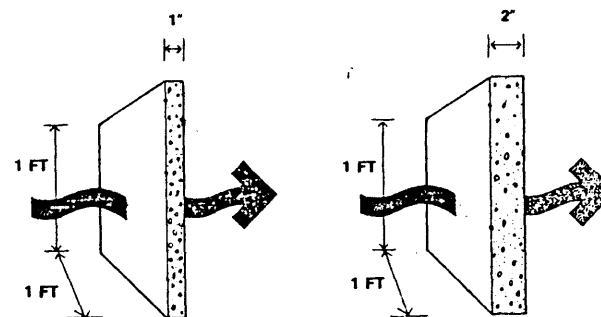
nature makes it undesirable. It is necessary to control the access of outside air, since the amount that can be let indoors fluctuates with the temperature and quality of the outdoor air. In areas of heavy pollution, a perfect isolation of the indoors is necessary. In winter, the infiltration of cold air contributes significantly to the increased heating loads. Infiltration occurs through the cracks around the windows, doors, and other perforations of the walls as well as the cracks between badly fitted wall elements. The presence of cold winds increases the rate of infiltration. Therefore, in the design of an energy-efficient wall, it is essential to:

- avoid placing it in the direction of the prevailing cold winds,
- provide the least possible openings on a windward facade,
- control the choice of the wall elements and the execution of the construction details.

The heat transfer through the wall itself is a more complex phenomenon involving processes of conduction, radiation and convection.

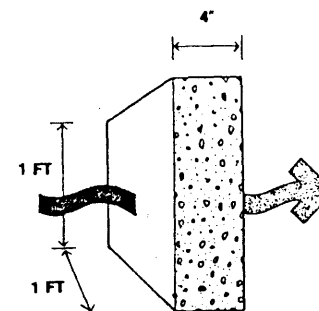
"Conduction is the process in which heat energy is transferred between molecules within a substance, or between two substances in physical contact, by direct molecular interaction. The warmer molecules bump into and pass some of their vibrational energy to adjacent molecules. The direction of heat flow is always from warm to cool. As the molecules at the surface of a material are heated by solar radiation, they pass this energy to cooler adjacent molecules dispersing the heat through the material so that it takes on a more uniform temperature. The rate of heat flow or the thermal conductivity (k) of a substance is dependent on the capability of its molecules to send and receive heat.

"Convection is defined as the transfer of heat between a surface and a moving fluid, or the transfer of heat



CONCRETE

Conductivity (k) =	12.0	12.0
Conductance (C) =	12.0	$\frac{12}{2} = 6.0$
Resistance (R) =	$\frac{1}{12} = 0.08$	$\frac{1}{6} = 0.17$



	12.0	Btu/hr-sq ft-in-°F
$\frac{12}{4} =$	3.0	Btu/hr-sq ft-°F
$\frac{1}{3} =$	0.33	hr-sq ft-°F/Btu

by the movement of the molecules from one point in a fluid to another. In convection processes, heat again always moves from warm to cool. As the cool molecules of a fluid such as water or air come into physical contact with a warm surface, some of the vibrational energy at the surface of the material is transferred to the adjacent fluid molecules. The greater the temperature difference between two substances, the more heat will be transferred. Conduction from the surface of the material to the fluid is the initial heat transfer process, but as the fluid is warmed, it expands, becomes less dense and rises. As the warmer fluid molecules rise, they are replaced by cooler molecules. This results in a continual movement of the fluid. When heat alone is responsible for this movement, the process is called NATURAL CONVECTION. The convection process also works in reverse. As a warm fluid comes in

contact with a cool surface, the warmer molecules transfer some of their heat to the cool surface, become heavier and sink. For example, warm air in contact with a cold glass window induces a downdraft of cool air at the floor near the window." 4.

Radiation is the process by which energy is emitted by the movement of the molecules of a substance. All materials radiate thermal energy all the time because of the continuous vibration of their molecules. The amount of energy radiated depends on the temperature of the radiating surface as well as on the emissivity, that is, the ability to give off thermal radiation, of that surface. Most building materials have emissivities of 0.9, which means that they radiate 90% of the thermal energy theoretically possible at a given temperature. The degree of emissivity of a material depends on its substance as well as the finish of its surface; highly polished metals, for example, emit less energy than those with a rougher surface. Materials differ more in their capacity to absorb heat than to radiate it. Depending on the density and composition of its surface, a certain material will absorb, reflect or

transmit the radiation that strikes it.

Conduction and convection transfer heat between the air and the wall materials. Radiation from bodies (sun outside, people and appliances inside) is absorbed by the wall and reradiated to the colder environment. The factors that influence the rate of this transfer are related to the physical properties

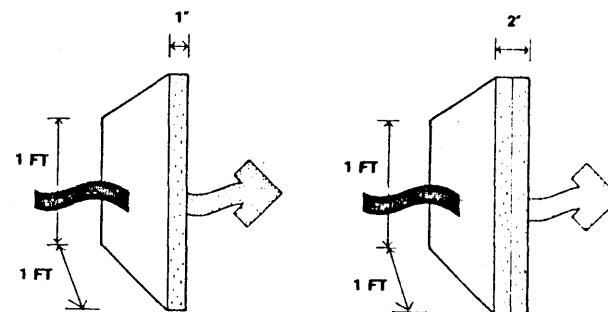
Time Lag of Heat Flow through Walls and Roofs

Construction	Time Lag (hours)
Walls:	
Brick: 4-inch	2.3
8-inch	5.5
12-inch	8.0
Concrete, solid or block: 2-inch	1.0
4-inch	2.6
6-inch	3.8
8-inch	5.1
10-inch	6.4
12-inch	7.6
Glass: window	0.0
block'	2.0
Stone: 8-inch	5.4
12-inch	8.0
Frame: wood, plaster/no insulation	0.8
insulated	3.0
brick veneer, plaster/no insulation	3.0
insulated	5.5

of the material - conductivity, absorptance and emittance, and heat capacity - as well as to environmental conditions - temperature difference between the indoor and the outdoor and the wind velocity, the latter with impact on the convective transfer.

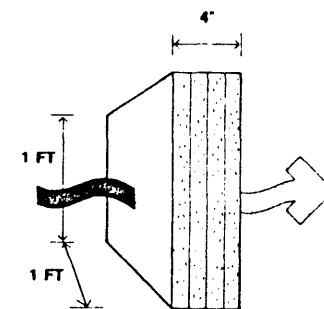
Heat capacity, which is a direct function of the specific heat and density of a material, describes the ability of the material to store heat. Heat flow is slower in a material with high heat capacity; this creates a time lag between the moment the heat reaches the surface of the wall and the moment it is transmitted into space again.

Heat transfer through the wall can theoretically be completely blocked with the aid of insulation. In practice, restrictions related to the size and placement of the insulating materials make only partial insulation possible. The use of insulation reduces the conductivity of the wall by adding the high resistance values of the insulating material. Most insulators are based on the low conductivity of the air and they are made of materials that contain a multitude of air pockets. Air spaces between two layers of wall materials can also provide an effect-



INSULATION

Conductivity (k) =	0.20	0.20
Conductance (C) =	0.20	$\frac{0.20}{2} = 0.10$
Resistance (R) =	$\frac{1}{.20} = 5$	$\frac{1}{.10} = 10$

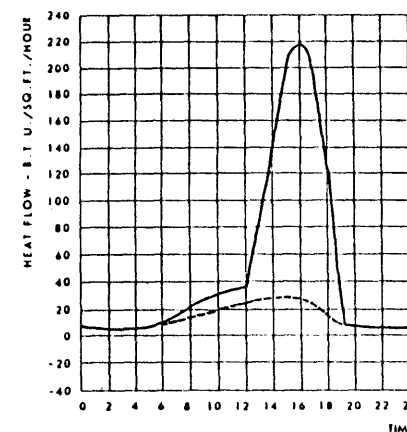


	0.20 Btu/hr-sq ft-in-°F
$\frac{0.20}{4} =$	0.05 Btu/hr-sq ft-°F
$\frac{1}{.05} =$	20 hr-sq ft-°F/Btu

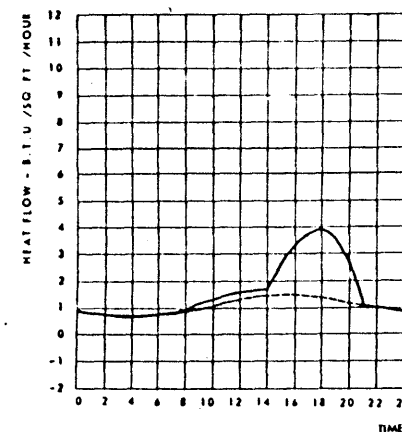
ive insulation if the width of the space is small enough to inhibit natural convection.

This insulating method is used in sandwich panels as well as in glass elements. Due to the high conductivity of the glass, windows cause considerable problems when heat transfer is to be avoided. The most efficient method of reducing conductive losses through glass is the use of several panes of glass with narrow, tightly sealed air spaces between them. The use of high reflectivity, low transmittance glass reduces the heat gains from solar radiation.

A more efficient way of dealing with solar radiation at the envelope level is to control its access rather than to permanently block it. This can be achieved with the aid of the shading devices. Moveable shading devices like louvers, awnings and shades are attached to the walls and they can be added or removed at the occupant's will. Fixed shading devices, like overhangs for Southern exposure and vertical fins on Western and Eastern elevations, are part of the building structure and therefore their provision is an important design decision. Although the use of fixed shading devices appears as an obvious necessity,



Heat transmission of a glass pane.



Heat transmission of a wooden wall.

