5-1980

An Energy Conscious High Rise Office Building

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AN ENERGY CONSCIOUS HIGH RISE OFFICE BUILDING

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by

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A terminal project submitted to the faculty of the College of Architecture, Clemson University, in partial fulfillment of the requirements for the degree of Master of Architecture

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Chairman

[redacted]

Head, Department of Architectural Studies

[redacted]

Dean, College of Architecture

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DEDICATION

TO MY FAMILY WHO GOT ME THROUGH THE MOST DIFFICULT TIMES WITH CONSTANT LOVE AND ENCOURAGEMENT.

Project Identification

1

The project pursued here is the design of a 34 story (including lobby and two mechanical levels) speculative office building in downtown Philadelphia, Pennsylvania. The building is of mixed occupancy type with a total gross square footage of approximately 874,000 square feet. There is to be about 28,400 gross square feet per floor to be designed at 73% efficiency. The building is expected to have a total population of about 6300 persons, or 203 persons per floor, or an average density of 140 gross square feet per person. The building is located in an area that is part of an urban renewal project called the Market Street East Redevelopment Project. The redevelopment project is basically a mixed use development combining public and private transportation with commercial and business space. One of the proposed office towers for the project will be used for this study.

At the time of this writing, actual construction of office space on Market Street East has not yet begun. Therefore, since no client exists for a tower in the proposed location, the problem will be dealt with as a hypothetical study using schematic information from the coordinating architects of Market Street East.

The main purpose of this project is to investigate methods of energy conservation in high rise office design. The technology employed in the design will not exceed the state-of-the-art. The study will focus on three main architectural factors: building orientation to sun and wind, building shape, and the building skin. These factors will be compared to each other in relation to resulting energy consumption, functional efficiency, and building image. Other issues investigated will be interior spacial organization, site selection, and building accessibility. Additionally, economic considerations will be discussed in a general manner.

Background 2

Residential and commercial buildings are now responsible for approximately one-third of U.S. energy consumption. About 50% of the energy used in the built environment, though, is wasted. Of particular interest is the use of energy in office buildings. A recent study for the U.S. Department of Energy (DOE) found that buildings constructed prior to World War II used 42,000 to 52,000 BTU/sq. ft./yr. less energy than their modern counterparts.[1] This has prompted the U.S. government, through the Energy Conservation and Production Act of 1976, to develop energy performance standards for all new buildings by 1980.

The AIA Research Corporation has just completed two phases of a three phase program to develop these energy performance standards for DOE. Phase 1 involved a survey of 237 office buildings built since the 1973 oil embargo. These, therefore, represented the first generation of buildings in which energy use may have been a design consideration. According to the study, the average national energy use in office buildings is 64,000 BTU/sq. ft./yr.. In Philadelphia, it was slightly higher at 65,000 BTU/sq. ft./yr..[2] Phase 2 of the project involved the redesign of present buildings with energy as a design consideration and using existing technology. The results showed that 40% of the energy used in existing buildings can be saved simply through careful design.[3] A similar survey of office building energy consumption in Philadelphia was conducted in 1973 by the National Electrical Manufacturers Association (NEMA). Office buildings of similar scale to the one designed for this project had energy consumption rates ranging from 90,000 to 220,000 BTU/sq. ft./yr..[4]

In high rise building design, energy conservation has only recently become a consideration. The basic deterrent to sensible energy use has been economics. The initial costs of energy saving techniques will pay for themselves through saved fuel costs in a number of years, and then continue to reduce energy costs. For a corporate building, where the owner pays for the operation and maintenance, this can become an economically attractive proposition. In the case of the speculative office building, though, where the developer expects a short return time on his initial investment, energy conservation only means a longer investment return time. In addition to these deterrents to save energy, utility rates for electricity usually are less for more energy used. In essence, it becomes economical to waste energy.

The escalating price of energy in whatever form, the sometimes questionable availability of certain fuels at certain times, and the folly of the sheer waste of usable energy, seems to suggest that energy consumption will have to be controlled to a much greater degree than presently occurs. The speculative high rise office building is a particularly germane issue in regard to energy conservation due to this building type's preponderance in major cities, and as a building type that deals most directly with an energy versus economics battle.

The building in this study is located on an urban renewal project called the Market Street East Redevelopment Project. This project was actually started about 1954 by the Philadelphia City Planning Commission. Although the project has gone through several study and design changes, its basic form and purpose has remained the same. It is an attempt to combat the growth of suburban commercial and office development and renew the central business district of Philadelphia. It will focus most of the city's major commercial and office potential in one easily accessible location in center city. Its goals, as stated by the project's coordinating architects are: "to reverse the downtown decline in retail activity, to help the downtown get a major share of the anticipated office demand, to complete the interface of Philadelphia's transit system, and to create a humane pedestrian environment for business, shopping, working, and entertainment."[5]

The project is essentially a megastructure which will provide termini for the city's commuter rail lines, subway lines, and public and inter-city bus lines. Parking garages are along its entire 4 block length and will be easily accessible to the city's expressway system due to the traffic patterns already existing in downtown Philadelphia. All of the transportation facilities are directly connected, via underground concourses or overhead walkways, to a multi-level, skylit, pedestrian mall. The mall forms a "spine" for the project into which the various commercial and office spaces "plug in".

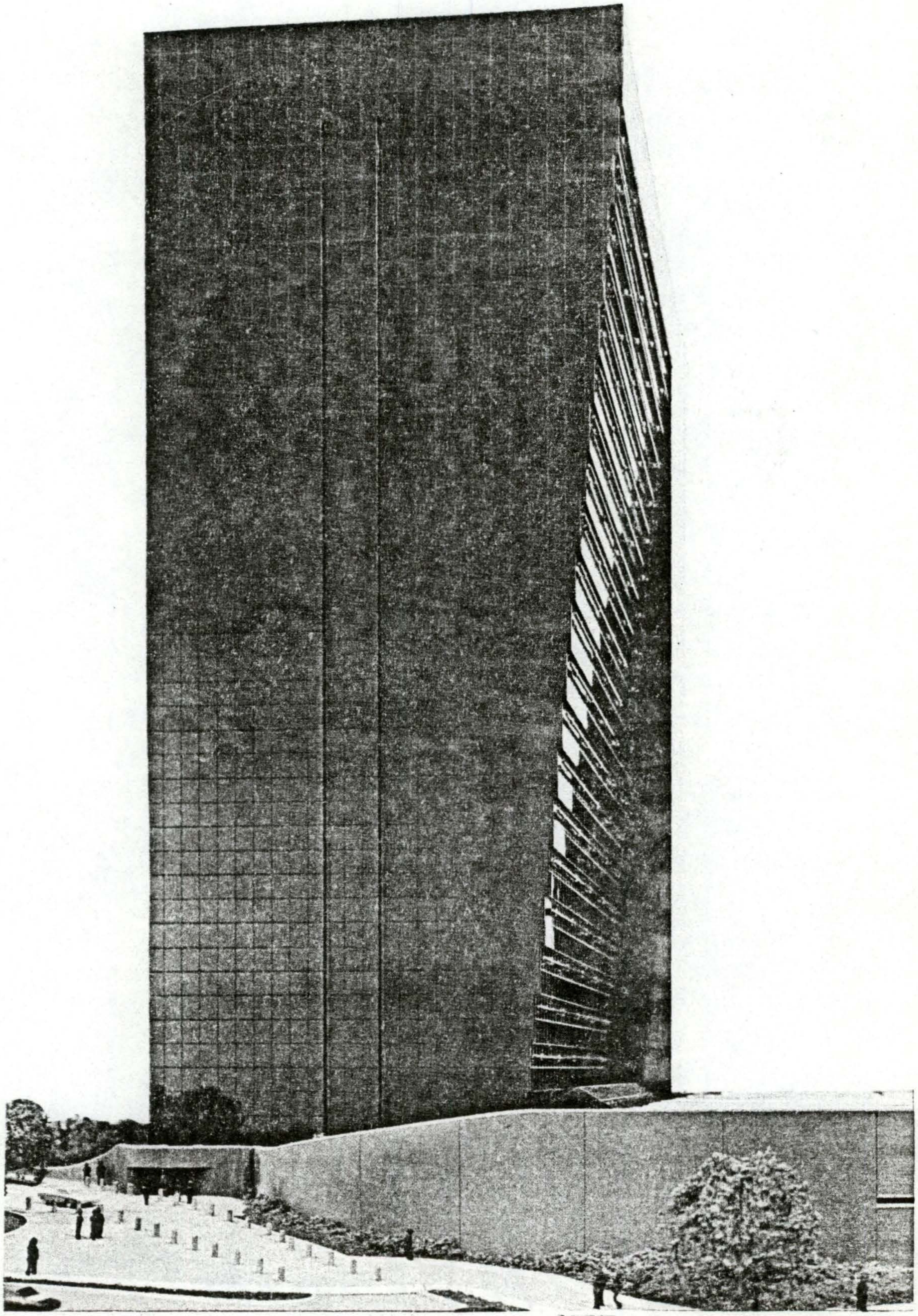
An energy conservative office building is well suited to the concept of Market Street East. Although energy use was not a design consideration in the project's development, it nonetheless will result in energy efficiency in another field; transportation. Current estimates are that 85% of those arriving at Market Street East will do so by some form of public transportation - a highly energy efficient means of travel.

Case Studies

3

CORPORATE HEADQUARTERS, GEORGIA POWER COMPANY, ATLANTA, HEERY & HEERY ARCHITECTS & ENGINEERS, INC.

