# ANALYSIS OF ADAPTABILITY OF COMPONENT BUILDING SYSTEMS TO MULTI-STORY OFFICE BUILDINGS

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# CHAPTER I

# INTRODUCTION

There has not been a sudden revolution in the building industry toward industrialized building systems with the exception of a few short lived booms in prefabricated housing. However, out of the necessity to build more buildings and to build them faster, the last three or four decades have seen the increased use of larger and more complete building components. These components have grown from nails and bricks to precast panels and prefab bathroom and kitchen units and in some instances, to complete living units. These changes evolved slowly and thus went unnoticed, but industrialization of the construction business is upon us. Although, it is not utilized to the extent that some futurists would like to see it, it is here and becoming more the ordinary method than the exception.

With the increased popularity of many industrialized building systems, it is necessary that the architect investigate and analyze the systems as to both their favorable and their detrimental characteristics so that he may choose the most appropriate system. Each building type has its own set of general requirements and each building system has its own peculiar characteristics. Therefore, the purpose of this thesis is to interrelate these two aspects so as to be able to find the value of a component building system to multi-story office buildings.

The process to be used in analyzing the building systems is of more importance than is the selection of the most appropriate component building system for multi-story office buildings. The importance of the process is based upon the belief that given the proper tools and methods, any competent architect can analyze any building system's suitability to any building or building type.

The process is based upon a method of trial, judgment, and elimination. In the trial phase, the component building system is adapted as well as possible to the building type and size being used. The system is then judged as to its fulfillment of the major criteria of the building type. The systems that are then found to be least appropriate are eliminated and those remaining are analyzed further on the basis of more specific and detailed criteria. The trial, judgment, and elimination process continues until only one system remains.

# CHAPTER II

# COMPONENT BUILDING SYSTEMS

Two things that can define component building systems are the fact that they are parts of buildings or groups of buildings and are all built in a factory or production plant and delivered to the site. The size of a component building system is a relative thing. It could include anything from bricks and nails to buildings completed in a factory and delivered to the site. One author has this to say about size:

> The scale of prefabricated components is governed in practice by economic criteria such as handling, storage, transport and distance from factory (weight is no longer a dominant factor with the use of plastic units); in theory, however, design flexibility is the criterion. (17)

One of the major purposes of component systems is to eliminate, or at least cut down considerably, the number of site man-hours. This requires that production be transferred from the building site and the workbench to the factory. This, in turn, implies the development of new techniques of joining components on the site. Building then becomes an assembly process different from previous methods of construction. However, it differs only in degree, in that previous methods dealt with large numbers of small simple components in contrast to a small number of large complex system components.

A definition of component building systems is found in Alfred G. Bossom's (2) discussion of prefabrication.

> Broadly speaking prefabrication is: (a) using a well thought out design, breaking it down into separate standardized parts,

> which are manufactured away from the site in comfortable surroundings free from weather conditions, and with the right type of tools and equipment at hand and proper supervision; and (b) assembling these separate parts into their completed sections in the factory, where they are also packed ready for dispatch to the site upon which they will ultimately rest.

## Standardization

One of the characteristics essential and common to all component building systems is standardization, which includes repetition, and interchangeability. This characteristic's necessity is pointed out by Konrad Wachsmann (14) in <u>The Turning Point of Building</u>.

> As one of the great virtues of industrialization is the ability to turn out products of uniform, peak quality, meeting the requirements of all to the same degree, while using the most suitable materials in the best possible form and achieving the highest standards in the most economical way, the industrial process can only have its full effect within a system of all-pervasive order and standardization.

The characteristic of standardization and resulting repetition is the most discussed and criticized aspect of component building systems, especially among architects. Most critics of standardization feel that the systems will create monotony, an undesirable feature. However, there are others who feel the opposite. Carl Koch (9) feels that it is not objectionable and puts it this way.

> The word "repetition" conjures up, for many people, a nightmare of monotony and ugliness, but it shouldn't because repetition is actually a key element in every esthetically satisfying composition. The standard component is found universally in nature--and in art.

If its standardized components have been carefully proportioned, the total building can be made intrinsically sound in proportion; and it will form a strong framework within which the variety of surfaces can add interest without degenerating into chaos. The discipline afforded by standardization can go a long way toward the elimination of the most immediately obvious failure of modern buildings in cities and suburbs--a lack of coherence which stems from both accidental and deliberate attempts to achieve individuality. True individual expression is not only possible, but is enhanced, by incorporation into an overall pattern, rather than into the current artificial multiplicity of materials, slopes and roof colors. Historically, this principle may be seen in the basically repetitive nature of the patterns of the 18th and 19th century architecture of Bath, England, in that of Beacon Hill in Boston, or of the Greek island towns, all composed of basic patterns and similar materials, colors and textures, but with rich variation in detail.

> We are used to standard sizes in many standard things, and the average man is quite content to buy a standard shirt, hat or tie, but there is nothing to force everyone to wear a blue shirt with a blue tie or a standard sized bowler-hat with standard brown boots. Everyone accepts the standard parts, selects his colours and disposes of them over his body in whichever way pleases him best. (18)

## Modular Co-ordination

Standardization, repetition, and interchangeability, are necessary to component systems and can be justified esthetically. In effect, they are the reason for another basic characteristic: modular co-ordination. In contrast to objects made by hand, the mass-produced article must embody an abstract system of modular co-ordination so that the harmonious relationship of the various parts and elements can be achieved.

This abstract system results from the precise theoretical and practical investigations into measurements and measuring methods, the determination of proportions and the dimensioning of everything from the smallest components to the building as a whole. Konrad Wachsmann (14) writes in <u>The Turning Point of Building</u> that

> modular co-ordination systems relate not only to rectangular and plane surfaces but also to space and volume, to points, lines, surfaces and bodies, no matter whether projected on a plane or in space or characterized by compound curves. They also determine the installations, the distribution of connectors, the dimensioning of equipment and moving parts and in some respects, in the abstract sense, time and motion.

Konrad Wachsmann goes on to describe the various modules that must be considered in determining a modular system.

> The material module is the outcome of raw material sizes, production engineering requirements, qualitative properties, eventual possibilities of technical application, market requirements and economic conditions.
>
> The performance module is determined by the way material can be used to best advantage. However, in this connection the idea of performance should not be interpreted as mechanical, acoustical, chemical, electrical or calorific performance, it is rather a question of certain structural properties and technico-economic conditions.
>
> The geometry module defines the proportional system governing the structure, the individual element and the overall planning.
>
> The handling module is governed by factors of a physical nature, originating in transportation, storage and erection procedures.
>
> The structural module determines the relationships and position of all the structural elements, which differ from the filler elements in that they carry load.
>
> The element module defines the dimensional relationships among all the objects with surface-defining characteristics.
>
> The tolerance module determines the position of the joints which, placed at the necessary intervals, take up dimensional displacements due to the accumulation of small inaccuracies.
>
> The installation module determines the relationships and the position of cables, pipes, ducts and outlets within the building system as a whole.
>
> The fixture module determines the dimensional and proportional order of all permanently built-in objects and appliances, which, without being part of the structure, must be adapted to the modular grid.
>
> The planning module is the sum of the results to which investigations of all the other module categories have led. The planning module can only be understood as a sort of theoretical guide or as a control system for checking the organic

> interrelationship of all the other modules. In practical applications it is necessary to find a synthesis of the problem, a common denominator, from the interplay of structural module, element module, component module and installation module.

## Integration

Integration, another of the basic characteristics of component building systems, is the problem causing element of the above discussed modular co-ordination systems. If it were not for the need to integrate the mechanical, the structural, and various other factors into a single component, modular co-ordination would be much simplified. But building, conceived merely in terms of structure, combining horizontal and vertical surfaces to divide and envelop space, does not satisfy, even in its material aspects, all the requirements of this age. The mounting and justifiable demands for perfect environmental control can only be met by simultaneously integrating all the complex mechanical and electrical services and other equipment with the structure, the factory-made element and the entire assembled building. For, in the technical sense, the modular, static, dynamic and mechanical problems have now become a unified whole.

> The architect must find a means of arriving at solutions which integrate the complexities of his building by their very nature; to free himself from solving one joint, one corner, or one trade at a time. (3)

## Joints

The joining or connecting of components is as much a problem to modular co-ordination as is integration. Joints, the last basic characteristic of component building systems, should not be thought of as objects of shame and accordingly need not be concealed with seal strips, etc. Konrad Wachsmann (14) has this to say about joints.

> These joints not only indicate zones of contact but scrupulously define any object they enclose. They not only reflect processes of aesthetic importance but represent the results of technical functions and are to be understood as such. Their place is determined by materials and methods, structural principles, standards and modular order.

## Component Systems

All of the basic characteristics of component building systems have been discussed and it is appropriate now to break component systems down into groups and types. There are three major groups and these are broken down further into nine basic types of systems as shown in Figure 1.

## Economics

The economical possibilities are still supported by a classic comparison:

> An automobile engine built the way an average house is built might well cost $10,000. That engine built in Detroit costs $200; yet it is an incredibly complex assembly of precisioned machined parts--parts that by functional necessity are far more complex and far more precise than in a house; and the engine is made of special alloys that are far more expensive than any of the materials in the average house. (9)

## Summary

Component building systems have been defined as factory produced building parts delivered to the site for assembly and the basic characteristics of standardization, modular co-ordination, integration and joints were found to be problems, but nothing that could not be solved in the hands of capable men. The component systems were broken down into nine basic types for the further purposes of this study and a

FRAME AND PANEL

(This refers to any kind of structural framing system combined with non-structural wall, floor and ceiling panels.)

1. Bay-framing-and-Panels
2. Truss-framing-and-Panels
3. Space-frame-and-Panels
4. Tension-framing-and-Panels
5. Geodesic-framing-and-Panels

CELLULAR

(This system implies complete individual units, containing walls, floor, ceiling and roof, mechanical equipment and sufficient structure to be an independent entity.)

6. Cellular-with-framing (Contains a separate structural frame into which the cells are placed.)
7. Cellular-without-framing

STRUCTURAL PANELS

(This system is based on walls, floor and ceiling panels that are structurally independent of any framework.)

8. Load-Bearing-Panels (Horizontal and vertical panels which support more than their own weight.)
9. Shell-Structure-Panels (Component panels of a shell type structure.)

Figure 1. Classification of Component Systems.

brief statement about economics was put forth.

The following comment of Lawrence Garvin, (3) Associate Professor and lecturer on building technology at Clemson College, South Carolina, states the essence of this chapter:

> The idea of prefabrication is enticing. It continues to be so, notwithstanding its lack of complete success. While few good examples persist on the market, the idea seems valid, and the question thus arises as to whether or not it is the specific application which has been fruitless, rather than the general idea.

# CHAPTER III

## MULTI-STORY OFFICE BUILDINGS

Office buildings might very well be--if there is such a thing--the universal building type. Office buildings range from the very small, relatively simple, and low in cost, up to the multimillion dollar range--very large and extremely complex. While most other building types are, for the most part, highly specialized functionally, office buildings may house a vast variety of functions and these functions are ever changing in many of various ways. New purposes, new needs, increasing automation, more complete artificial climatology--all of these factors require the architect to strive to find new and better ways of satisfying the office building needs.

Within the scope of this study, the office buildings to be considered and used for analysis will be of the speculative type and vary in height between eight and twenty stories. By speculative type it is meant that the building will be used for such rental purposes as to make it a profitable investment for the owner.

> Since it is a commercial venture, an office building that fails as an investment would be better never built. Commercial considerations will inevitably dictate both its working size and rentable shape. (1)

According to Kenneth Riphen in his book Office Building and Office Layout Planning, (12) for this type of office building, between 67 and 80 per cent rentable floor space is generally considered acceptable. These financial requirements must of course be tempered by zoning requirements, common sense, and aesthetics; but the end result must please the investors.

Also for the purposes of this study, the physical environmental considerations to be employed are those that would apply to the majority of the continental United States. These are admittedly general, but will serve the purpose quite well for this type of study. The site will have no limitations as to size and shape so long as it can be contained within the average city block (a square 300 feet on a side).

Figure 2 is a check list on office buildings made up as a basis for analysis.

## Types of Functional Spaces

As indicated in Figure 2, there are ten general types of functional spaces. These spaces are those that house the various types of office worker. These types are typists, secretaries, machine operators, clerks, specialist staff (such as draftsmen, receptionists, telephone operators and filing clerks), transitory staff (salesmen and inspectors), managers and supervisors, advisory staff, executives and service staff. As can be seen from the many types of office workers and the many types of spaces required, an office building is a complex thing. To further point out the complexities, needs of some of these various spaces will be briefly discussed.

There are two kinds of office spaces, one being the private office and the other the general office or open layout office. The private office has the advantages of privacy and controlled comfort, but makes for a higher cost of construction. Executives and their secretaries, and to a limited extent, managers and supervisors need private offices.

A. Types of Functional Spaces
    1. Private Office
    2. General Office
    3. Archives and Storage
    4. Conference Room
    5. Reception Area
    6. Lavatories
    7. Corridors
    8. Services
    9. Computer Equipment
    10. Special (laboratories, studios, etc.)

B. Flexibility

C. Building Size
    1. Height
    2. Square footage per floor

D. Building Shape and Form
    1. Plan
    2. Section
    3. Elevation

E. Construction
    1. Structure
    2. External Walls
    3. Partitions
    4. Floors and Ceilings
    5. Finishes
    6. Module

F. Mechanical
    1. Heating, airconditioning and ventilation
    2. Artificial lighting
    3. Sanitation
    4. Services
        a. Electrical and Telephone wiring
        b. Water and Gas supply
        c. Rubbish disposal
        d. Mail service
    5. Fire Protection
        a. Fire resistant construction
        b. Access to parts of building
        c. Stand pipe
        d. Sprinklers
        e. Escape routes

Figure 2. Office Buildings' Check List.

G. Acoustics
    1. External to Internal
    2. Internal to Internal

H. Vertical transportation

I. Orientation

J. Insulation

K. Sun Control

L. Economics
    1. Construction Cost
    2. Efficiency of Space
    3. Story Height
    4. Maintenance
        a. Window cleaning
        b. Painting necessary

M. Additional Environmental Features
    1. Natural lighting
    2. Size and Shape of spaces
    3. Art work
    4. Courts and Plazas
    5. Landscaping
    6. Furniture
        a. Standard
        b. Special
            1) Built-in
            2) Modular
            3) Movable
    7. Colors

Figure 2. (Continued)

Within the United States, the vast majority of office workers: typists, clerks, and special staff are housed in general office space. General offices lack privacy, are often noisy, and require better artificial lighting and air conditioning equipment than is required in the compartmented layout. It has the advantage of flexibility and economy of space along with the following advantages pointed out by Riphen (12):

> Basically, the theory of integrated space calls for open general office areas with a minimum of partitioning, of either the fixed or movable type. This type of plan is gaining many adherents today, since it generally offers more flexibility, economy of space, easier worker supervision, and equality of facilities for all parts of the office in comparison with the older, more conventional compartmented layout of office space in which partitions are used to create custom-built departmental units.

It is generally accepted among the authors of office building books that some of the minimums to be considered regardless of type of office space are 500 cubic feet or 45-65 square feet per office worker. Also the shortest dimension of an office should not be less than 8 feet. These are minimums and should not be thought of as average or standard.

Archives, storage and conference rooms are of such variety in shape, size, and purpose that there is little if anything that is standard about them. However, the proportion of width to length of most conference rooms is best when it is between 1:1 and 1:1½ (12). Reception areas require that they be located carefully and kept neat in appearance while laboratories and studios require isolation, quiet, good light and airconditioning control, as well as provision for special equipment.

The width of corridors should never be less than two unit widths (20"-22" per unit width) and seldom less than three. Lavatories and services should be located and sized according to dictates of floor size and shape.

One of the more startling developments in the increasingly complex world of office building architecture is the growing use of electronic data processing machines for the automation of business functions formerly performed by people. The main thing these machines have to recommend them is that they are able to perform such tedious, boring tasks as inventory control, payroll accounting, and myriads of similar jobs, with great speed and extreme accuracy.

> Machine-tabulating rooms or, in the case of very large companies, electronic data-processing centers, housing a computer and its associated equipment, pose special structural, mechanical, and physical problems in the office. With an electronic data processor, floor reinforcement is very often necessary, and special electric power lines capable of carrying heavy loads are essential. The entire room must be sound proofed and isolated from the rest of the office and requires special airconditioning as well because of the heat generated by the equipment. Very often there must be special treatment of the floor, beyond reinforcement, to reduce vibration caused by the machines. (12)

The above indicates only a small portion of the vast complexities of office building design, but knowledge of these needs at least makes analysis possible, if not easy.

## Flexibility

Flexibility is especially critical in speculative office buildings because of the ever changing of tenants and because of the characteristic of renting tenants to change in size and demands. In a small firm (which the majority of renting tenants are), expansion can be a real problem, for the advent of one or two extra staff demands a proportionately large expansion in physical size.

> The change in office work, and therefore, in the use of office space is so likely that more flexibility is essential. Usually this is taken to mean the facility for putting up and taking down partitions, but this probably creates more problems than it solves. For one thing, the functional requirements of light partitions and their soundproofing characteristics are in obvious conflict. Possibly these problems will be resolved by the omission of partitions altogether. (20)

Omission of partitions is only one of the many possible solutions to flexibility problems and many of these solutions might well be inherent in component building systems. This remains to be analyzed in the studies.

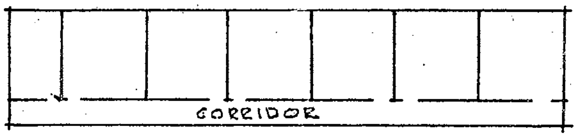
## Building Size and Shape

The shape of an office building is determined to a large extent by the type of zoning used, (assuming that the site does not control the shape). There are basically three types of zoning arrangements as shown in Figure 3.

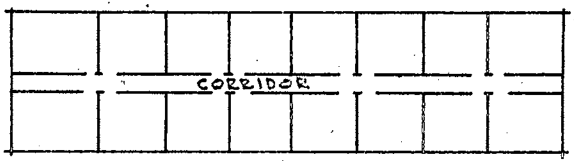
Although these types are often combined and arranged in different ways to achieve a variety of plans, these three basic types of zoning are the controlling factors of building shape. Another factor that contributes to the shape of an office building is the distance from exterior windows a space can be and still be rentable. The area not more than 26 to 30 feet from daylight (inner plus outer office) pays larger rentals than dark space--hence the popular slab form. Constructing large-area floors with much inside space is in most cases penny-wise and pound-foolish, for such space brings a lower rental in good times and possibly none in hard times.

With regard to building height, two factors control. One is the number of floors and the second is the floor-to-floor height. The benefits of constructing tall buildings are the premium rental rates the

**Single Zone** - Office space with rooms on just one side of the corridor is not economical.



**Double Zone** - is typical and economical.



**Triple Zone** - for very high buildings.

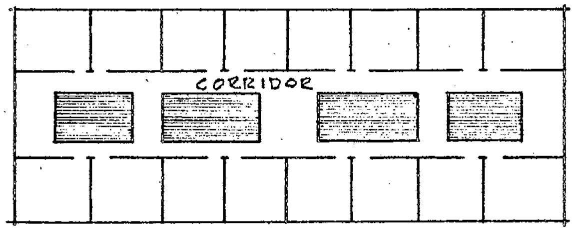


Figure 3. Types of Zoning.

upper floors bring because upper level floors are quieter and cleaner, and offer daylight, privacy, prestige, and a view.

The floor-to-floor height is determined by the structural and mechanical depth required plus the desired floor to ceiling height. The depth required for structure and mechanical equipment is directly dependent on the type of construction and the requirements of the mechanical equipment to be used, while the floor to ceiling height is mostly controlled by psychological factors. According to Richard Roth (13), "while 8'-6" is a good height for any office up to 20'-0" x 24'-0", in open clerical spaces, such as found in insurance company layouts, it would seem oppressively low."

## Construction

Construction, as far as this study is concerned, will be of component building systems as discussed in Chapter II.

## Mechanical

It is a foregone conclusion that every new large office building will be airconditioned. Because of the large cooling loads airconditioning systems have to handle due to the sun, lights and business machines, a large part of the building space and building budget is taken by airconditioning.

> Requirements as to the atmospheric condition of offices:
> 1) The optimum temperatures for human comfort should be constantly maintained.
> 2) The relative humidity should be between 40 and 60 per cent.
> 3) The air movement should not exceed 0.66 ft./sec.
> 4) The supply of fresh air should be sufficient to ensure that the odor of human perspiration does not become noticeable and that air contaminating agents originating inside

> or outside the office do not adversely affect the health and well-being of the occupants. (6)

In order to satisfy these requirements, an airconditioning system must perform the tasks of heating and cooling, of regulating the humidity to suit the temperature maintained in the room, and of cleaning the air.

In buildings with large glazed areas the deciding criterion for the performance of the airconditioning equipment is not so much its heating capacity in winter as its cooling capacity in summer.

If the building is equiped with an airconditioning system, all the windows can be provided with fixed glazing, which is much less expensive than hinged or pivoted sashes, besides avoiding the heat losses inevitably associated with such sashes in consequence of imperfect closure. The effect of these latent leaks increases with wind velocity and with the height of the building.

Central station systems of either the "all-air" or "air-water" types are used most frequently.

In an "all-air" system, all of the cooling and dehumidifying is accomplished by air distributed from a central station to the spaces to be conditioned.

An "air-water" system distributes only sufficient air to furnish ventilation and dehumidifying capacity to a conditioned space. The remainder of the cooling load is handled by a coil in the terminal unit which is connected to a central source of cold or hot water.

"All-air" and "air-water" systems are further classified as high or normal velocity and high or normal pressure. High velocity systems have duct velocities in excess of 2,000 feet per minute, and high pressure systems are those in which a pressure drop at the air terminal may exceed 0.25 in. water gauge.

Favorable features of the high-pressure system are small ducts, the absence of return ducts, and individual temperature control.

A disadvantage of high-pressure systems is the noise caused by the high air velocities in the supply ducts. By installing suitable sound-absorbing devices in the ducts it is possible, however, to keep the noise below the general level of noise prevailing in an ordinary office.

Another consideration with regard to mechanical equipment in offices is the necessary apparatus for proper lighting conditions.

The function of office lighting may be considered as a tool that enables people to do a certain type of work under favorable conditions. A good office lighting system must comply with the following requirements:

> Uniform illumination of 200-500 lux on the working surface. Inconspicuous color of the light, careful screening of lamps, limited contrast in brightness (light density) between the source of light and its surroundings. (6)

Although it is accepted that good lighting is needed in an office building, too often "good" is taken as only meaning "enough". Quantity of light is readily provided today, but designers are only beginning to follow the lead of research workers and concentrate on quality as well. The problem of providing quality is one of resolving demands from four quarters: the emotions, the eye, the light source, and the economics of the building.

## Acoustics

Noise is probably the major environmental problem in most offices today. The following quotation expresses the possible dangers resulting from a lack of acoustical control.

> In considering acoustic environment, clarity and simplicity must be the aims. Sounds should be of ascertainable direction and explicable nature; noise levels should be kept low; background noise should not be obtrusive, nor irregular; background conversations should be totally unintelligible; and there should be no unnecessary or unusual noises. Failure to achieve these aims results in a fatiguing environment, even with low noise levels; with high noise levels fatigue is greatly increased and at the highest levels physiological damage is done. (10)

A rational attitude to noise control is based on four steps: location of the noise source, discovery of the means of sound transmission, choice of a suitable method of control, and the application of this method in the particular circumstances.

Sources may be divided into external and internal ones. External sources include the weather, traffic (road, rail, water, and air), crowds, industry, and ground vibrations. Internal sources are speech, communications systems, business machines, feet, doors, and service plant (lifts, ventilation, heating, plumbing). But for all these sources there are only two means of transmission: structure- or earth-borne (including vibrations), and airborne.

Control methods may be broadly grouped in six categories, which are here listed in order of diminishing effectiveness. A noise may be:

1) Stopped--by eliminating the source.
2) Segregated--by planning against structure- or airborne transmission.
3) Obstructed--by isolating or insulating against structure- or airborne transmission.
4) Absorbed--by true absorption, or by dissipation.
5) Masked--by controlling background noise.
6) Identified--by making its direction and source apparent.

## Vertical Transportation

This section deals with stairs, escalators, and elevators.

Escalators are seldom used in office buildings and almost never in multi-story office buildings, so they will be dismissed as unimportant in this study. It is necessary in any multi-story building that at least two fire stairs be provided with their entrances sufficiently separated so as to assure safe exit of the occupants from the building. This will be the only consideration with regard to stairs. The remainder of this chapter will deal with elevators in enough detail in order to show the make-up of a table to select the number and size of elevators that will be required for the various sizes and heights of office buildings to be used in this study. The following is that information.

It was established from Table 24-2 (7) that each office building occupant would require approximately 100 square feet. Since the various building sizes have been set, the building population can be calculated by dividing the square footage by 100. The first floor would be eliminated from this calculation since its occupants would not be serviced by elevators.

"The passenger-carrying capacity of an elevator system is expressed as the percentage of the building population that can be carried one way in five minutes." (7) For office buildings this percentage is "from 12% to 15%." (7) For the purposes of this table, 13 per cent will be used.

Table 24-3 (7) gives the relationship between elevator speed and distance of travel. This figure is given at the top of the table along with the number of floors and height which is calculated by multiplying the number of floors by 12 feet. Knowing the elevator speed in feet per minute and the number of floors to be served, the round trip time in seconds of the various sizes of elevators can be interpolated from

Table 24-5. (7) From Table 24-6 (7) can be found the passenger capacity of the various sizes of elevators.

With this data, it is possible to utilize the following formula to calculate the number of elevators necessary to handle 13 per cent of the building population in five minutes.

$$NE = \frac{13\%\ BP \times RTT}{300 \times NPT}$$

where NE = number of elevators
BP = building population
RTT = round trip time in seconds
NPT = number of passenger per trip
300 is 5 minutes converted to seconds.

In office buildings, passengers do not like to wait more than "25-40 seconds" (7) for an elevator. To check to see if there are enough elevators so that this interval is not exceeded, it is necessary to divide the round trip time by the number of elevators, thus getting the interval between elevators. If the interval exceeds 40 seconds, more elevators must be used. This often indicates that a larger number of small elevators will work better than a smaller number of large elevators.

Utilizing the formulas given and all the data from the tables indicated, it is possible to calculate the number of each size elevator needed for size and height of office building. The results of all these calculations are given in Table I. In reading this table, "4-2500" means four 2500 pound capacity elevators will work for this indicated size and height. In each group of possibilities one size of elevator has a rectangle around it. This indicates the most economical factor followed by the smallest size of elevator. Reference can be made to this table then to find the various workable possibilities and the most economical one of these.