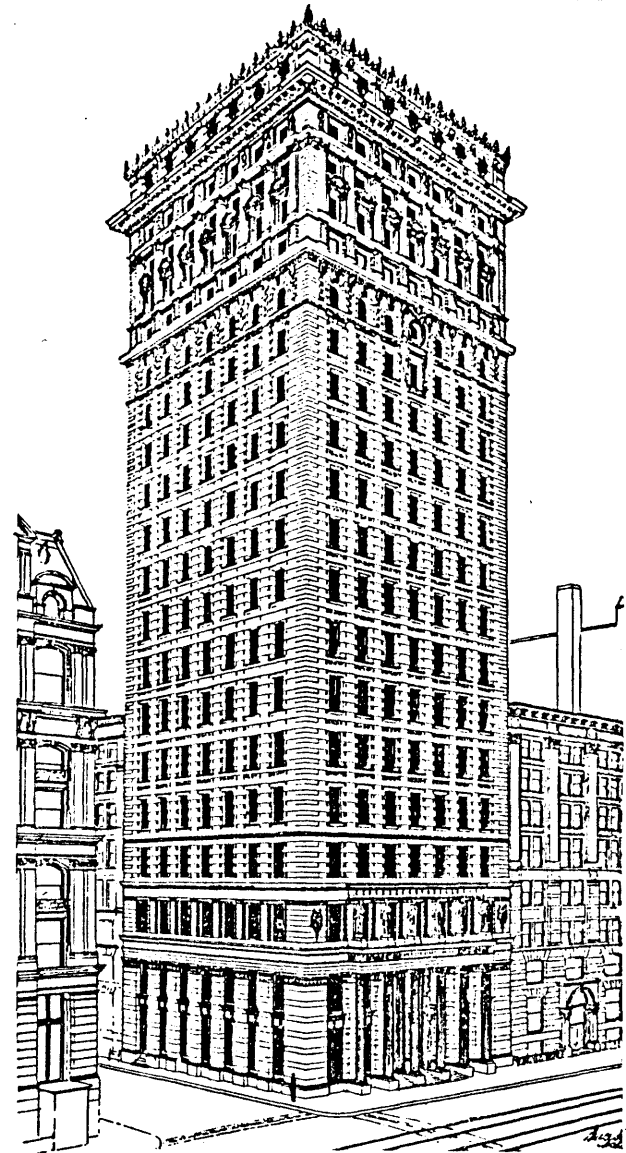
The high rate of heat transmission of glass comparative to that of a wooden wall

aesthetic considerations, which have always dominated the envelope design, led to their disregard in all the periods of the skyscraper's life.

PREWAR PERIOD

We are used to perceiving the differences between skyscrapers of various periods as functions of their volume and their envelope design. The distinctiveness of the building skin has been usually considered only in one dimension, the aesthetic one, although its design and structure have had a considerable impact on the changing energy efficiency of the highrise.

The shift to lighter materials and large expanses of glass, characteristics which marked the transition to the postwar architecture, are also the causes of the increased energy consumption. The mass of the walls is one of the features that determine the energy performance of the envelope. Prewar buildings were steel skeletons clad in brick, later in concrete, often faced with terra cotta tiles. The self-supporting facade elements of the steel frame building, although not so massive as the earlier bearing walls, were yet considerably thicker and contained more mass than the typical curtain wall which exclusively forms the outer shell of the office buildings since the 1950's. The use of materials with high specific



The massive envelope of the prewar skyscraper

heat (brick, concrete, terra cotta) contributed to the good thermal storing capacity of the walls. The delay in the heat transfer produced a time lag between the moment of extreme conditions outdoors and the effect of these conditions indoors. The indoor temperature swings contributed to a more balanced environment and thus to a more efficient use of mechanical space conditioning.

Thus on a hot summer day the solar radiation which peaks around noon would affect the indoors only hours later at a time which, in offices, is close to the end of the working day. This leads to reduced cooling loads in general and especially during peak electricity consumption hours. In winter the slower heat flow rate reduces the heat losses. Also, on a sunny day, the wall stores the heat from solar radiation and releases it into the rooms when the outside air is colder and the conductive losses through the window proceed at a faster rate. This again lessens the temperature swings and, by allowing a more uniform heating rate, improves the efficiency of the energy consumption.

The amount of glazing is the other element that

determines the quality of the envelope as an energy transfer medium, since glass, of all building materials has the lowest thermal resistance and allows the penetration of solar radiation.

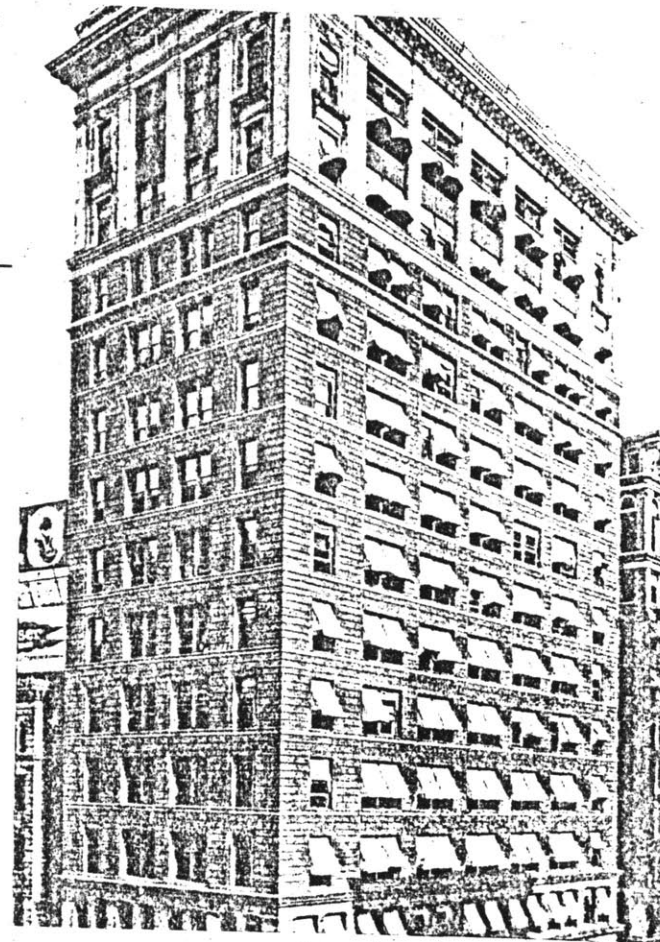
In the first half of this century, glazing was more a matter of natural lighting than of architecture image. Although there were differences in the types of fenestration, the size, proportions and distribution of the windows were important stylistic elements (see the horizontal window bands of the Chicago School versus the classical vertical perforations of the New York buildings), and the variations were small and within the same concept: that of the window as a source of light. The reduced glazing area, compared to more recent buildings, is in great part responsible for the differences in energy consumption reported in the study done by the Syska-Hennessy firm. With less glass area, conductive heat transfer, and, most important in office buildings, direct solar gains, are drastically lowered.

The stylistic requirements of the skyscraper architecture of the period did not allow the use of fixed

shading devices. The expressive forms of the latter would have given the elevations an image that would have conflicted with the prevailing taste. The international style, with its outward emphasis of the structural grid, offered the formal framework for incorporating shading elements. Yet, as the development of the style coincided with a period of abundant energy sources, the issues concerning passive climate control were greatly ignored.

Although fixed shading elements were nonexistent on prewar skyscraper elevations, moveable shading devices were extensively used on most buildings in order to alleviate the effects of the sunshine at the time when mechanical air conditioning was not yet invented. As most of these shading devices were on the exterior, they provided better protection against radiation and overheating than the interior devices used in modern buildings.

Another feature that contributes to the selective nature of the prewar building envelope is the openable windows, which allowed the occupants to control the contact with the outdoor environment as well as to control the natural ventilation.



Exterior shading devices

POSTWAR PERIOD

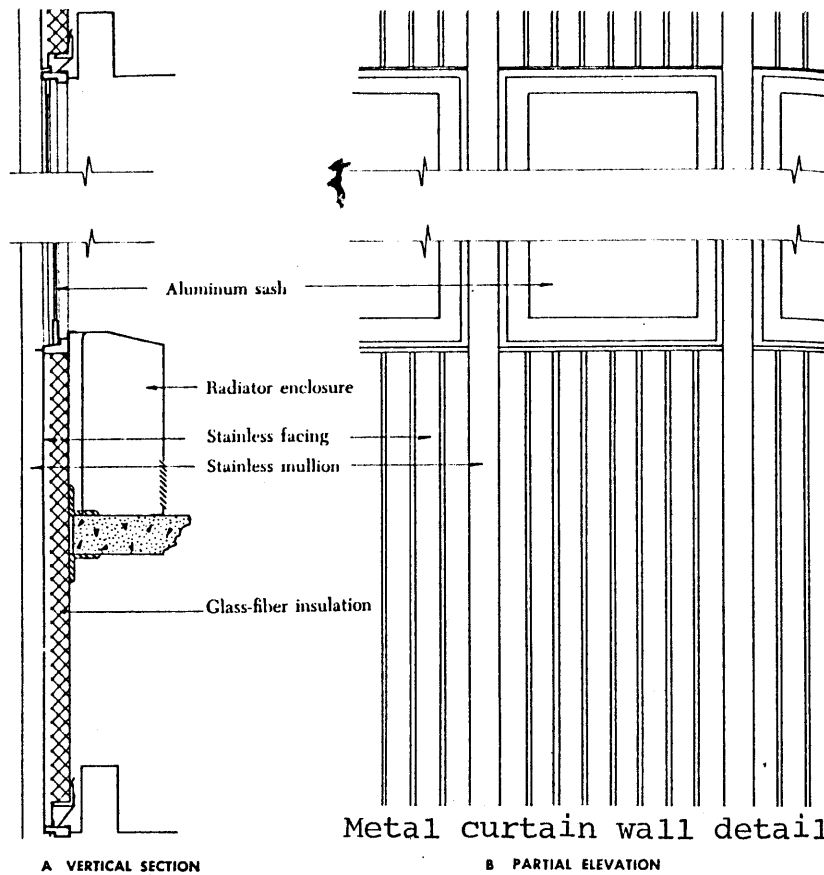
The most striking characteristic of the postwar office building is its excessive glazing. Glass in the modern buildings is no longer only an element of the window, a translucent wall material meant to let the necessary light in while also offering the basic shelter from adverse natural conditions. There are now buildings in which glass completely conceals the structure, where even the elements that support the glass are reduced to the minimum expression.