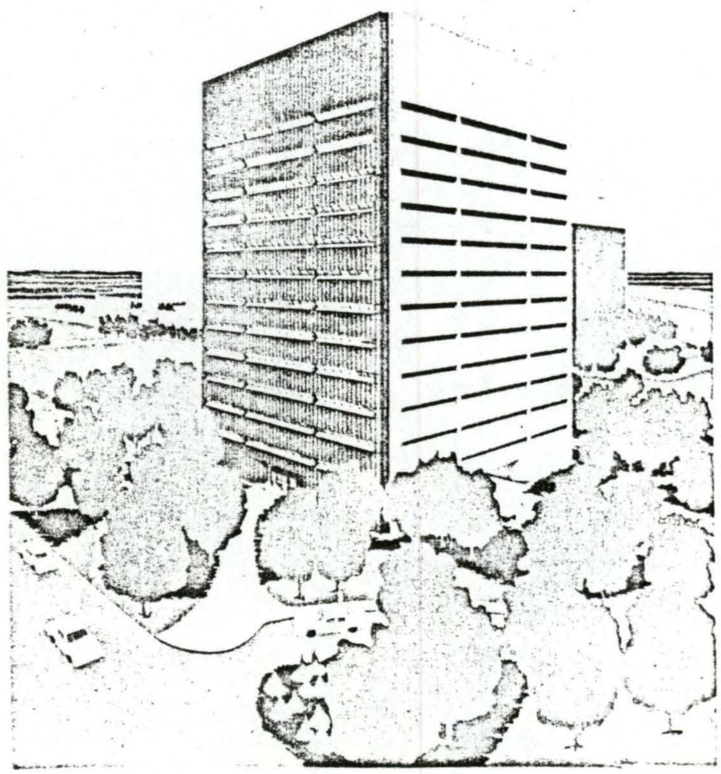
This is a 24 story, 764,000 gross square foot corporate office building in which energy conservation and solar energy utilization were primary design determinants. The architectural design, and the mechanical and electrical systems chosen, are expected to reduce the building's energy consumption to 55% of the average Atlanta office building. The south facade of the building is recessed and shaded to prevent summer solar heat gain. The east and west ends contain the elevator and mechanical cores which eliminates the need for vision glass on those facades resulting in well insulated east and west walls. The walls of the building are reflective, opaque, insulated glass panels in non-vision areas, and reflective, insulated vision glass. The area of vision glass is only 20% of the total wall area of the building. The mechanical system consists of solar driven absorption refrigeration machines, as a primary source of chilled water,powered by 23,760 square feet of linear parabolic solar collectors. Additional chilled water supply comes from a double bundle heat centrifugal refrigeration machine, or a standard centrifugal refrigeration machine. A 300,000 gallon chilled water storage tank is included to store excess chilled water and/or allow off peak generation of chilled water. Hot water is supplied by a 50,000 gallon storage tank charged by the solar system and/or the heat of rejection from a double bundle condenser, or electric hot water boilers. Conditioned air is distributed through a variable volume air system with automatically controlled electric heat provided at perimeter ducts. The lighting system utilizes task oriented fluorescent lighting with high pressure sodium lights providing some general illumination. This results in a building lighting load

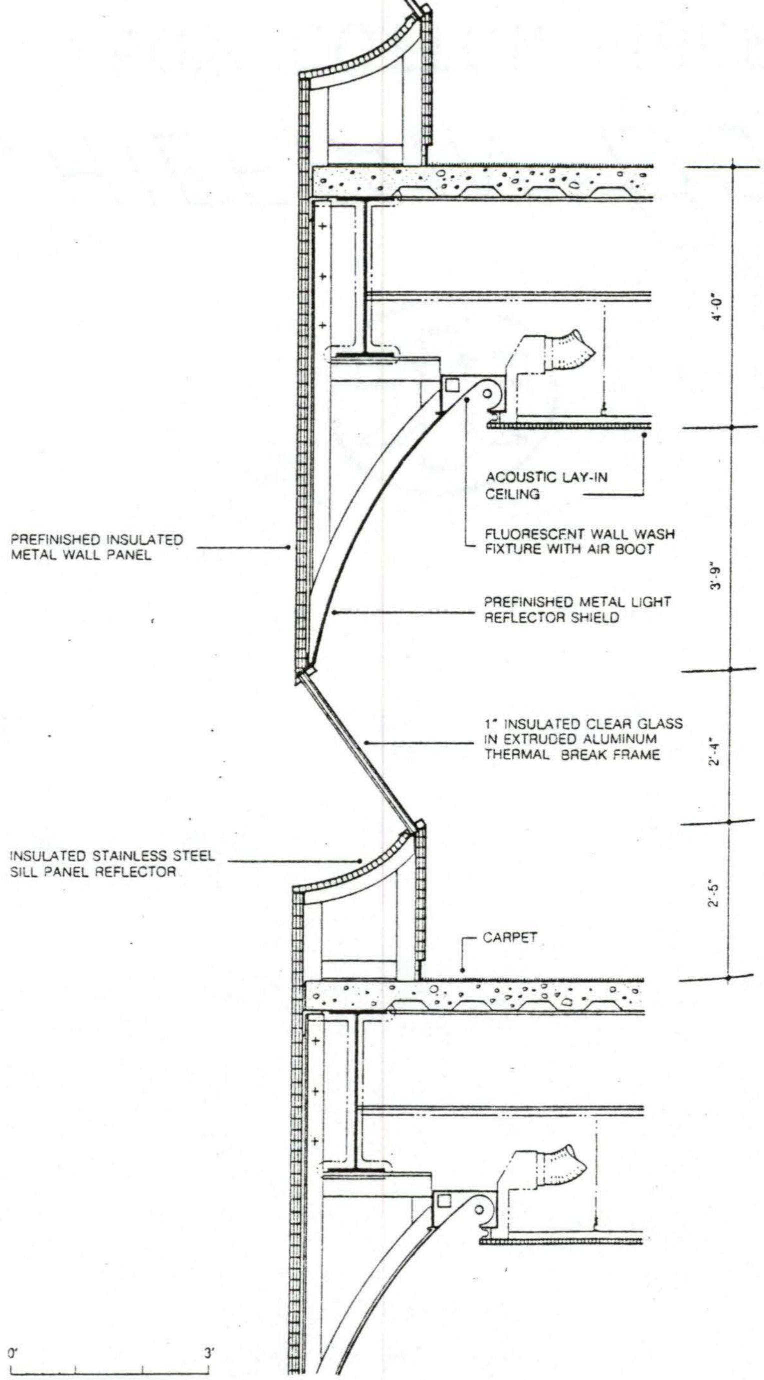


of 1.6 watts per square foot. Further energy conservation develops due to widespread use of landscape office planning, and the functional grouping of related departments to reduce elevator use. The solar system is expected to pay for itself from reduced energy in 15 years. The Georgia Power Company, though, wanted to show a commitment to developing new energy sources, and they felt that the publicity generated by the system would be economically beneficial. If the cost of the solar system and heat reclaimation devices were not included in the office tower cost, the tower would be competitive in price as a speculative office and still conserve considerable energy due to its design features.[6]

SPECULATIVE OFFICE BUILDING, DETROIT, GUNNAR BIRKERTS & ASSOCIATES

This is a commercial building with partial occupancy by the IBM Corporation. Heating and cooling loads are kept to 54,000 BTU/sq. ft./yr.. This is accomplished by having 20% of the exterior wall as window glass in a surface aperature that is only 18% of the exterior wall area. It is done by slanting the glass which prevents direct heat gain. In addition to this energy conserving feature, artificial lighting in the building is kept below 2 watts per square foot. Usual building lighting can be anywhere between 3 to 5 watts per square foot. The south and west building facades are painted to reflect heat since these are the hottest faces. The north and east facades are painted grey to help them absorb any heat to reduce their

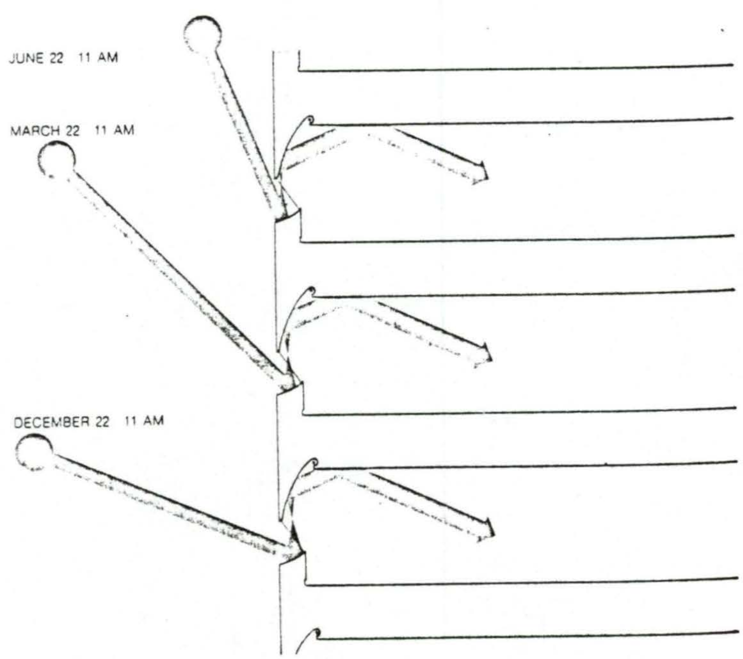




ACOUSTIC LAY-IN CEILING
FLUORESCENT WALL WASH FIXTURE WITH AIR BOOT
PREFINISHED INSULATED METAL WALL PANEL
PREFINISHED METAL LIGHT REFLECTOR SHIELD
1" INSULATED CLEAR GLASS IN EXTRUDED ALUMINUM THERMAL BREAK FRAME
INSULATED STAINLESS STEEL SILL PANEL REFLECTOR
CARPET
4'-0"
3'-9"
2'-4"
2'-5"
0'
3'

SECTION

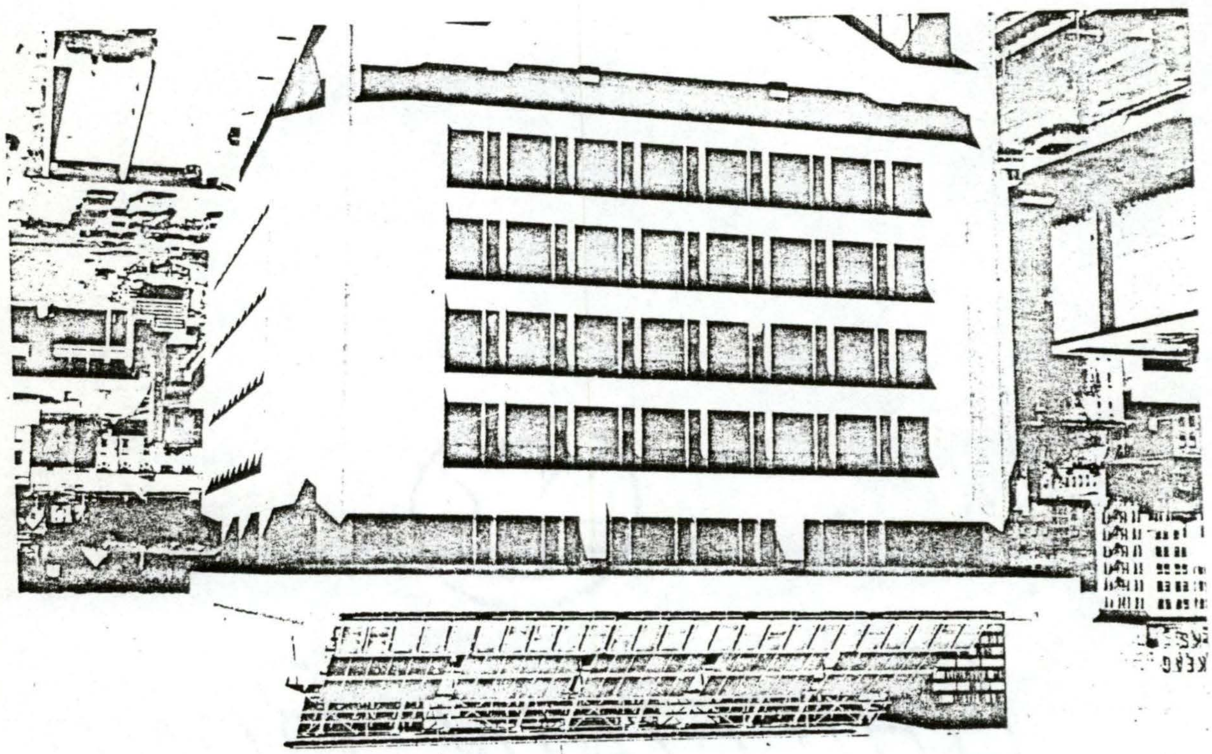
heat loss. The building's energy savings come from the facade design which constantly introduces natural light into the interior areas of the building as well as perimeter spaces. The design also reduces peak solar loads by 40% and produces a $21,000 savings per year in operating costs based on comparison with a standard vision wall. Although not necessary, the facade design is repeated on all sides of the building. This was done for economic reasons that the production of specialized wall treatment for varying wall orientations increases building costs. The wall design is expected to pay for itself from energy savings in 8 years.[7]