## TABLE I

## ELEVATOR SELECTION GUIDE

| | 8 floors<br>200 fpm*<br>96'** | 10 fl.<br>300fpm<br>120' | 12 fl.<br>400 fpm<br>144' | 15 fl.<br>500 fpm<br>180' | 18 fl.<br>700 fpm<br>express to top 8 fls.<br>216' | 20 fl.<br>700 fpm<br>express to top 8 fls.<br>240' |
|---|---|---|---|---|---|---|
| 50 people/ floor<br>5000 sq ft | 350 people# | 450 | 550 | 700 | 850 | 950 |
| | 46/5 min.## | 59/5 | 72/5 | 91/5 | 52/5 | 52/5 |
| | 3-2000 | 3-2000 | 3-2000 | 4-2000 | 3-2500 | 3-2500 |
| | 4-2500 | 4-2500 | 4-2500 | 4-2500 | 4-3000 | 4-3000 |
| | 4-3000 | 4-3000 | 4-3000 | 4-3000 | 4-3500 | 4-3500 |
| | 4-3500 | 4-3500 | 4-3500 | 4-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 4-4000 | 4-4000 | 5-4000 | | |
| 75/fl.<br>7500 sq ft | 525 | 675 | 825 | 1050 | 1275 | 1425 |
| | 69/5 | 88/5 | 108/5 | 137/5 | 78/5 | 78/5 |
| | 3-2000 | 4-2000 | 5-2000 | 6-2000 | 3-2500 | 3-2500 |
| | 4-2500 | 4-2500 | 4-2500 | 5-2500 | 4-3000 | 4-3000 |
| | 4-3000 | 4-3000 | 4-3000 | 4-3000 | 4-3500 | 4-3500 |
| | 4-3500 | 4-3500 | 4-3500 | 4-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 4-4000 | 4-4000 | 5-4000 | | |

## TABLE I (Continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 100/fl. | 700 | 900 | 1100 | 1400 | 1700 | 1900 |
| 10,000 sq ft | 91/5 | 117/5 | 143/5 | 182/5 | 104/5 | 105/5 |
| | 4-2000 | 5-2000 | 6-2000 | 8-2000 | 3-2500 | 4-2500 |
| | 4-2500 | 4-2500 | 5-2500 | 7-2500 | 4-3000 | 4-3000 |
| | 4-3000 | 4-3000 | 4-3000 | 6-3000 | 4-3500 | 4-3500 |
| | 4-3500 | 4-3500 | 4-3500 | 6-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 4-4000 | 4-4000 | 5-4000 | | |
| 125/fl. | 875 | 1125 | 1375 | 1750 | 2125 | 2375 |
| 12,500 sq ft | 114/5 | 146/5 | 178/5 | 228/5 | 131/5 | 132/5 |
| | 5-2000 | 6-2000 | 7-2000 | 10-2000 | 4-2500 | 4-2500 |
| | 4-2500 | 5-2500 | 6-2500 | 8-2500 | 4-3000 | 4-3000 |
| | 4-3000 | 5-3000 | 5-3000 | 7-3000 | 4-3500 | 4-3500 |
| | 4-3500 | 4-3500 | 5-3500 | 7-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 4-4000 | 5-4000 | 6-4000 | | |
| 150/fl. | 1050 | 1350 | 1650 | 2100 | 2550 | 2850 |
| 15,000 sq ft | 137/5 | 176/5 | 215/5 | 273/5 | 156/5 | 156/5 |
| | 6-2000 | 7-2000 | 9-2000 | 11-2000 | 5-2500 | 5-2500 |
| | 5-2500 | 6-2500 | 8-2500 | 10-2500 | 4-3000 | 4-3000 |
| | 4-3000 | 5-3000 | 6-3000 | 9-3000 | 4-3500 | 5-3500 |
| | 4-3500 | 5-3500 | 6-3500 | 8-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 5-4000 | 6-4000 | 8-4000 | | |
| 175/fl. | 1225 | 1575 | 1925 | 2450 | 2975 | 3325 |
| 17,500 sq ft | 160/5 | 205/5 | 250/5 | 318/5 | 182/5 | 183/5 |
| | 7-2000 | 8-2000 | 10-2000 | 13-2000 | 6-2500 | 6-2500 |
| | 6-2500 | 7-2500 | 9-2500 | 12-2500 | 5-3000 | 5-3000 |
| | 5-3000 | 6-3000 | 7-3000 | 10-3000 | 5-3500 | 5-3500 |
| | 5-3500 | 6-3500 | 7-3500 | 9-3500 | 4-4000 | 4-4000 |
| | 4-4000 | 5-4000 | 6-4000 | 9-4000 | | |

## TABLE I (Continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| 200/fl. | 1400 | 1800 | 2200 | 2800 | 3400 | 3800 |
| 20,000 sq ft | 182/5 | 234/5 | 286/5 | 364/5 | 208/5 | 208/5 |
| | 8-2000 | 9-2000 | 11-2000 | 15-2000 | 6-2500 | 7-2500 |
| | 6-2500 | 8-2500 | 10-2500 | 13-2500 | 6-3000 | 6-3000 |
| | 6-3000 | 7-3000 | 9-3000 | 11-3000 | 6-3500 | 6-3500 |
| | 5-3500 | 6-3500 | 8-3500 | 11-3500 | 5-4000 | 5-4000 |
| | 5-4000 | 6-4000 | 7-4000 | 10-4000 | | |
| 250/fl. | 1750 | 2250 | 2750 | 3500 | 4250 | 4750 |
| 25,000 sq ft | 228/5 | 293/5 | 358/5 | 455/5 | 260/5 | 260/5 |
| | 10-2000 | 12-2000 | 14-2000 | 19-2000 | 8-2500 | 8-2500 |
| | 8-2500 | 10-2500 | 12-2500 | 17-2500 | 7-3000 | 7-3000 |
| | 7-3000 | 9-3000 | 11-3000 | 14-3000 | 7-3500 | 7-3500 |
| | 6-3500 | 8-3500 | 10-3500 | 13-3500 | 6-4000 | 6-4000 |
| | 6-4000 | 8-4000 | 9-4000 | 12-4000 | | |

* Elevator speed
** Building height
\# Building occupants
\#\# Number of occupants to be handled per 5 minute period

The number and size of elevators given in the 18 and 20 floor columns are only those required for the top eight floors. The number required for the lower 10 or 12 floors is the same as those given in the 10 and 12 floor columns.

## Orientation, Insulation, and Sun Control

Orientation is most generally controlled by the site. But for the purposes of this study the site is not considered to be a limiting factor. Climatic conditions will therefore be the controlling element of orientation.

Closely allied to orientation is sunshading. This may range from the use of trees to the design of complex adjustable louvres, but in all cases the problem remains the same: when to intercept the sun's rays, where, and how. It must be admitted that there are situations in which the "when?" can be answered by "never," but these are exceptional, and "when?" is a question of deciding for how long a season or at what times of the day sunshading is necessary. Geographical location and weather conditions can provide an answer to this after relatively simple investigation. The next question "where?" can always be given the ideal answer of "outside"; the sun's rays should be stopped before they have a chance to heat up either the building shell or the air inside. In practice this is often an expensive place to stop the radiation; the screening must be over a larger area, and if adjustable, can be very complex. It is also subject to the effects of the weather. Nevertheless, it stops more heat than internal shading. "How?" can be answered in many ways: orientation is the first of these, followed by plan form, location and area of windows, fixed and adjustable sunbreakers, heat-resisting glass, and blinds and curtains of all kinds.

The problem of interrupting sunlight before it reaches the skin of the building promises to create a whole new series of patterns, textures, and even profiles for our tall and our low buildings.

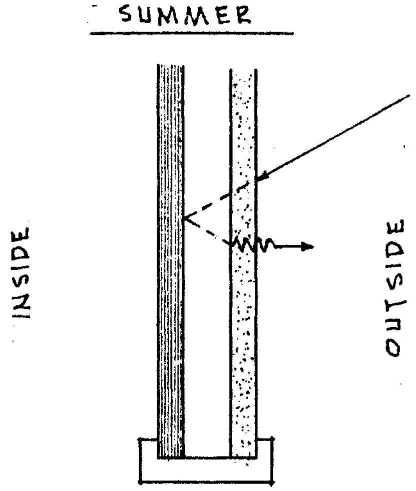
Insulation is closely related to sun control and orientation as both have a direct effect on it. The following discussion of insulation is taken from Manasseh and Cunliffe (10).

> Cavity walling, both in traditional and component construction brings with its good insulation the problem of condensation. The temperature gradient through the wall must be calculated accurately, and a ventilated cavity avoided if possible, for such ventilation can increase the heat transmission by as much as 12%. Windows are susceptible to both heat loss and heat gain, and while double glazing (at an optimum spacing of 3/4 in.) is the remedy for the former, heat-resisting glass as a solution to the latter is an embarrassment in winter when solar radiation would be welcome. A recent development, using an ingenious combination of double glazing, heat resisting glass, and reversible windows is an interesting advance in this field. [Figure 4.] There must also be efficient sealing of doors and windows; this alone can reduce the heat loss of a building by 10%. Floors and roofs have insulation problems in common, despite their different functions. Whether they are to be used as part of the thermal reservoir or not influences the position of their insulation, especially when the space heating is by an embedded floor or ceiling system; and this is made more important if they form the division between different tenancies.

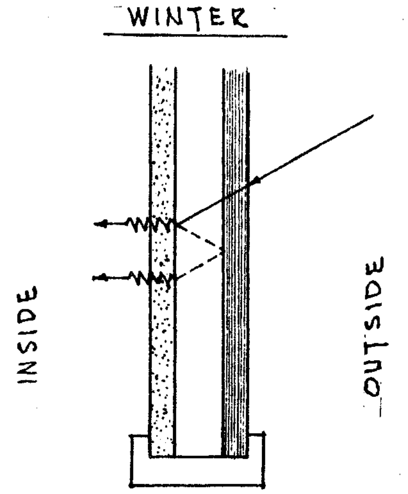
## Additional Environmental Features

Nearly everything discussed in the preceding sections has a psychological effect on the office worker and thus is an environmental factor. However, there might be mentioned briefly here some of the lesser important building features, but equally important with regard to environment.

> Morale and efficiency increase as space allotments are made more generous. Desks separated from, rather than abutting on, each other give each worker more of a sense of pride



Sun's rays converted by heat abs. glass to low frequency waves which cannot pass through plate glass, so escape out by conduction and convection.



Sun's rays converted by heat abs. glass to low frequency waves which cannot reflect through plate glass, so escape inwards by conduction and convection.

Figure 4. Reversible Double Pane Window.

> and prestige in his job, less of a feeling of being part of an assembly line. Moreover, aside from the intangible prestige factor in the workers' minds, a spacious uncrowded office is usually less noisy and more relaxing physically than one that gives an impression of being crowded. (12)

> The general assumption is that windows should provide daylight for working illumination, but in actual fact the principle function of a window today is probably to provide a view to the outside. Nevertheless, people will work apparently happily where there are no windows at all, providing, of course, that there is adequate artificial illumination. (20)

At present, the plaza idea seems to be restricted to projects for corporate clients willing (and able) to make a conspicuous gesture for the sake of the prestige such a scheme lends their business headquarters. However, the hard fact remains that when a part of such a space is leased, it yields top returns. It may be interesting to note, that office staff usually react unfavorably to highly finished and expensive prestige buildings on the grounds that such provisions have been made more to impress outsiders than to provide the staff with comfortable conditions.

This points out the two sides that commonly present themselves when considering environment. No matter what the considerations to be utilized, a great amount of thought must be given to environmental features such as these as well as to those of color, furniture, art work and landscaping.

## Conclusion

> With increasing mechanization we are likely to see develop one stratum of machine minders and another stratum of junior management who plan and sift the machine's work. This latter class is likely to increase in size and will expect to be housed in small, well fitted private offices. In the meantime, people doing unskilled tasks will be housed in large, open spaces.
>
> It seems to me that as mechanization becomes more efficient, these machine minders will handle more machines, and become fewer in number. At the same time, the junior

> management group are likely to increase in numbers and, as they will wish to communicate with one another, it will no longer be practicable for them all to sit in isolated offices. The partitions, the doorways, the corridors, are the barrier to communication. This barrier is not lessened by the telephone. It seems probable, therefore, that the large open space, which is current practice in America, and in architects' offices for that matter, will come to be increasingly adopted in the future. (20)

Regardless of what the future holds, it is quite apparent that flexibility in all aspects of the office building is a must if it is to satisfy even today's needs.

# CHAPTER IV

## FIRST STAGE STUDY

Figure 1, found in Chapter II, shows the classification of component building systems into three major groups which are then further broken down into nine specific types of systems. Of the nine systems, two (truss-framing-and-panels and geodesic-framing-and-panels) can be eliminated immediately since these two systems fail to adapt to multistory construction.

The elimination of the two systems leaves seven to be studied in the first preliminaries. These seven systems are:

1. Load-bearing-panels (horizontal and vertical)
2. Bay-framing-and-panels
3. Space-frame-and-panels
4. Tension-frame-and-panels
5. Shell-structural-panels
6. Cellular-without-frame
7. Cellular-with-framing

Table I in Chapter III is made up to select the number and size of elevators for the various floor sizes and building heights that might be used in the studies to follow. For the purpose of the first studies, one average size and height of building was selected so as to eliminate some of the variables that might otherwise occur. The floor size selected for this purpose is approximately 15,000 square feet and the building height is 10 floors. Selecting the size and number of elevators from Table I gives five elevators of three thousand pound capacity.

Designing a basic core around this information provides for another standardizing factor. The core, Figure 5, is designed to be monolithic concrete which will serve as shear walls to stabilize the building which is otherwise component structured. Along with the elevators, the core will also contain the restrooms, a janitor's closet, and a mechanical equipment room and in some cases the fire stairs.

Figures 6 through 12 were prepared as the first preliminary studies to be analyzed. They are analyzed in a rating manner according to Table II which will be amplified further here in written form. Table II is a rating scale which has injected into it an importance factor. The plans and sections of the seven component systems are judged primarily in this preliminary stage on their adaptability to multi-story building construction and to the particular functions required of an office building.

The rating scale on which the component systems were scored is as follows:

1--Excellent

2--Good

3--Average

4--Poor

5--Bad

This score was then multiplied by the importance factor placed on that particular aspect of office building construction or function. The higher totaled scores indicate the component systems' inappropriateness to multi-story office buildings.

The component systems' particular suitability to the various types of rooms or spaces that made up office buildings is the most important consideration for this first analysis. It is broken down into seven types of spaces which were rated individually with regard to the component system. Following the drawings is a discussion of the ratings given and the reasons for them.

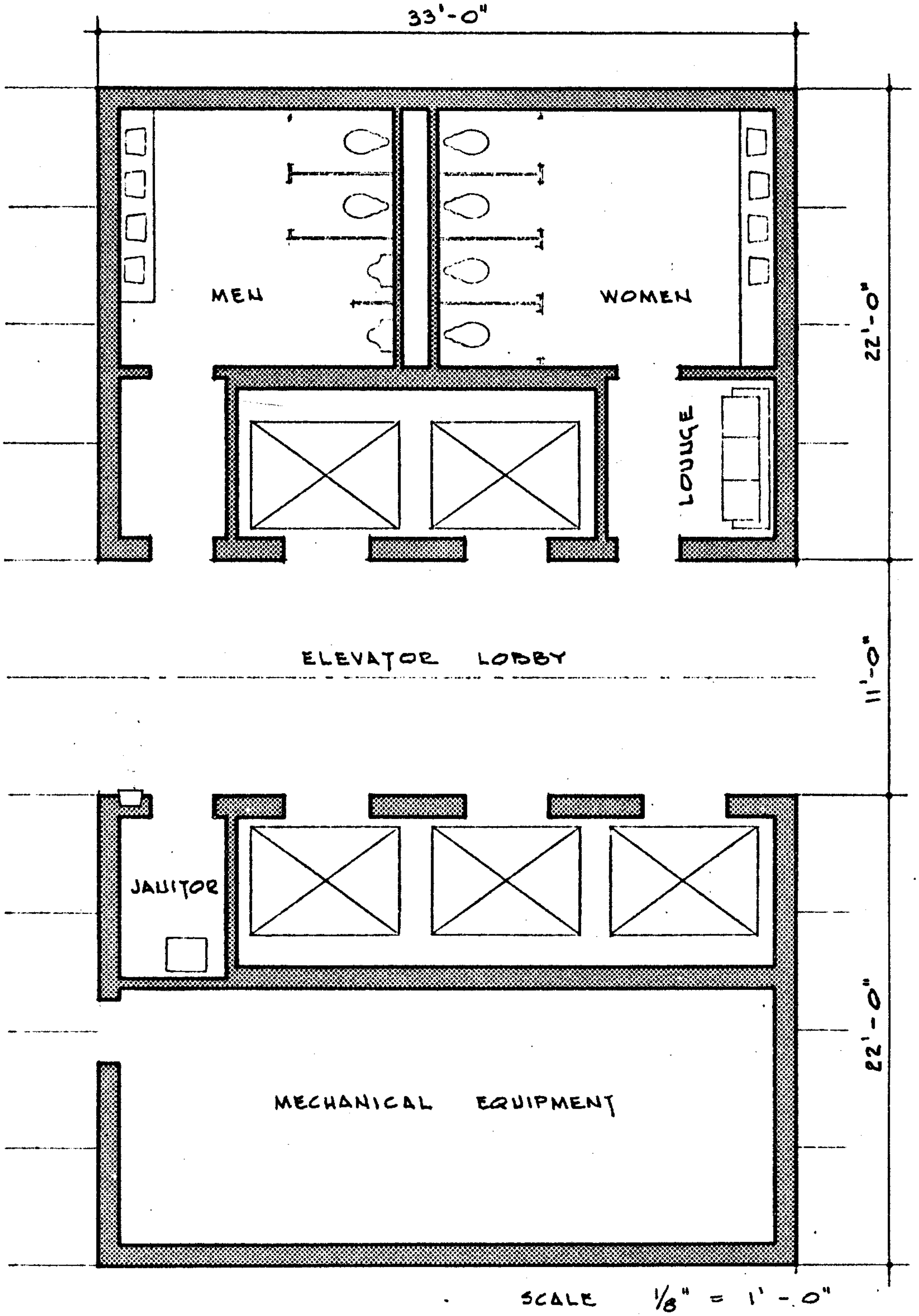


Figure 5. Typical Core Plan.

- TEN LEVELS @ 16,400 □' PER LEVEL
- RENTABLE FLOOR SPACE - 76.7 %

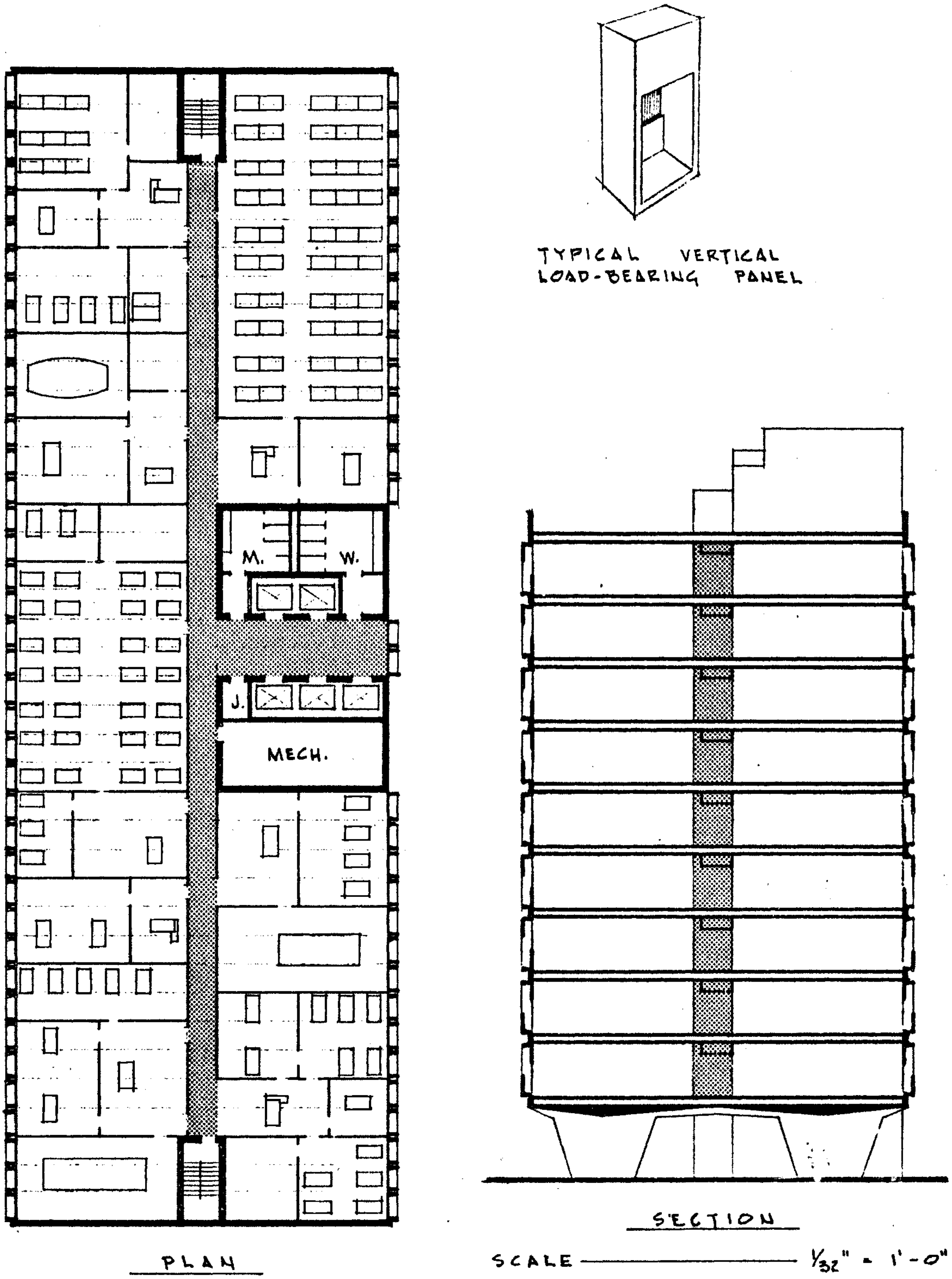
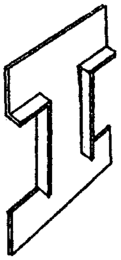
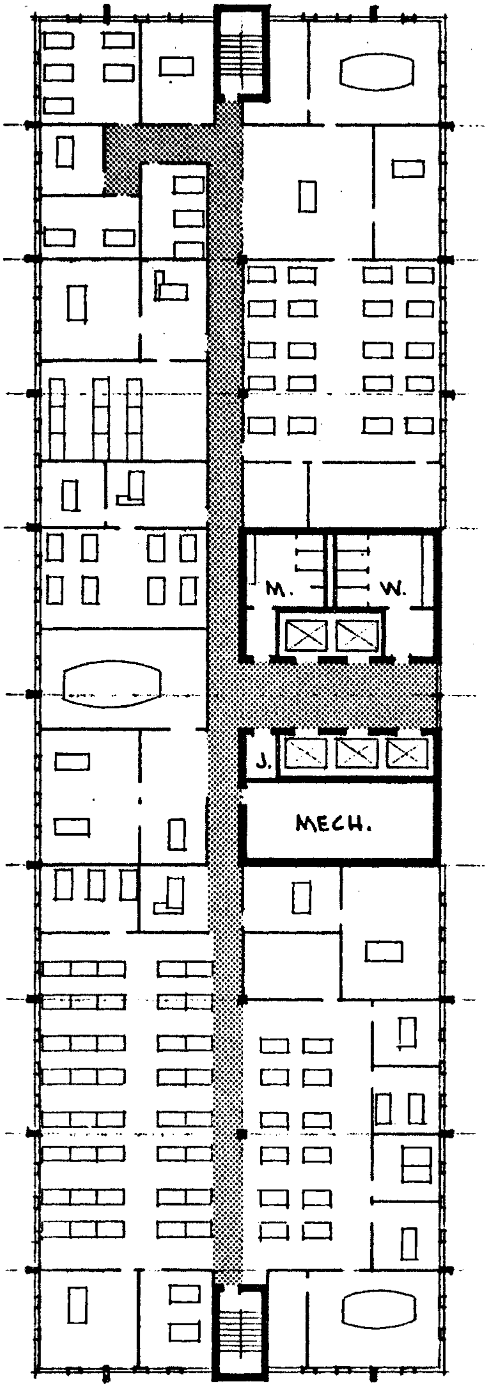


Figure 6. Load-Bearing-Panels.

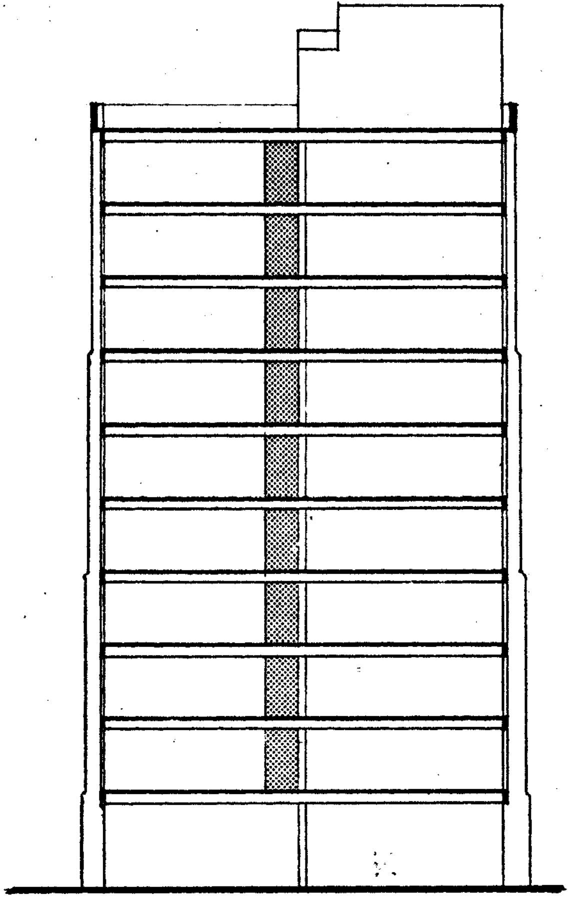
• TEN LEVELS @ 15,000 □' PER LEVEL
• RENTABLE FLOOR SPACE - 77%



EXTERIOR
WALL PANEL



PLAN



SECTION

SCALE ——————— 1/32" = 1'-0"

Figure 7. Bay-Framing-and-Panels.