Large glass areas are not the only feature of the envelope that led to poor energy performance. Lack of mass and with it of storage capacity, increased infiltration due to bad assemblage of the curtain wall elements as well as the lack of exterior shading devices, all contributed to a increased heat transfer potential of the building shell.

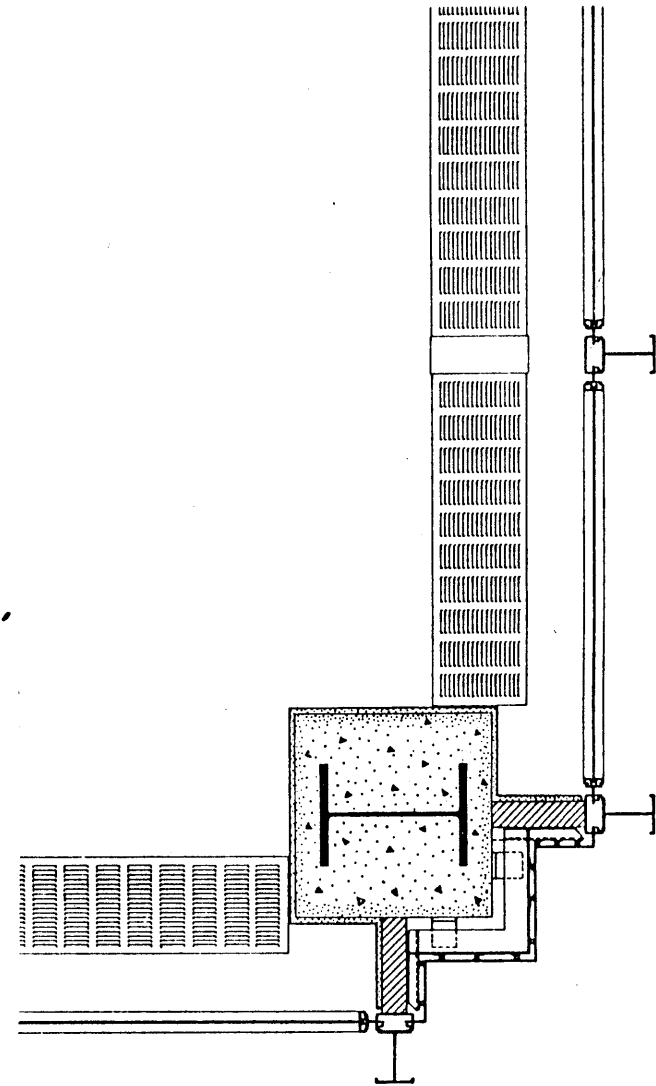
Another characteristic of the contemporary office buildings is the complete sealing of the interior environment. The inhibition of the natural ventilation thus resulted in adding to the energy loads.



Most of the above mentioned features are a result of the exclusive use of the curtain wall construction for the past three decades. The curtain wall is a special category of exterior nonbearing walls whose only role is that of separating the interior from the exterior. Its appearance was made possible by the union of frame construction and industrialized building.

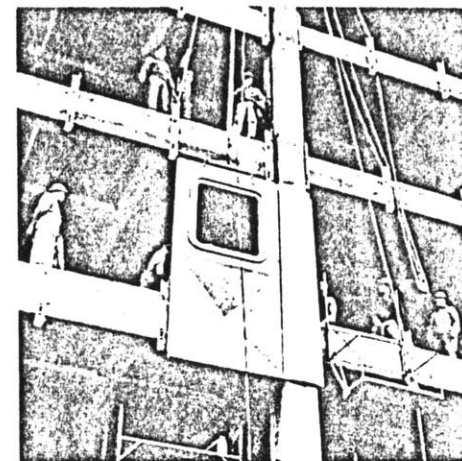


Detail of the Seagram Building curtain wall



Curtain walls are composed of light weight, modular, serialized building elements, constructed and finished in a shop, which are attached or hung to the structure on the site. Some advantages of the curtain wall are closely related to its prefabrication. Improved productivity is one effect of the shift of part of the production from the building site to the factory. Productivity is increased by the reduced labor consumption, by the doubled productivity of the on-site operations, as well as by the faster manufacturing rate which comes with standardization. Another good effect of the factory production is better and more controllable work conditions. The industrialized production allows for the experimentation of new materials and wall components. An example is the sandwich panel whose structurally weak layers are more easily assembled horizontally in a shop than vertically on the site.

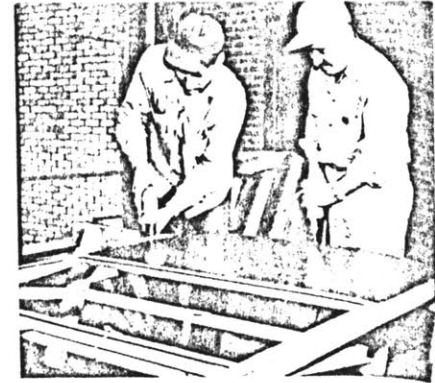
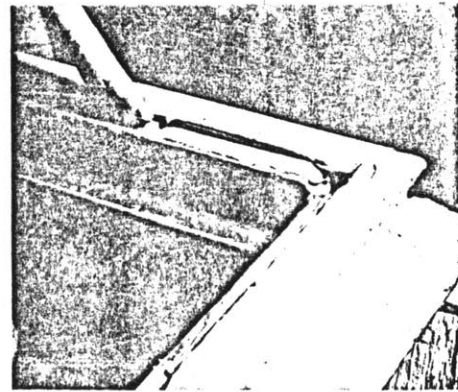
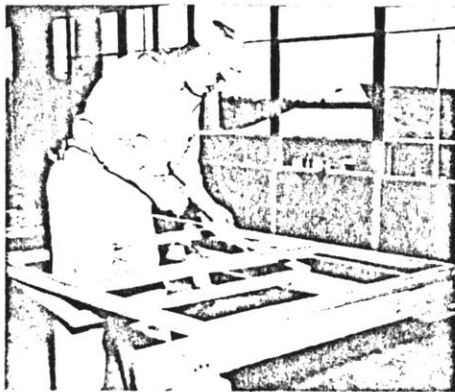
With minimal requirements for structural strength and with the possibility of using non-traditional building materials, low mass soon became the most important characteristic of the curtain wall. In terms of energy performance, this translates into low thermal storage capacity. Some of the new ma-



Mounting curtainwall elements

materials, like plastics and metals, have low heat capacities. Traditional materials, like brick and concrete, are used in thicknesses that do not insure the mass necessary for considerable heat storage. Therefore, the building skin cannot provide the time lag that in older buildings alleviates the effects of extreme temperatures.

The curtain wall is completely dependent on insulation for its good energy performance. Due to the nature of the sandwich panel, the installation of insulation is less laborious than in traditional walls. This apparent advantage, though, is countered by the problems generated by the discontinuous character of the curtain wall, and thus the overall



b.

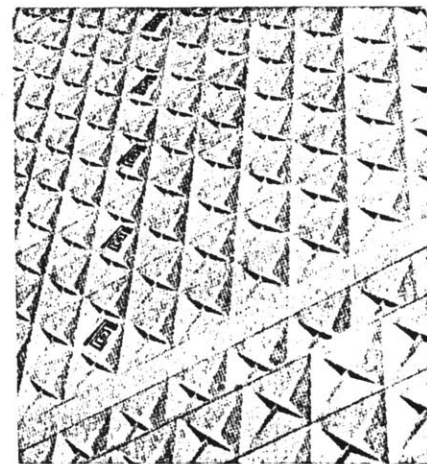
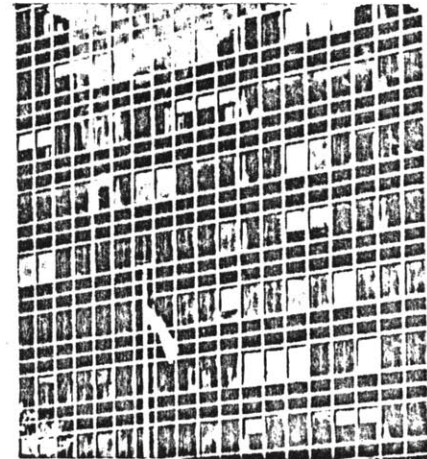


d.

Manufacturing curtain wall elements

energy performance remains unsatisfactory. Despite the impressive progress in building technology, adequate joining and fitting of the facade elements is still an unsolved issue. Faulty curtain wall joints allow for thermal bridges that increase the conductive heat transfer as well as for leakage of air and water. As shown before, air infiltration accounts for considerable heat losses.

Solving these problems requires detachment from the indifference to energy conservation that characterized the energy-abundant postwar decades. Increased interest in improving the thermal performance of the curtain wall can lead to the good design and careful execution necessary to make it an effective building skin.



CHAPTER 4



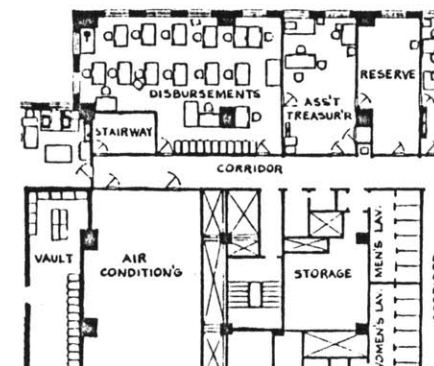
INTERIOR

Subtle influences in energy consumption come from the elements that define the interior spaces, that is, the dimensions of the office units, the distribution of the furniture, as well as the texture and color of the finishing materials.

In terms of workspace organization, there are two types of office interiors: the traditional office units separated from each other by floor to ceiling partitions, and the open space office, where a common space is divided into specific work areas by low partitions.