GSA BUILDING, MANCHESTER, NEW HAMPSHIRE, DUBIN, MINDELL, BLOOM ASSOCIATES

This is a seven story 175,000 square foot office building designed to use 40% less energy than a comparable canventional building. The building is basically a laboratory for different energy conserving systems and methods. The building is approximately cubical in form to maximize the ratio of interior space to exposed exterior area. The building's double-glazed windows are shaded to permit entrance of winter sunlight, but to exclude summer sunlight. The entire north facade of the building is windowless to reduce heat loss. A solar heating system using 10,000 square feet of flat-plate solar collectors is expected to provide 30% of the building's heating requirements. Its use as an energy laboratory has revealed some interesting things about some energy conservation systems:

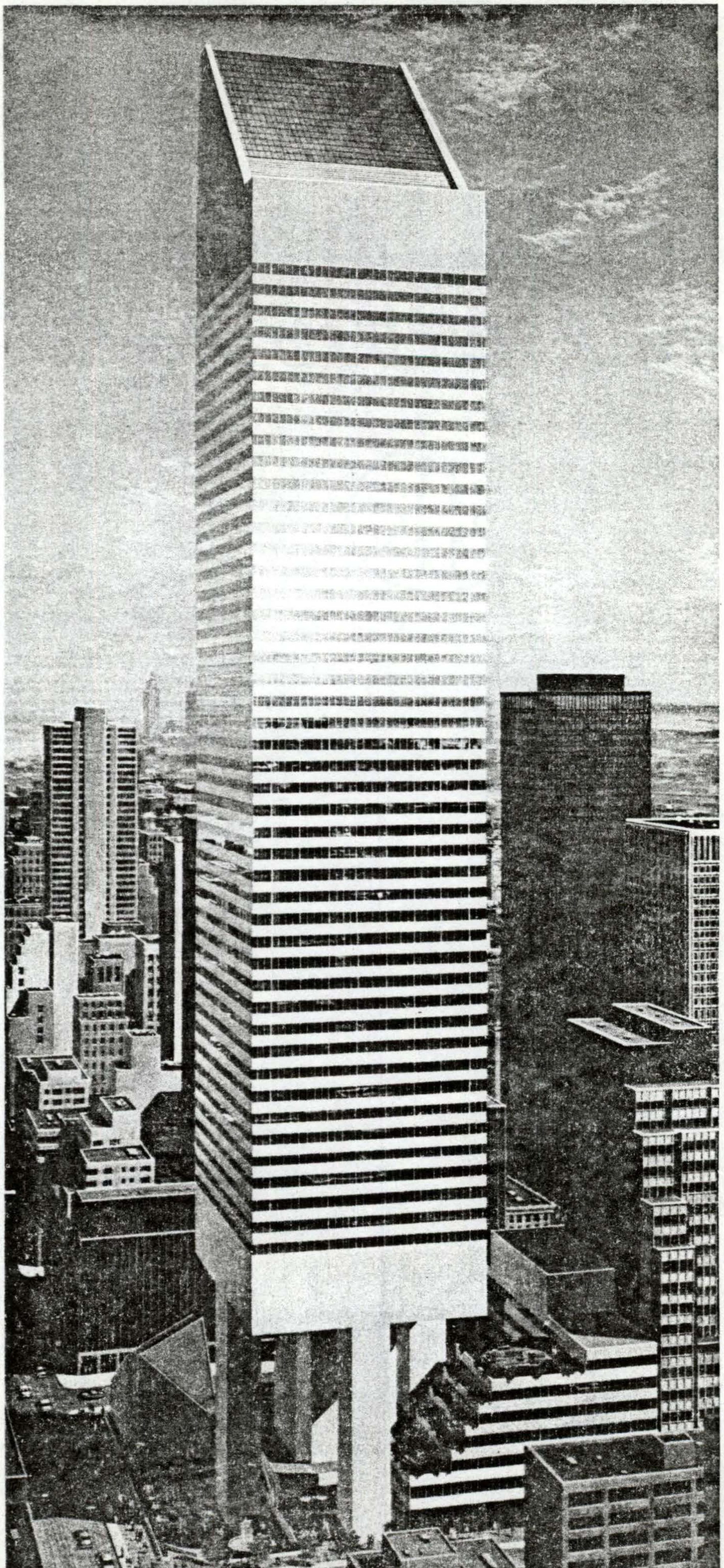
1) Solar collectors on the roof were added later and are from different manufacturers. They are designed to be adjusted seasonally which requires additional man-hour cost.
2) Sodium lights were used in some interior spaces. These are highly energy efficient, but in some cases they require long start up times, and their color can produce a displeasing effect on the perception of carpet colors, furniture colors, clothing and cosmetic coloring.
3) Windows on some areas of the building produce a claustrophobic effect in some cases due to their small size. Also, blinds contained between some windows malfunction and there is no access to them.[8,9]



CITICORP CENTER, NEW YORK, HUGH STUBBINS & ASSOCIATES

This is a 46 story, 1,000,000 square foot office tower and retail complex primarily for First National City Bank. The tower is square in plan to provide a high ratio of interior space to exposed surface area. Less than 50% of the exterior surface area is vision glass. The glass used is of a reflective double-glazed type. The opaque surface areas are of insulated aluminum spandrel panels to reflect light and heat. It is estimated that only 20% of solar radiation will be transmitted into the building. Lighting wattage has been reduced by 50% as compared to usual lighting levels. The building uses double-deck elevators which carry more people per trip for the same amount of energy used in conventional elevators. The reduction of the number of elevators needed produces a significant reduction in energy consumption for vertical transportation. Air fibers placed at the supply air intakes reduce the air volume necessary for the building and reduce the degree of heating or cooling of outdoor air required. The fibers also provide cleaner air. The mechanical system is computer operated to allow the most efficient energy use. A solar cooling system was designed for the tower to generate heat by the solar collectors which would have been used to recharge a liquid desiccant dehumidification system. The solar installation, however, was not carried out for many reasons:

"1) Solar energy was considered for the Citicorp building after an earlier concept of condominium apartments in the crown was abandoned. The building was designed, structural steel ordered, general contractors and subcontractors identified, and construction was underway when the solar idea was conceived. The solar system, then, was an add-on that had to be attached to an in-place system.



2) The collector delivery and installation schedule had to be closely coordinated with the building construction to use already installed hoisting and rigging equipment. The solar system could not delay the construction schedule.

3) There was apprehension by all concerned of placing collectors atop a 900 foot tall building.

4) Uncertainty existed regarding which trade groups would install the collectors.

5) Constraints had to be placed on the size and weight of the collector modules to facilitate handling during installation and reduce labor costs.

6) Some type of warrenty was needed for the nearly 1000 modules.

7) Collector modules were to be designed and constructed to minimize additional structural steel over that required for the curtain wall they'd replace.

8) It was calculated that careful use of outside air was a low cost way to save energy comparable to the amount saved by a solar energy system.

9) At that time, production of solar collectors in many cases was not to the point to respond to a job of this magnitude on the time schedule needed.

10) There was sparse response from industry.

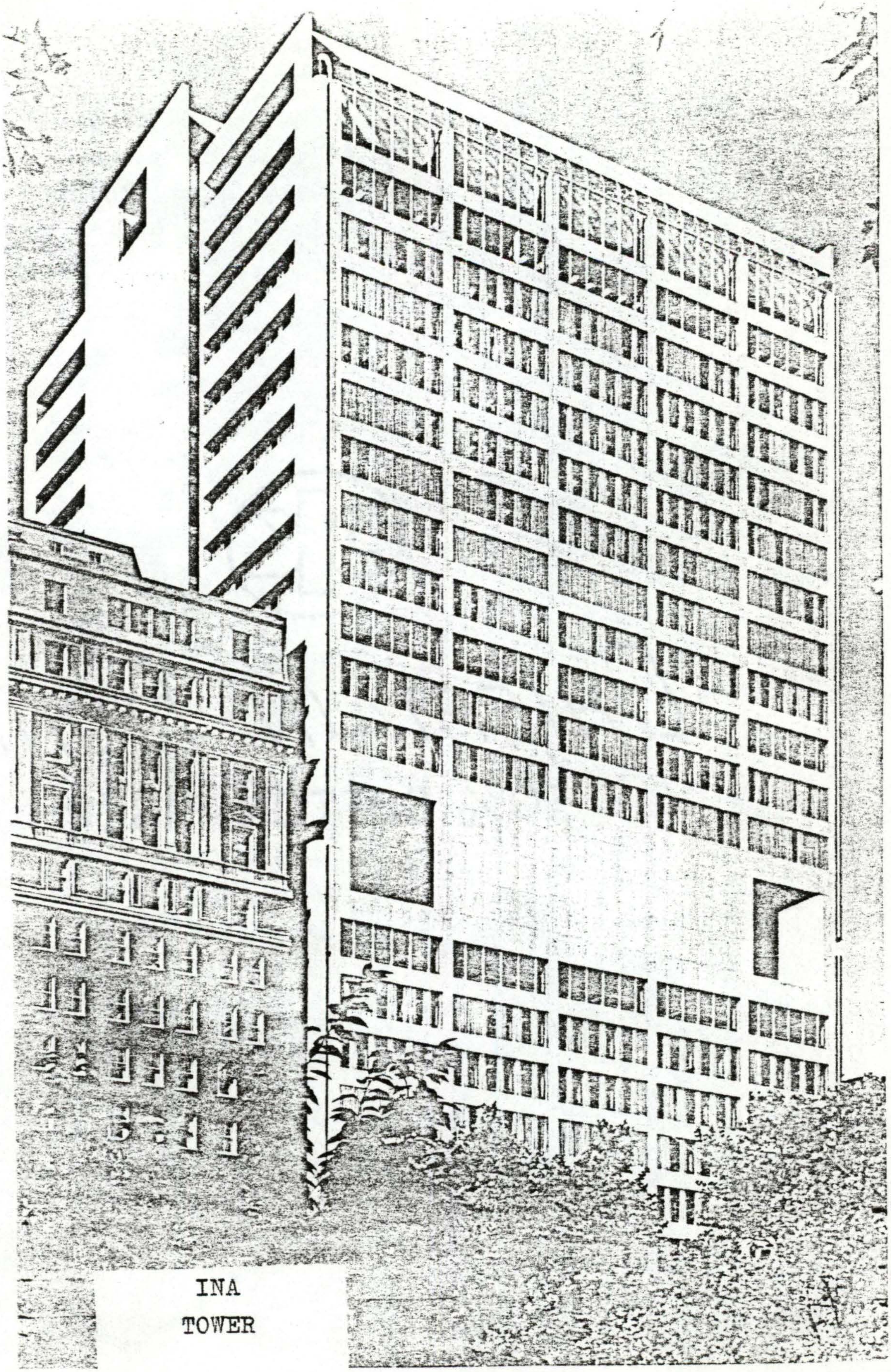
11) Conservative cost estimates were given with intolerably long payback periods

12) Conventional HVAC system design changes resulted in less energy savings from the solar system with no reduction in the solar system's cost.