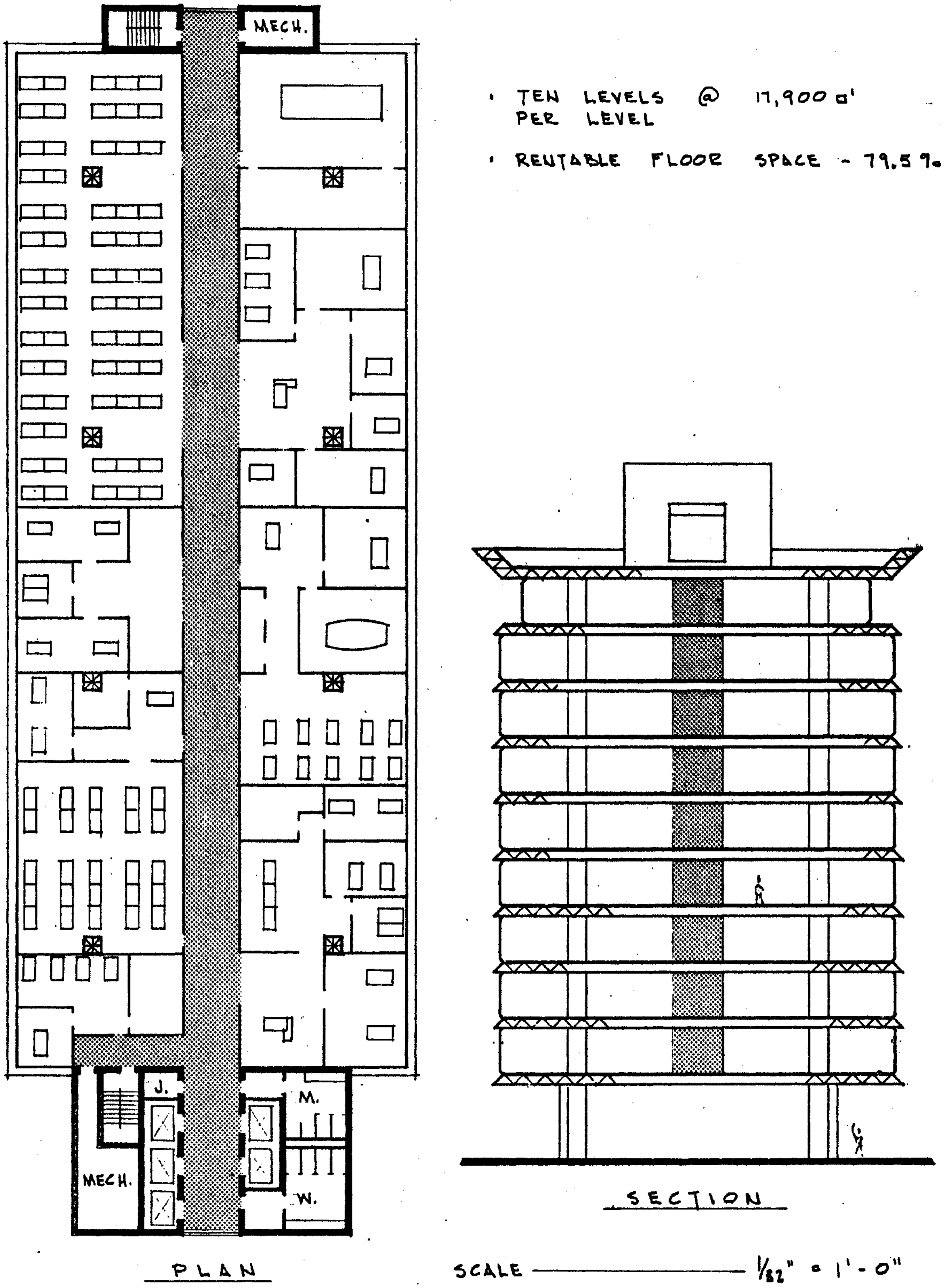


**Figure 8. Space-Frame-and-Panels.**

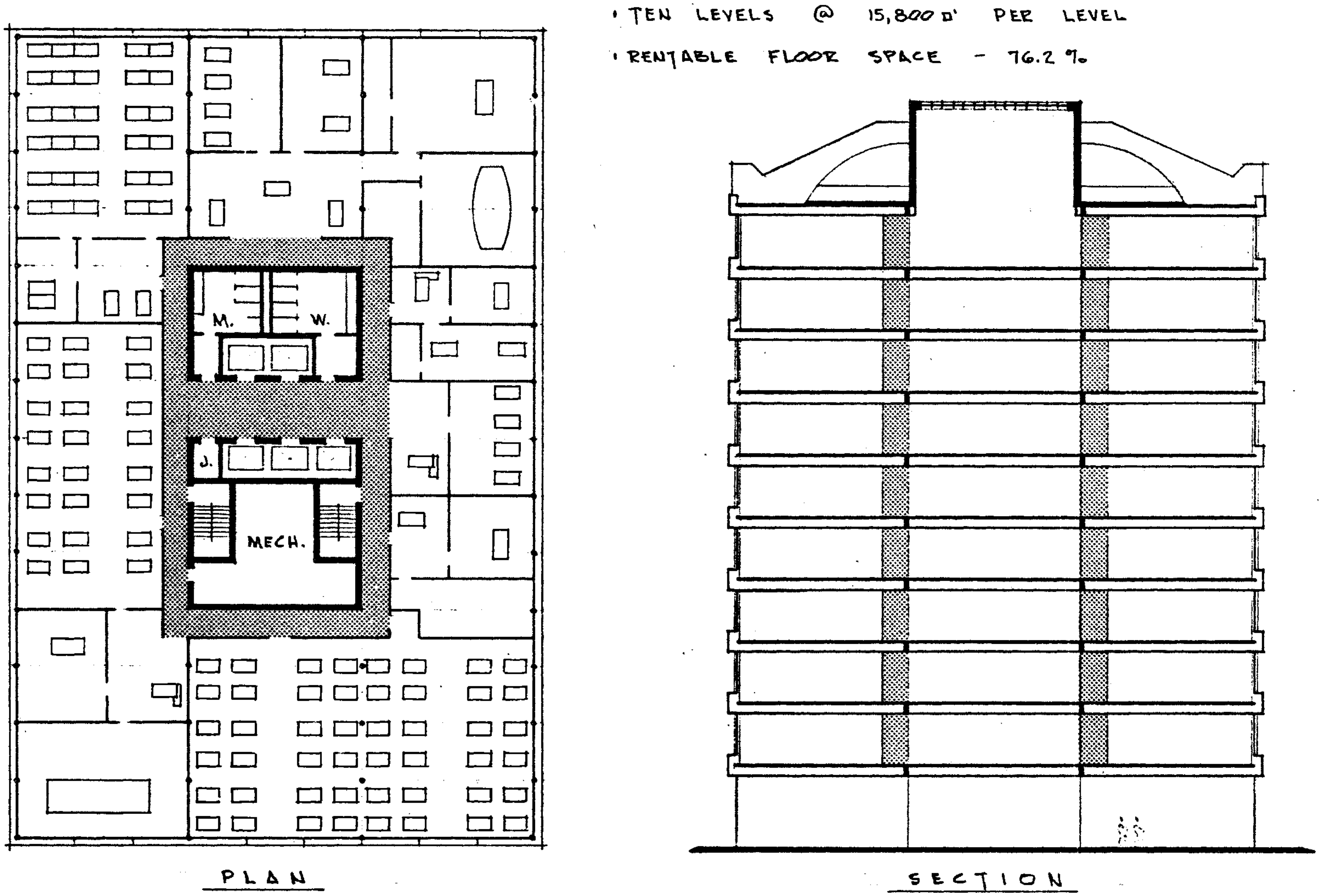


Figure 9. Tension-Frame-and-Panels.

- TEN LEVELS @ 16,000 □' PER LEVEL
- RENTABLE FLOOR SPACE - 73.2 %

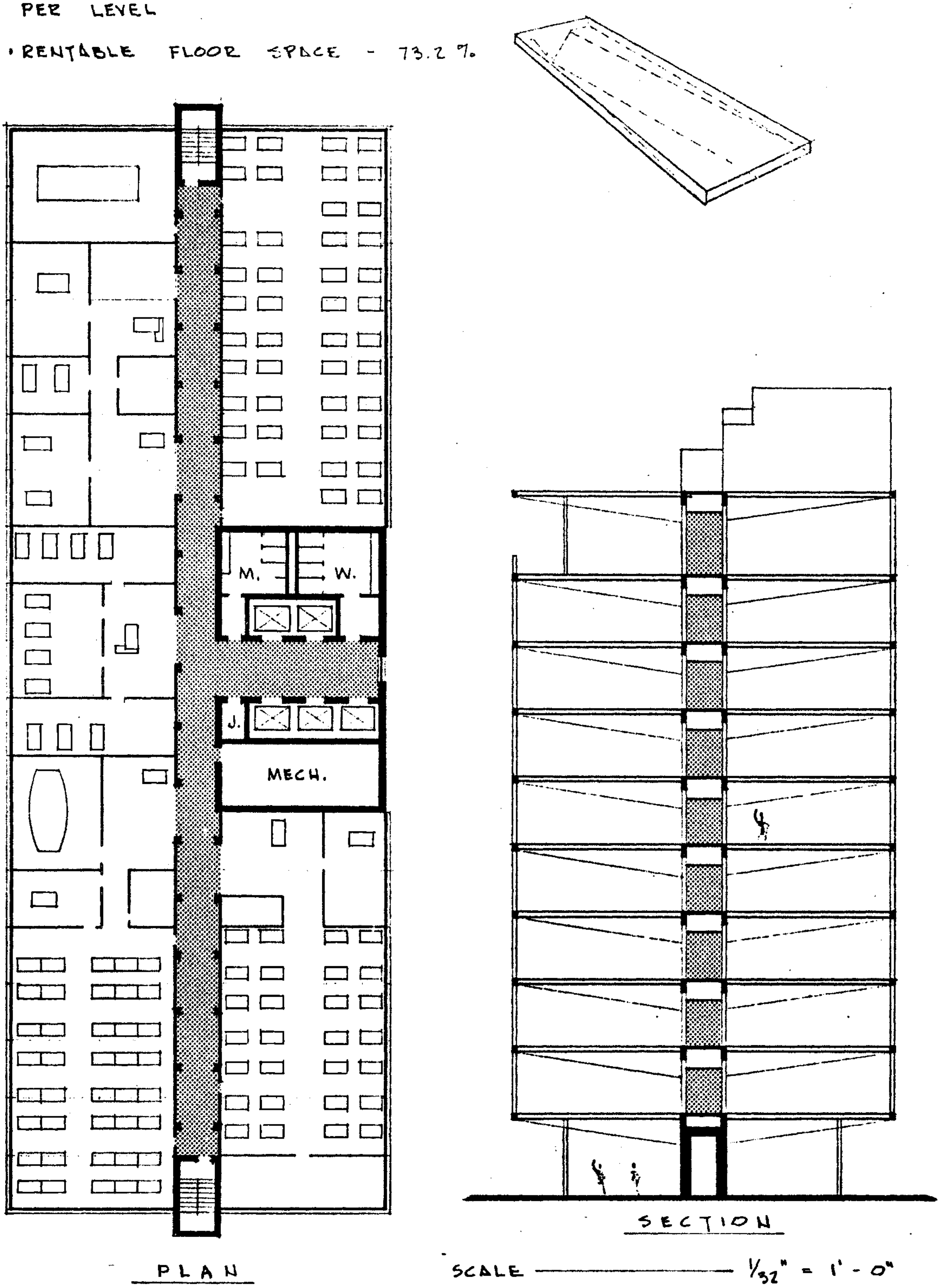


Figure 10. Shell-Structural-Panels.

- TEN LEVELS @ APPROX. 17,[illegible] □' PER LEVEL
- RENTABLE FLOOR SPACE - 80% MAX. 81.4%

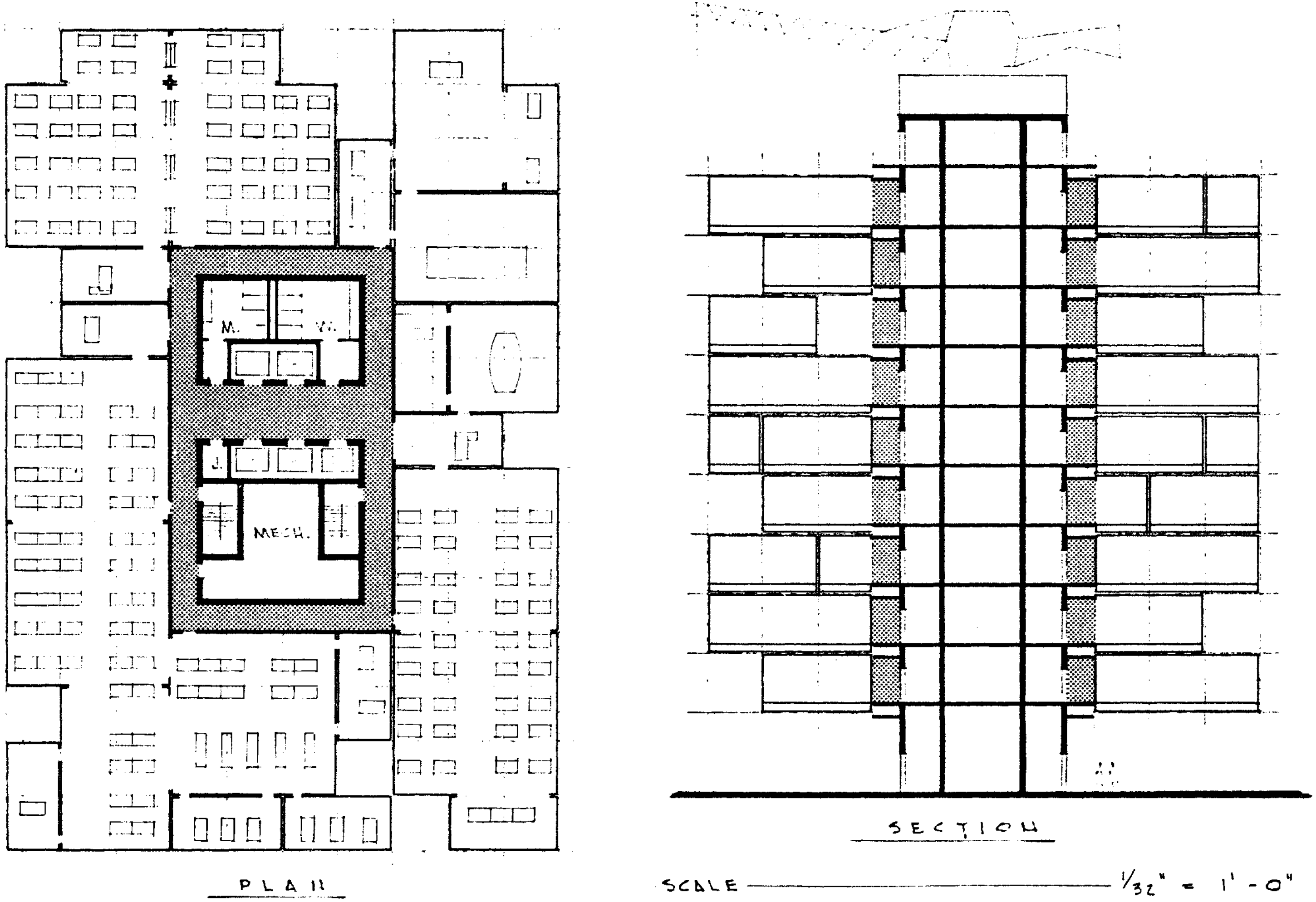


Figure 11. Cellular-without-Frame.

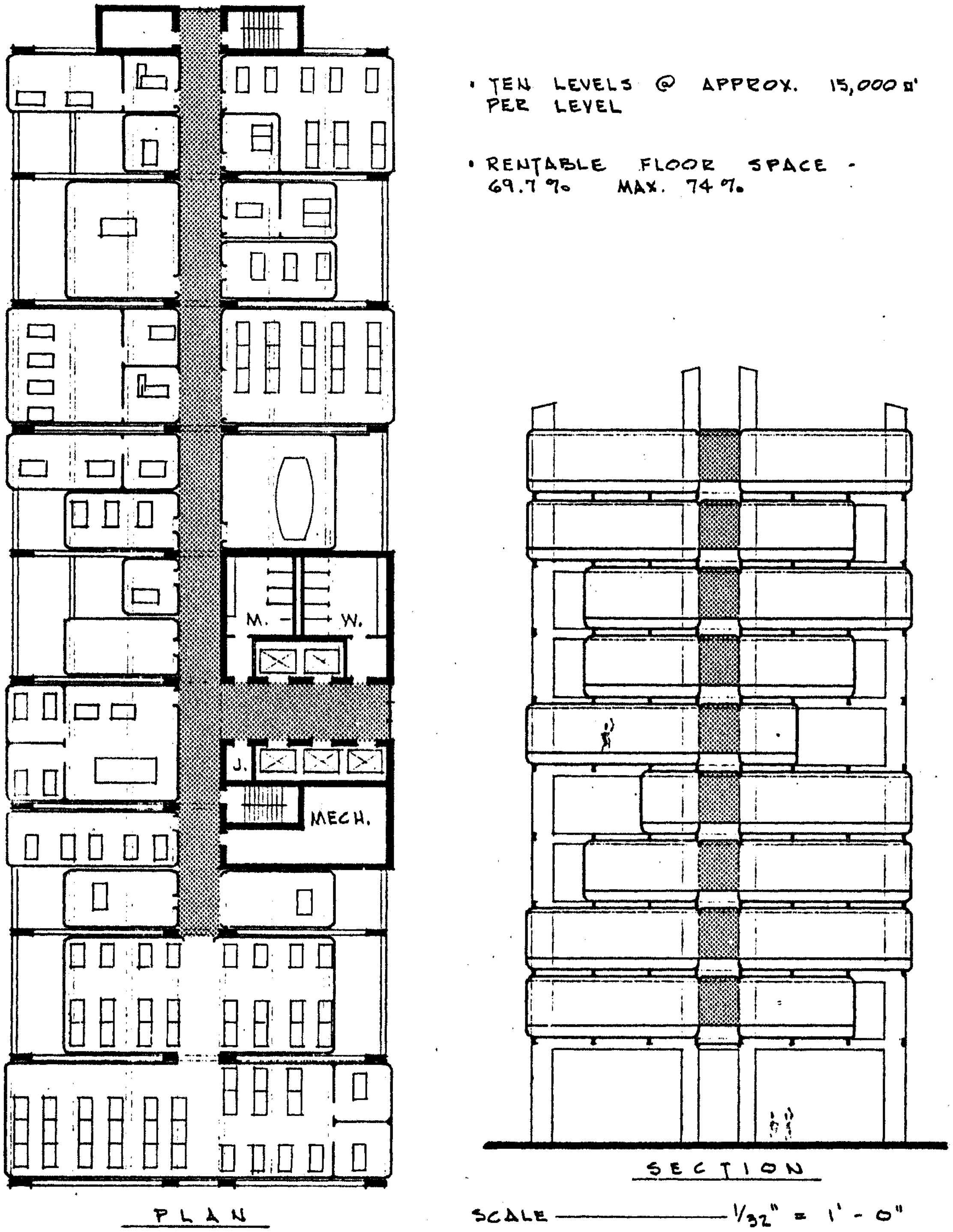


Figure 12. Cellular-with-Framing.

## TABLE II

## FIRST STAGE RATING SCALE

| Number in ( ) indicates the Importance Factor<br>Low Medium High<br>(1) (2) (3) | Load-Bearing-Panels | Bay-Framing-and-Panels | Space-Frame-and-Panels | Tension-Frame-and-Panels | Shell-Structural-Panels | Cellular-without-Frame | Cellular-with-Framing |
|---|---|---|---|---|---|---|---|
| Private Office (3) | 9 | 9 | 12 | 12 | 12 | 6 | 3 |
| General Office (3) | 6 | 6 | 6 | 6 | 9 | 6 | 15 |
| Archives & Storage (3) | 9 | 9 | 9 | 9 | 12 | 6 | 12 |
| Conference Room (2) | 6 | 6 | 6 | 6 | 8 | 4 | 6 |
| Corridors (2) | 4 | 6 | 8 | 6 | 8 | 8 | 8 |
| Computer Equip. (3) | 9 | 9 | 12 | 12 | 12 | 6 | 6 |
| Special (labs, etc.) (2) | 6 | 6 | 8 | 6 | 8 | 4 | 4 |
| Subtotal | 49 | 51 | 61 | 57 | 69 | 40 | 54 |
| | | | | | | | |
| Efficiency of Space (2) | 6 | 6 | 4 | 6 | 8 | 4 | 10 |
| Story Height (1) | 2 | 2 | 2 | 2 | 4 | 3 | 4 |
| Artificial Lighting (1) | 3 | 2 | 3 | 2 | 4 | 2 | 2 |
| Escape Routes (1) | 4 | 4 | 3 | 2 | 4 | 2 | 3 |
| Acoustics, Ext. to Int. (1) | 3 | 3 | 4 | 4 | 4 | 2 | 2 |
| Acoustics, Int. to Int. (3) | 9 | 9 | 9 | 9 | 9 | 3 | 3 |
| Subtotal | 27 | 26 | 25 | 25 | 33 | 16 | 24 |
| | | | | | | | |
| Flexibility (3) | 9 | 6 | 6 | 9 | 12 | 9 | 12 |
| Plan (1) | 3 | 3 | 3 | 3 | 3 | 1 | 2 |
| Section (1) | 3 | 4 | 4 | 4 | 3 | 2 | 2 |
| Elevation (1) | 3 | 4 | 4 | 5 | 4 | 1 | 2 |
| Subtotal | 18 | 17 | 17 | 21 | 22 | 13 | 18 |
| | | | | | | | |
| TOTAL | 94 | 94 | 103 | 103 | 124 | 69 | 96 |
| | | | | | | | |
| Average | 2.85 | 2.85 | 3.12 | 3.12 | 3.76 | 2.09 | 2.91 |

## Discussion of Ratings

The private office demands privacy and needs access to a circulation space or corridor. It is usually a rather small space, from 100 to 500 square feet. For these purposes, the cellular-with-framing system is particularly appropriate because it naturally breaks spaces down into relatively small spaces near or next to the central corridor and provides excellent privacy because each space has its own walls. The adjoining space, if there is one, again has its own walls, thus providing for excellent acoustical conditions. For this double wall situation and its adaptability to small spaces, the cellular-without-framing system works well for private offices.

The space-frame and tension-frame systems, because of their particular suitability to large open spaces, do not adapt themselves well to small private offices. Either some offices are unavoidably interior spaces without exterior light or large spaces are left in the interior again without exterior light. The shell-structural-panel system is not easily divided into small spaces because of its undulating ceiling surface.

General offices require large open spaces for secretarial or clerical pools. This makes the cellular-with-framing system the least workable for the same reasons it was so favorable for private offices. The shell-structural-panel system also has a weakness here because its central structural supports divide the space.

The cellular-without-frame works well for archives and storage areas because it adapts to various size spaces well. It also provides good separation without hampering accessibility. This accessibility consideration is what makes the cellular-with-frame system undesirable.

In conference rooms, the proportion of width to length is as important as the size. A proportion between 1:1 and 1:1½ will usually serve this purpose best. The cellular-without-framing system is again most adaptable because it provides a separated, yet accessible space that has good acoustical qualities. The shell-structural-panel system is the least appropriate because again it is hard to divide into desired sizes and shapes.

The load-bearing-panel system works quite well for various corridor layouts because of its 5'-6" module which is equal to 3 unit widths wide. The shell-structural-panel system does not adapt well because of its 11'-0" bay width and its definite central corridor. Neither of the cellular systems are very applicable because the cells are too large to serve as corridors. The corridors in these two systems are preplanned and permanent.

Computer equipment and other business machines need be located conveniently and yet acoustically separated from the adjoining office spaces. This acoustical separation consideration makes the two cellular systems desirable as well as the fact that new or more modern equipment could be installed in a cell at the factory and then replace or supplement an old cell of equipment. The weight of the equipment and the vibrations set up by it make lightweight structures such as the space-frame and tension-frame undesirable. They are also undesirable because of the acoustical consideration.

Special rooms such as laboratories, studios, etc. are similar to business machine equipment spaces and are thus best suited to the same systems and vice versa.

From the totals of the above ratings, with the importance factor considered, the cellular-without-frame is found to be the most adaptable to the various types of rooms. The shell-structural-panel system is the least adaptable with the space-frame-and-panel system being poor as well. The cellular-with-framing system was in the middle of the seven systems, but was the only one to have a 5 rated score. This occurred with regard to the general office. Since the general office is a very important part of office buildings in the United States, the cellular-with-framing system is less desirable than would seem to be indicated by the figures.

Next to be rated are some of the mechanical and economical features that can be at least partially evaluated at this time. Efficiency of space was calculated by dividing the rentable floor area by the gross building area. These calculations were based on the building size and height used for this preliminary study and are subject to variation as the size and height of the buildings are changed. However, from investigation, we can assume that the cellular-with-framing system will always have low efficiency because of the required amount of corridor per rentable space. This applies similarly to the shell-structural-panel system as can be seen in Figure 10.

The floor to floor height affects the economics of the building as does the efficiency of space. The shell-structural-panel and cellular-with-framing systems again have poor ratings, thus making them more costly buildings. Both cellular systems have increased ceiling height because each cell has its own ceiling and floor, rather than being able to share a floor-ceiling combination as the other systems. The cellular-with-framing requires still more added depth because of the framing beams. The shell-structural-panel system has a large floor to floor height on account of the depth of the panels.

The undulating ceiling of the shell-structural-panels has a poor effect on any grid lighting system and the panels' hard surface requires that the lighting fixtures project as opposed to a flush mounting. This projection might obstruct freedom in placing interior partitions. The load-bearing-panel system has this same problem without the undulating ceiling. The space-frame system has a different problem in that the lighting panels must be highly co-ordinated with the structural system which limits their placement.

The escape routes were given a low importance factor because the condition is not as dependent on the system as the different plans derived from the system. The rating for this study was based on the accessibility to the fire stairs in the plan considered.

The acoustics ratings are far more important with regard to internal sound control than to external. This was because of the difficulty in analyzing the external sound control without material and form characteristic established. The cellular systems have exceptionally good interior acoustical conditions because each cell has its own walls, ceiling and floor and is not sharing it with the next.

The totals again show the cellular-without-frame system to be the most appropriate to multi-story office buildings, while the shell-structural-panel system is again the least appropriate. This is with regard to mechanical and economical factors.

The next and final section of the rating chart considers flexibility and building shape and form. Flexibility has to do with the ease and possibilities of changing the sizes and shapes of spaces. For this reason, the systems having open plans work the best and received the highest ratings.

Building shape and form is broken down into three parts: plan, section, and elevation, and is rated according to the systems' interest and integrity. This consideration gives the cellular systems high ratings because they reveal the varied internal spacial characteristics that are so typical of office buildings.

The totals of the entire rating chart show that based upon the evaluation of this preliminary study, the cellular-without-framing system is the most adaptable to multi-story office buildings. The least adaptable is judged to be the shell-structural-panel system. The five intermediate systems can be placed in two groups, one below average and the other above average. Two systems, space-frame and tension-frame received scores of 103 and can be placed in the below average group. The remaining three systems, load-bearing-panels, bay-framing-and-panels, and cellular-with-framing, received scores of 94, 94, and 96 respectively and are placed in the above average group.

## CHAPTER V

## SUMMATION TO FIRST STAGE

In order to analyze the component building systems in more detail in the second stage study and yet contain the project within length and time limits, all the systems that scored below average in the first stage study will be eliminated from further study. This does not mean that they are necessarily unworthy of further study nor that variations of these systems that were not analyzed would not score them above average. Brief examination of some of the possible changes or improvements that might have been made in the eliminated systems will be made in this chapter.

The load-bearing-panels system, the bay-frame-and-panels system, the cellular-without-frame system, and the cellular-with-framing system are those systems which scored above average on the first stage study and will be pursued and analyzed further in the next chapter or the second stage study. The space-frame-and-panels, the tension-frame-and-panels, and the shell-structural-panels systems scored below average scores and will be concluded at the end of this chapter.

The shell-structural-panels system received the lowest score. The major cause of this low score was the system's inherent characteristic of undulating ceiling surface. This created problems of subdividing spaces with partitions, thus affecting flexibility and the office shapes and sizes. It also has an adverse effect on lighting. These faults might have been overcome by incorporating false work below the undulating ceiling (this of course having an adverse effect on the integrity of the system), but this would only increase the already adverse characteristic of a large floor-to-floor height. Another characteristic that decreased the effectiveness of the system was the necessity of a central structural corridor to support the shell panels. This again might have been eliminated if the panels could be supported only off the core. All of these improvements, however, always create problems in other areas. It is only speculation that were these improvements made, the system would score above average.

Both the space-frame and tension-frame systems have the disadvantage of being light weight structures. While this is an advantage in many respects, it does present problems in the multi-story office building type. First of all, they lack stability that the heavier structures have. Mass is also a very big factor in absorbing noise and vibration. Noise being one of the major problems in office buildings, these two systems must be extremely altered from their inherent form to solve this noise problem which is taken care of by mass in the other systems. Also, the large open spaces that are in the nature of these two systems do not lend themselves readily to private office and other relatively small spaces. This could be remedied, but it would put the systems out of character.

It undoubtedly appears to the reader that integrity plays an important part in this project and indeed it does. This type of study is based on the intent of analyzing the inherent characteristics of the system in its pure state, not affected by modifications and adjustments. Probably any system could be falsified to the extent that it would be workable at the expense of its true self. Of course, it would no longer be a system, but a combination of systems. This combination of systems may very well be the appropriate solution to multi-story buildings, but the goal of this study is to analyze the various types of component building systems on the basis of their inherent characteristics.

# CHAPTER VI

## SECOND STAGE STUDY

The second stage study differs from the first stage in three respects. It deals with an increased number of buildings to be analyzed, an increased number of criteria by which they are analyzed, and is narrowed in scope only in the number of systems to be analyzed.

First of all, each system will be adapted to seven sizes, heights, and shapes of buildings, instead of each system being adapted to just one size and height of building as in the first stage. To expand the scope and reliability of the study still further, the component building systems will be analyzed on the basis of more criteria of office buildings. In the first stage study, the systems were analyzed as to their adaptability in the areas of functional spaces, limited mechanical and economical aspects. The second stage study will be analyzed in all of these areas plus those of environmental conditions, orientation, acoustics, more detailed mechanical conditions, construction, and additional economical considerations.

Table III is the rating chart for the second stage study as Table II was for the first stage. The scoring system and the use of an importance factor are the same. Also to be found in the upper left hand corner of Table III is a diagram showing the heights in number of floors and square footage per floor sizes of the buildings that the systems are to be adapted to. The plan shape in all cases is to be one of three types: blocky, or as near square as possible; linear; or an uncommon shape such as a T, L, or U shape. B, D, and G are square shaped plans; A, C, and F are linear shaped plans; and E designates the uncommonly shaped plans.

Figures 13 through 38 contain the drawings that are being analyzed and that supplement the discussion and explanation which follows them.