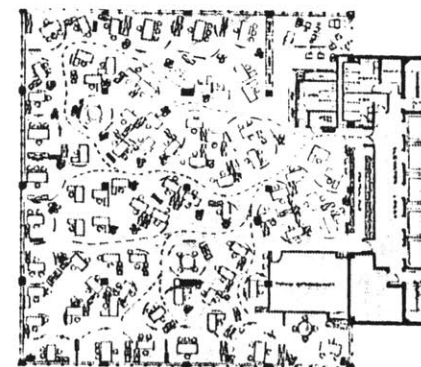
The open space office brought an improvement in the ergonomics as well as in the psychological effects of the work environment. Better communication and relations between different working units and a break in the monotony were the main positive characteristics on which its promotion was based. The change in space planning brought also changes in the energy consumption patterns.

The open plan, with its more efficient use of the space, results in a higher density and therefore less



Typical prewar office layouts.

Landscaped office floor



energy use per capita than the cellular office. The use of low partitions improves lighting, heating, and ventilating. Because of the possibility of "sharing" light, the illumination levels in an open space office can be substantially reduced to 25% lower than in the other type. Low partitions also allow for a deeper penetration of the daylight at ambient levels, if not task lighting levels. Partitioning elements facilitate the mounting of task lights which again could lead to a reduction in electricity consumption. Because of the free circulation of the air above the partitions, ventilation and heating also have the potential for higher efficiency: air can be introduced at the center of the space and then circulated to the periphery.

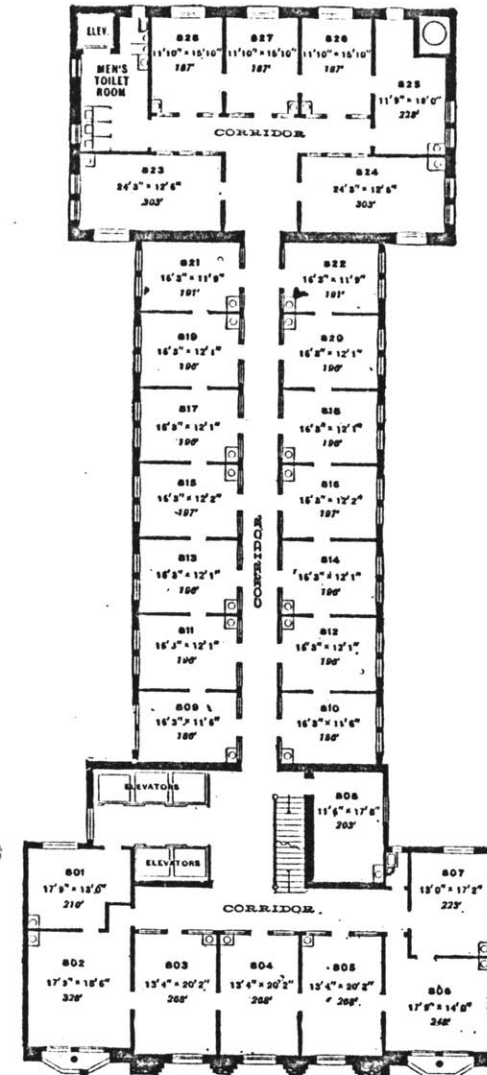
Although the open plan appears to offer definite advantages, its predominance in the postwar buildings did not coincide with a more efficient energy use. This is partly due to the exaggerated energy use standards, made possible by the low cost of fuel, which upset the potentially good effects of the interior planning. Other factors that caused an increased energy consumption were the changes in the space dimensions as well as finishing materials used.

The nature of the surfaces in the interior space is another element with impact on the energy performance. The thermal absorptivity of these surfaces determines the radiant coupling potential in the rooms. As shown in the previous chapter, radiation is a process of heat transfer between two bodies, one emitting, the other absorbing radiation. Heat flows from the warmer body to the colder one until an equilibrium is reached and the temperature of the two bodies becomes identical. The rate of this transfer depends on the emissivity of the radiant body and the absorptivity of the radiated body. A radiant coupling exists when there are no obstacles between the heat exchanging bodies.

Where construction materials provide heat storage capacity and where the radiant surfaces of the building elements are not obstructed, there is a continuous thermal transfer within the space, which contributes to an even heat distribution throughout the room as well as throughout the day. The resulting improvement in comfort reduces the role and quantity of mechanical climatization.

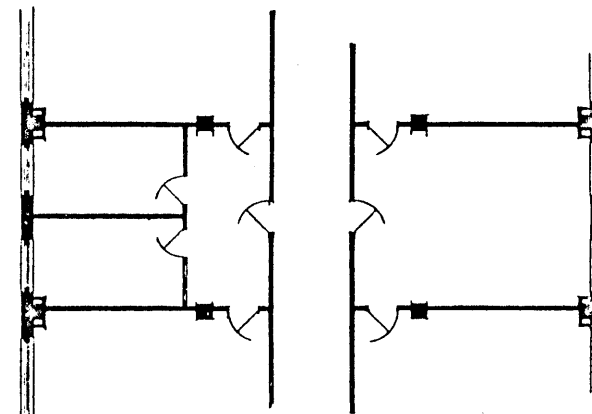
PREWAR PERIOD

High mass, provided by the partitioning elements, and the radiant coupling between the structure and the environment are the main features that distinguish in terms of energy performance the prewar office interior from that of the following period. The typical office layout, characterized by double loaded corridors with individual office cells along the windowed walls as well as the construction system of that time determined the ability of the space to respond to the interior climate. The dimensions of the units were determined on the one hand by the structural system, on the other hand by the necessity to allow maximum daylighting. Thus, the width of the offices reflected the sixteen to twenty foot dimensions of the structural bay, while the depth was usually calculated in relation to the height of the rooms in order to obtain natural light on most of the floor area. The ratios of depth to height recommended for proper daylighting were around 1-3/4 to 1 for spaces with windows on one side, and 4 to 1 for spaces with windows on both sides. The access of light to interior spaces like antechambers or corridors was often enhanced by glassed partitions and clerestories.



The relatively high ceilings as well as the isolation of the office units contributed to the phonic insulation within the office floor. Sounds were stopped from traveling to adjacent rooms by the heavy partition walls. Within the office cell, the noise was attenuated by the room height: since the intensity of the sound at one point is inversely proportional to the square of the distance between that point and the sound source, sounds reflected from a high ceiling lose more of their intensity by the time they reach the work plane than those reflected off a low ceiling. Noise was not a major problem and the use of sound absorbing finishing materials was not as imperative as it would become in the low-ceilinged open space of the postwar office.

Walls and ceilings could therefore be finished with hard surfaces -- they were usually exposed or plastered -- which allowed for an unobstructed contact between the structure and the environment. The hard surfaces facilitated the radiant coupling between building elements and air and people. The high heat capacity of the brick and of the concrete of the walls and floors provided the thermal storage capacity so important in creating a naturally even



THE CORRIDOR AND OFFICE UNIT

THE PRIMARY ELEMENT OF THE WHOLE STRUCTURE

The designer should keep this basic unit firmly in mind since the office building is essentially a multiplication of such units.

Contemporary recommendations
for prewar office design.

heat distribution. In summer, some of the excess heat can thus be absorbed by the structure and retained to be reradiated at a time when its presence would be of a lesser burden. Thus, peak cooling would not coincide with the peak electricity consumption and overall costs would be reduced. In winter, the radiant surfaces can function as heat sources when the heating elements are incorporated in them, as in the case of radiant ceilings or floors. Where radiant coupling is enhanced, the structure can also store some of the heat from solar gains and release it after these gains have ceased. The same redistribution of heat can occur with heat from other sources: radiators, luminaries. An even distribution of radiated heat can contribute substantially to the apparent thermal comfort; it has been demonstrated that radiative heat is more comfortable and subjectively more efficient than other forms of heat transmission. Apparent raises in thermal comfort can lead to slight reductions in heating requirements.

The reflectivity of the surfaces enhanced the distribution of light and heat in the interior space.

Wall reflectivities were due to the light colored finishes. The prevailing flooring materials, like asphalt tiles, vinyls, rubber, and wood, although chosen for their resilient qualities, had a polished surface that added to the reflectivity of the space.

POSTWAR PERIOD

The layout of the office floor changed with the introduction of fluorescent light and air conditioning. When natural light and air were no longer necessities, the area of the interior spaces became increasingly larger, while fewer units had direct natural light. The minor role of natural lighting and the dependency on artificial lighting led to lower room heights, as, on one hand, there was no need to seek maximum daylight penetration into the space, and, on the other hand, the low ceiling provided more efficient artificial illumination.

The open plan office theoretically responded

Approximate Reflection Factors

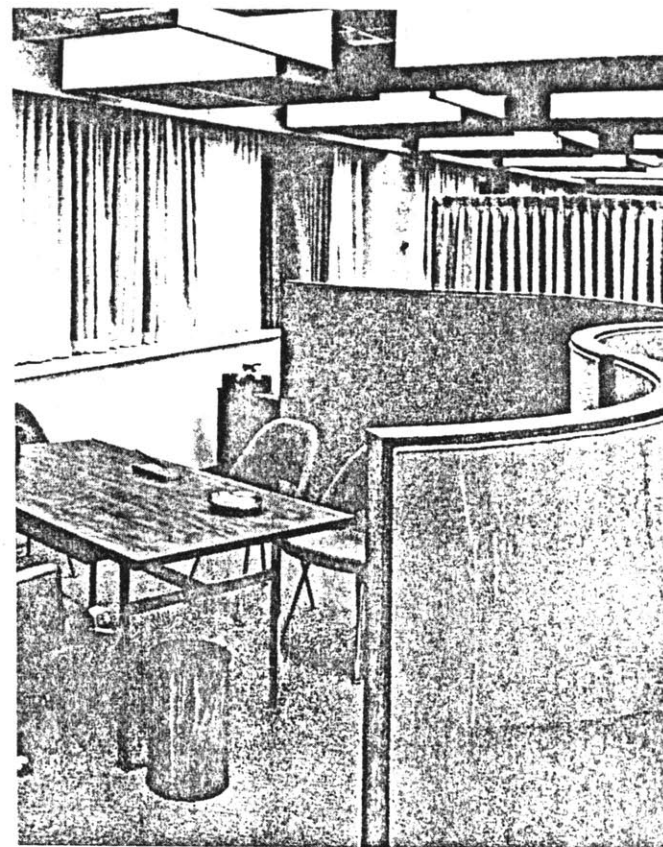
Medium Value Colors

White	80-85
Light gray	45-70
Dark gray	20-25
Ivory white	70-80
Ivory	60-70
Pearl gray	70-75
Buff	40-70
Tan	30-50
Brown	20-40
Green	25-50
Olive	20-30
Azure blue	50-60
Sky blue	35-40
Pink	50-70
Cardinal red	20-25
Red	20-40

better than the traditional plan to the energy related changes. Office landscaping, which had been experimented with in Europe in the 1960's and was introduced to the United States in 1967, offered a more efficient organization of the vast interior spaces. In addition to creating a varied and very functional space, it was also the only solution to securing a view of the windows for most areas of the floor. Although not an indispensable source of light, the window still remained an important visual link with the exterior, and its perception was a necessary factor in the psychological comfort.