13) Operating and maintenance costs were difficult to estimate."[10]

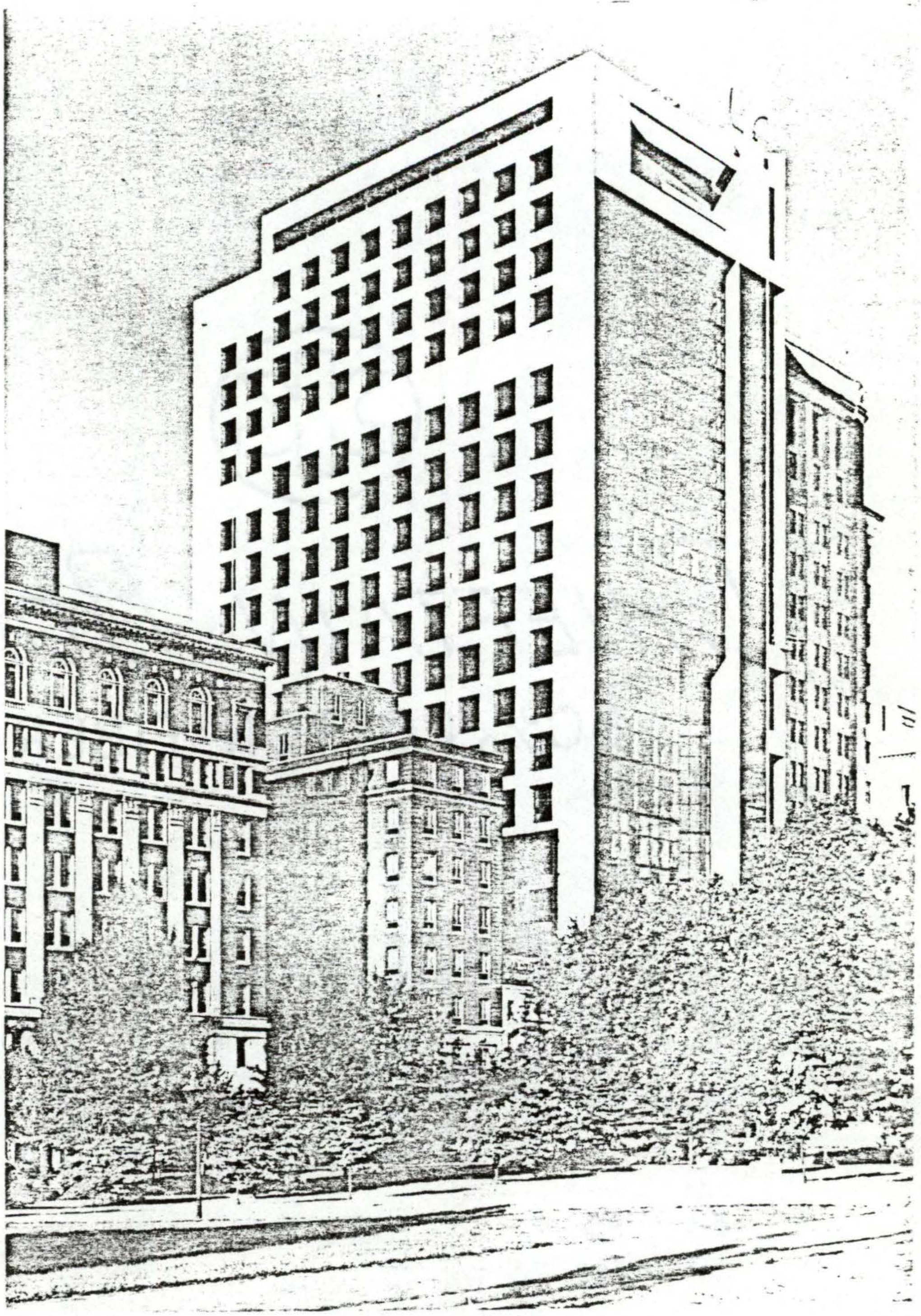
INA TOWER, and PENN MUTUAL TOWER, PHILADELPHIA, MITCHELL & GIURGOLA ASSOCIATES

The INA tower is a 27 story tower which houses corporate offices for an insurance company. The Penn Mutual tower is a 21 story addition to an insurance company's existing building. Both buildings utilize the same energy conservation technique of controlling solar radiation access through selective sunshading of the facades. On the Penn Mutual tower, the sunshading is only on the east facsde since the west wall is abutted on the company's original building. Further energy conservation is attained in this building by the use of insulated reflective glass and a mechanical system which provides separate controls for every three floors to allow selective off-hour use. The INA tower has sunshaded east and west facades and the upper portion of the south facade. The lower portion of the south facade is shaded by a nearby building. The INA tower, although a corporate owned and operated building presently, was designed at a cost typical of speculative office building development.[11]



INA

TOWER



PENN MUTUAL TOWER

Site 4

The site that the office tower is on imposes some considerations which take primary importance. The entire block beneath the tower, for two levels street and three above, is to be occupied by a shopping mall. The mall is designed similar to suburban shopping malls in most respects except that it is considerably more compact. Two levels below street contains a commuter rail station at the north-west corner, and truck service bays for the retail areas above. One level below street contains a subway station at the southwest corner with direct connections to an east-west running, skylit, pedestrian mall that bisects the site. The mall is surrounded by retail space including a department store at the western end. Street level and the two floors above are characterized by more retail stores around the pedestrian mall, and the department store at the western end. The department store acts as an "anchor" for the entire shopping mall. The Gimbels department store located across the street at the eastern boundary of the site acts as the other "anchor". All of these features are designed within the concept of the Market Street East Redevelopment Project to provide easy public transportation access to a pedestrian mall connecting to office and commercial facilities. It must be assumed that the developer of the commercial facilities (including the mall and rail stations) will be different from the office tower developer. This means that it will be highly desirable for the commercial space to have as little loss as possible from the office tower's elevator core, lobby, and connections to the mall and street. Also, the skylight of the mall is considered to be one of the major attractive features of the entire shopping mall. For this reason, it is necessary to retain the skylight as fully as possible.

In addition to the space requirements of the commercial areas and the office tower, there are also considerations of public transportation access to the site (see fig. 1). It is expected that 85% of those arriving to the site will do so by one of the 32 bus, streetcar, subway, or commuter rail lines that run directly to, by, or within short walking distance of the site. Most of those using public transportation will be using the commuter rail and subway lines which have stations at the northwest and southwest corners of the site and are directly connected to the pedestrian mall. Since the majority of the office tower's occupants will, therefore, arrive from the mall, it is important that good office lobby-to-mall connections be provided.

Those using private automobiles, or those walking to the site, should also have as convenient access as possible. A parking garage for 1000 autos will be constructed across the street from the tower and have direct connections to the mall. An auto drop-off area would be necessary at street level for those arriving by that means. Filbert Street, which borders the northern edge of the site, would be the best location for this since it is the lightest travelled street around the site and would have the least rush hour congestion from arrival and departure of occupants (see fig. 2).

With all of the above factors considered, the most suitable site for the tower was the northeast corner of the site. This area prevented any interference by the elevator core and lobby with the department store. The location also enabled an auto drop-off zone on the least travelled street, and permitted easy connections between the lobby and mall (see fig. 3).