## TABLE III

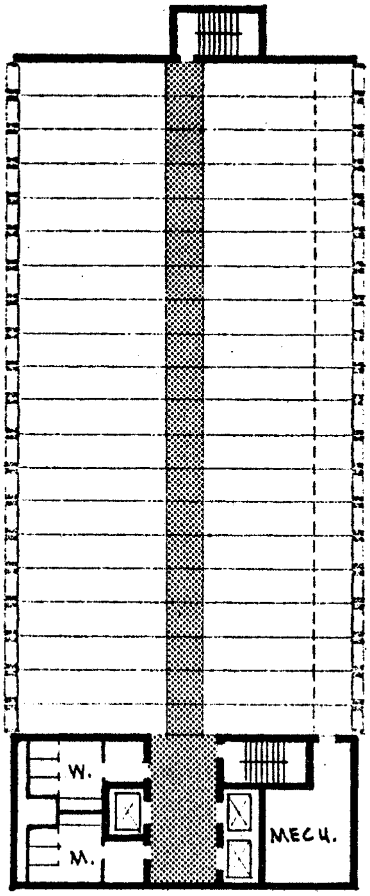
## SECOND STAGE RATING SCALE

| Sq. ft. | Number of Floors 8 | 10 | 12 | 15 | 18 | 20 |
|---|---|---|---|---|---|---|
| 7500 | A<br>B | | | | | |
| 15,000 | | C<br>D<br>E | | | | |
| 20,000 | | | | | F<br>G | |

| | Load-Bearing-Panels Plan | | | | | | | Bay-Framing-and-Panels Plan | | | | | | | Cellular-without-Frame Plan | | | | | | Cellular-with-Framing Plan | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | A | B | C | D | E | F | G | A | B | C | D | F | G | A | C | D | E | F | G |
| Private Office (3) | 9 | 9 | 9 | 9 | 12 | 9 | 12 | 6 | 6 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 3 | 3 | 3 | 3 | 3 |
| General Office (3) | 6 | 9 | 6 | 6 | 9 | 6 | 6 | 6 | 12 | 6 | 6 | 6 | 6 | 6 | 12 | 6 | 6 | 6 | 6 | 6 | 15 | 15 | 15 | 15 | 15 | 15 |
| Archives & Storage (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 12 | 12 | 12 | 12 | 12 | 12 |
| Conference Room (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 6 |
| Corridors (2) | 6 | 6 | 4 | 6 | 8 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Computer Equipment (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Special (labs, etc.) (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Flexibility (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Height (3) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 9 | 9 | 9 | 9 | 9 | 9 |
| Sq Ft per Floor (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 12 | 12 |
| Form of Plan (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Shape of Section (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Shape of Elevation (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 |

TABLE III (Continued)

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Construction Cost (1) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| Efficiency of Space (3) | 15 | 15 | 9 | 9 | 9 | 12 | 12 | 15 | 15 | 12 | 6 | 12 | 15 | 15 | 12 | 12 | 9 | 6 | 12 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Story Height (2) | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| Structure (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 6 | 6 | 6 |
| Wall Construction (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Partitioning (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Floors & Ceilings (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Air Conditioning (3) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Artificial Lighting (2) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Elec. & Telep. Wiring (2) | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Water & Gas Supply (1) | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Acoustics Ext-Int (2) | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Acoustics Int-Int (3) | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Orientation (3) | 12 | 15 | 12 | 12 | 12 | 12 | 12 | 9 | 6 | 9 | 6 | 6 | 6 | 6 | 6 | 9 | 6 | 6 | 6 | 6 | 12 | 12 | 9 | 12 | 12 | 9 |
| Sun Control (2) | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Functional Expression (3) | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 3 | 3 | 3 | 3 | 3 | 3 | 6 | 6 | 6 | 6 | 6 | 6 |
| Natural Lighting (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| Size & Shape of Spaces (2) | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 6 | 6 | 6 | 6 | 6 |
| TOTAL | 226 | 232 | 218 | 220 | 228 | 221 | 224 | 202 | 205 | 204 | 195 | 201 | 204 | 204 | 185 | 182 | 176 | 173 | 179 | 182 | 217 | 217 | 214 | 217 | 217 | 214 |
| | A | B | C | D | E | F | G | A | B | C | D | E | F | G | A | B | C | D | F | G | A | C | D | E | F | G |
| | Load-Bearing-Panels | | | | | | | Bay-Framing-and-Panels | | | | | | | Cellular-without-Frame | | | | | | Cellular-with-Framing | | | | | |



PLAN A

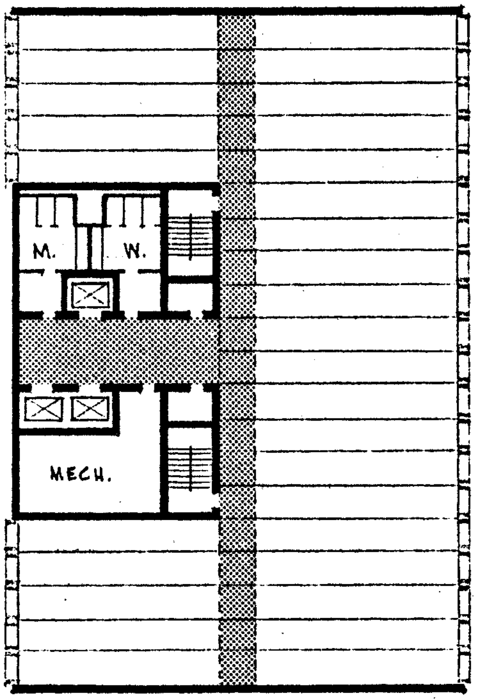
EIGHT LEVELS @ 7900 □'
PER LEVEL

RENTABLE FLOOR SPACE
68.4 %

SEE FIGURE 6 FOR
PLAN C

EIGHT LEVELS @ 8300 □'
PER LEVEL

RENTABLE FLOOR SPACE
65.7 %



PLAN B

Figure 13. Load-Bearing-Panels, Plans A and B.

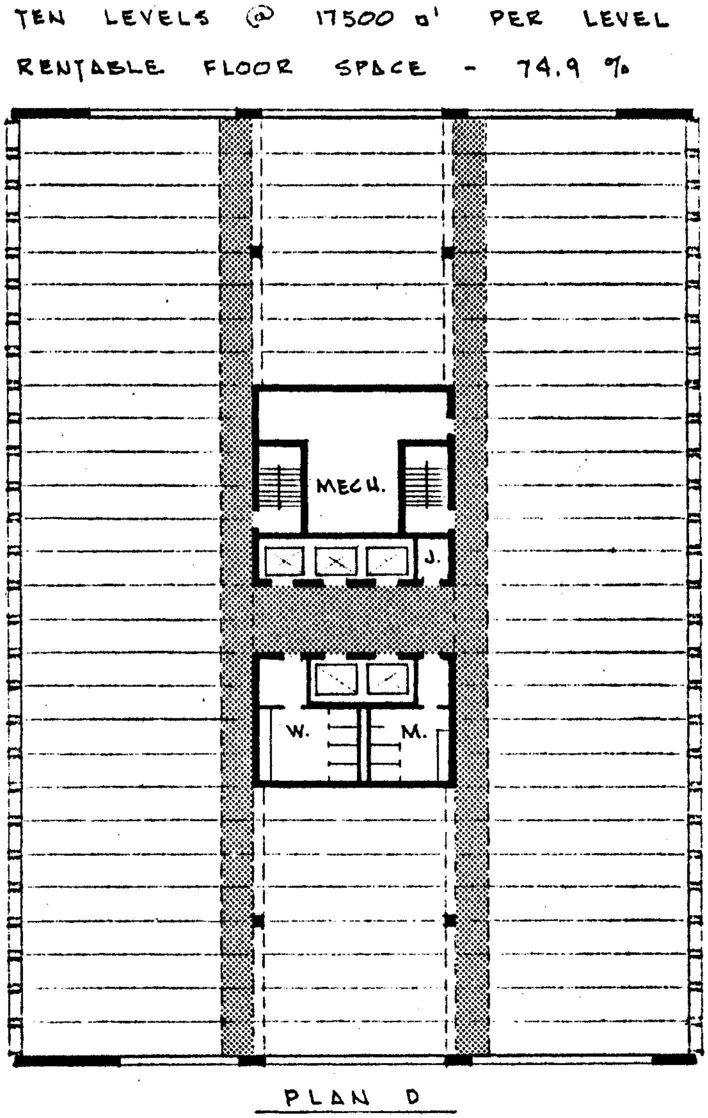


Figure 14. Load-Bearing-Panels, Plan D.

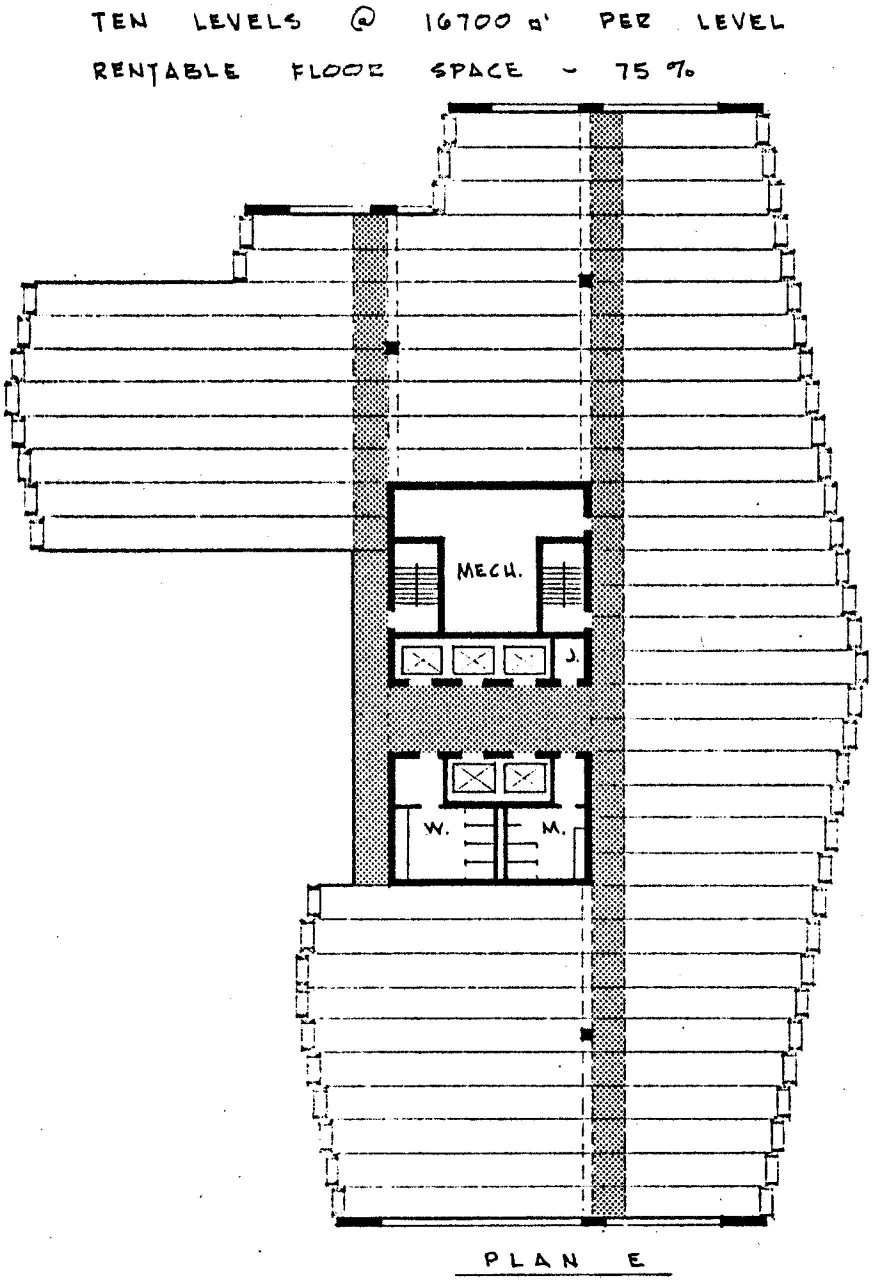


Figure 15. Load-Bearing-Panels, Plan E.

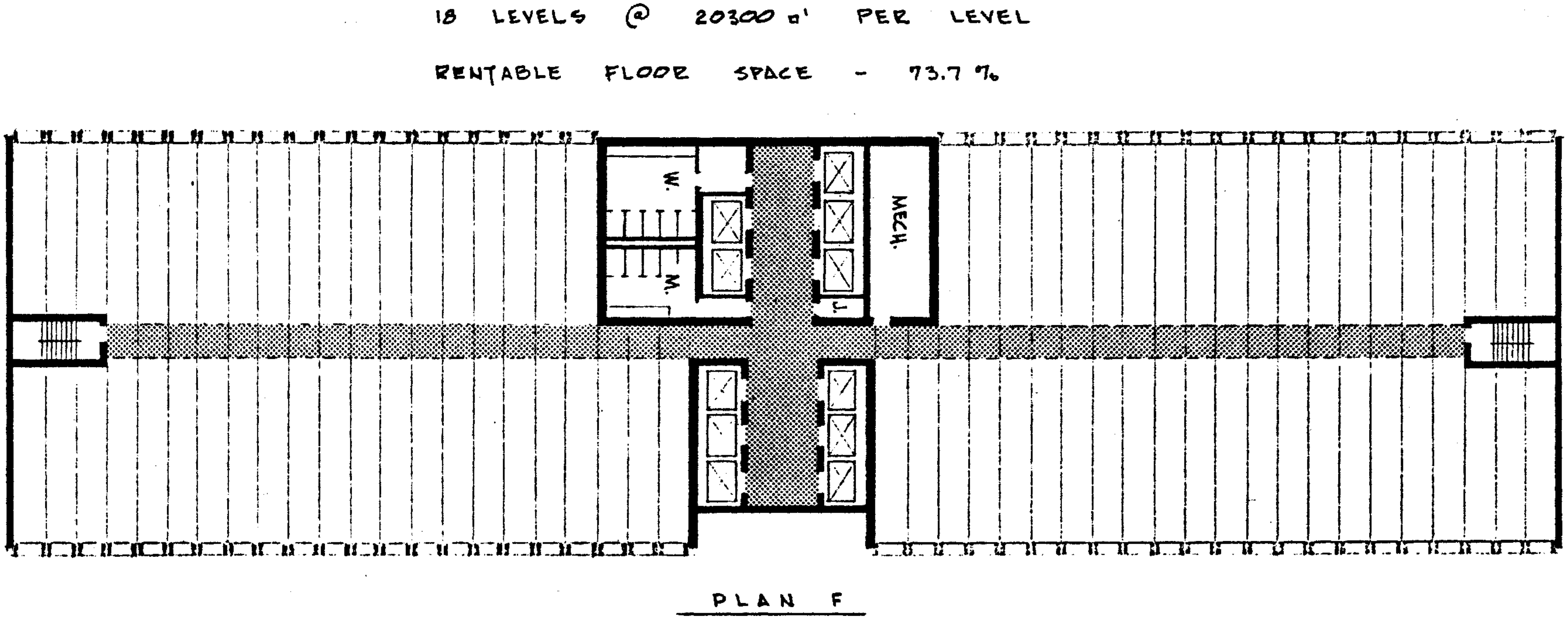


Figure 16. Load-Bearing-Panels, Plan F.

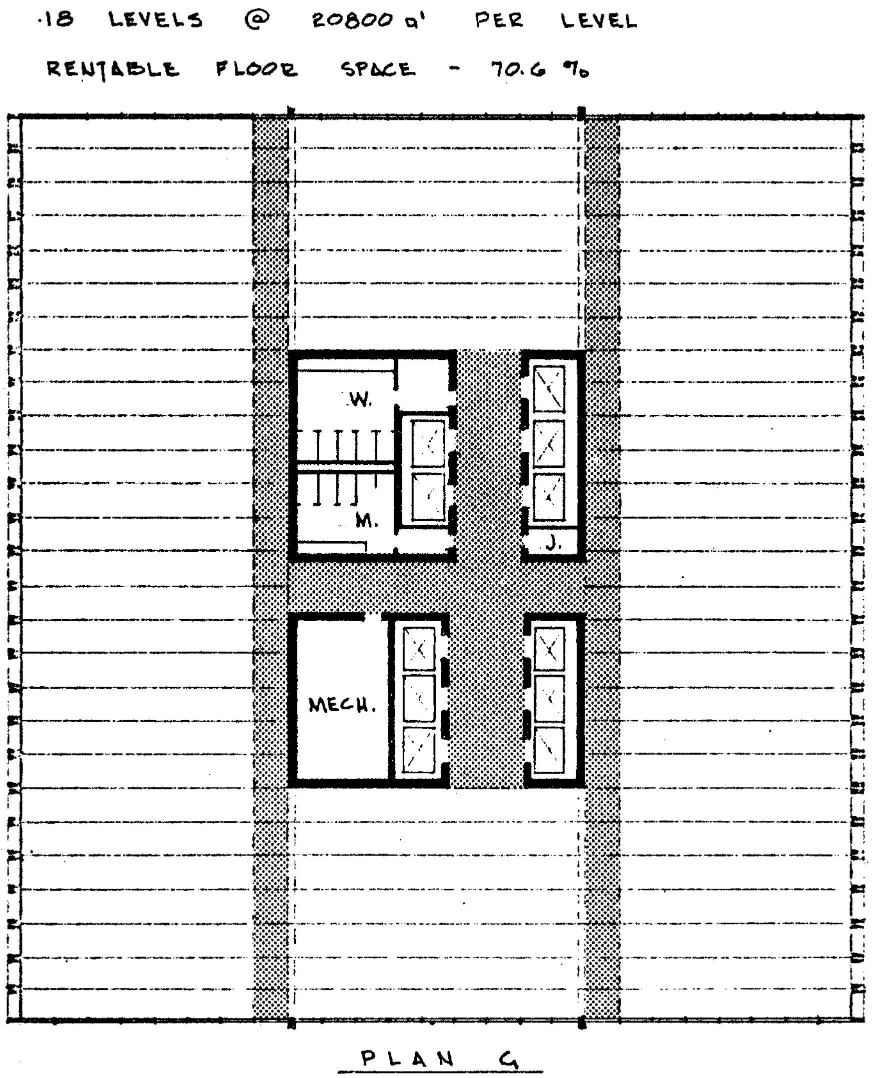
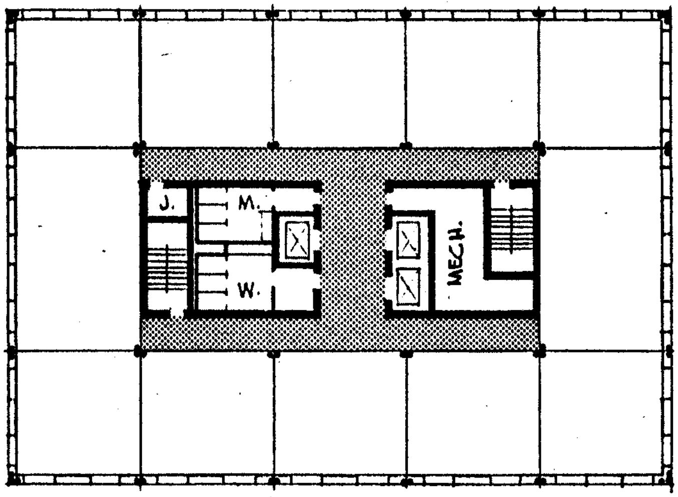


Figure 17. Load-Bearing-Panels, Plan G.

EIGHT LEVELS @ 7250 □' PER LEVEL

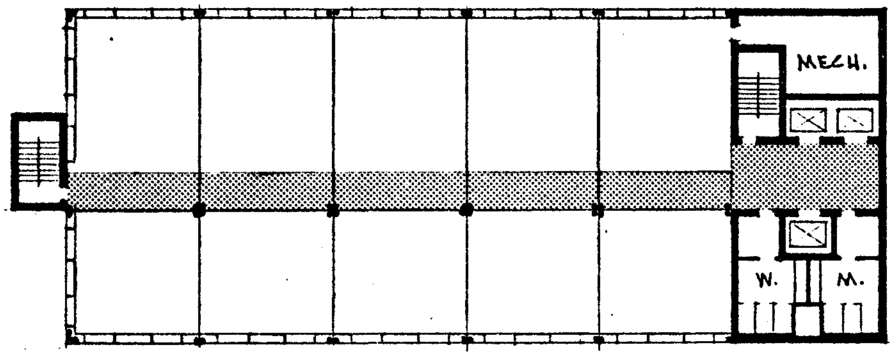
RENTABLE FLOOR SPACE - 67 %



PLAN B

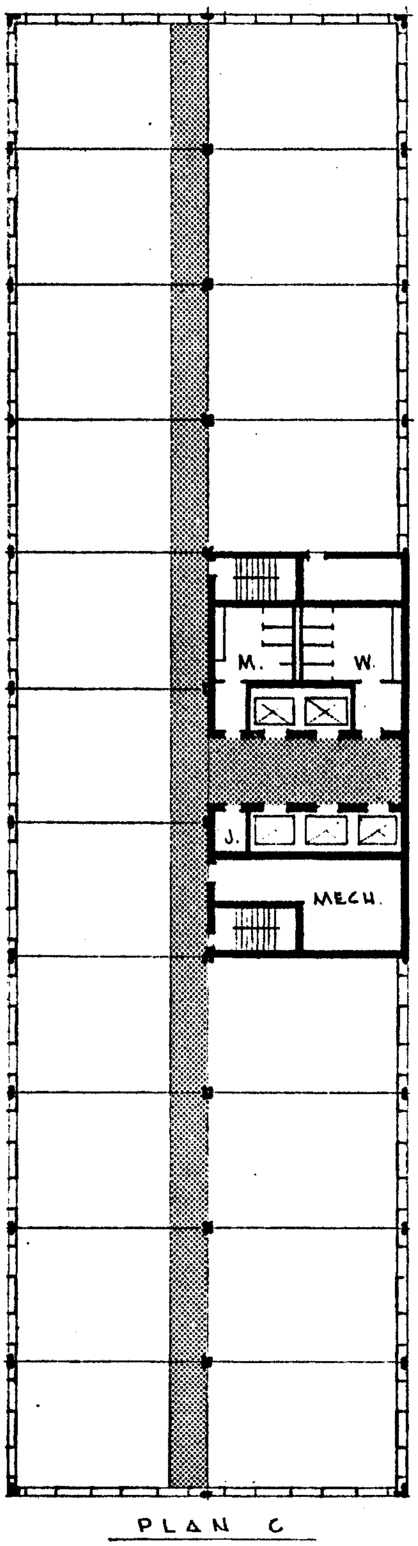
EIGHT LEVELS @ 8100 □' PER LEVEL

RENTABLE FLOOR SPACE - 68.6 %



PLAN A

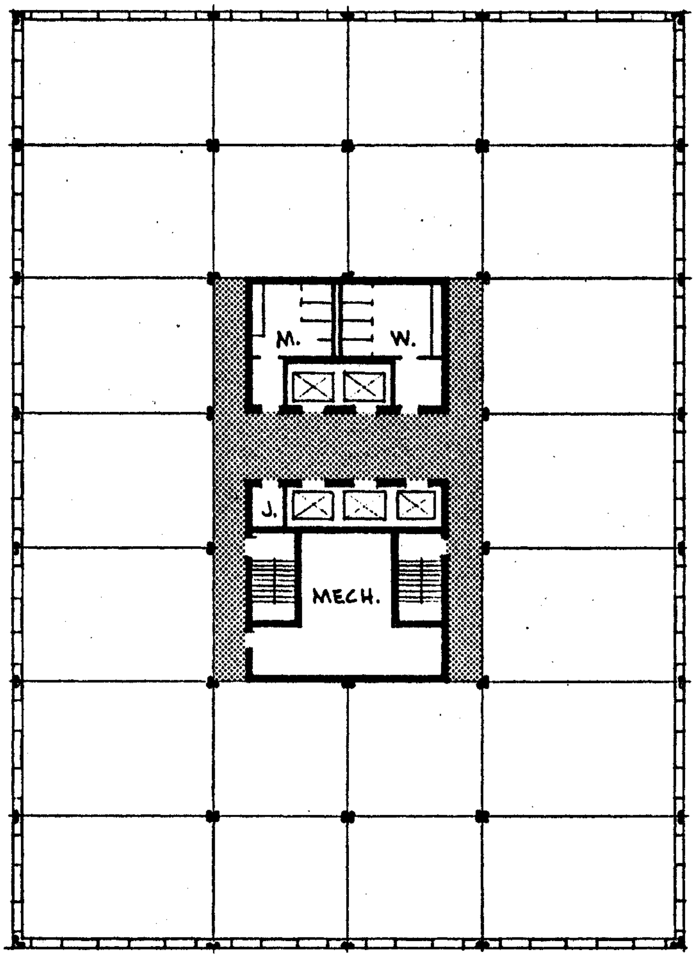
Figure 18. Bay-Framing-and-Panels, Plans A and B.



TEN LEVELS @ 15350 □'
PER LEVEL

RENTABLE FLOOR SPACE
72.7 %

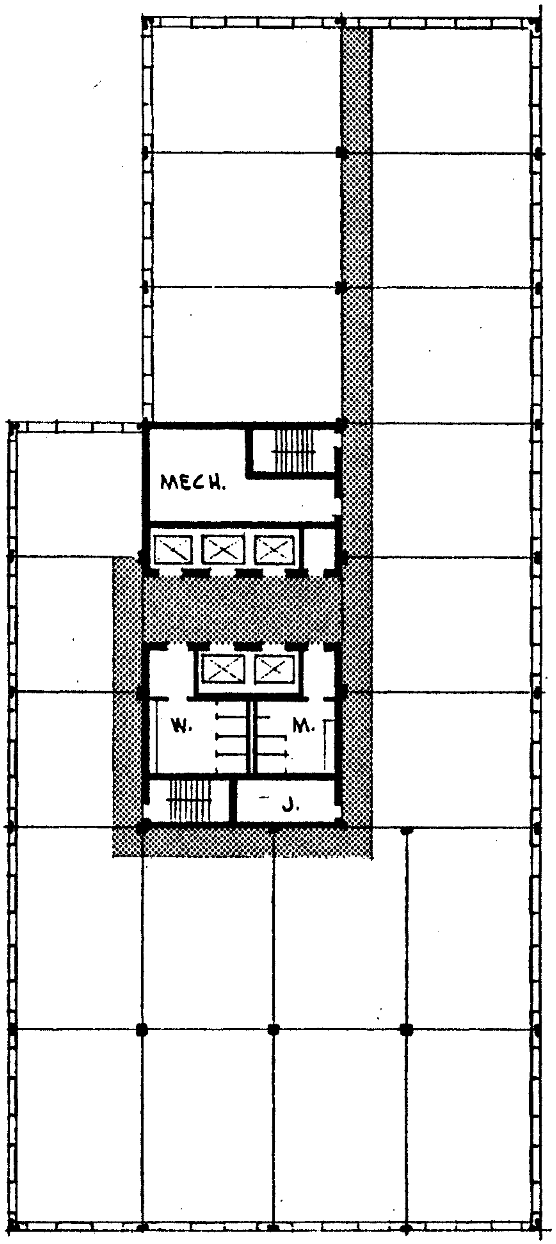
Figure 19. Bay-Framing-and-Panels, Plan C.



TEN LEVELS @ 16600 □' PER LEVEL
RENTABLE FLOOR SPACE - 79.5 %.

PLAN D

Figure 20. Bay-Framing-and-Panels, Plan D.