A new era in office interior design came with the introduction in the late 1930's of the suspended ceiling. Its numerous qualities made its acceptance so rapid and its use so widespread that by 1947 there already appeared standard kits which eased its assemblage.

The suspended ceiling can be thought of as a multipurpose power membrane that contains the energy related equipment of a building. It conceals



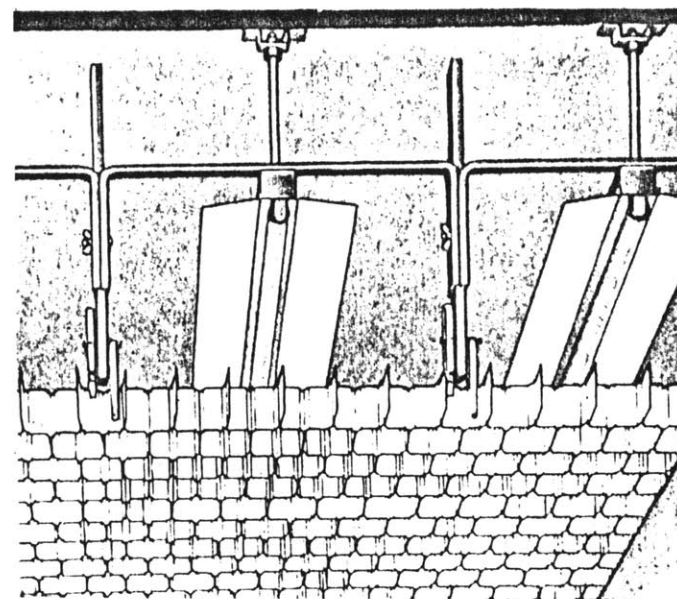
Detail of an open plan office

the transmission elements of heating, cooling, and ventilating, the electric cords and outlets, it incorporates the lighting fixtures as well as air outlets. The suspended ceiling became necessary as the mechanical equipment of a building became more complex.

"The equipping of most American buildings with comprehensive mechanical systems has stimulated the development of suspended ceilings to contain ducts, pipe runs, and service outlets."

When modularity became a characteristic of the suspended ceiling, its role expanded to include the luminous ceiling and the acoustic tile. These latter features were to have a significant impact on the energy consumption. The impact of the luminous ceiling was direct: the large number of fixtures induced extreme electricity consumption and also an increased amount of cooling to affect the heat gains.

The acoustic tile became necessary as the new office interior promoted noise problems. With the open



Suspended ceiling system, 1947
the Skyline Louverall standard
kit of parts.

space, as well as the low ceiling, sounds travelled freely and at high intensities between work areas. Sound absorbing materials on the ceiling and floor helped to inhibit the reflection of the sounds and thus diminished the overall noise. The floor, too, with the increasing use of the carpet as a finishing material, contributed to the sound absorbing quality of the rooms. The shift to soft floor materials was made possible by the increased availability of the vacuum cleaner, which eliminated the maintenance problems that had kept the carpet out of heavily used areas.

The acoustic tiles and the carpet eliminated the radiant coupling of the only massive elements in the open space office: the ceiling and the floor. The latter remained the only possible heat storage source after masonry and concrete partition walls disappeared. In the typical modern office building, the mass is concentrated around the service core, while the space is partitioned with elements that are either too thin to take advantage of the heat capacity of their materials, as in the case of gypsum board walls, or they employ materials

with low specific heat, like plastics. By eliminating the contribution of the construction components to the energy performance, the thermal comfort became completely dependent on proper mechanical space conditioning. This means not only increased heating and cooling loads, but also more complex and more costly distribution and control systems.

CHAPTER 5



LIGHTING

Lighting accounts for most of the energy consumption increase that occurred in office buildings in the period after World War II. Where, in the pre-war period, lights made up 15% of a total energy consumption of 80,000 to 100,000 Btu/sq. ft.-year, after the war it grew to 50% of a total of 200,000 to 300,000 Btu/sq.ft.-year, a ten-fold overall increase. Besides their direct impact on electrical energy use, lights contribute to the internal heat gains of an office building, which, in their turn affect the cooling loads: for every two excessive watts of lighting, there is an excessive watt of cooling. This led to a rise of light generated heat gains from one watt/sq.ft. to 4 to 5 watts/sq.ft.

These changes were determined by a growing reliance on artificial lighting in the period following the introduction of fluorescent lighting, and before the oil embargo of 1973. The present situation could be significantly improved by revision of the lighting methods and standards. A 50% reduction in electrical usage, which is possible to attain, would mean a 10% reduction in air conditioned loads and would lead to a 3% reduction of the national energy.

consumption, an amount of electricity that equals the output of 30 plants with 1,000 MWatt capacity each.

Architectural decisions, such as the increased floor area, were not the only causes for the extravagant electricity use. Equally important were the exaggerated lighting levels required by the codes. With the apparently abundant fuel, electricity became cheap enough to not contribute as a financial consideration. The resultant tolerant attitude of the consumers towards electricity use was exploited by the lighting fixtures manufacturers who advertised the benefits of higher illumination levels.

The differences in illumination levels required in the two periods were made possible by the difficulty of scientifically assessing the sufficient amount of light for various activities. Proper illumination is hard to determine because of the variations related to human vision. First, there is a wide variation between human eyes, differences in sensitivity occurring even between normal ones; second, the power of vision changes with age; third, the eye is adaptable to a wide range of light in-

tensities -- one can read at 0.05 foot-candles as well as at levels above 1,000 foot-candles. The difficulty in measuring the strain and the fatigue of the eye caused by inadequate lighting conditions is another factor.

The effect of light on the eye is not only a function of quantity, but also of quality, since glare can often be more harmful than low lighting. Discomfort is produced by direct glare from light sources which are too bright or inadequately shielded, and by annoying reflections of bright areas in specular surfaces. When light is reflected from the visual task, a substantial loss in contrast can result. These problems can only be solved by a careful design that would secure the proper selection of the lighting sources and their adequate placement relative to the working areas.

In buildings where daylight was the main source of light, the measures taken to secure visual comfort included the use of shading devices, the placement of the desks perpendicular to the windowed wall, and the use of indirect light.

The modern response to the visual comfort problems was the provision of uniform, abundant and diffuse artificial lighting while reducing the role of the natural light by limiting it to small proportions of the floor area, and by restricting its penetration into the space with the use of low transmission glass.

Daylight is the most desirable form of lighting both from the point of view of economics and that of environmental quality. As B.L. Collins shows in his study "Windows and People: a literature survey, psychological reaction to environments with and without windows," people prefer spaces with windows for the contact with the outside world and the quality of natural light. British surveys of office personnels, done by Wells in 1965, Markus in 1967, and Manning in 1965 indicate that around 80% of the subjects surveyed expressed a strong preference for daylight in their offices. A U.S. survey, "Windowless Offices" by T. Ruys, indicates that the reasons for disliking the absence of windows is the lack of daylight. Also, the change in lighting levels

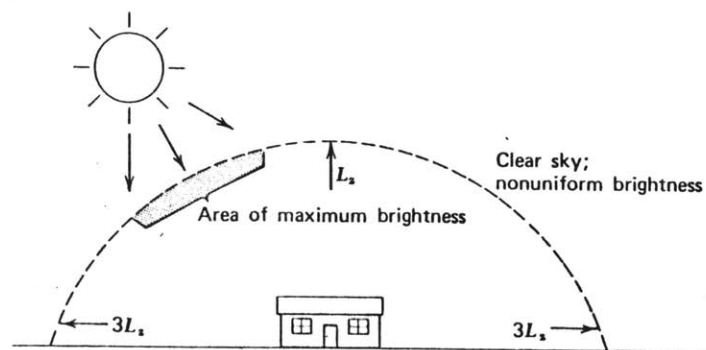
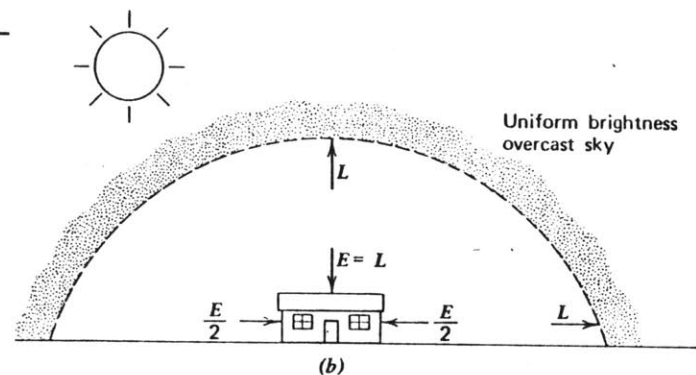
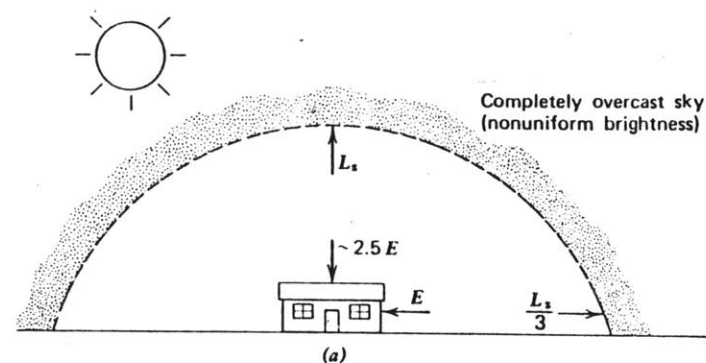
throughout the day, the variations of the quantity and quality of light determined by seasons or weather, all contribute to a highly dynamic character within the internal environment.