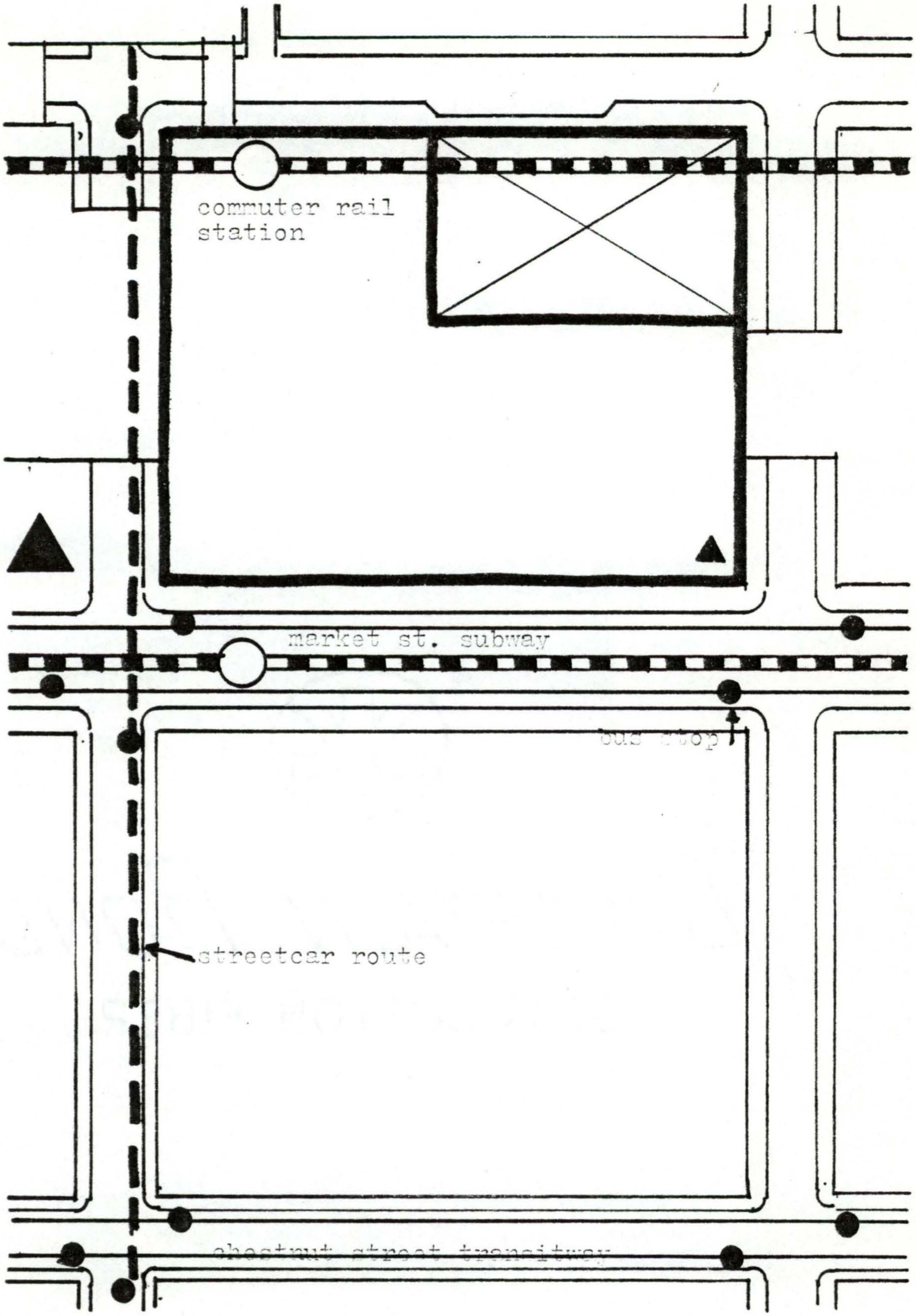


FIG. 1 PUBLIC TRANSPORTATION ACCESS

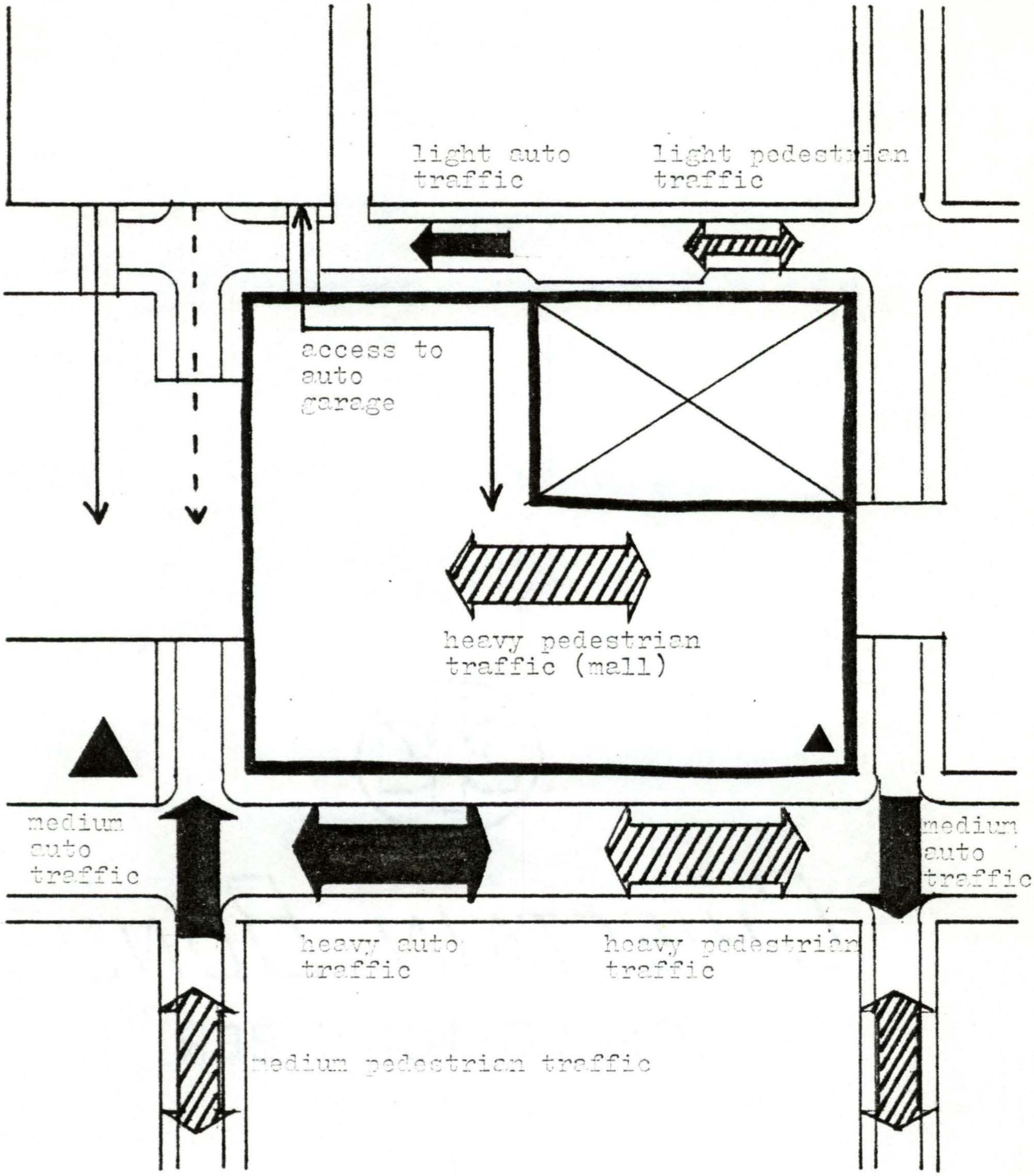


FIG. 2 AUTO AND PEDESTRIAN FLOW

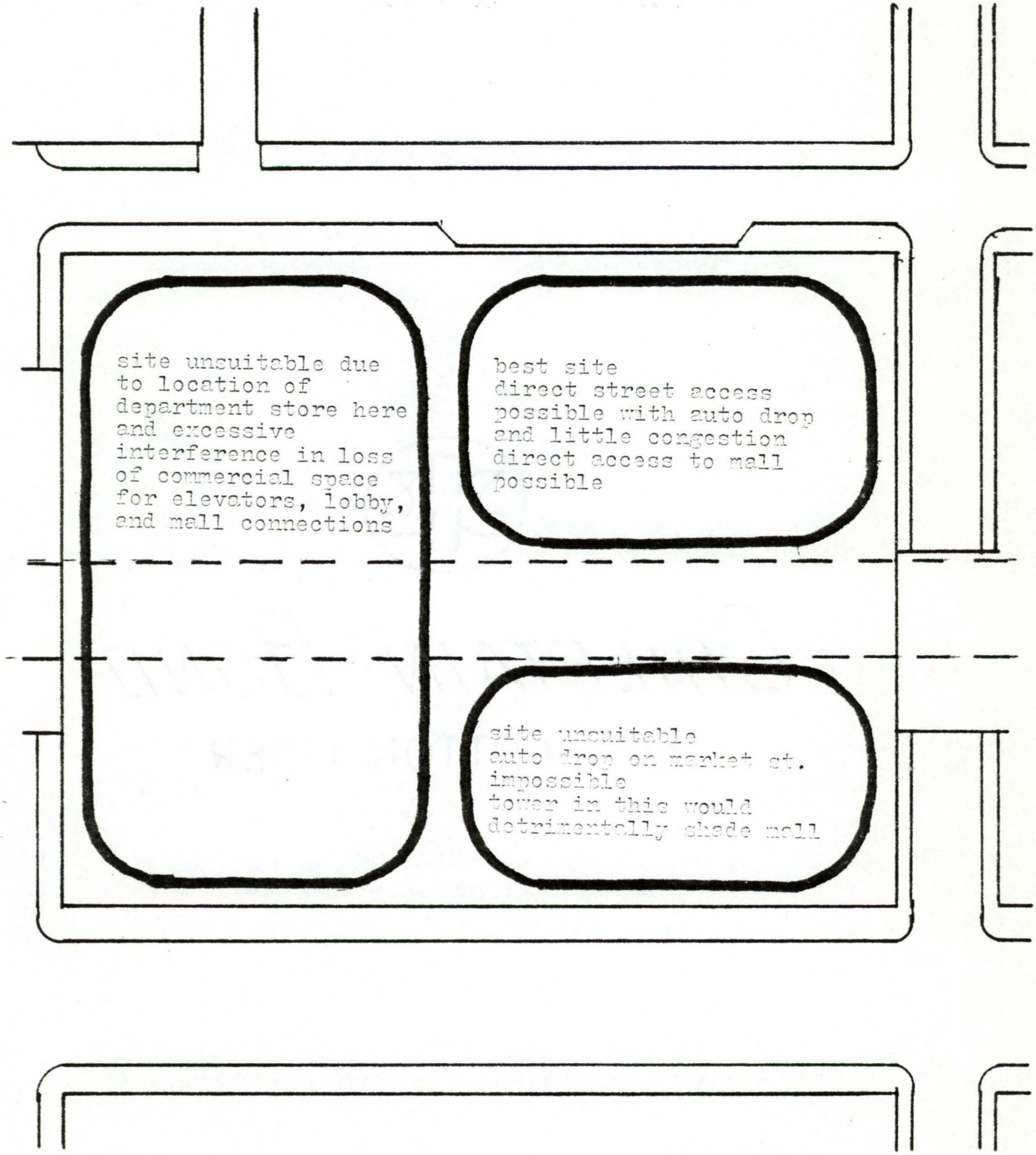


FIG. 3 SITE SELECTION

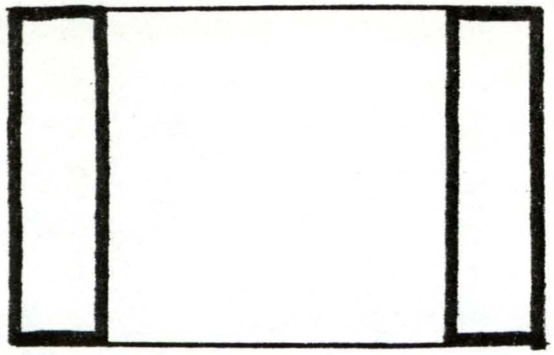
Concept

5

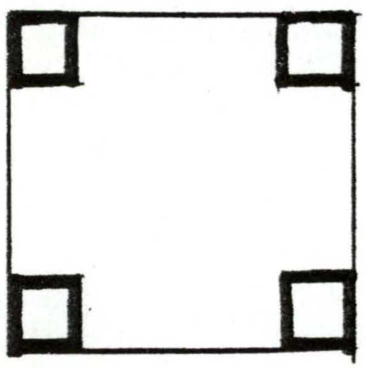
The use of certain energy conservation techniques and systems with each other in a particular climate, for a particular comfort level, and at a reasonable cost and payback time, usually means that a certain degree of compromise between these parameters must be made. In order to properly assess the most effective energy, comfort, and economic combination requires the use of a computer. A complete analysis of all the factors involved with the design of an economical energy efficient building is outside the scope of this project. The attempt here is to analyze the basic architectural factors of building shape, orientation, and skin that can affect a building's energy consumption. In addition, thewe factors are compared to each other in relation to the effect on the building's functional effeciency, and the building's image.

Of primary importance in the design of this type of office space is that it be functionally efficient. Since the tenants are unknown, it is impossible to predict what their space and organizational requirements will be. It is best, then, to provide space that is usuble by any office type and is flexible enough to allow offices of various sizes on multi-tenant floors. Large glass areas are generally considered to be more marketable. It could be argued that glass is excessively used in present office buildings, and that a minimum amount can be designed which will satisfy the economic, psychological, and energy requirements for this office building. Finally, another highly desirable feature of office buildings are corner offices.