TEN LEVELS @ 15430 □' PER LEVEL

RENTABLE FLOOR SPACE - 72.2 %

PLAN E

**Figure 21. Bay-Framing-and-Panels, Plan E.**

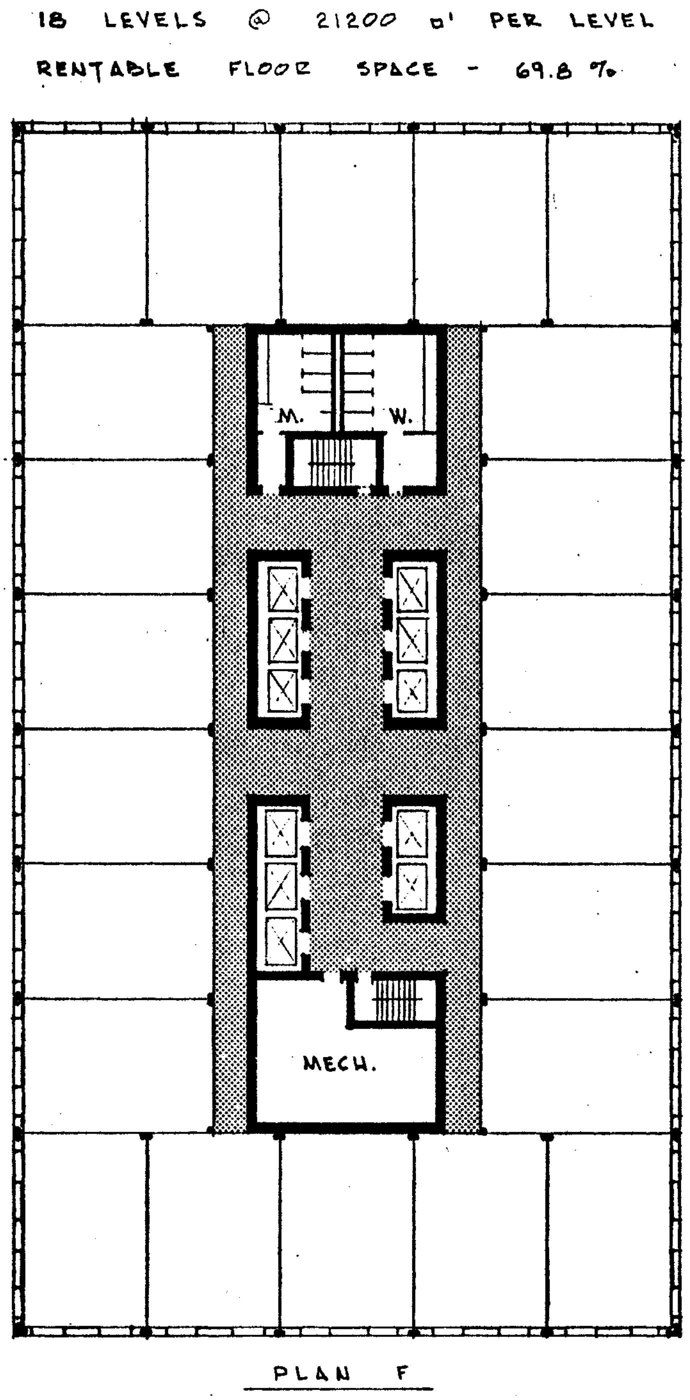


Figure 22. Bay-Framing-and-Panels, Plan F.

18 LEVELS @ APPROX. 19900 □' PER LEVEL

RENTABLE FLOOR SPACE - 67.4 %.

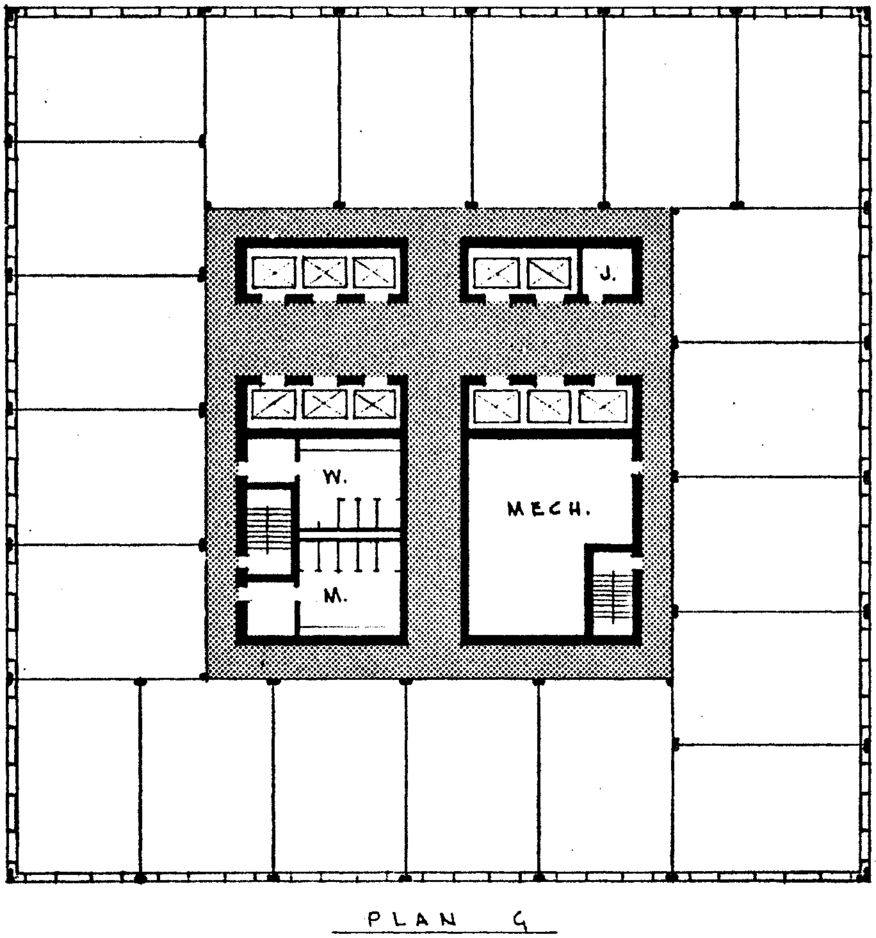
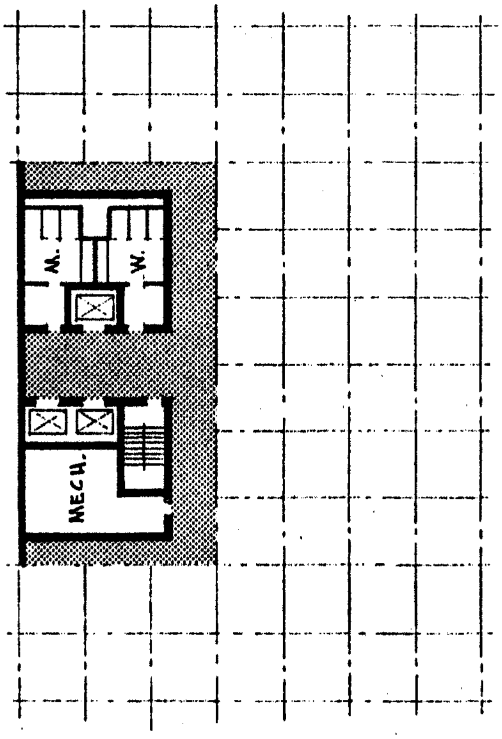


Figure 23. Bay-Framing-and-Panels, Plan G.



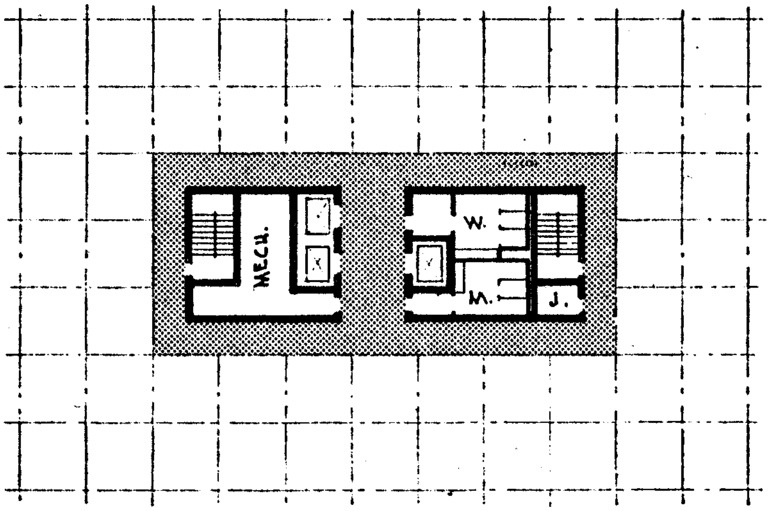
PLAN B

EIGHT LEVELS @ APPROX.
7500 □' PER LEVEL

RENTABLE FLOOR SPACE -
MAX. 74.3 %

EIGHT LEVELS @ APPROX.
8000 □' PER LEVEL

RENTABLE FLOOR SPACE -
MAX. 73 %

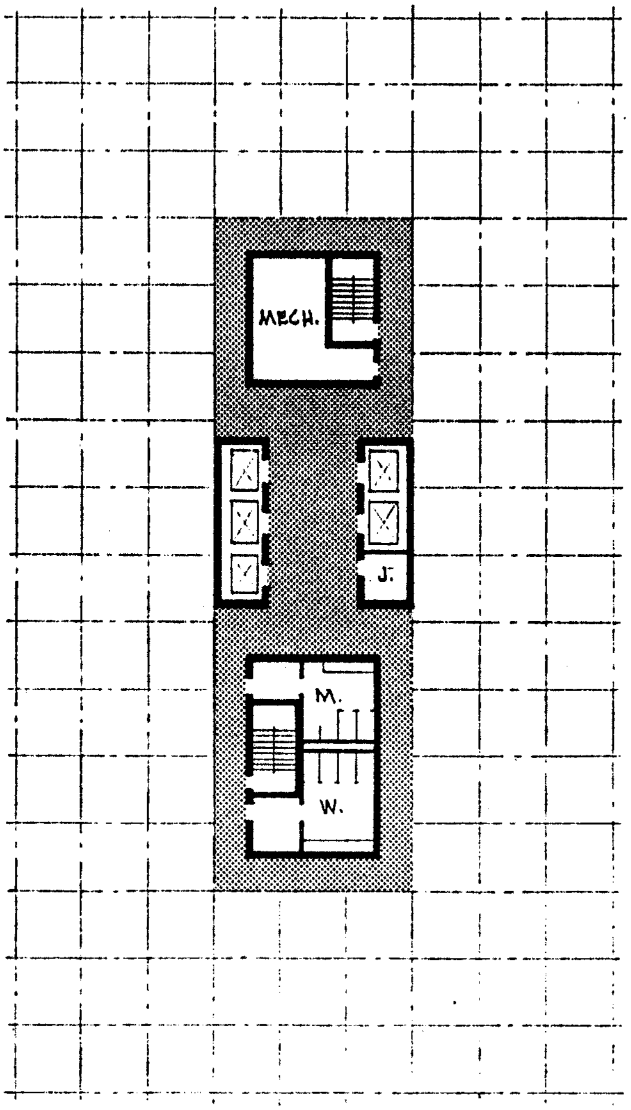


PLAN A

Figure 24. Cellular-without-Frame, Plans A and B.

TEN LEVELS @ APPROX. 16000 □' PER LEVEL

RENTABLE FLOOR SPACE - MAX. 79.2 %



- SEE FIGURE 11 FOR PLAN D

- PLAN E INAPPROPRIATE FOR THIS SYSTEM

PLAN C

Figure 25. Cellular-without-Frame, Plan C.

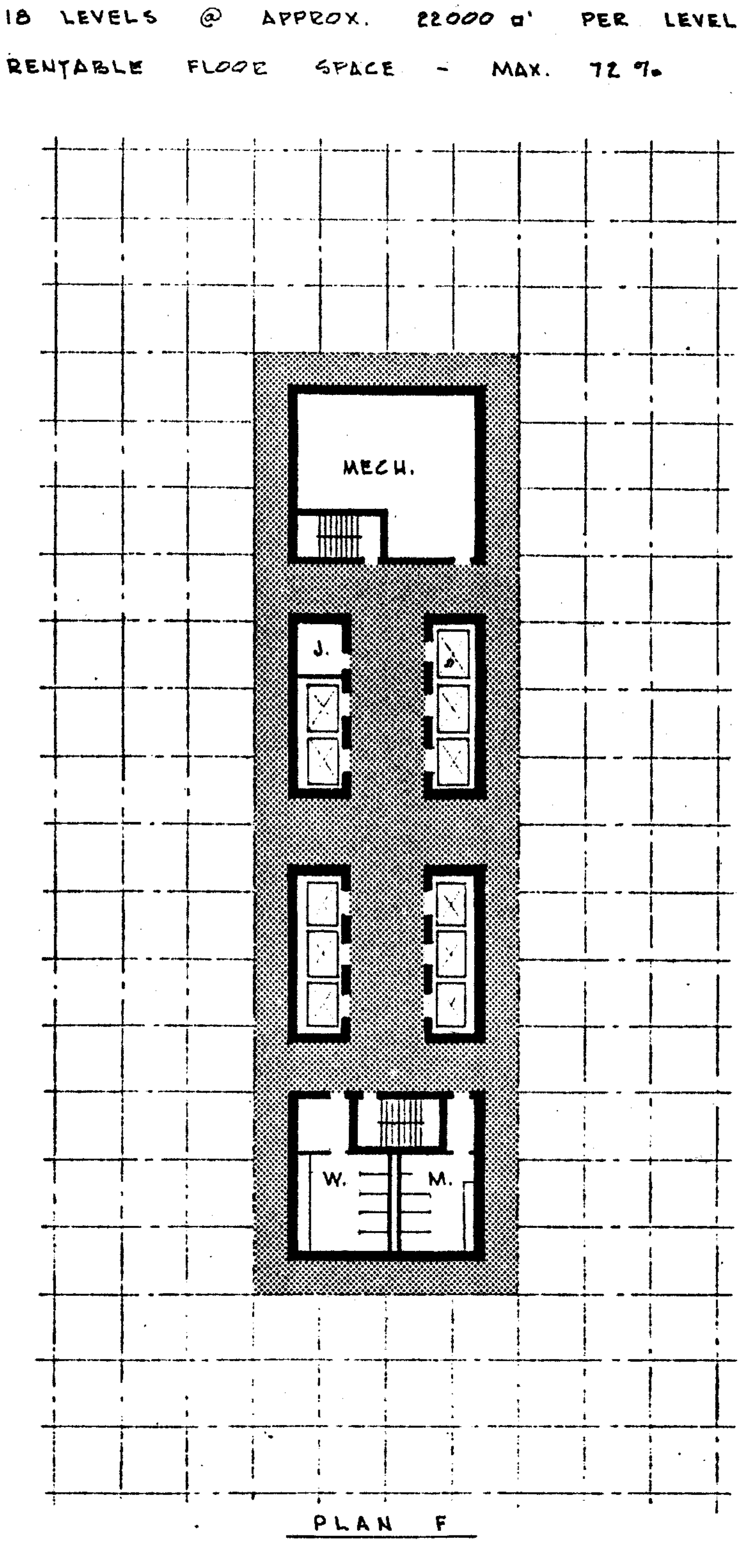
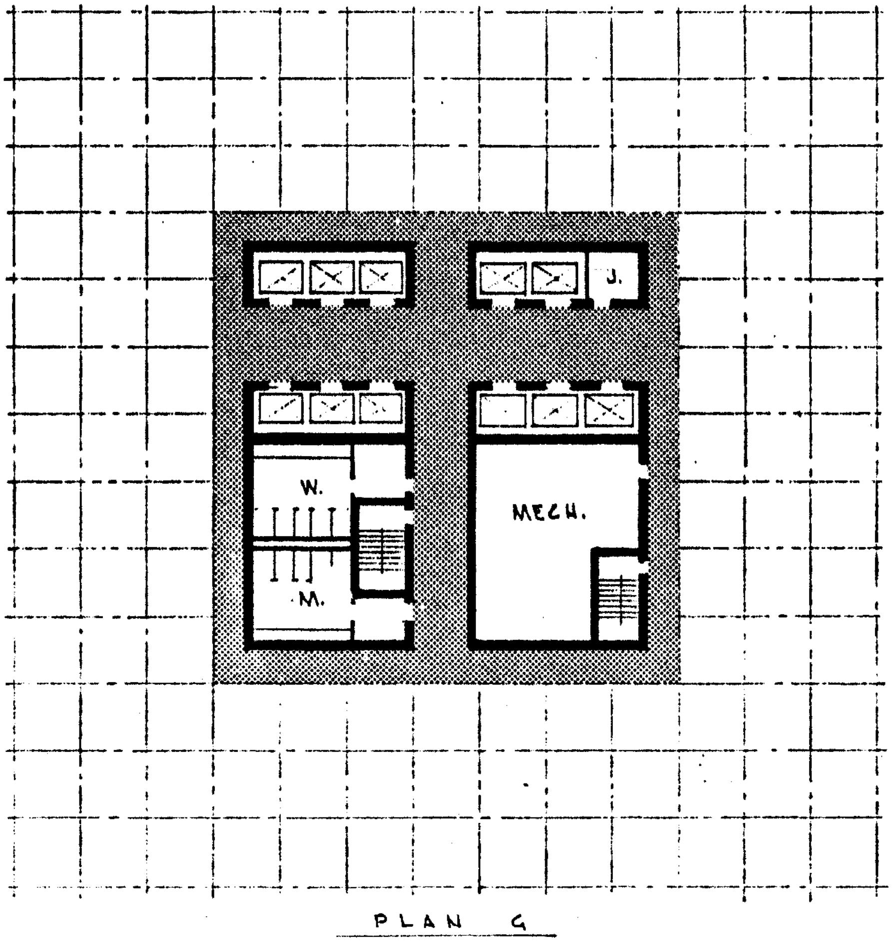


Figure 26. Cellular-without-Frame, Plan F.



18 LEVELS @ APPROX. 19000 □' PER LEVEL

RENTABLE FLOOR SPACE - MAX. 71 %.

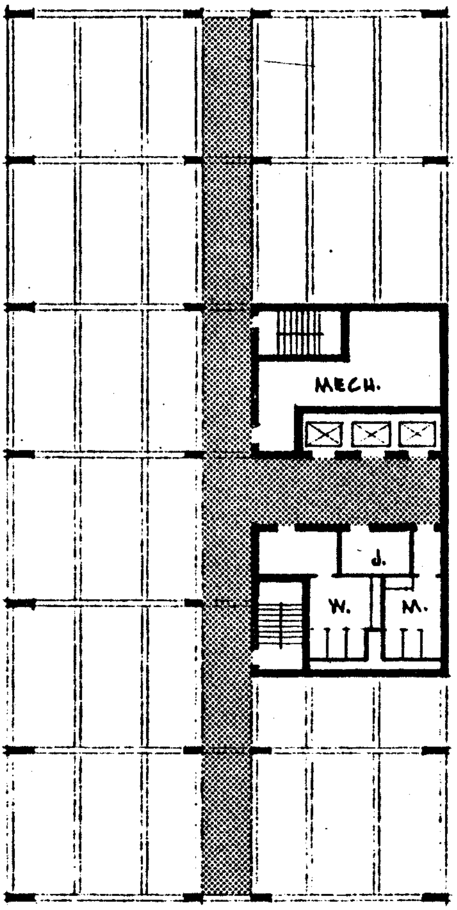
Figure 27. Cellular-without-Frame, Plan G.

18 LEVELS @ APPROX. 17000 □'
PER LEVEL

RENTABLE FLOOR SPACE -
MAX. 69.4 %

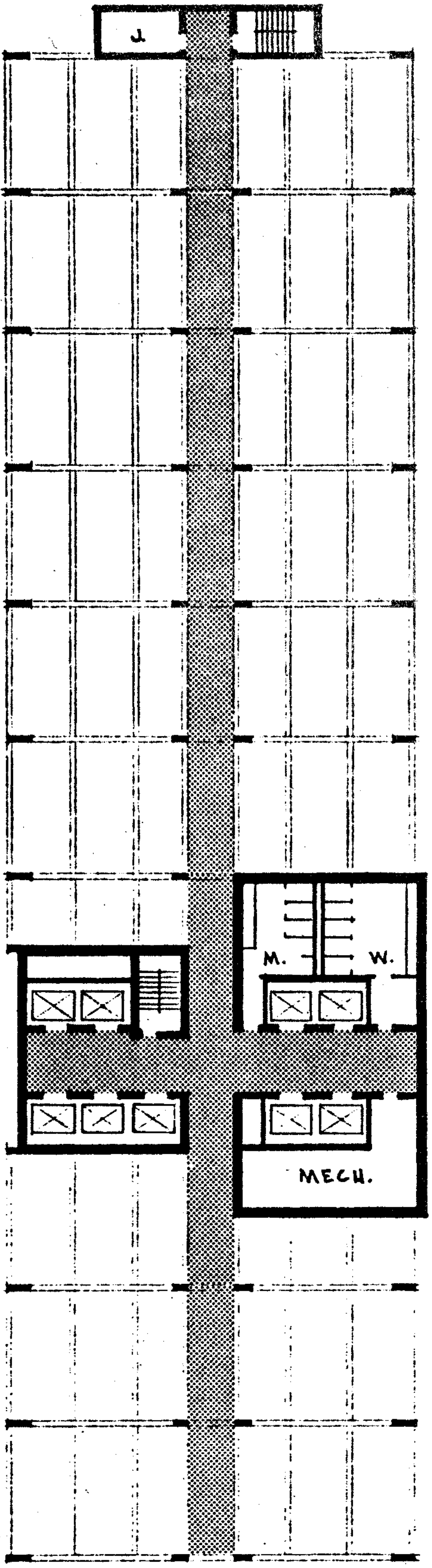
EIGHT LEVELS @ APPROX. 9000 □'
PER LEVEL

RENTABLE FLOOR SPACE -
MAX. 69 %



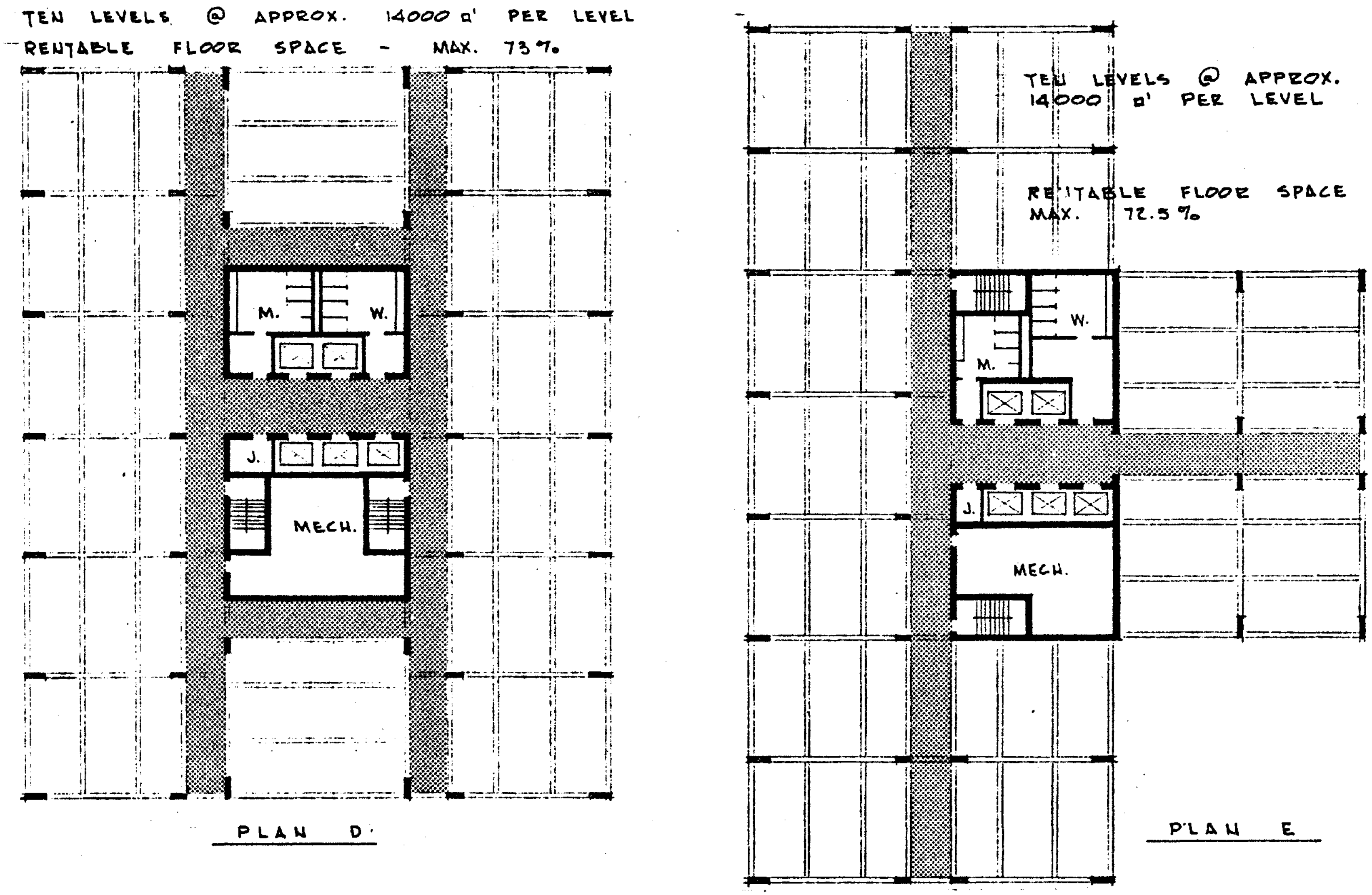
PLAN A

- PLAN B INAPPROPRIATE FOR THIS SYSTEM
- SEE FIGURE 12 FOR PLAN C



PLAN F

Figure 28. Cellular-with-Framing, Plans A and F.



PLAN D

PLAN E

Figure 29. Cellular-with-Framing, Plans D and E.

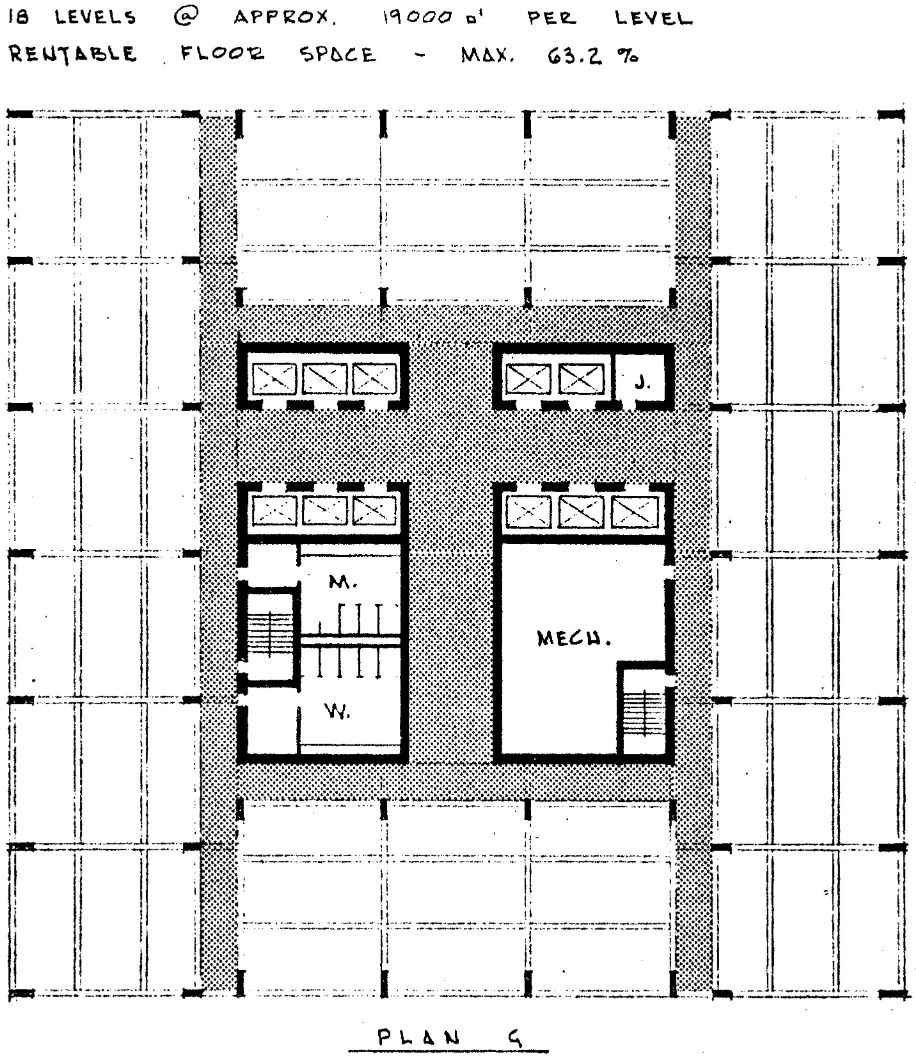


Figure 30. Cellular-with-Framing, Plan G.