When direct solar rays are controlled and the glare from reflected sunshine is avoided, visual comfort is greater in daylight. Veiling reflections at task points are eliminated since the direct illumination from a side window strikes the desk top at relatively large angles of incidence. The horizontal nature of window light also helps to define surface textures and to improve the modeling of objects within the interior. Another advantage of light coming from the side is its efficiency, side illumination being three times more effective than overhead illumination.

Economically, daylight can not be equalled since it comes from a free and never exhaustible source, the sun. Yet, the non-uniform character of the daylight -- which depends on the time of the day and of the year, the orientation of the building, and the weather -- makes it difficult to predict

the amount of daylighting in a room. The illumination level of the space is influenced by the condition of the sky. Thus, the amount of light received from an overcast sky and the direction from which this light reaches the windows depends on the luminance distribution of the sky, which varies with the location, time, density and uniformity of the overcast; a uniformly overcast sky is brighter overhead than at the horizon. On clear days, the sky luminance varies with the position of the sun and the amount of atmospheric dust, and the sky is usually brighter near the horizon than overhead. The quantity of light reaching a window depends not only on the sun and luminosity of the sky, but also on the reflectivity of the ground and neighboring buildings.

Besides the direct light from the sun and the light diffused by the sky, another important component of the light reaching a window is that reflected from the ground and from neighboring buildings. In the conditions of a crowded city and when considering daylight in highrise buildings, the reflectivity of the buildings are of greater importance than that of the streets. Therefore, the



use of reflective exterior finishing materials increases the amount of light both in the urban space and in the buildings.

Designing with artificial lighting is made easier because of the constant and known intensity of the light. The problems related to an adequate illumination design come from the need to avoid glare in general and veiling reflections in particular. This requires a careful placement of the light sources in relation to the work place, controlling the differences in lighting levels of different areas in order to avoid fatiguing contrasts, and the use of adequate lighting fixtures.

Electric lighting is the recent result of a relatively short but intense period of research, striking inventions and rapid development. Its emergence ended the millenia-long dominance of the candle as a light source, and the century-long life of the gas lamp. It started at the beginning of the 18th century with a vacuumed glass globe that emitted a faint glow when rotated at high speed and then rubbed with the hand. The electric arc

lamps marked the first step towards commercial lighting. In 1857 the lighthouse at Dungeness, England used it for the first time outside a laboratory. A type of arc lamp improved by the Russian Yablochov and consisting of two parallel carbon rods used alternating current to secure an equal rate of erosion of the rods. This kind of arc lamp was the first to be used in a public space in Cleveland in 1879.

The first commercial use of Edison's lamp occurred in 1880 on board the steamship Columbia. Shortly after that, in 1882, the electric lamp finally reached residences.

The tungsten lamp, invented in 1907, marked another step forward, followed by the invention in 1913 of the lamp filled with rare gases to reduce the consumption of the filament. In the following decades, the efficiency of the lamps improved rapidly with the use of better alloys for the filament, new gases and better bulb designs.

<i>Source</i>	<i>Efficacy (Lumens per Watt)</i>
Candle	0.1
Oil lamp	0.3
Original Edison lamp	1.4
1910 Edison lamp	4.5
Modern incandescent lamp	14-20
Tungsten halogen lamp	16-20
Fluorescent lamp ^a	50-80
Mercury lamp ^a	30-60
Metal-halide lamp ^a	60-80
High-pressure sodium ^a	90-100
Low-pressure sodium	120-140

^aIncluding ballast losses.

Efficiencies of various
lighting sources

Electric lighting did not attain the efficiency that would make it economical for extensive use until the introduction of the fluorescent lamp. The first investigations with fluorescent coatings were done in the 1930's in France and Germany. In 1934 there was a low voltage lamp under development in the United States. It was, though, only in 1938 that it was introduced commercially, by Westinghouse-GEC as the "Lumiline" tube. The interest in fluorescent lighting faded during the war, then revived in 1945 after which date it became almost exclusively used in commercial and educational buildings.

PREWAR

Although in the period between 1882 and 1940 amazing progresses were made in electrical lighting, the low efficiency of the incandescent lamps in general and of the lamps of the early part of the century in particular, made artificial lighting too costly to be used without restrictions. Daylighting was therefore preferred and buildings were designed with it as a determinant factor.

The availability of natural light was the crucial factor in the suitability of a space. In an article written in 1892 by D. Adler, one of the pioneers of the highrise office buildings, the importance of daylighting for the vitality of a building and of a whole neighborhood is shown. He makes the point that, if a building has rooms with no access to natural light, the owner will only be able to find undesirable tenants for those spaces, and the rents he will receive will be too low, while the maintenance and elevator costs will be the same as for a

building with higher rents. He therefore advises future owners to consider not only providing natural light in all the interior spaces, but also to plan their buildings so as not to obstruct each other's light.

The situation, of course, changed since 1890 due to improvements in electrical lighting, but daylight remained important for the desirability and rentability of the space in the following half-century.

Therefore, the building configuration and the design of the interior spaces were determined by the need to have maximum natural lighting.

"Experience has shown that only under quite unusual conditions is it possible to carry a sufficient volume of daylight for purposes of reading and writing -- as found necessary in the transaction of ordinary office business -- to a greater distance than twenty-five feet from the source of light." ⁵

This was D. Adler's recommendation; he also suggested



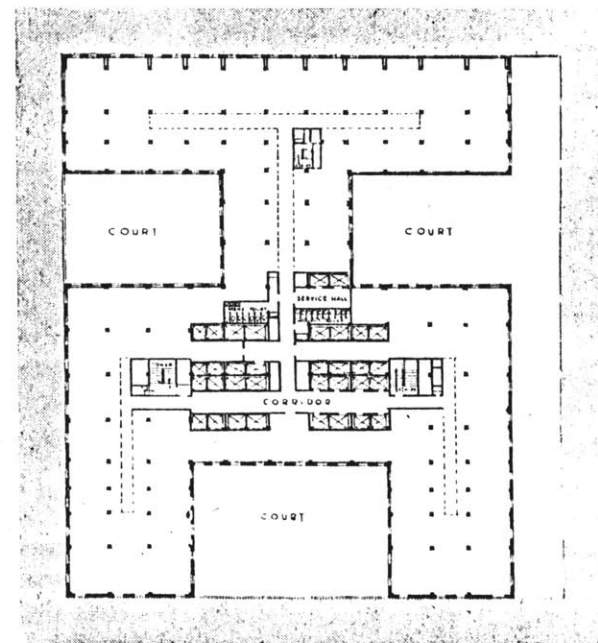
Too generous an "envelope." A dark unusable mass inside

Recommended configuration for prewar buildings

a maximum building width of 65 feet. Others considered 40 to 60 feet as the maximum transversal dimension of an office building.

To secure this requirement, a large building needed to consist of several wings separated by light courts, either completely enclosed by the building or open on one side. The resulting buildings were "U," "H," "L," or "O" shaped. The dimensions and orientation of the courts was also designed to allow light and sunshine to reach most windows.

"If the courts be made square or nearly so, they will be so proportioned as to throw the shadow of the south wall on the north wall at the highest point that it can reach and only the top of the court will ever get direct light, while if the court be made rectangular and with the long axis north and south, the light at noon day will penetrate to the very bottom during at least a part of the year, and will go the maximum distance at all times. If the court is open to the south,

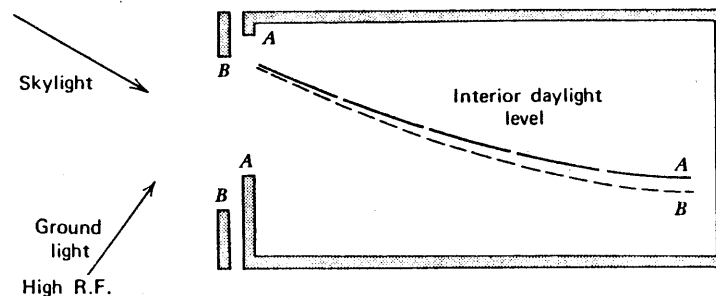


every office that gives on it will get a glimpse of the sun every day that it is visible at all. The courts should be generally from 6 to 25 feet wide depending on the width of the lot and the size of the offices." 6.

The depth of the rooms and from it the width of the building depended also on the height of the floors. With usual ceiling heights above 10 feet, the area that received natural light was significantly greater than that of the future 9 feet high office buildings.

The light-colored and hard finishes of the ceiling helped to reflect light onto the desks. The reflectivity of the plastered masonry walls or exposed concrete walls also contributed to the luminosity of the space.

The inherent problems of daylighting, that is, the discomfort of glare and heat gains from direct sunlight, were countered with the use of shading devices.



Daylight penetration into a room as a function of the skylight intensity, the reflectivity of the ground and the window opening.

Awnings, the most popular of these, and the most thermally efficient since they were on the outside of the walls, had also disadvantages which made their use problematic.

"While not particularly expensive in first cost, the annual installation, removal, repairs and storage represent a large outlay each year. Awnings are without question a fire hazard, for building occupants will persist in flipping cigarette butts out of open windows, and the fireproofing of awnings is not practical. Awnings when down make offices much darker and lights will be burned which would otherwise be out." 7.

Around 1920, architects were advised to provide venetian blinds, especially the light reflecting and diffusing ones, instead of awnings.

The main characteristics of the artificial lighting in the prewar period were its role as an auxiliary to natural lighting as well as low illumination

level requirements.

Artificial lighting between 1882 and 1938 was exclusively provided by incandescent lamps. The highest recommended levels were around 40 to 50 footcandles, with cautioning against possible overheating of the space. 10 footcandles was considered minimal for task lighting while 3 to 5 footcandles were suggested for ambient lighting.