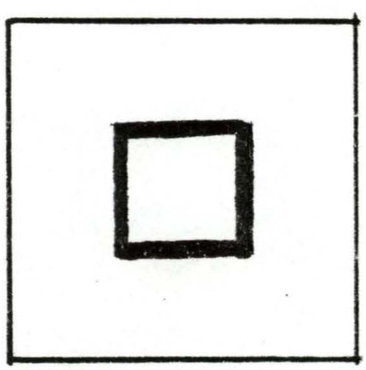
The functional aspects of the office building begin to affect an early design consideration of the location of the elevator core (see fig. 4). One approach would be to place the elevator and mechanical cores on the east and west ends of the building. This would be highly energy conservative



although highly energy conservative due to solid east and west facades, does not perform well funtionally for this type of office bldg. no corner offices possible flexibility in office size severely limited



does not permit highly desirable corner offices creates large internal area which is difficult to divide into useful office space when floor occupied by more than one tenant

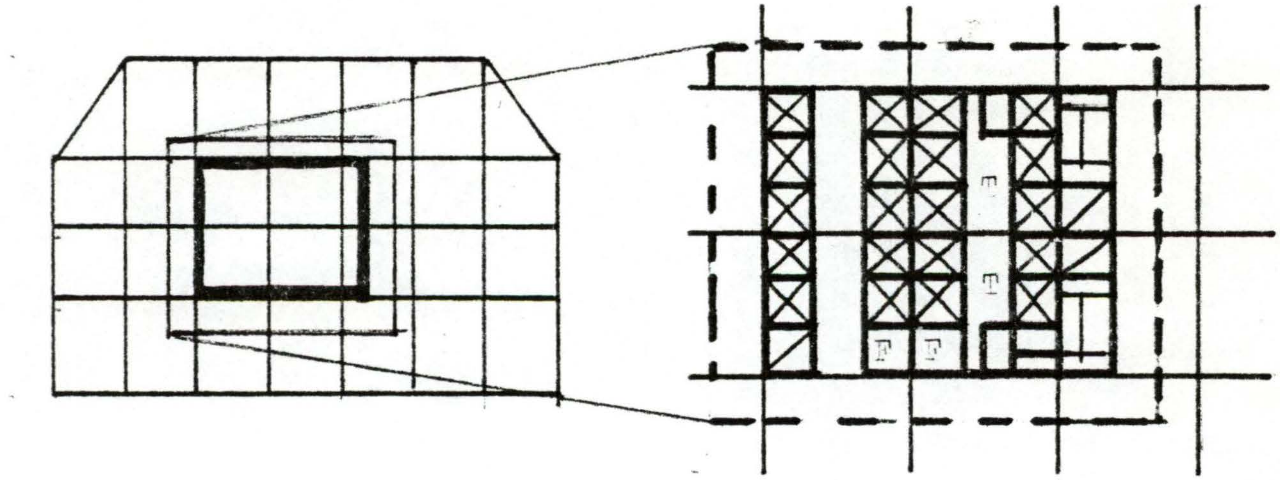


corner offices possible high degree of flexibility in office size possible

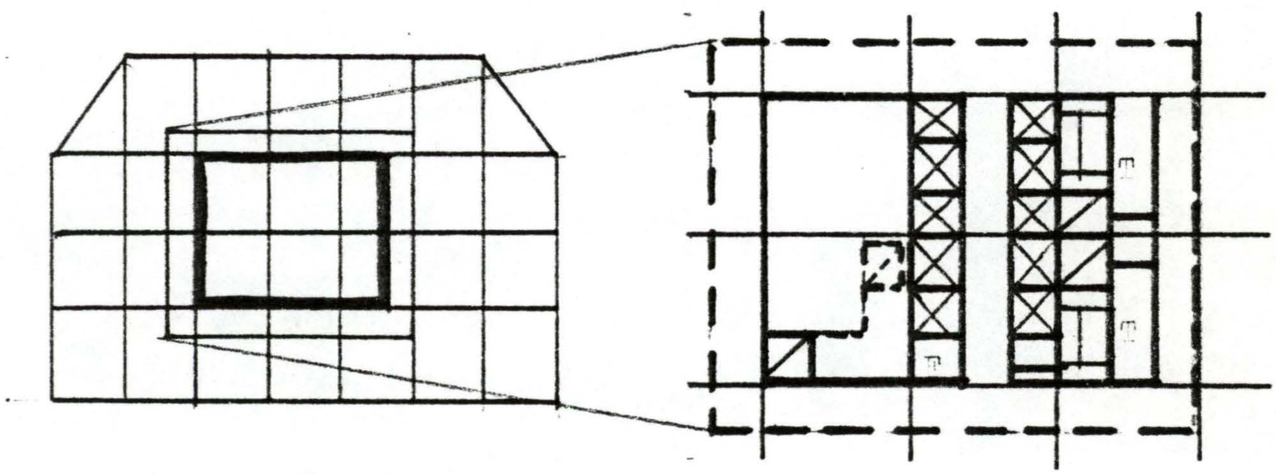
FIG. 4 ELEVATOR CORE LOCATION ANALYSIS

since there would be no glass on the exteriors there. However, this scheme usually does not permit the development of corner offices, and it can severely limit the flexebility and efficiency of the internal space which must make some provisions for a corridor. The cores could also be placed at the tower corners. This has the same problems of the previous scheme, though, in not permitting corner offices, and creating large internal areas which are difficult to subdivide on multi-tenant floors. The most usable solution (and the most typical) is a centrally located mechanical and elevator core. In this scheme corner offices are easily accomodated, and a high degree of office space flexibility is possible. After the building's analysis for its energy, functional, and image requirements developed into a preliminary design, the elevator core was designed as seen in figure 5. This produced an efficiency, including corridors, of 74% on floors 1 to 15, 72% on the 16^{th} and 17^{th} floors, and 80% on floors 18 to 31. The average building efficiency is 75%.

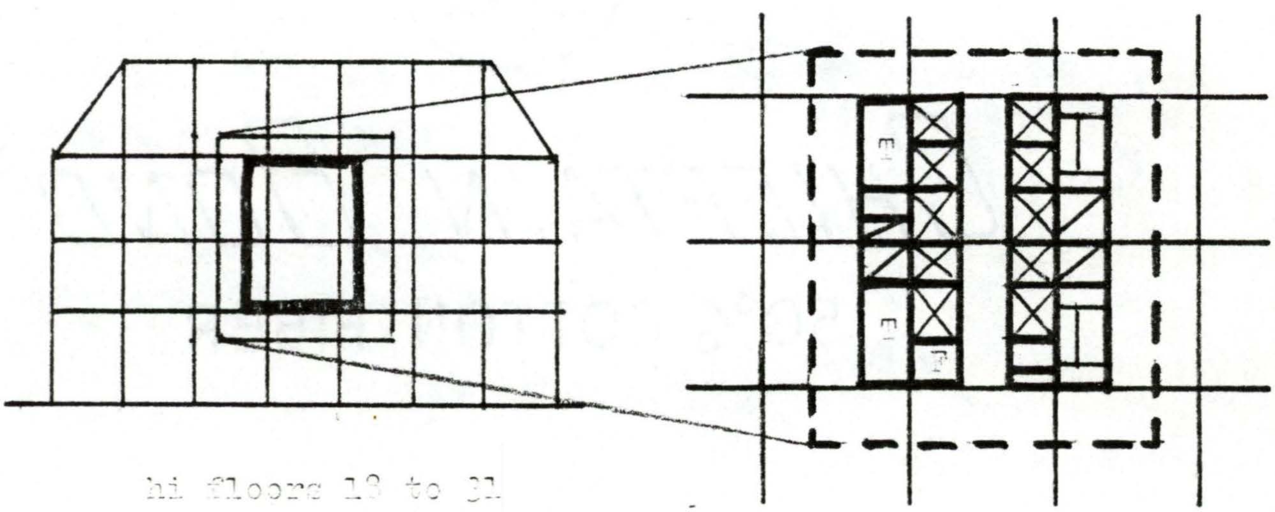
The factor of building image requires some special explanation. The developer of a high rise speculative office building usually attempts to construct it for the least initial capital investment that will yield an acceptable return in a relatively short amount of time. The usual result of this is the typical steel and glass box that is seen in major cities. However, in some cases a unique building design can increase the marketability of the office space. The building in this case would aid in providing a highly desirable corporate image or visibility on the city skyline. Although the construction of a high image building may require a greater initial capital investment, it is possible that it would be recovered in an acceptable time period through either a greater initial occupancy than normal (tenants attracted by the high visibility of



lo floors 1 to 15



floors 16, 17



hi floors 18 to 31

FIG. 5 ELEVATOR CORE SCHEMATICS

the building), a higher rental rate that might be possible to charge for location in a desirably visible building, or some compromise of these.

Penzoil Plaza in Houston, Texas is an example of how high image can increase a building's marketability. Much of the credit for its nearly 100% occupancy at its opening is given to the dynamic and unique building design. Although the design created some premium for special construction, it was profitable for the developer in the end (see fig. 6).[12]

If building image can be a marketing tool qhich can produce profits for a developer, then the incorporation of energy conservation in the architectural design might provide an image that a developer would be willing to pay the premium for. The ideal result would be a more profitable building, a reduced payback period for the energy conservation system since it would be paying for itself by reduced energy costs as well as increased profits, and a perhaps better incentive for a developer of a speculative office building to desire energy conservation. All of the case studies provide good examples of how energy conservation in design can provide attractive images for offices. Three of the case studies, the INA tower, Gunnar Birkerts' building in Detroit, and the Georgia Power Company corporate headquarters, are probably the best examples of image from energy criteria since they were also designed on budgets typical of speculative office buildings.