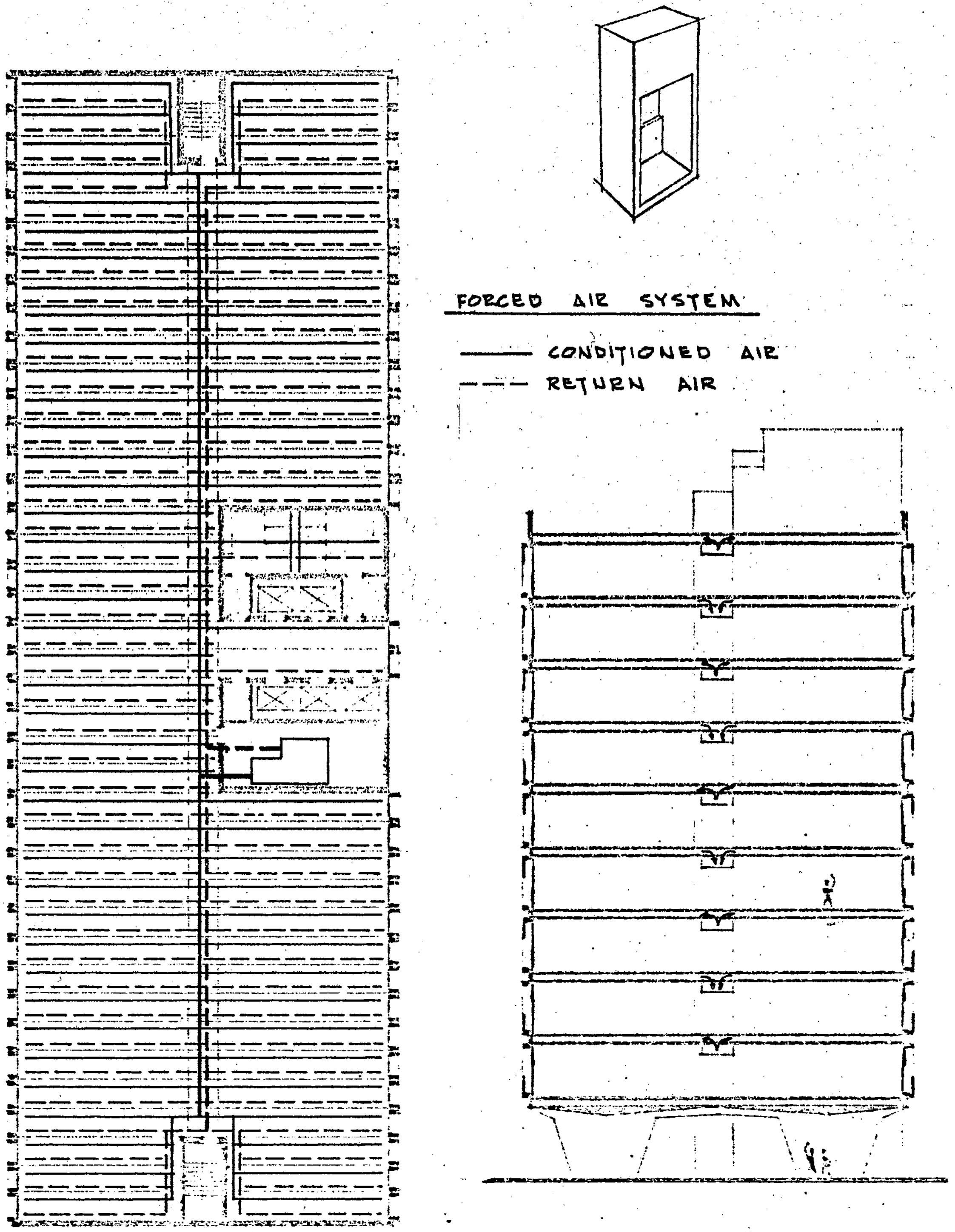


Figure 31. Load-Bearing-Panels, Mechanical.

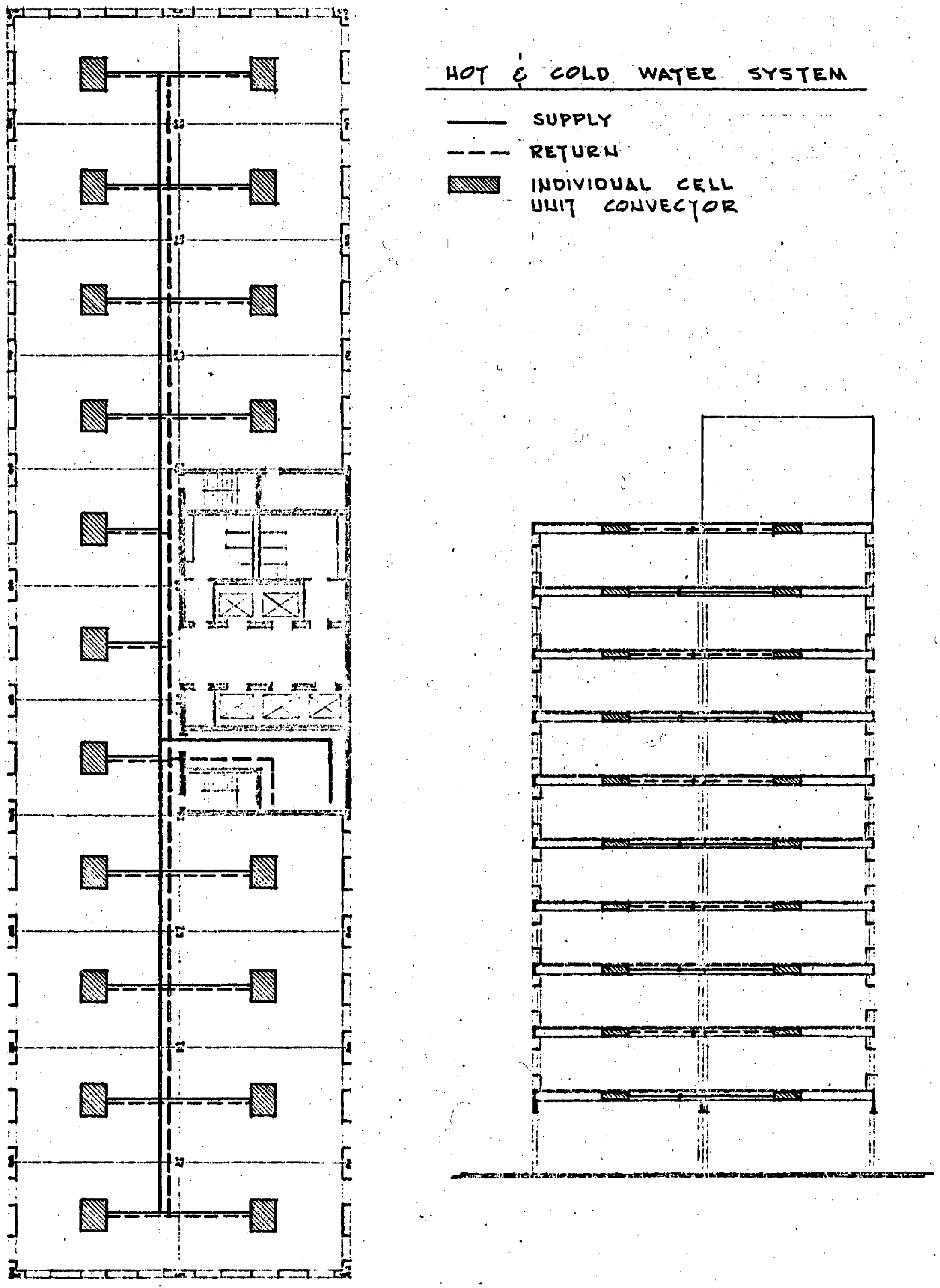


Figure 32. Bay-Framing-and-Panels, Mechanical.

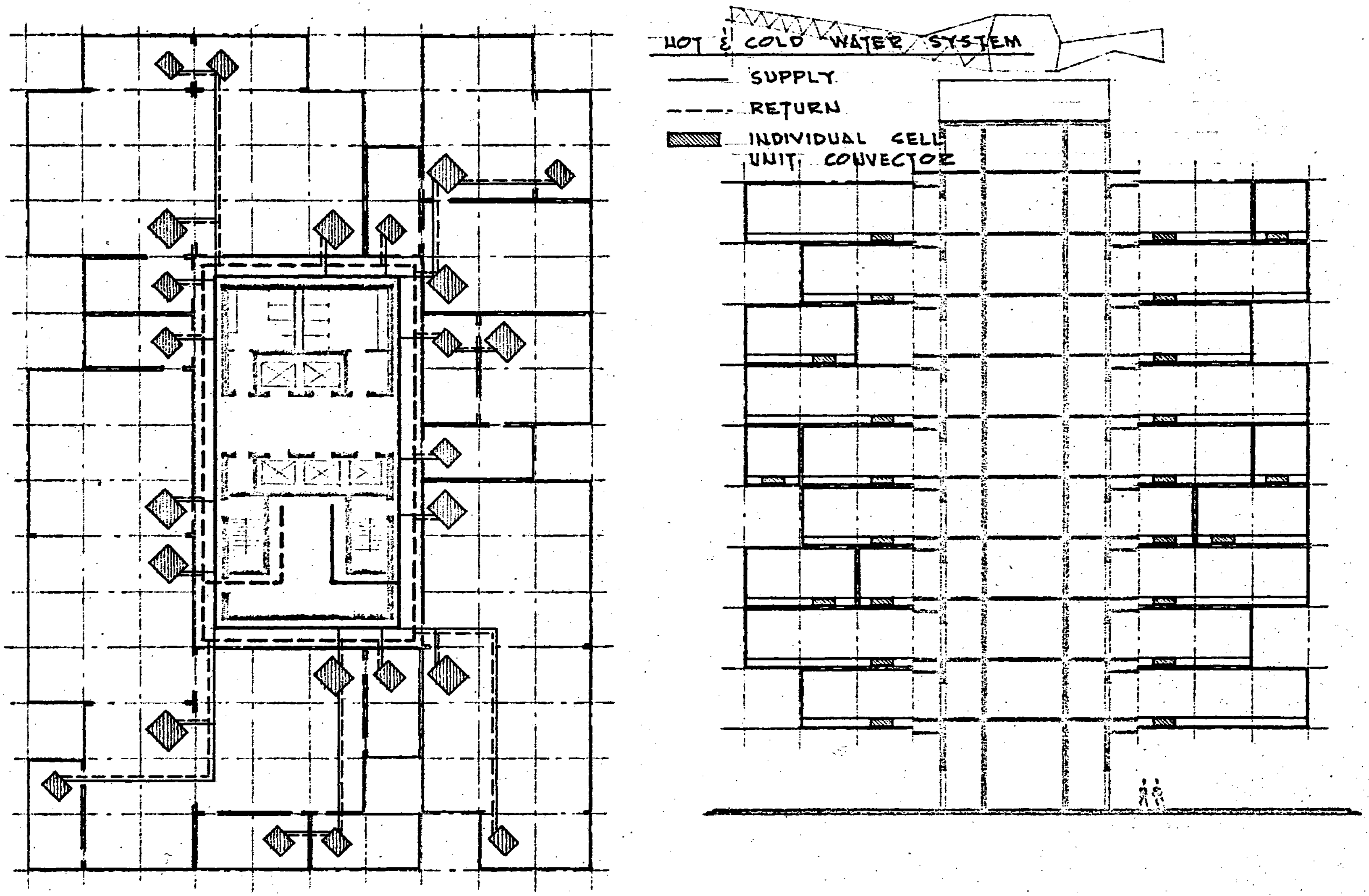


Figure 33. Cellular-without-Frame, Mechanical.

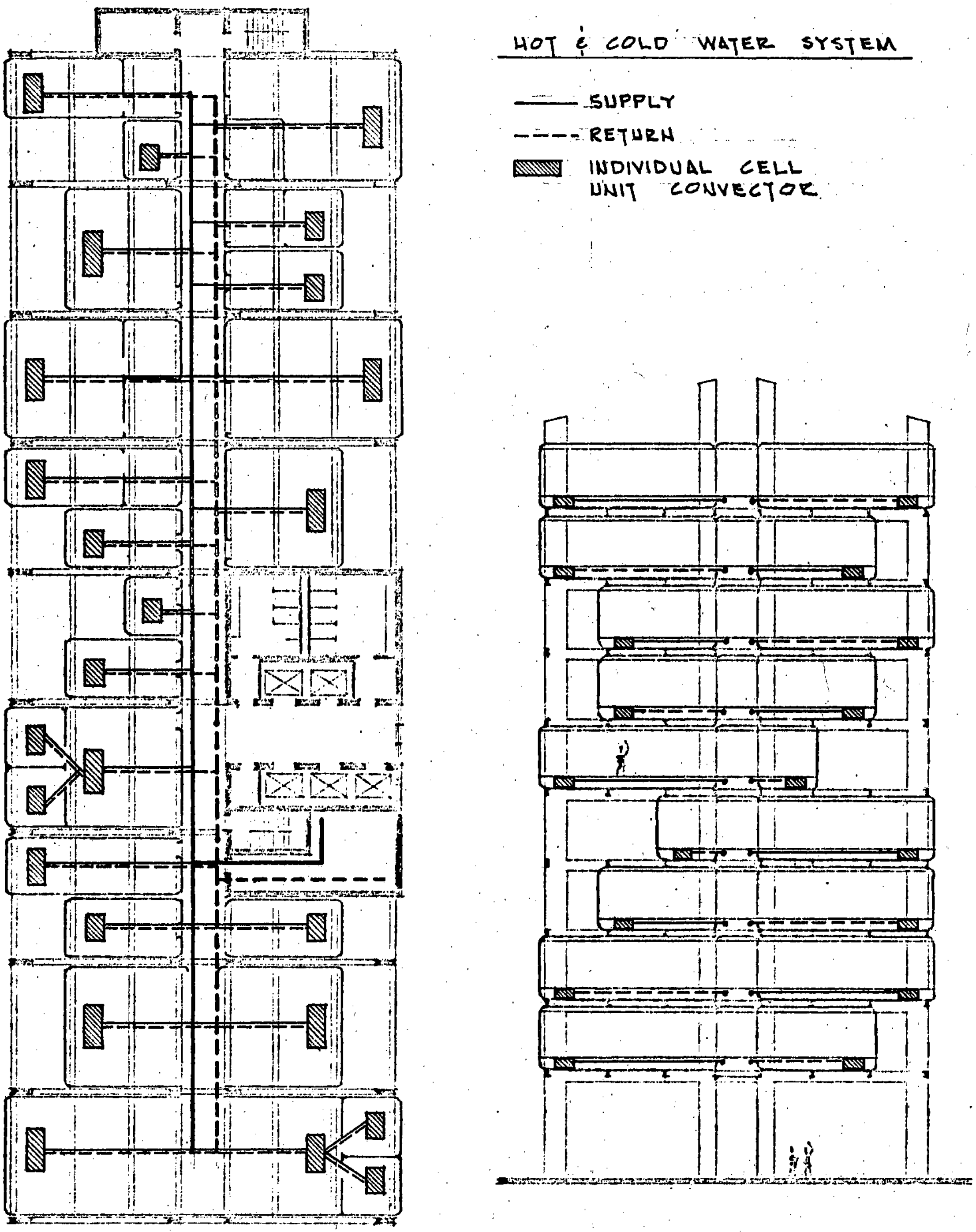
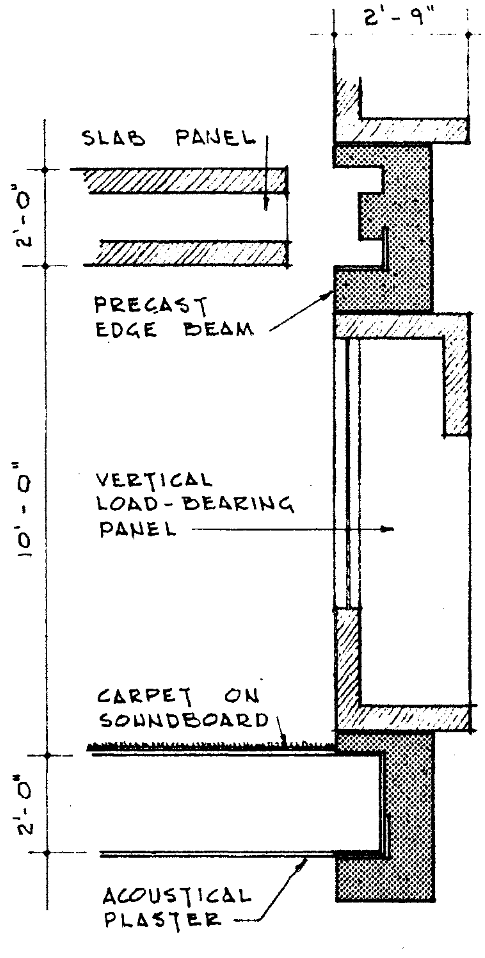
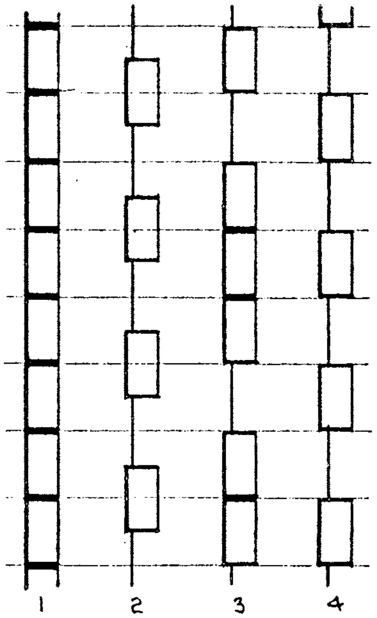


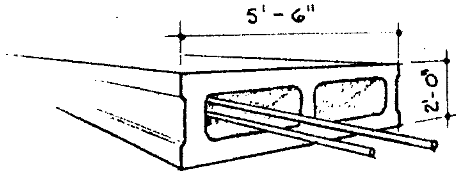
Figure 34. Cellular-with-Framing, Mechanical.



SECTION 1/4" = 1'-0"



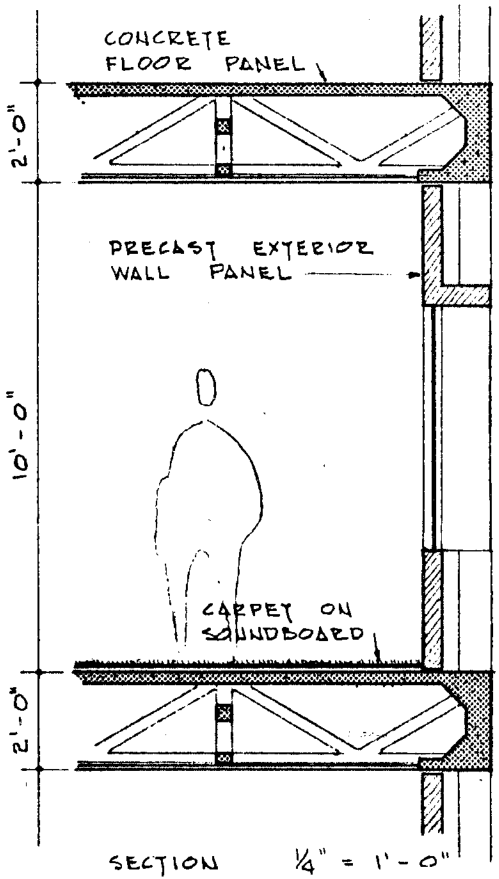
POSSIBLE ARRANGEMENTS OF VERTICAL LOAD-BEARING PANELS



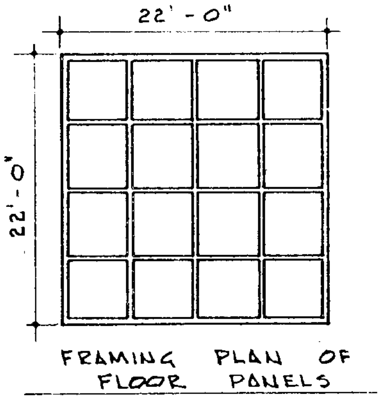
SLAB PANEL

EXTRUDED CONCRETE OR CAST IF PRESTRESSING IS DESIRED

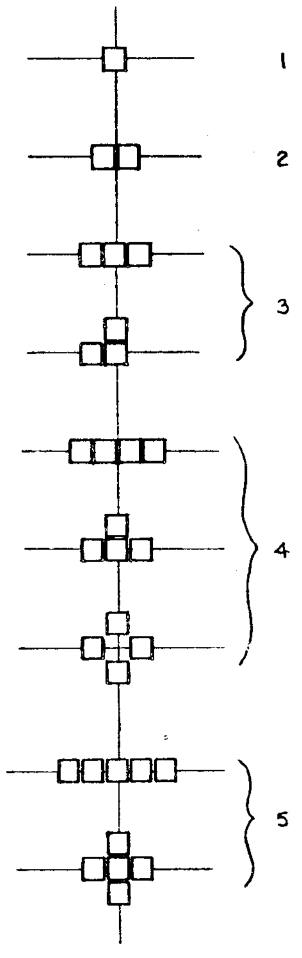
Figure 35. Load-Bearing-Panels, Structural.



SECTION ¼" = 1'-0"

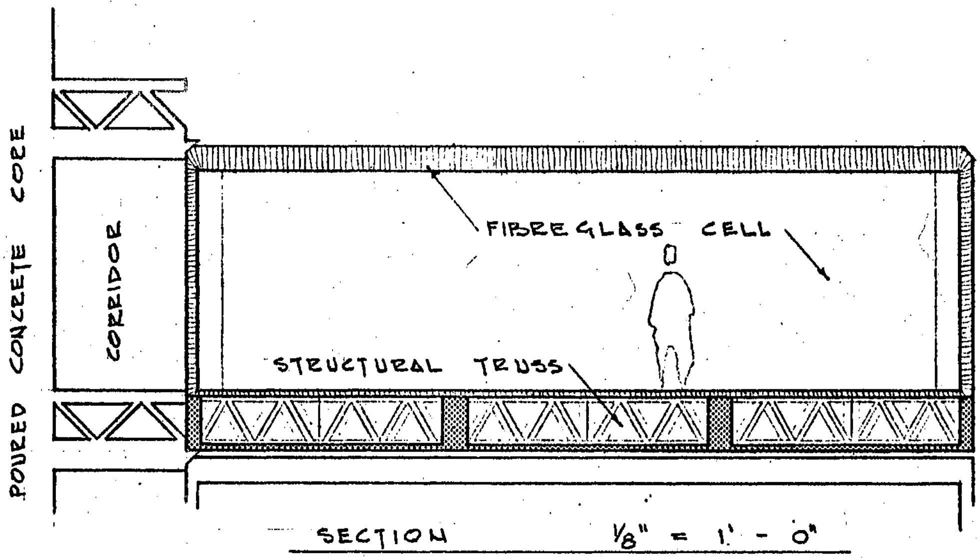


FRAMING PLAN OF FLOOR PANELS

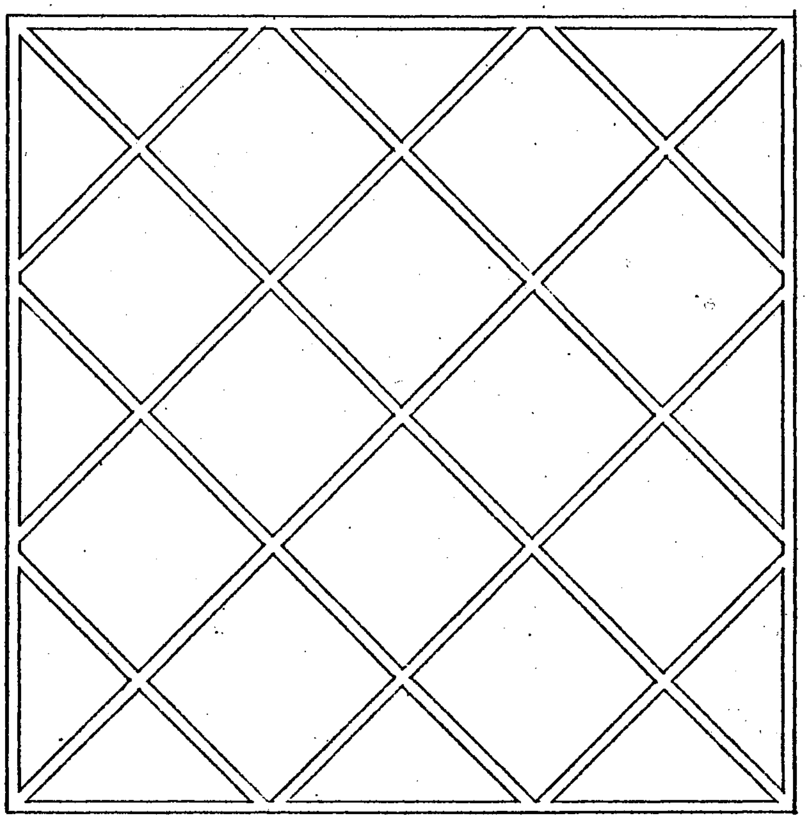


POSSIBLE COLUMN ARRANGMENTS

Figure 36. Bay-Framing-and-Panels, Structural.

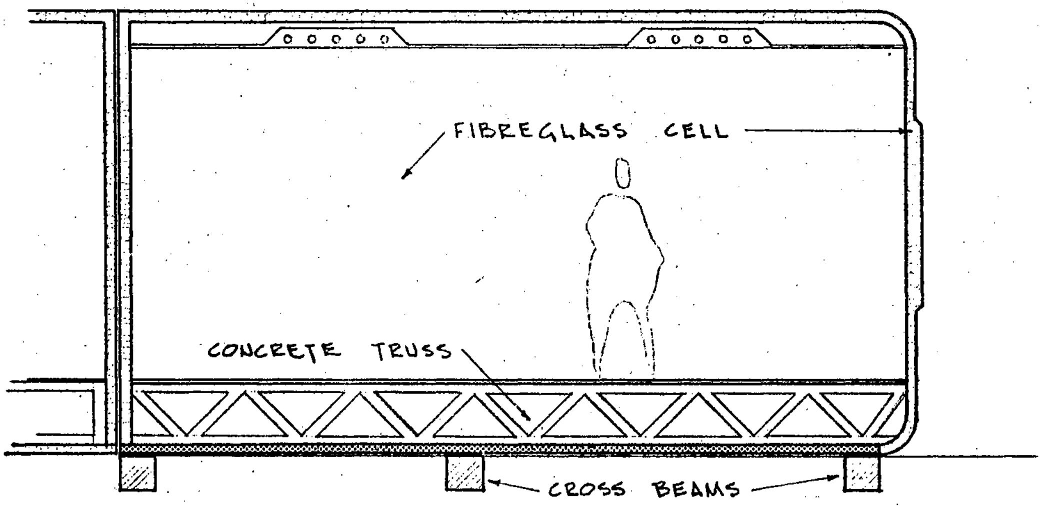


SECTION $\frac{1}{8}" = 1' - 0"$

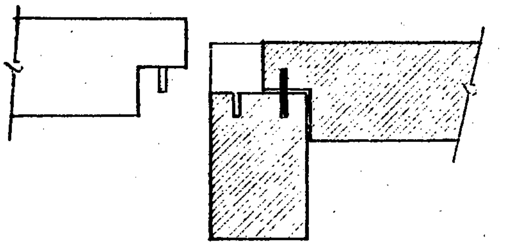


FRAMING PLAN $\frac{1}{8}" = 1' - 0"$

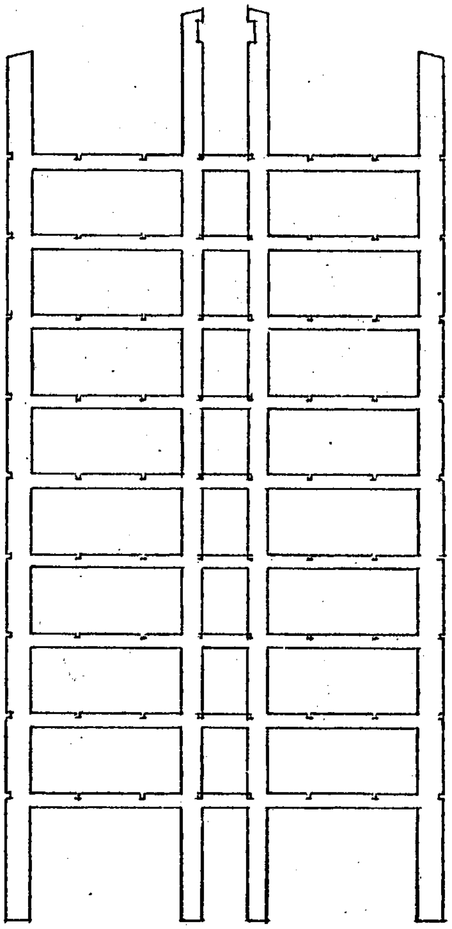
Figure 37. Cellular-without-Frame, Structural.