In the first decades of the century there was a marked differentiation between ambient and task lighting. Corridors and spaces between desks had lighting levels as low as 3 footcandles while at the work areas higher levels, up to 50 footcandles, were secured by drop lamps and desk lamps.

Among the disadvantages of the above-mentioned lamps were: the high cost of wiring and the concentrated intensity on one spot with a resultant high contrast, 25 to 3, between the environment and the work area.

The three types of lamps used for general lighting were
- direct light lamp, with a reflector or globe above the lamp; the cheapest solution but with the draw-

backs of uneven distribution, deffective diffusion and possible glare,

- the semi-direct light lamp, with a translucent bowl or reflector under the lamp projecting part of the light onto the ceiling; more current consuming but less injurious and fatiguing to the eye,
- the indirect light lamp, which was considered the best for visual comfort. Since it relied on an opaque reflector under the lamp, frequent cleaning was a problem to be considered. The current consumption was also the highest.

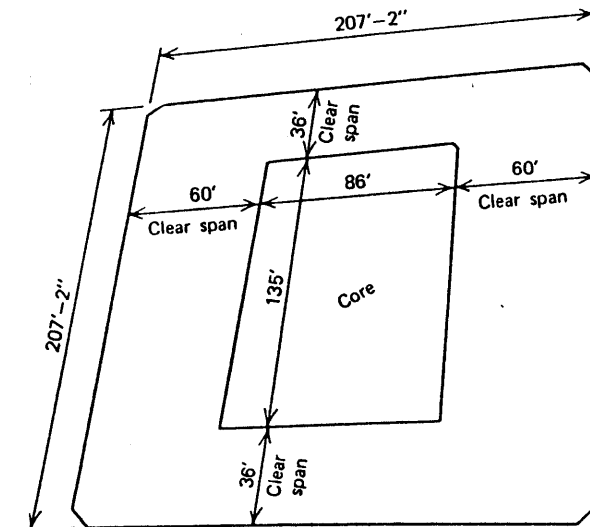
The economical distribution of the lighting fixtures and space use of electric current, due to differentiated lighting levels, offset the disadvantages generated by inefficient lamps and expensive electricity production.

The reduced lighting did not contribute with significant internal heat gains. Because of this, and the use of moveable shading devices and electric fans, the lack of air conditioning did not lead to unbearable indoor conditions. It contributed instead to the overall low energy consumption.

POSTWAR PERIOD

The appearance of the postwar skyscrapers offers the first clue to the changes which led to high energy consumption. The solid volume characteristic to these buildings reduced the value of the wall to area ratio; the light courts of the previous period have been replaced by enclosed spaces, this leading to an increase of the floor area with a simultaneous decrease of the perimeter. Until 1961, the area of a floor of the tower had been limited by the 1961 Zoning Resolution to only 25% of that of the lot. The 1961 law's allowance of a tower floor area of 40% further reduced the ratio of wall to area. This resulted in a minimization of the role of natural lighting in the overall lighting of the buildings.

Dependence on electrical lighting and high levels of illumination characterize the lighting of the postwar offices. Continuous electricity consumption at high intensity accounted for the 50% share of the lights in the total energy use before the conservation measures taken after the 1973 oil embargo.



Typical Floor.
Dimensions Are
Approximate

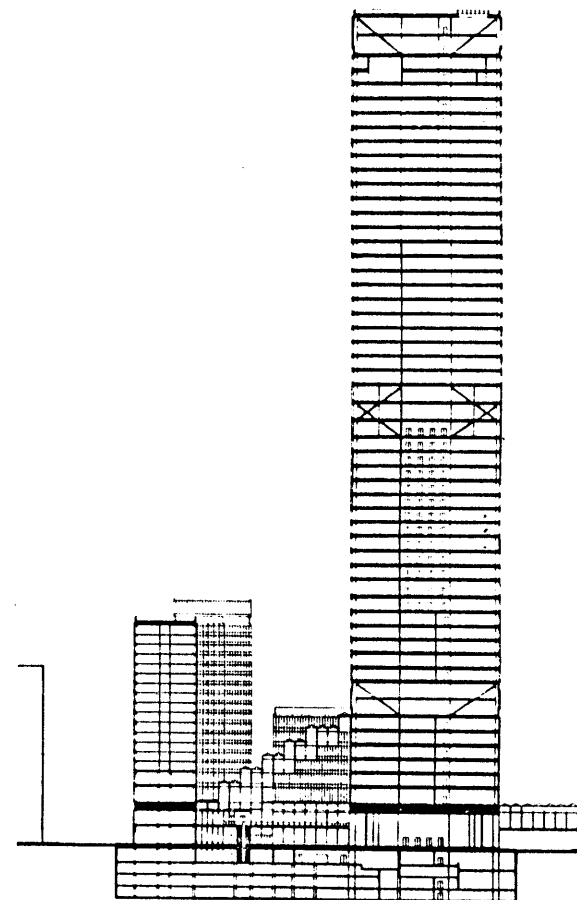
(b)

Dimensions of the World Trade Center Tower floor.

Daylighting became less significant as only a small portion of the floor benefitted from it. As shown in the previous section, the penetration of daylight into a space is limited and varies with the height of the room and the size of the window. Although most modern offices have wholly glazed walls, the contribution of the windows to the illumination of the overall space is reduced by the following factors:

- the predominance of the interior space over the peripheral area,
- the reduced ceiling heights, which were generally below ten feet,
- the reduced reflectivity of the ceiling surface,
- the more frequent use of low transmittance glass, which limits the amount of natural light entering the space.

The use of colored glazing appeared on one hand as a necessity to limit the excessive solar gains resulted from large glazed areas, on the other hand as a fashionable aesthetic expression. Dark glass influenced not only the illumination of the indoors, but also that of adjacent buildings and urban space since it reduced the general luminosity of the environment and, with it, the reflected light component of the daylight. Mies

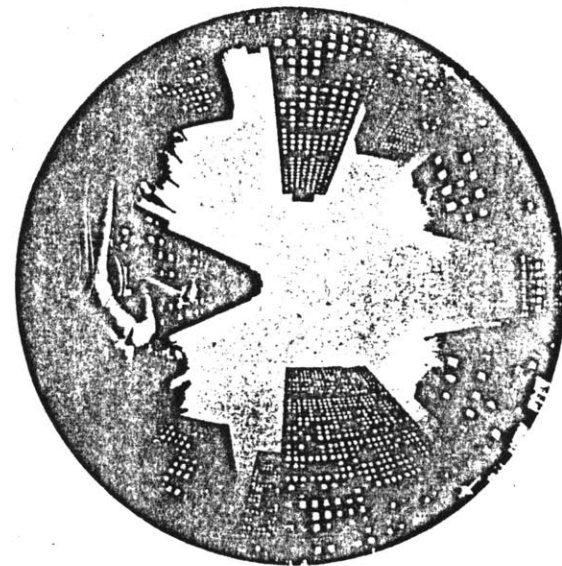
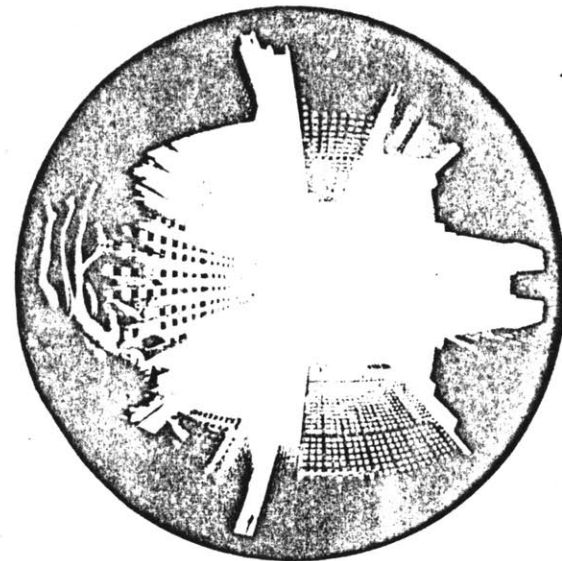


Floor height to building depth ratio in a modern office building.

van der Rohe's masterful employment of dark colored glass in the Seagram Building set an example which was widely followed in the next decades, unfortunately without the same aesthetic success. The result was the emergence of numerous dark boxes which robbed the environment of light, not only with their bulk, but also with their non-reflective exteriors, which contributed to the darkness of the streets.

The low interest in daylighting was paralleled by the lack of concern for the relationship between health and light. It is interesting to observe the coincidence between the attention to health-related effects of lighting and that related to the cost of the energy. The first reemerged from a period of dormancy after the 1973 oil embargo, at the time when the cost of energy was a poignant issue.

Since then, the relationship between natural light and the human body has again been under investigation. Recent studies show the necessity of sunlight for the human health, the ultraviolet component being the most influential. The effect of the latter on the formation of vitamin D, a necessary element in the absorption of dietary calcium, had been



known for a long time. New experiments demonstrated the good influence of ultraviolet rays on the resistance to infections, fatigueability of the visual receptor, the working capacity. UV light also provokes a fall in the blood pressure, changes in skin temperature and metabolic rate, and it affects the general psychological state. The role of the whole light spectrum is also under investigation. Results so far show a good human response to the presence of natural light. J. Wurtman, an M.I.T. scientist, relates decreased visual fatigue and higher productivity to the presence of natural light. A study of small school children in Michigan shows a higher rate of absenteeism in windowless schools. Studies of psychological reactions to windows are summarized by B. Collins in "Lighting research and technology."

Before these issues arose, in the two decades prior to 1973, artificial lighting was regarded as a panacea: buildings could operate any time of the day and night, architects were freed from the constraints imposed by the need to include daylighting in their design solutions, and, in windowless buildings, the storage space could be maximized by the use of the entire

wall and the interior environment could be completely shut off from the exterior.

The owners were delighted by the versatility of the large open floor as the rental desirability was no longer determined by the availability of natural lighting, but by the possibilities of better subdivision of the rented space.