The building shape was the first factor analyzed for the office tower (see fig. 7). Building shape can significantly reduce energy consumption by maximizing the interior space to exposed exterior area ratio. The shape which has the highest ratio is a sphere. However, spheres are neither

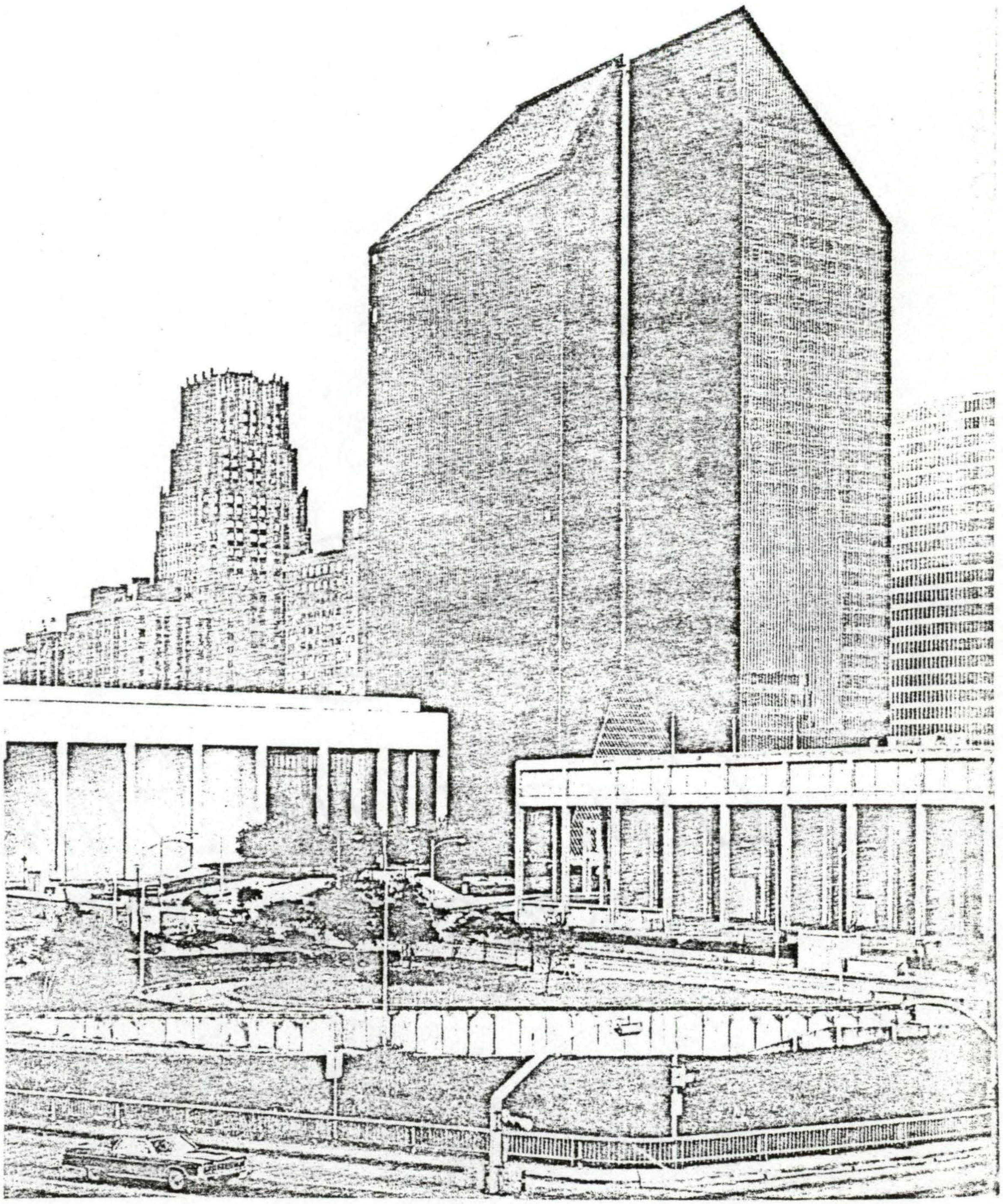
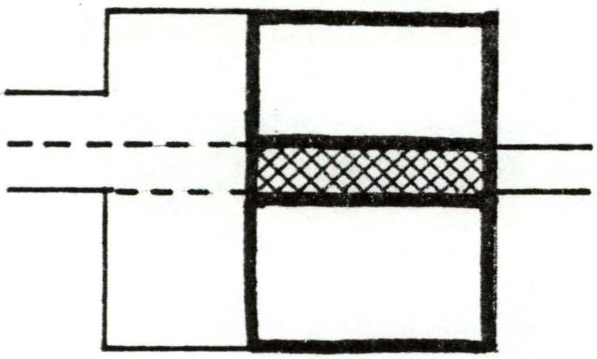
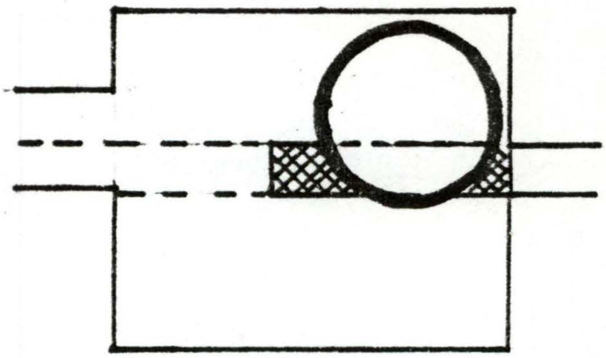


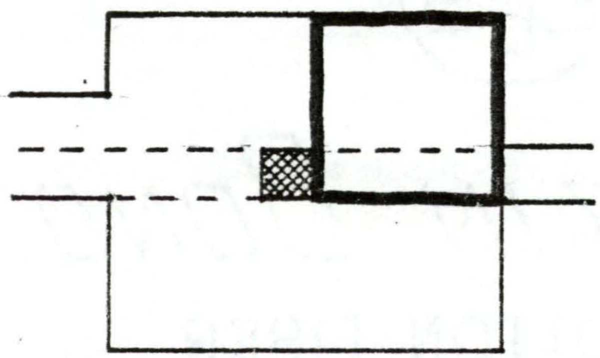
FIG. 6 PENZOIL PLAZA



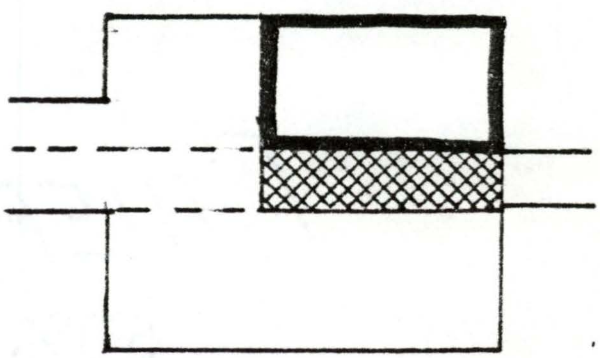
most energy conservative by skin exposure, can work well functionally, can provide high interior and exterior visual appeal



uses 37% more energy than atrium, creates functionally difficult spaces, would substantially cover mall glazing, provides high visual image



uses 45% more energy than atrium, funtionally efficient, would cover most of mall glazing, average visual image created by <u>shape</u>



uses 54% more energy than atrium, funtionally efficient, no interference with mall glazing, average visual image created by <u>shape</u>

FIG. 7 BUILDING SHAPE COMPARISON

economically nor functionally usable. The next best building type and shape is an atrium building. The shape is most closely cubical giving the highest interior space to exterior area ratio possible on a rectilinear grid. The additional glazing to cover a central lightwell, and the additional roof area still do not diminish an atrium building's thermal efficiency below that of the more typical high rise shapes. A study, by the firm of Thompson, Ventulett, Steinbach and Associates with Brody and Anglin of Atlanta, compared their design of the North Carolina National Bank Tower in Charlotte, North Carolina with a hypothetical atrium office building on the same sight with the same architectural program. Their results showed that an overall energy savings of nearly 50% was possible by using an atrium scheme in combination with other simple energy conservation techniques such as glass area reductions, south facade shading, and decreased floor-to-floor heights.[13] In another case, the GSA building in Topeka, Kansas, which is an atrium scheme, uses only 26,000 BTU/sq. ft./yr. of energy compared to an average office building's use of 100,000 to 250,000 BTU/sq. ft./yr. in that area.[14] An atrium type building inherently saves energy costs in other ways than through its shape. The introduction of a covered lightwell at the interior of the building can aid in reducing interior lighting levels which, in turn, reduces the cooling load of the building. Also, the lower height of an atrium building can result in energy saved by smaller and fewer required elevators.

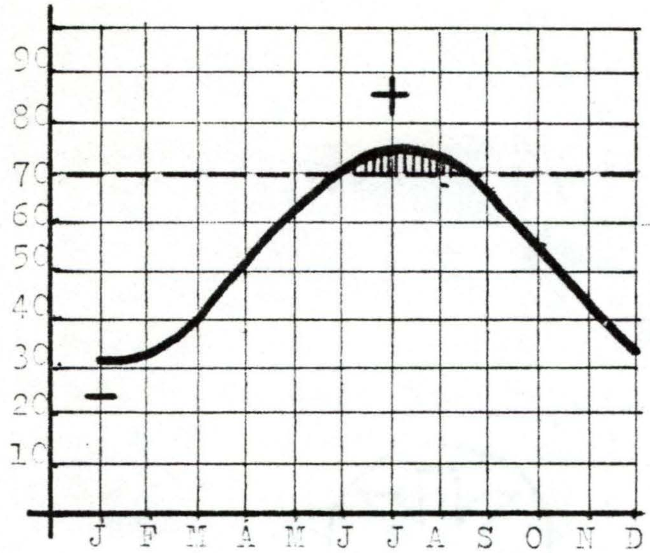
An atrium scheme can work well functionally on this site. It adapts structurally to the mall and stores below, and would provide usable office space. It could also provide a highly marketable image by carrying the concept of a skylit mall to its visual extreme. The atrium scheme, however, can only be utilized in certain cases where there is enough buildable ground area for the larger building footprint. Although enough area exists on the site, the atrium building would not demonstrate what can be done to conserve energy in the more typical high rise office building. For this reason this solution was not pursued.

A circular plan building was found to be the next most energy conservative shape after the atrium. It was found to use only 37% more energy by surface exposure than the atrium and could provide a high visual image. However, a circular tower does not work well functionally for a speculative office building. The degree of flexibility required on each floor for internal arrangements must be maintained at a maximum for the building to function economically. A circular plan requires special wall partitions within offices, or to separate offices, that may be prohibitively expensive. Also, the diameter of a circular tower would be so large that it would substantially cover the skylight glazing of the mall. This shape was, therefore, unacceptable for the tower.

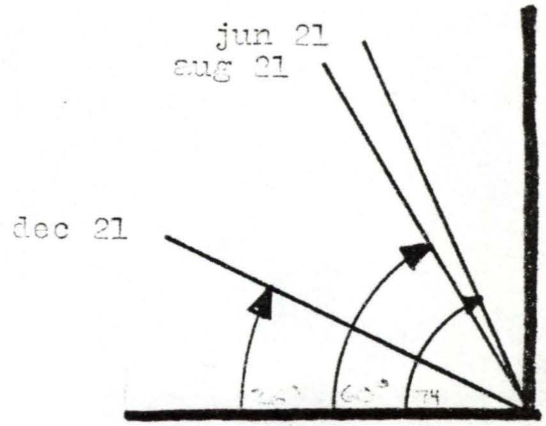
A square plan tower is most definitely functionally usable as office space. A square tower would use 45% more energy than the atrium by surface exposure. Its image might be considered average if only shape is taken into account. But, for the square footage needed, a square tower would cover most of the skylight glazing of the mall. This made it an unacceptable solution.