SECTION 3/16" = 1' - 0"



DETAIL OF CONNECTION CROSS BEAM TO TRANSVERSE FRAMING 1/2" = 1' - 0"



TRANSVERSE FRAMING

Figure 38. Cellular-with-Framing, Structural.

## Discussion of Ratings

Those aspects that shall be discussed in this chapter which give reasons for the ratings in Table III are the particular building system's effects on the size of the building, on the construction of the building, on the mechanical equipment, on the orientation, and on the environmental conditions of sun control, functional expression, natural lighting, and size and shape of spaces.

With regard to height, the load-bearing-panel system was rated poor, the cellular-without-framing system was rated good, and the cellular-with-framing system and the bay-framing-and-panel system were rated average. The load-bearing-panel system has a definite limitation on the height that can be achieved by a building. The height limit, of course, depends on the strength characteristics of the vertical load bearing panels and unless there was a method of significantly decreasing the number of panels as the load decreases toward the top, the panels would not be utilizing their designed strength characteristics. The cellular-without-framing system has no height limitation because the component parts are supported off the core. However, the core would have a height limitation and thus it would be the controlling factor.

The size of the building in area per floor was rated good for the bay-framing system, poor for the cellular-with-framing, and average for the other two systems. The bay-framing system was rated good because it essentially has no size limitation because of the building system. Since one bay is not dependent upon another structurally, a bay can be added as desired. On the other hand, the cellular-with-framing has definite limitations because of its linear characteristics.

The cellular-without-framing and the load-bearing-panel systems have definite limitations but not to the extent that they should be rated poor.

The structural construction consideration was given an average rating for all the systems except the cellular-without-framing system. It received a rating of poor. This system presents many unusual structural problems because the cells are cantilevered off the core. This requires that the system incorporate structural joints and a method of hoisting and inserting the cells in place. These are accompanied by many lesser problems that are common to any construction. The system, does, however, have the advantage that very little of the total construction is carried out at the site.

All of the systems except the load-bearing-panels were rated good with regard to the construction of the external walls and the floors and ceilings, and it was rated average. In the load-bearing-panel system, the external wall panels serve as major structural members and the horizontal structural panels also serve as floor and ceiling. In the other systems, the external walls are non-structural and the floor and ceiling surfaces consist of panels on a structural framework. In all the systems, the interior partitions were scored average and in all cases, they are factory produced. In the cellular systems, the partitions are built into the cell at the factory while in the bay-framing and load-bearing systems, the panels are joined together at the site.

In concluding the discussion on the construction, it is appropriate to point out that the two cellular systems involve a lesser amount of site construction, having a greater amount of factory assembly. However, this advantage also carries with it the disadvantage of transportation of heavy and bulky components to be handled and joined at the site. The other two systems, load-bearing and bay-framing, are just the opposite in these respects. At any rate, in all cases, the advantages and disadvantages seem to nearly balance and cancel each other out.

With regard to heating, airconditioning and ventilation, the two cellular systems received poor ratings while the bay-framing system was rated average and the load-bearing system received a rating of good. The cellular systems are not readily adaptable to any type of central airconditioning system and appear to work best with individual cell units which would make the system more expensive. However, the cell units do have the advantage of better area control of environment. Also, the large number of high pressure connections required in the cellular systems work to their disadvantage and this is also to some extent a disadvantage in the bay-framing system. The load-bearing-panel system has to its advantage a duct system built into the horizontal panels. This works quite well with the exception that the major ducts feeding the panel ducts must be mounted above or below the floor or ceiling.

The load-bearing-panel system was rated poor for its effect on artificial lighting while the two cellular systems were rated good and the bay-framing system, average. Since the horizontal panels serve as floor and ceiling in the load-bearing-panel system, it is necessary that the lighting fixtures be mounted below the ceiling, thus eliminating the possibilities of a flat ceiling. This in turn, places limitations on the locating of interior partitions. The other three systems allow for the placement of the light fixture flush in the ceiling, but the two cellular systems have the advantage that in their systems this task is carried out at the factory and can be located appropriately for the job to be done in that particular area without particular consideration for a grid pattern.

The electrical and telephone wiring consideration gave all of the systems except the load-bearing-panel system a rating of good. The load-bearing system received a rating of poor because the wiring has to be run in the duct space and because this duct space runs only one direction. The others received ratings of good because the wiring is easily accessible and has few, if any, limitations as to direction or location.

With regard to orientation, the load-bearing-panel and cellular-with-framing systems received a rating of poor as a general rule. This is primarily because of their linear characteristics. The best orientation is with the long axis running north and south so that the majority of the building may get east and west light. The bay-framing and the cellular-without-framing systems were rated good as a general rule and this was primarily because of their more square characteristic shape which allows for most any kind of orientation. Associated closely with orientation is sun control and natural lighting. All systems were rated good on this count primarily because through good design of the systems this aspect can be taken care of quite adequately.

The cellular-without-framing system received the rating of excellent on functional expression. This is one of the few excellent scores given. It received this rating because of its unique characteristic that the appearance of the building is changed at any time the function is changed. If just one cell is removed or replaced by a different one this is expressed in the building's appearance. The cellular-with-framing system received a rating of good on this count for the same reason with the reservation that the framing does not change with function changes. The load-bearing and bay-framing systems were rated poor because of their lack of any functional expression. In their cases, once the building is constructed, there is virtually no appearance change no matter what, if anything, is changed inside.

With regard to size and shape of spaces, all of the systems received a rating of average except the cellular-without-framing system. It has the inherent capability of providing spaces of a greater variety of sizes and shapes than is allowed in the other systems because of their structural characteristics. Because of its ability to have cells opening totally into one another and its allowing for more than one ceiling height, it was rated good.

Taking everything into consideration, we have only to look at the totals of Table III to see how the systems ranked in their adaptability to multi-story office buildings. The cellular-without-framing system is the most adaptable, followed by the bay-framing-and-panels system and then by the cellular-with-framing system. The load-bearing-panels system received the highest score and was thus the least adaptable of the four systems. The conclusions to be drawn from the second stage study will be found in the following chapter.

# CHAPTER VII

## SUMMATION OF SECOND STAGE

As summation to Chapter VI and the second stage study, each system will be discussed with consideration of its faults and the changes or improvements that might be made. However, as stated in Chapter V, most any change that improves a system in one area has detrimental effects upon some other area. Also, the characteristics of the pure system are what is being analyzed, and not the many varieties or combinations of systems.

It is first appropriate to discuss how all the systems were affected by the floor area and height of the building. In all cases the building of medium or average size and height (10 floors and 15,000 square feet per floor), received the best rating while the relatively small building received the poorest rating. The larger buildings of 18 stories and 20,000 square feet per floor in most cases were rated nearly equal to the medium sized building. The major factor hurting the rating of the small building of 8 floors and 7,500 square feet per floor was the efficiency of space. This is natural since a certain amount of space is taken up by the core and service facilities which does not increase proportionally with the rest of the building when the building is made larger in floor area or number of floors.

The load-bearing-panels system received its first below average rating for its adverse effect on the height of a building. This could be taken care of by designing all the vertical panels to carry whatever load is required of them at the first level. However, this would then cause an uneconomical use of materials when these same panels were used in the upper floors. Another equally uneconomical solution would be to use several different panels of different design strengths. The load-bearing-panel system was also rated below average for two mechanical considerations: artificial lighting and wiring. Both aspects were discussed adequately in Chapter VI and will not be elaborated on further here. The system's ill effect on orientation received another poor rating. This can be overcome by running the horizontal panels in both directions as Harry Weese (15) did in his proposed system. This made the building more square and adaptable to any orientation, but at the same time greatly complicates this otherwise relatively simple type of construction and means added cost. The last thing the load-bearing-panel system rated below average on was its functional expression. The system appears to have no alternative within itself that will improve this adversity which is common to most all multi-story construction types used today.

The cellular-with-framing system's below average ratings were for its effects on large open rooms, flexibility, plan shapes, efficiency of space and story height. These have already been dealt with in Chapters IV and V and shall not be continued further here. Like the load-bearing-panel system, this system has ill effects on orientation because of its natural linear characteristics. This, as in the previously mentioned system, can be overcome at the expense of economy and the best use of the system.

The bay-framing-and-panels system received below average ratings on only one aspect not previously discussed in Chapters IV and V. This was the system's bad effect on functional expression. Here, as in the load-bearing system, there appears to be no effective way of remedying this situation for it is a natural adverse characteristic of the system.

The cellular-without-framing system received the highest rating both on the first and second stage studies and will be analyzed further and more completely in Chapter VIII. For this reason, its strengths and weaknesses will not be dealt with here.

All four systems have several characteristics favorable to multi-story office building construction along with a few inherent faults. Any one of the systems might have been selected and could have been expected to meet the requirements.

# CHAPTER VIII

# FINAL STUDY

Size and time limitations of this study dictate that not all systems can be studied still further. It is also not necessary, for the final study will serve primarily as an example of how well each system should be analyzed within itself before confident comparison can be carried out fairly. One reason for selection of the cellular-without-framing system is that to this author's knowledge, there has not been carried out and published a study of any system of this type. Therefore, since the system is both new and unique and appears from the two preliminary studies to have great potential, at least for its adaptability to multi-story office buildings, it has been selected for an example examination.

A few photos (Figures 39, 40 and 41) of a study model are presented first for familiarization of the system to be investigated in this chapter. The model is of a 12 story, 15,000 square feet per floor speculative office building.

## Site

The cellular-without-framing system has a distinct effect on the siting of the building. Because it is necessary to be able to remove and replace office cells on all sides, the building can not be located directly adjacent to another multi-story building. It requires an

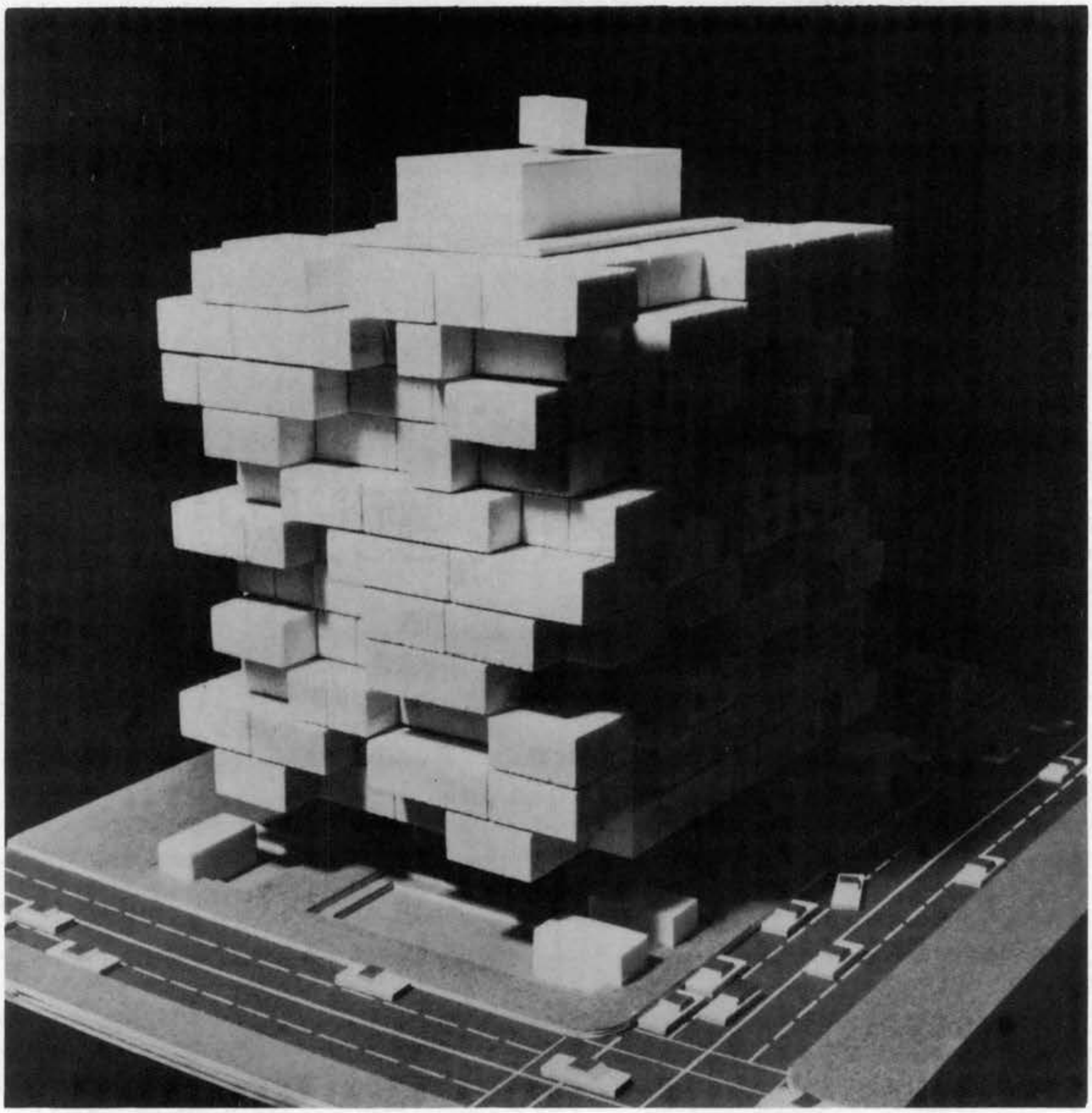


Figure 39. Study Model - Perspective.

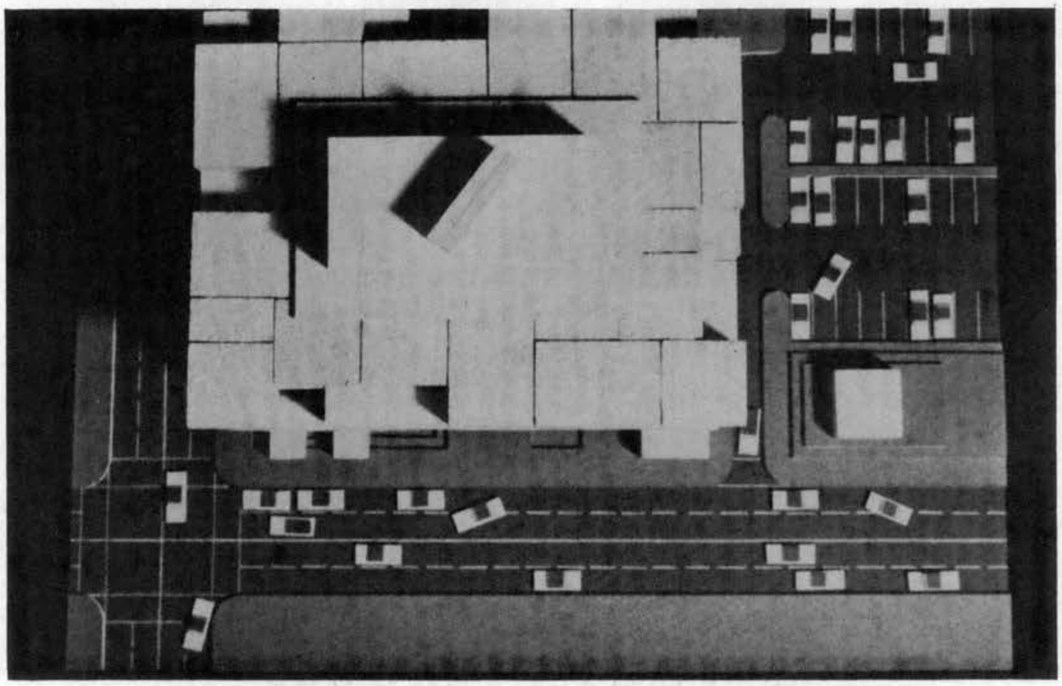


Figure 40. Study Model - Plan.

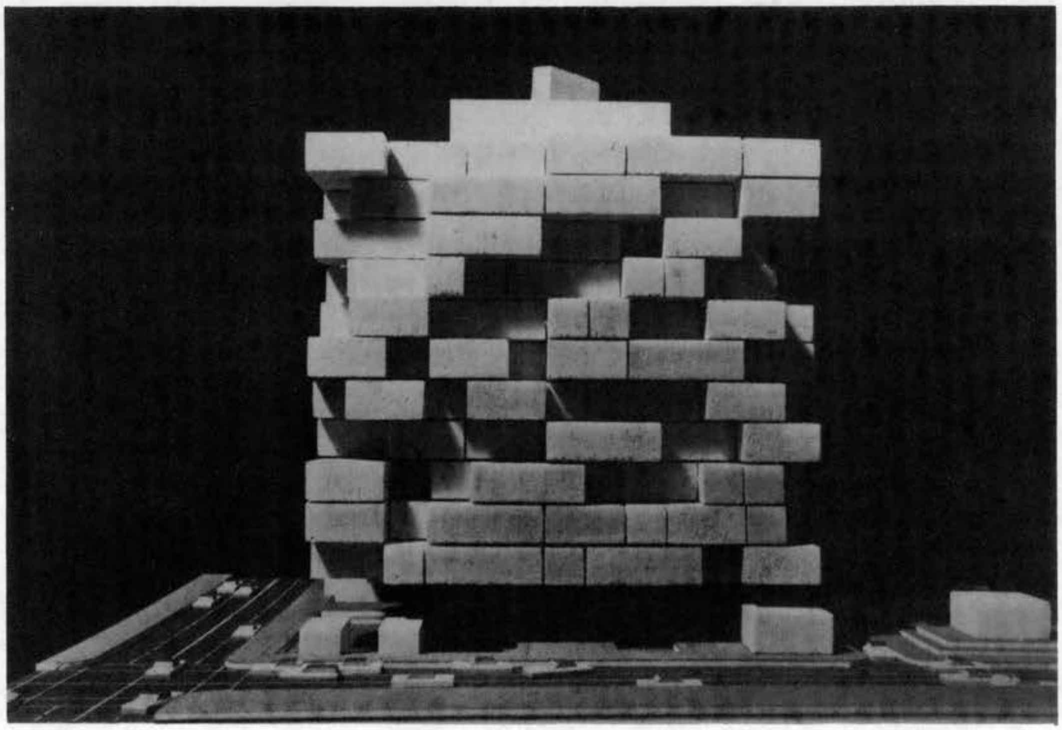


Figure 41. Study Model - Elevation.

unobstructed space similar to that shown in Figure 42.

The spreading-out characteristic of multi-story buildings carries with it the advantage that all sides are accessible to light, air and a view. Also, the system would create more open spaces to be developed with landscaping, courts, or gardens.

In addition, this system has advantageous characteristics with regard to siting because all the cells are supported off the core. This helps make the building adaptable to almost any site, whether flat, gently sloping, or steep, as is shown in Figure 43.

## Module

Of primary importance in any standardized component building system is the selection of a module that is adaptable to the building function and the building system. According to Jurgen Joedicke (6), and Manasseh and Cunliffe (10); a 10'-0" module is quite applicable to the proper functioning of an office building. From this author's experience, a module of 11'-0" is also workable.

The module selected for this study will be a double module of 11'-0" and 2" in both directions (Figure 44). The 2 inches allows for clearance between cells and the cells would be sized 11'-0", 22'-2" and 33'-4" in either or both directions as shown in Figure 45. This 11'-0" outside dimension on the smallest cell allows for a 10'-0"+ inside dimension leaving 4 to 6 inches for wall thickness.

The vertical module selected is 13'-0" and 2" (Figure 46). This was determined by a 9'-0" floor to ceiling height with 1'-0" allowed for roof and ceiling support and recessed lighting. The remaining 3'-0" is alloted to the floor and structural support also allowing

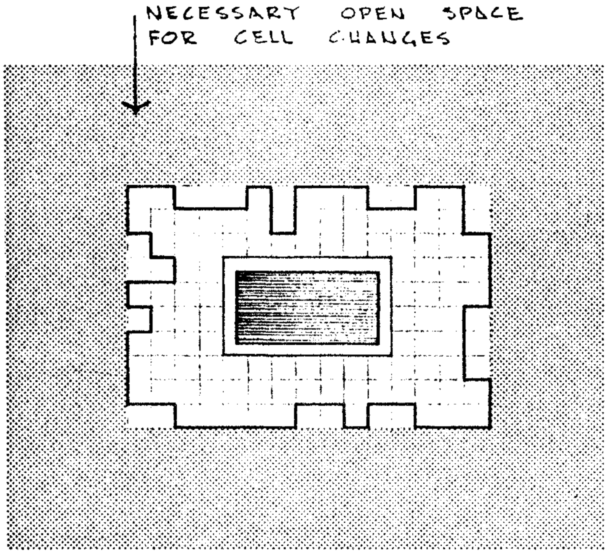


**Figure 42. Plan of Unobstructed Space.**

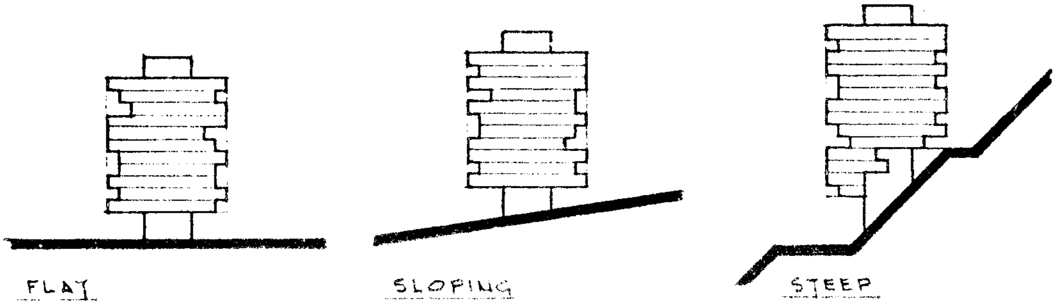


Figure 43. Siting Possibilities.

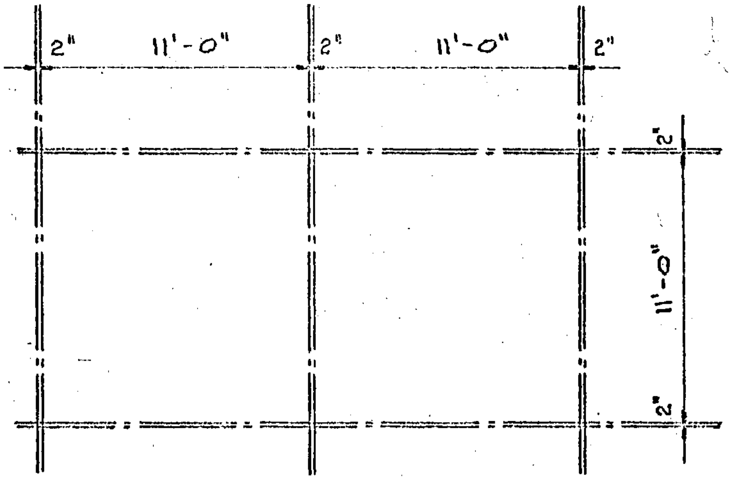


Figure 44. Double Module for Plan.

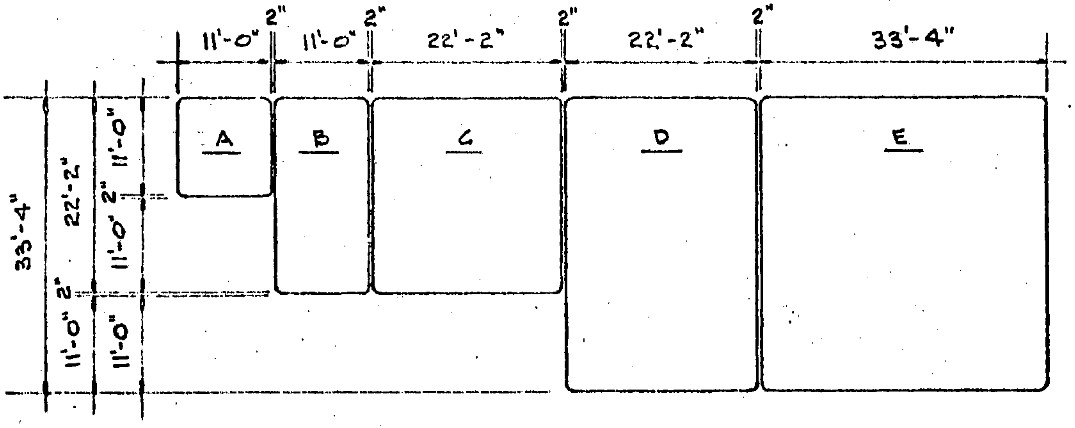


Figure 45. Various Cell Sizes.

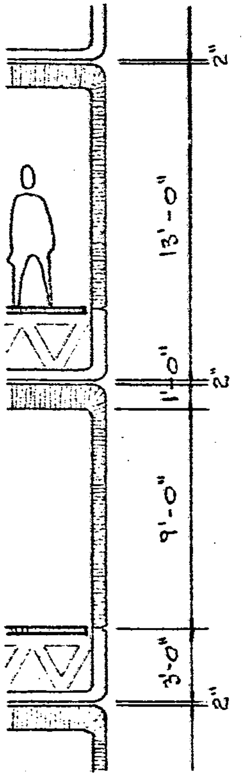


Figure 46. Vertical Module for Cells.

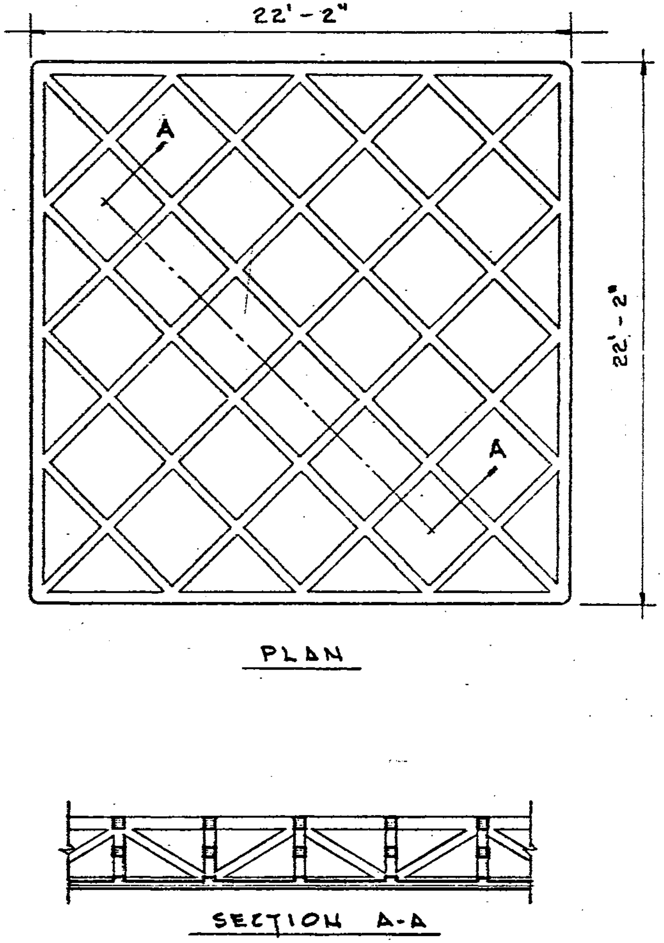


Figure 47. Cell's Structural Framing.

sufficient room for mechanical equipment.

Any module or group of modules might have been selected so long as they met the requirements of the building and the building system.

## Structure

The cellular-without-framing building system appears to have its major drawback in its inherent structural characteristics. In order to eliminate external framing, it is necessary that the cells contain within themselves enough structural strength to be cantilevered off the core and support all the loads that will be placed on them plus the strength to support another cell. There will be cantilevers up to 44'-6" on the sides and even more on corners.

There appear to be two general ways of framing the cells, both having good and bad characteristics. The first is to utilize the cell walls as beams or at least as trusses. This would allow a beam or truss of 12 to 13 feet deep which would easily handle the cantilever loads mentioned. This system would be ideal and easy to utilize if it were not necessary that at least some of the cells open up an entire side to another cell to provide open spaces larger than any individual cell would have.

The other structural possibility is to use a material of sufficient strength in the 3'-0" base portion to support the loads. This is the most desirable, as it leaves the upper portion of the cell free of structural requirements other than those required to support the ceiling and roof. It is feasible that a high strength steel or an advanced plastic truss framing as shown in Figure 47 would carry the required loads. Heavy loads such as computers and storage areas would have to be placed in close proximity to the core so as to eliminate excessive stress on the system. The diagonal arrangement of the floor trusses provides two directional support so as to carry loads of cells connected to its sides or front.