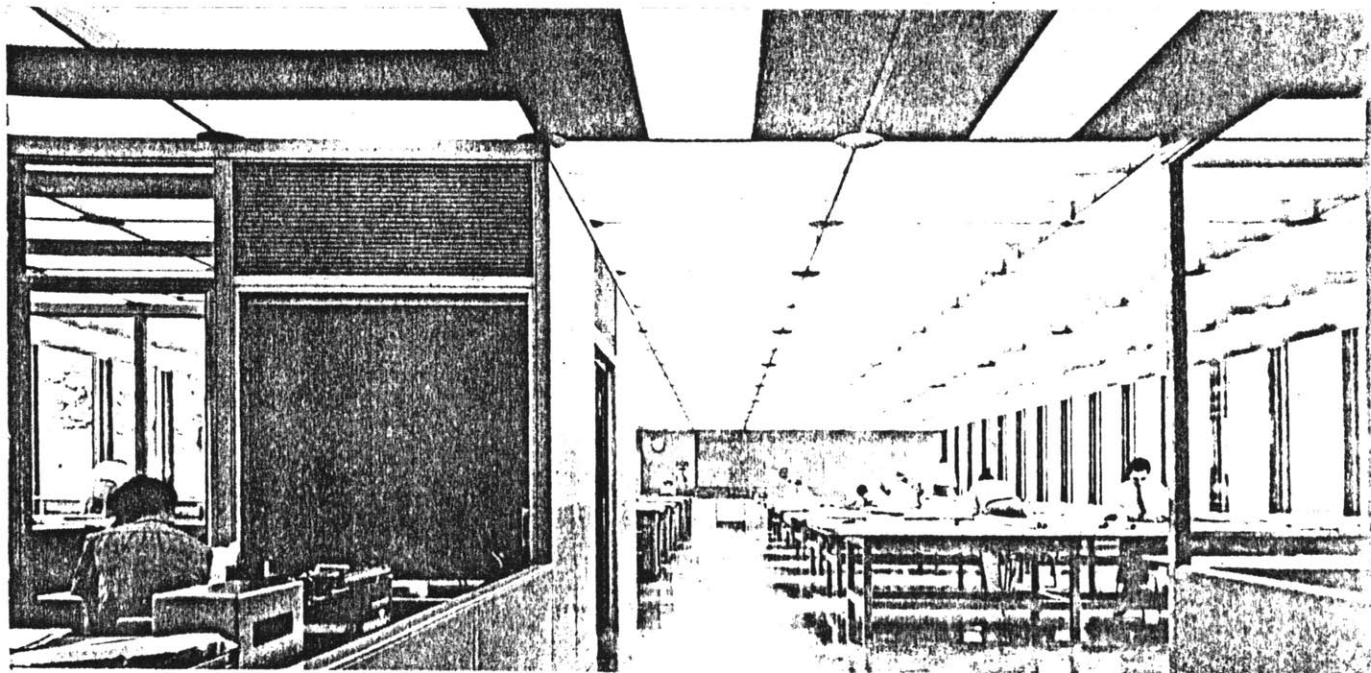
In addition to large areas where artificial lighting was exclusive, an important contribution to the excessive use of electricity came from the exaggerated requirement regarding illumination levels and visual comfort.

Illumination standards were generated by what W. Lam calls a "shotgun approach," that is, an oversimplified way of solving the problem of adequate lighting. According to this method, one had to provide the light needed for the most difficult task everywhere in the office space. The engineers promoting this attitude did not try to tailor the luminous environment to suit the special needs of activities that are neither frequent nor of long duration. They assumed that light should be so distributed that the most difficult task

could be performed for the entire duration of the working day at any place in the office floor. The lack of a selective adaptation of the environment went even further: the perimeter areas, which, during the day benefit from sufficient daylighting, were supplied with artificial lighting in the same pattern as the interior spaces, since the entire system operated on a general switch.

Among the extravagant requirements established by this approach were the contrast ratios set at a maximum

Luminous ceiling in a modern office building



value of 3 to 1, although the human eye can comfortably adapt to higher ratios (the sun/shadow contrast is 2 to 1). The recommended lighting levels were also increased by 50% from the average 20 footcandles before 1940.

The luminous ceiling, so popular in the 1960's offered the technical solution to satisfy all the new requirements. It offered almost perfect brightness ratios, a uniform distribution of light intensities over the floor area, and it secured diffused lighting. Its ambiguous and irrelevant nature as well as the great energy waste it promoted aroused criticism, and in the 1970's there were increasing attempts to create a less monotonous illuminating system. The new types of lighting still maintained the general deficient characteristics of the system, that is, a uniform distribution, high intensities and centralized control.

New attitudes towards lighting design are now being promoted by leading experts in energy and lighting. R. Stein, for example, believes in a possible 50% conservation of energy used for lighting if certain measures would be taken to change the present lighting technique.

Offices	
General	
Cartography, designing, detailed drafting	200 ^a
Accounting, auditing, tabulating, bookkeeping, business machine operation	150 ^a
Regular Office Work	
Good copy	70 ^a
Regular office work—reading, transcribing, active filling, mail sorting, etc., fair-quality copy	100 ^a
Corridors, elevators, escalators, stairways	20
(Or, not less than $\frac{1}{2}$ the level in adjacent areas.)	

Lighting levels in a modern office; the requirement for regular work lighting more than doubled since the prewar period.

Selective switching is one such measure. It would allow for different areas of the floor to be lighted according to the nature of the task and the occupancy at specific times. The separate switching of the peripheral areas would allow turning off the lights when daylight is sufficient; this alone would lead to savings of 25% in lighting loads and 10% in air conditioning. Computing the lighting loads realistically and assuring more specific and localized variations of lighting levels is yet another helpful measure.

A rational use of electric lighting is only part of the solution to the efficient lighting of office buildings; it should not be substituted for daylighting both for economical and qualitative considerations. Due to the nature of the office activities, the occupancy pattern allows for the use of daylight for most of the time the building operates. Electricity should only compensate for inadequate natural lighting in areas whose placement cannot provide windows and during periods of the day like the beginning and the end of the working day in winter, and during days with unfavorable weather conditions, when the intensity of the outside light is too low.

CONCLUSIONS

Learning from the positive characteristics of highrise office design in both periods, one can synthesize the features of the future energy efficient building. Incorporating energy saving elements, its energy profile would shift towards that of the prewar offices, with less internal gains and less overall consumption.

A first step would be a proper orientation of the building. This would require long elevations parallel to the North-South axis, and minimal East and West facades. The treatment of the elevations should respond to their orientation. No glazing on the Eastern and Western elevations, or glazing reduced to the minimum necessary for daylighting, when it can not be avoided, would help to solve the problem of excessive solar gains in summer when the radiation of the low East and West sun can not be satisfactorily blocked with shading devices. Since South oriented windows can be appropriately shaded, it is adviseable to have the largest glazed area in this orientation. Shading devices incorporated in the structure and emphasised formally, provide also expressive architectural images; Le Corbusier's brise-soleils decorate buildings of the earlier part of the prewar period in France and Brasil, but they did not find a fertile ground in the U.S.

Besides providing solar control, the role of the building envelope should be further extended to make it into an effective membrane. Improvements in the manufacturing and mounting of the facade elements would eliminate the leakage of water and air, so detrimental to both the resistance of the materials and to the heat transmission. Recent energy consciousness has already influenced the attitudes of owners and builders towards the tightness of the wall; window mounting details, which, during the past two decades had been treated lightly and have traditionally caused excessive infiltrations, are now being improved and the detail of execution regarded with attention.

In highrise buildings light weight construction materials are necessary in order to relieve the structure from excessive dead loads. This hinders the use of the traditional thermal mass; brick and thick concrete. New heat storing materials, investigated in solar energy research, offer future solutions to increasing the heat capacity of the building skin without increasing the weight.

Daylighting the work areas is the most important objective of the future energy conserving building. In order to secure

this the configuration of the building and the interior dimensions would have to borrow characteristics of the older buildings. It is therefore necessary to increase the ratio of wall to floor area. This implies slab type buildings with depths of around 60 feet, or a return to the building shapes determined by light courts. It would also be necessary to change the dimensions of the office; ceilings would have to be higher in order to increase the depth of daylight penetration. Higher reflectivity of the interior surfaces, to help the distribution of the light, require light color finishes. In terms of layout, in the open space office there should be a greater attention paid to the placement of the desks relative to the windows in order to avoid creating dark areas immediately behind the partitions. Light colored reflective ceilings would partially alliviate the problem of a uniform light distribution with an apparent multiplication of the light source, thus reducing the directionality of the light from the window.

Designing the office plan for daylighting is also a step towards natural ventilation. With most of the floor being in the vecinity of the windows outside air would reach the working areas. In order to obtain this it would be necessary to provide operable windows, a drastic move away from the totally sealed modern highrise. Operable windows cause problems at high floors where powerfull winds make their mani-

pulation difficult and create unpleasant drafts. Lower height would, from this point of view, be more effective.

Height limitation improves the overall luminosity of the outdoor environment and thus affects positively the availability of daylighting. Another advantage of lower buildings (between 15 and 40 stories) is a reduction in the number of elevators which impacts directly the electricity consumed for their operation and indirectly the expenses related to the defficient ratio built to useable area.

Another feature of prewar architecture which would positively affect energy conservation is the wider range of indoor comfort. Allowing for greater differences between the minimal and maximal temperatures, higher humidity, could lead to substantial savings in heating and cooling loads. The changes in the indoor environment in addition to the energy benefits would also improve the quality of the life. Contact with the outside -- visually, by observing the changes in the quality of light and physically, with the air movement -- would decrease monotony, would contribute to a more dynamic, and therefore more stimulating, environment.

A selective environment offers more satisfaction to the

users by allowing them to control and adjust their environment to their needs. The selective operation of the mechanical systems and their localized distribution so as to respond to various needs and times contributes to energy savings.

Less reliance on power and implicitly less use of electricity would lead to less overall energy consumption.

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3 _____ "The How and Why in Behavior; Social Psychology for Architects"
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4 _____ "The Passive Solar Energy Book" by E. Mazria

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