The cells are connected to each other and to the core with tension rods in the upper portion of the spandrel beam. The bottom of the spandrels are held apart by cellular pneumatic tubes to take any shock and allow for easy adjustment. The shear between cells is carried by the enlarged cross section of the tension rods. Figure 48 shows the above discussed structural connections. All connections between cells, structural or non-structural, would be sealed by cellular pneumatic tubes as shown in Figures 48 and 49.

## Walls, Floors, and Ceilings

The cells' walls (external and partition) and ceiling would be fabricated to standard specifications in one piece at the factory. This portion of the cell would be made of a plastic laminated over insulation and then fused with a plastic solvent to the structural base. The floor panels made of wood pulp material bonded by plastic, would be laid over the structural base and tacked to it. Over this subfloor, carpet or other suitable finishing materials would be placed. If built-in furniture is desirable, it would be fabricated and fastened into the cell at the factory. Once the cell is complete, it is ready for delivery to the site.

The cell can easily be disassembled by sawing the upper portion of the cell from the structural portion and can then be reassembled with new or different parts.

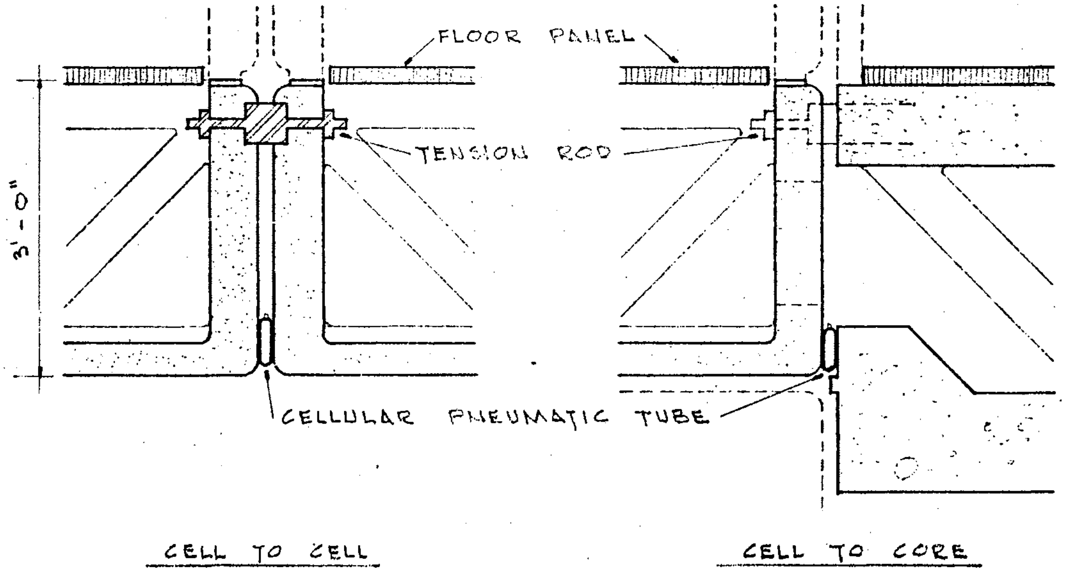


Figure 48. Structural Connections.

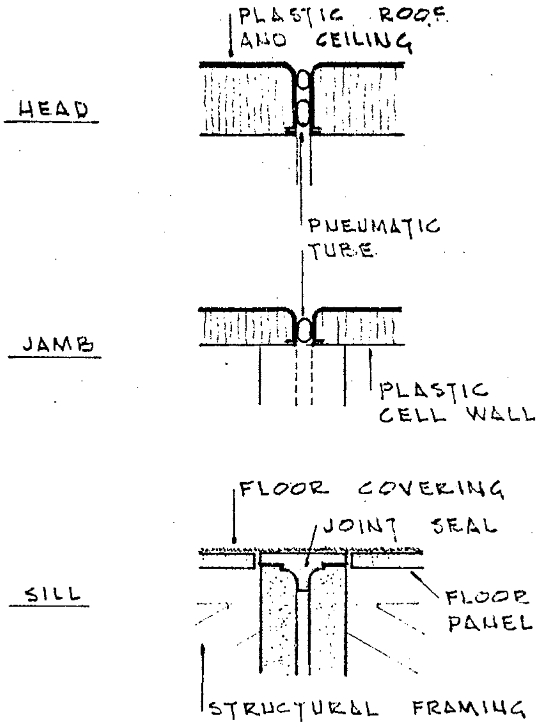


Figure 49. Sealed Joints Between Open Cells.

## Mechanical

All the mechanical equipment is installed in the cell at the factory and only remains to be hooked-up at the building site. The artificial lighting is placed in the ceiling in a predetermined pattern and is wired to the electrical network under the floor. This network is provided for easy tapping at any desired portion of the floor space. Combined in this network would be the telephone wiring.

The heating, airconditioning, and ventilation will be handled by an individual cell unit supplied with hot and cold water from the core. There is adequate space under the floor to house the unit and the ducts required. Fresh air can be drawn from the outside, cleaned, humidified or dehumidified; heated or cooled by the cell unit; and then circulated. This system has the disadvantage of requiring several small units instead of the usual case of a few large units in the core which would cut the cost of equipment. At the same time, this system lets the individual cell's occupants control their environment much better and puts the cost of operation on those using their environmental conditioning system most.

The major portion of the plumbing will be contained in the core where the restrooms will be located. This does not eliminate the placement of some plumbing in the cells. There should be adequate slope of drainage pipes in the structural space for usual purposes. Grinders and pumps could be easily installed for unusual drainage loads. Connections to the core would be with flexible hoses.

## Core

Vertical circulation, in the form of elevators and fire stairs;

restrooms and mechanical space; and the lobby and corridor space make up the core. The core also contains all the vertical chases for services such as gas and water pipes, mail service, rubbish disposal, electrical and telephone wiring, and chimney and air duct space.

The core would not be factory constructed as the cells, but built on the site of a heavy and massive structural material such as concrete. The core must ultimately provide support for all of the cells and withstand any eccentric loading or wind loads that might occur. In short, it must carry the entire load of the building both vertically and horizontally. In the common construction of multi-story buildings at present, the core is called upon to provide up to 50% of the vertical load, and most generally 100% of the shear loads. Thus, this system requires more structural strength in its core than is required in other systems.

On top of the core or penthouse would be a telescoping crane used to lift the cells into place. The telescoping sections will allow the cells to be moved easily horizontally and will be housed in an enclosure when out of use for better appearance. A counter balance could telescope out the back side of the crane to balance the load of the cell and a counter weight. The purpose of the counter weight is to balance the weight of the cell and hold it horizontal when the lift is secured to one side of the cell.

## Flexibility

The flexibility of the cellular-without-framing system has both favorable and unfavorable aspects. On the favorable side is the speed at which a major change can be made. For example, it would be quite possible to remove and replace three or four cells overnight. All of the cell changes could take place at night or on weekends, thus not affecting the other occupants of the building in any way. Also, on the favorable side is the flexibility of size and shape of spaces. It is possible to open whole sides of cells into each other creating larger spaces; however, they must always correspond to the 11'-0" and 2" module. With regard to height, a cell might be 1½, 2, etc. stories in height with a sloping or curved ceiling and roof.

The unfavorable factor affecting flexibility is the difficulty of transporting and handling the heavy, bulky cells. This would be a considerable drawback to flexibility.

## Size

The cellular-without-frame building system has one weakness with regard to size of the building. The system fails to adapt itself well to floor areas of under 10,000 square feet per floor by sacrificing efficiency of space and limiting maximum depth. This is not overly objectionable as the smaller floor areas are seldom desirable in a speculative office building. The system, however, is not adversely affected by increasing the floor area to at least 20,000 square feet. The preceding conclusions are drawn from the findings in Chapter VI.

Another drawback with reference to size is the system's effect on the height of the total building. Its floor to floor height is from 12 to 18 inches more than is required in most multi-story office buildings being constructed by conventional means today. This makes for a considerable increase in total height.

While the system tends to increase the height of the building, it has little effect on height limitation. The building can be built as high as can be supported by the core. Since the cells are cantilevered off the core, the cellular system has no effect on the maximum height whatsoever.

## Orientation

The cellular-without-frame building system has no inherent effect on orientation. This might be looked upon as both advantageous and detrimental. It is advantageous in that the length of the building, if it is so shaped, can run east-west or north-south as dictated by the site. The detrimental aspect is that the system shows no regard for sun, wind, or any other climate effect. This does not mean that the cell itself cannot be designed and placed in such a way as to effect good sun control, insulation, acoustics, and other environmental conditions.

This building system's outstanding effects on acoustics have been dealt with adequately in Chapter VI and shall not be further elaborated on.

## Integrity

If there is any single aspect which makes this building system favorable from a design standpoint, it would have to be its integrity. Inherent in the system is the definite expression of change, both interior and exterior, which occurs with every change in function or arrangement. Note the changes in Figures 50 and 51 which express changes in cells. Even with these quite apparent changes, the building as an entity still retains its character. Figures 52-55 show the consistancy of character of the building from many different views. To a designer,

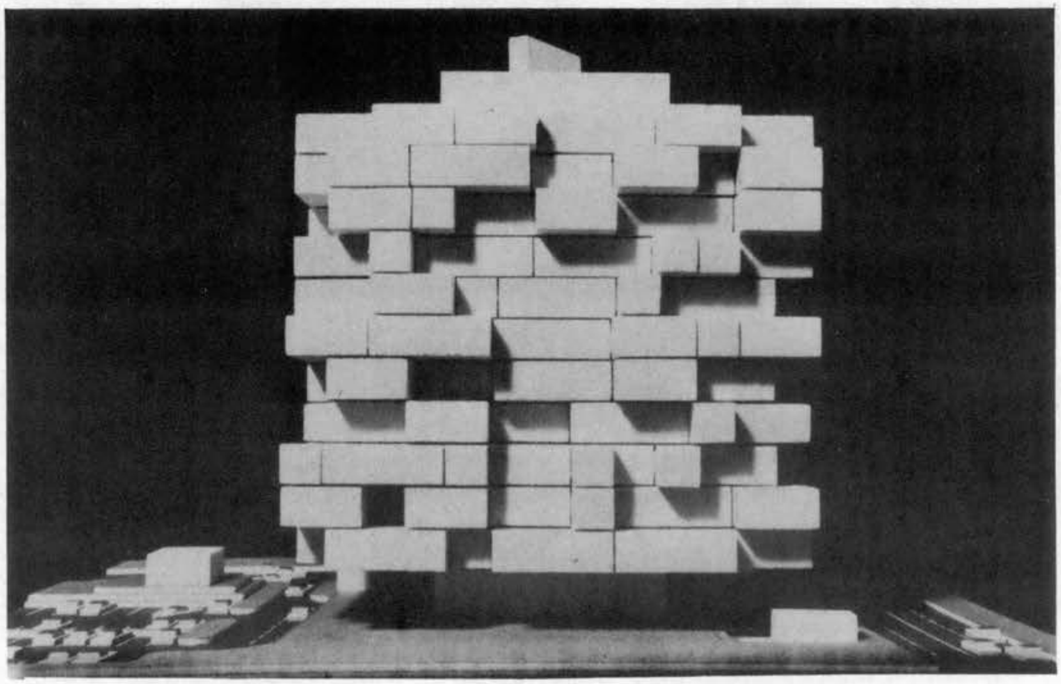


Figure 50. Study Model - Facade #1.

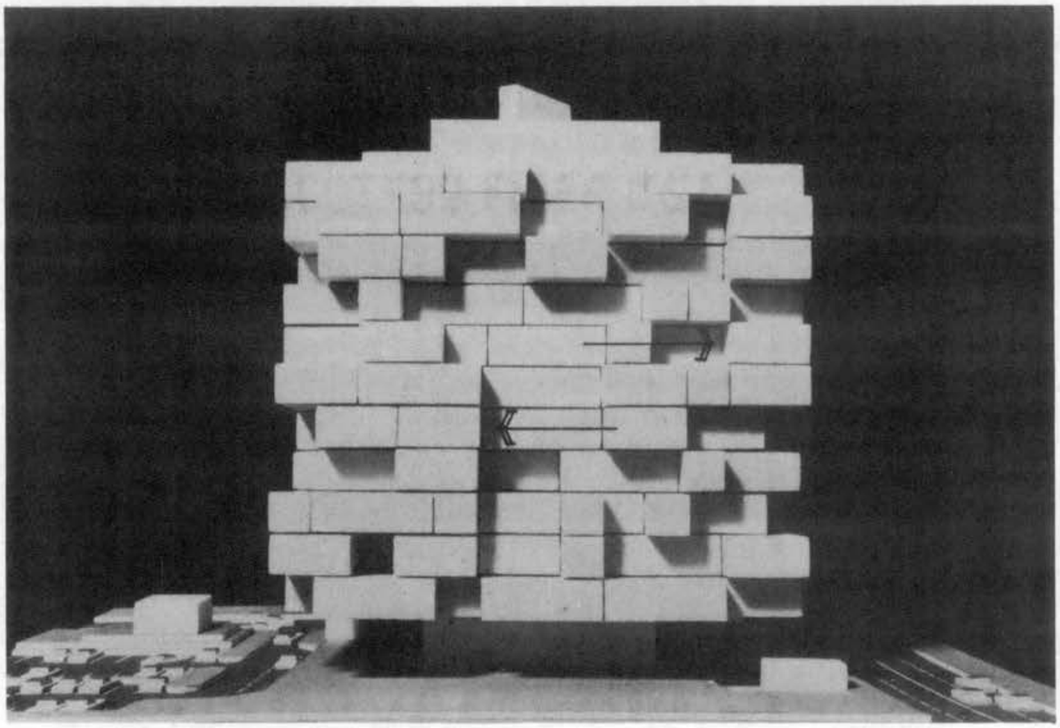


Figure 51. Study Model - Facade #2.

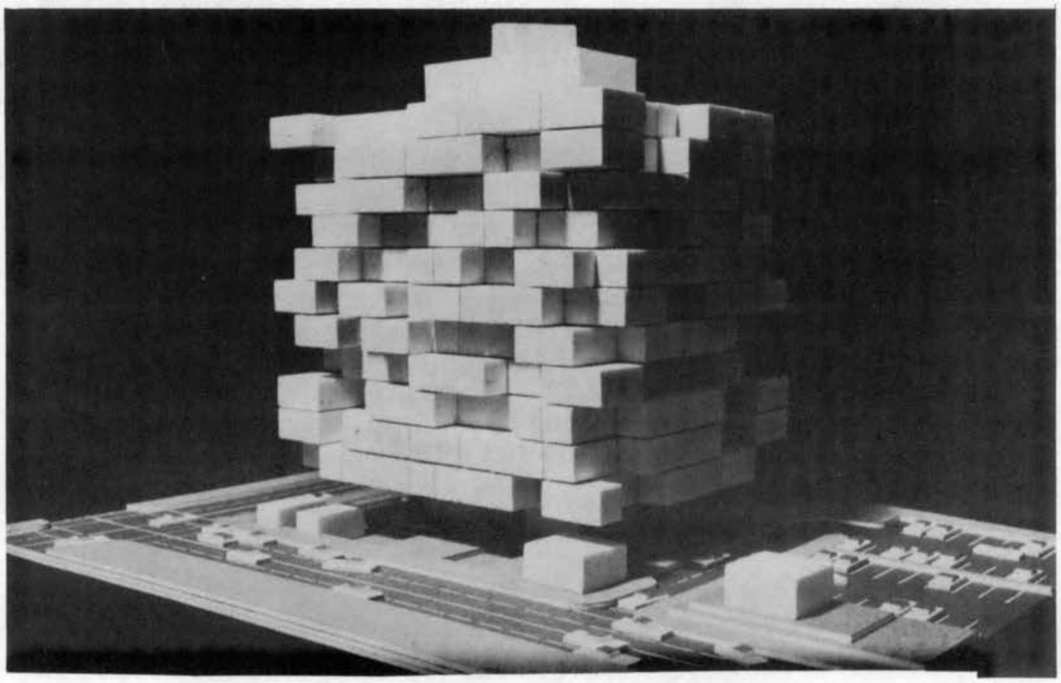


Figure 52. Study Model - High Perspective.

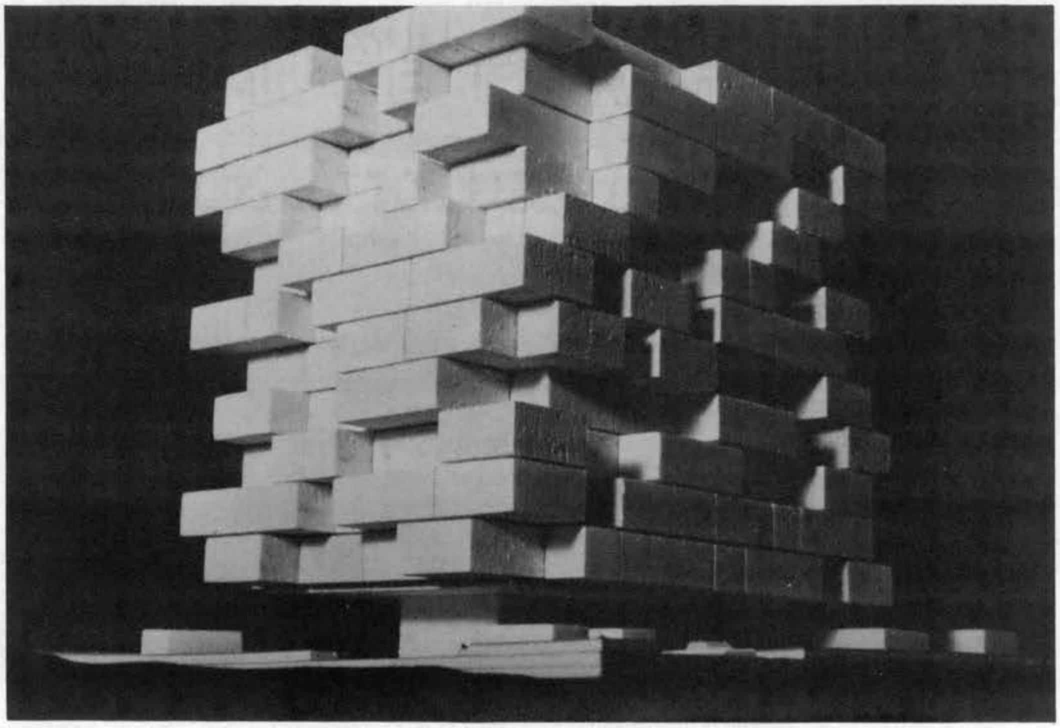


Figure 53. Study Model - Low Perspective.

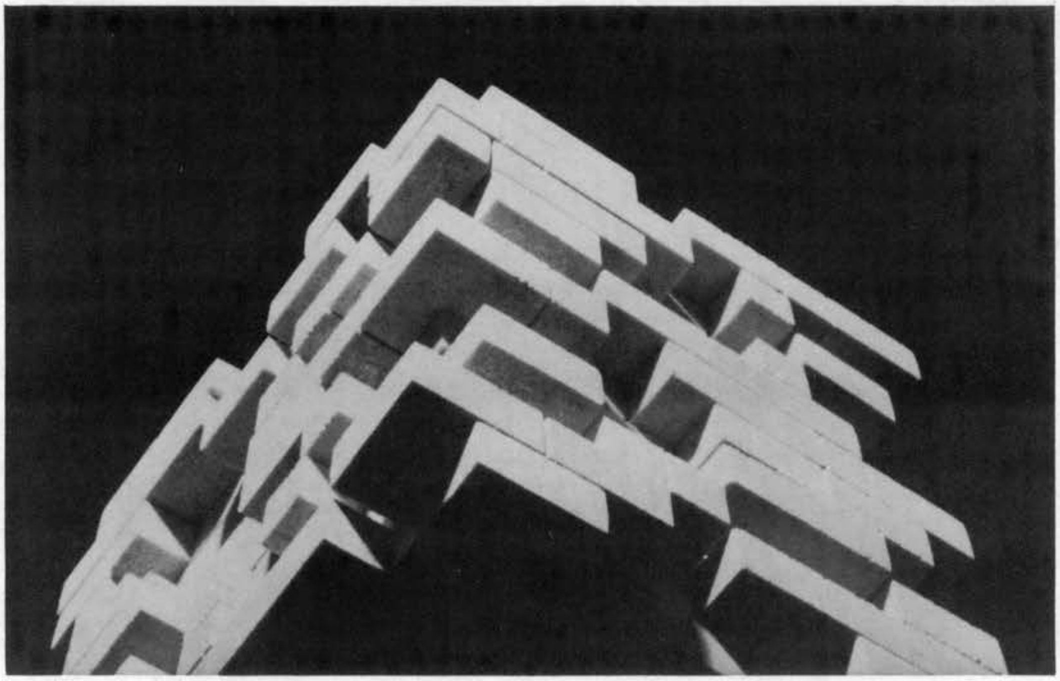


Figure 54. Study Model - Looking Up.

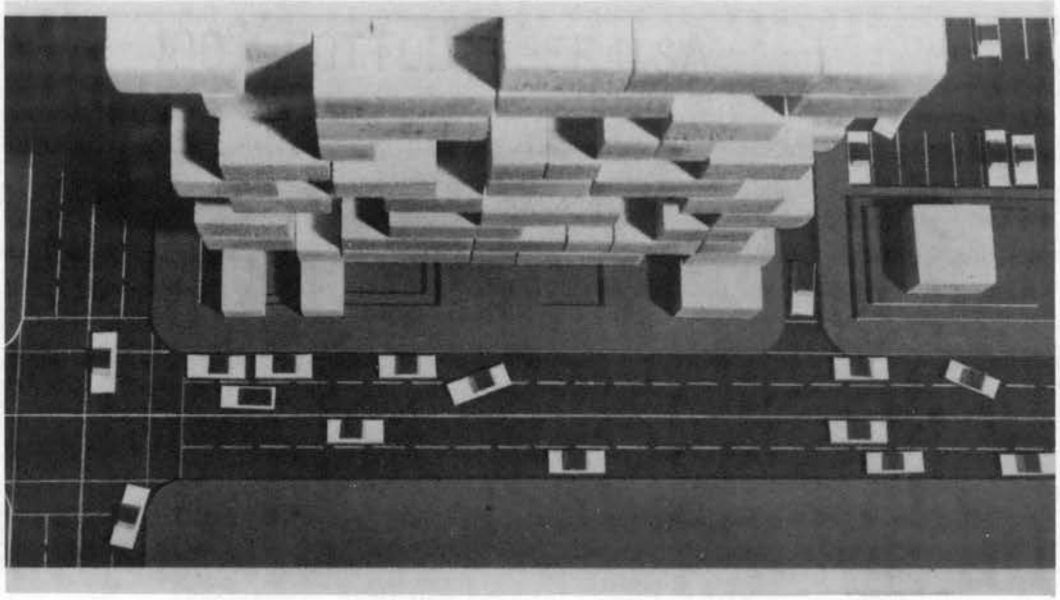


Figure 55. Study Model - Looking Down.

these two factors, expressing change and retaining character, are very important features that the cellular building systems offer that cannot be found in any of the other systems studied.

Along with these desirable features come the accompanying problems of control. Since it would be desirable for the individual cells to be of many different colors and facade designs, combining them at random and still retaining unity is quite an obstacle to overcome. This is seen only as an obstacle, not a barrier. Co-ordination of design of facades and selection of proper hues and values of the various colors would make it possible to combine any two cells without conflict.

## Economics

It is very difficult to draw conclusions for economical considerations. So many external factors, outside of the system itself, affect economics. Labor rates, location, and transportation are a few of the factors that vary and change economical considerations. However, a few general conclusions might be drawn.

The increased cost of transporting the large, bulky cells and the necessity of increased mechanical equipment would probably cancel out the savings of factory fabrication and ease of erection and making changes in the building.

Other economical considerations that would be to the system's benefit are the reusability of cells after the first owner has made a change, and the elimination of lay-up time for redecoration. For example, if an office expands and needs additional space, they could trade-in their old cells on new and larger ones. Their new cells could be properly equiped and exchanged for the older ones over a weekend, thus eliminating a lay-up time while the office is enlarged. The old used cells could easily be repaired and sold to a new owner much as used cars are resold. These two advantages of the cellular system affect the efficiency of time and materials, both very important to the broader economical factors of the industry and the nation.

## Conclusion

To sum up this chapter briefly, a simplified list of the favorable and detrimental characteristics of this cellular-without-framing system follows:

Credits:

- Functional integrity
- Opens building to light and air on all sides
- Adaptable to any site slope
- Total integration of structural and mechanical
- Speed and ease of making major changes
- Flexibility
- No height limitation
- Good acoustical control
- Efficient use of time and materials
- Factory construction and decreased site labor

Debits:

- Transportation of cells
- Structural aspects
- Co-ordination of colors and cell design
- Increased number of mechanical units

Debits (continued):

Does not adapt well to floor areas under 10,000 square feet

Disregard for sun and climate orientation

# CHAPTER IX

## SUMMARY AND CONCLUSIONS

Considerable time was spent researching and condensing all available material on industrialized component building systems and office buildings. Standardization; modular co-ordination; integration of structure, mechanical equipment, function, and aesthetics; and jointing were found to be the major factors to be considered when designing or working with an industrialized building system. For the purposes of this study, the systems were subdivided into three groups (frame and panel, cellular, and structural panels) and classified as nine basic types. Two of these basic types were eliminated because they did not adapt to multi-story construction.

The condensed information on office buildings was organized into a check list on which to base the analysis and judgments of the various building systems. Of all the considerations, flexibility was found to be of central importance to speculative office buildings and was a key factor in judgment of the building systems.

With the building systems classified and an office building check list formed, the method of study was to interrelate the two aspects. Trial applications were made, judged as to the system's adaptability to multi-story office buildings, and the least appropriate systems were eliminated from further study. In the first stage study, trial applications were made of the component building system's suitability to an average size and height office building. The judgments were based on the system's adaptability to office building functions, some major mechanical and economical considerations, flexibility, and building shape. On the basis of these judgments, ratings were made. The totaled ratings showed cause for elimination of three building systems from further study because of inappropriateness.

Four component building systems remained to be advanced into the second stage study. Trial applications were made on office buildings of seven different sizes, heights and shapes. The systems were judged and given ratings on all criteria on the office building check list. This made for a more detailed study of the four systems than was made in the first stage study. From the totaled ratings, one system, the cellular-without-framing was found to be the most appropriate in both the first and second stage studies. The other three component building systems were eliminated and the cellular-without-framing system was advanced to the final study.

The final study was designed to serve as a sample analysis of a single component building system. It dealt with the system in more detail and compared the system's inherent advantages and disadvantages. The cellular-without-framing system was found to have more favorable than detrimental characteristics as listed in the conclusion of Chapter VIII. However, some of these unfavorable characteristics would be difficult to overcome.

It was found that the system of analysis as above summarized worked successfully in bringing the many elusive aspects of component building systems and multi-story office buildings together in a way that they might be logically and systematically analyzed. From this system of analysis, the following general conclusions were drawn.

Each building system studied had inherent strengths as well as its weaknesses. The possible exception was the shell-structured-panel system and this system undoubtedly has its place in other building types. Both the space-frame and tension-frame systems had the qualities of being light weight and providing for large open spaces. The lack of mass, however, hindered the systems' ability to control noise and vibration and support heavy loads. The load-bearing-panels and the bay-framing-and-panels systems are more closely related to the customary types of construction for office buildings than are the other systems. This made the two systems average or slightly above average on their total scores as the customary is the base of relativity.

Of all the systems, only the two cellular systems had the quality of expressing aesthetically and in plan, section, and elevation the constant changes in function of this building type. This quality alone gave the two systems considerable strength of which the cellular-without-frame system did not lose in other areas of consideration as did the cellular-with-framing system. The cellular-with-framing system lost considerable merit in its failure to adapt to general open office space and its lack of efficiency of floor space for rental purposes. The cellular-without-frame system did not suffer these setbacks, but found its major weakness in structural considerations. The system's strengths outweighed its weaknesses considerably and was rated as the most adaptable building system to multi-story office building construction.

## Suggestions for Future Study

It has been shown that this process of analysis is workable, but further study with some changes would undoubtedly improve it. The judgment and rating phases could be strengthened considerably and have more validity if three or more qualified individuals' judgments were averaged to obtain the rating. Also, instead of studying only the inherent qualities of a single system, a combination of the strengths of the various systems into one system might prove beneficial.

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# VITA

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