A rectangular plan tower was chosen as the best shape for the building. Compared to the other shapes, it uses the most energy; 54% more than the atrium by exposed surface area. Its image might be considered only average by shape. However, the rectangular plan provides functionally usable office space, and does not cover the mall skylight. The selection of a rectangular plan for the tower exemplifies that some energy conservation techniques cannot always be used. Even if a significant amount of energy can be conserved, there may be bigher priorities (i.e. retention of the mall skylight, usable, flexible office space) which must prevail.

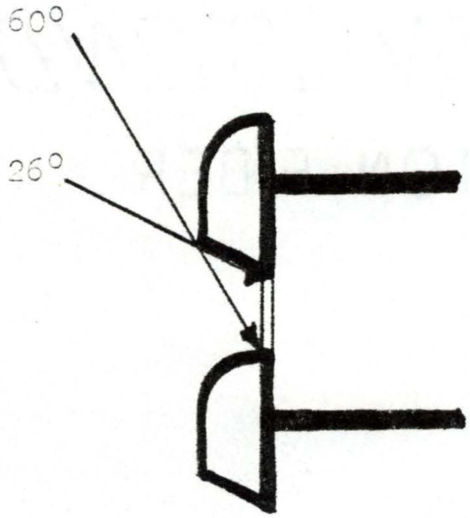
The poor energy efficiency of a rectangular shape for the tower suggested that the treatment of each facade, based on its solar orientation, could significantly control energy consumption. The south facade required the shading of high, hot summer sun to reduce summer solar heat gain, and required the admittance of low winter sunlight when solar heat gain was desirable. This resulted in the sunshading of the south facade (see fig. 8). The sunshade is designed to exclude sun during the months when solar radiation is greatest and the average ambient outdoor temperature is above the accepted comfort temperature of 70 degrees. As seen in the detail of the south facade in the next section, a small fin hangs below the sunshade. This fin enables a complete shading of the southern glass areas during the summer months without causing the sunshade to be, perhaps, excessively deep. The east and west walls are subject to the most drastic seasonal changes in sunlight direction and intensity. During the summer, significant amounts of unwanted solar heat gain will begin in the early morning on the east facade, and will linger in the late afternoon on the west facade. Three solar control methods were compared to reduce the effect of these conditions (see fig. 9). An overhang to completely shade the window areas of the east and west facades was considered. It would provide the best protection from unwanted heat gain, but due to the low angles of the sun on the facades, the overhangs would probably be of excessive length. A sawtooth pattern was



average monthly temperatures

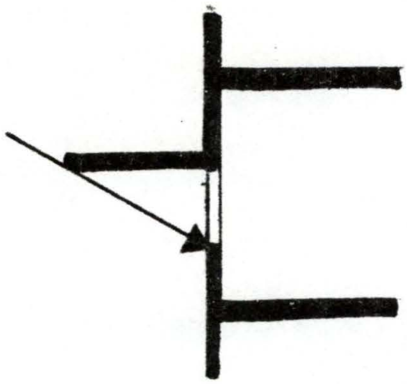


solar angles

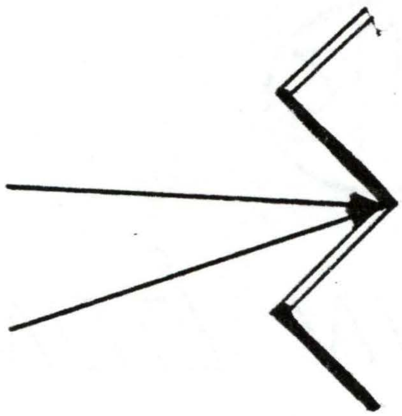


resultant south facade
design shades intense
summer sun and allows
desirable winter sun in

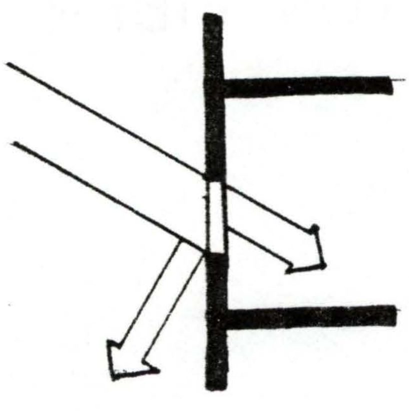
FIG. 8 SOUTH FACADE DESIGN CRITERIA



overhang
summer heat gain characteristics would be the same as north glass, but overhang length becomes possibly excessive



sawtooth facade
prevents excessive heat gain in summer, but also eliminates desirable heat gain in winter



reflective glazing
provides good thermal performance to reduce summer heat gain, and allows some winter sunlight into the building

FIG. 9 EAST AND WEST WALL DESIGN CRITERIA considered with glass areas facing to the north. This provided good control of summer morning and afternoon sun, but completely eliminated the possibility of receiving any desirable heat gain during the winter. The use of insulated reflective glazing was found to be the best compromise technique for the east and west facades. It provided good thermal performance in reducing summer solar heat gain, while still allowing some winter sunlight into the building. The north facade is basically one that must be well insulated since it is the coldest side. It receives no direct sunlight, and experiences cold winter winds. Although the north facade's heat loss may be advantageous in the summer, the lack of significant solar heat gain year round and the length of the heating season in Philadelphia dictates that insulated glass be used.

After the facades were designed according to their orientations, the building skin was designed to maximize their energy conserving potential. Non-vision areas of the building are well insulated on the south sunshade, and use insulated steel panels on the other sides. The "U" value of these areas is .044. Although thick concrete walls or panels could've provided additional thermal mass to the building, they would also increase the structural requirements. Highly insulated steel or glass panels achieve similar thermal values as concrete while reducing the structural requirements and therefore structural costs.

Vision areas are reduced to a minimum. The sill of the glass is 3 feet above the floorline. This was the highest sill level possible that allowed vision out of the glass while seated in an office. The window head is 7 feet above the floorline. This was seen to be the minimum height possible without risking a claustrophobic feeling. The fact that many doors are 7 feet high contributed to the reasoning that this window height should be sufficiently comfortable.

All of the glass is double glazed and either is tinted grey or is a grey reflective glazing. The north and south glazing is tinted grey without a reflective coating. The southern facade's sunshade shields against the summer sun and allows in the winter sun that would only be hindered by a reflective glazing. The northern facade receives no direct sunlight, but still receives diffuse solar heat gain that is useful in the winter. The east and west facades, since they're exposed to early and late solar gains, use a reflective grey coating. The glass appears to be uniform as it goes around the building, but is really different depending on the facade orientation. The glass also has attached to its inner light a material known as a heat mirror. This is a thin transparent film which is reflective to infrared radiation emitted by room temperature surfaces. The heat mirror surface in combination with the insulated glazing reduces the conductive, convective, and radiative heat losses to such an extent, that perimeter under-glass heating convectors are unnecessary.[15]

The combination of the energy considerations resulted in the building concept (see fig. 10). The southern face of the building was treated as a special facade due to its articulation to create the sunshade. The other faces of the building, a glass and steel skin, were seen as a taut wrapped skin behind the special southern facade. A building form developed which provided the most literal translation of the concept by angling the two northern corners of the building. The angled edges were not perceived to diminish the functional efficiency of the office space considerably, while they also added to the building's image from the unusual shape. Also, when

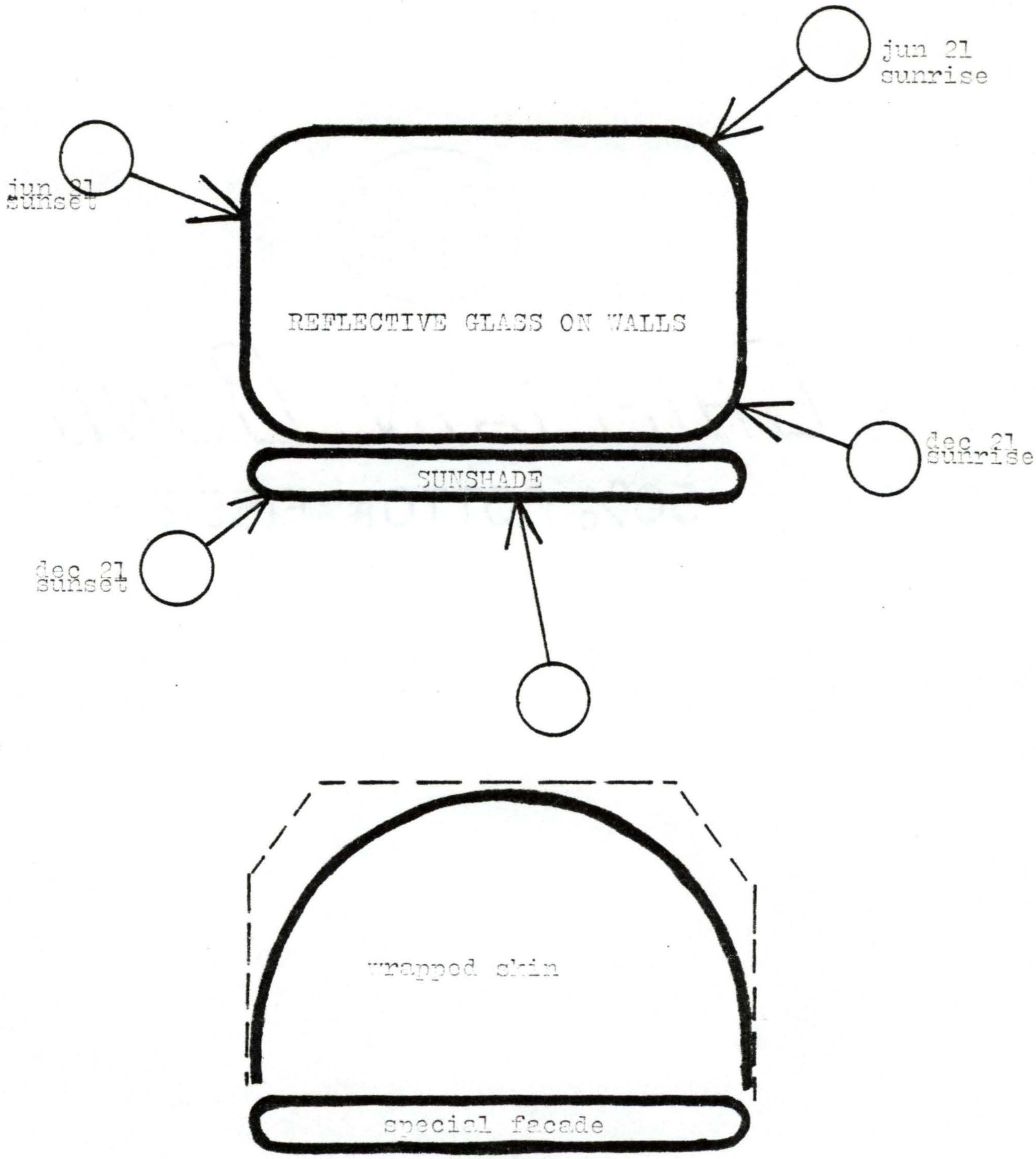


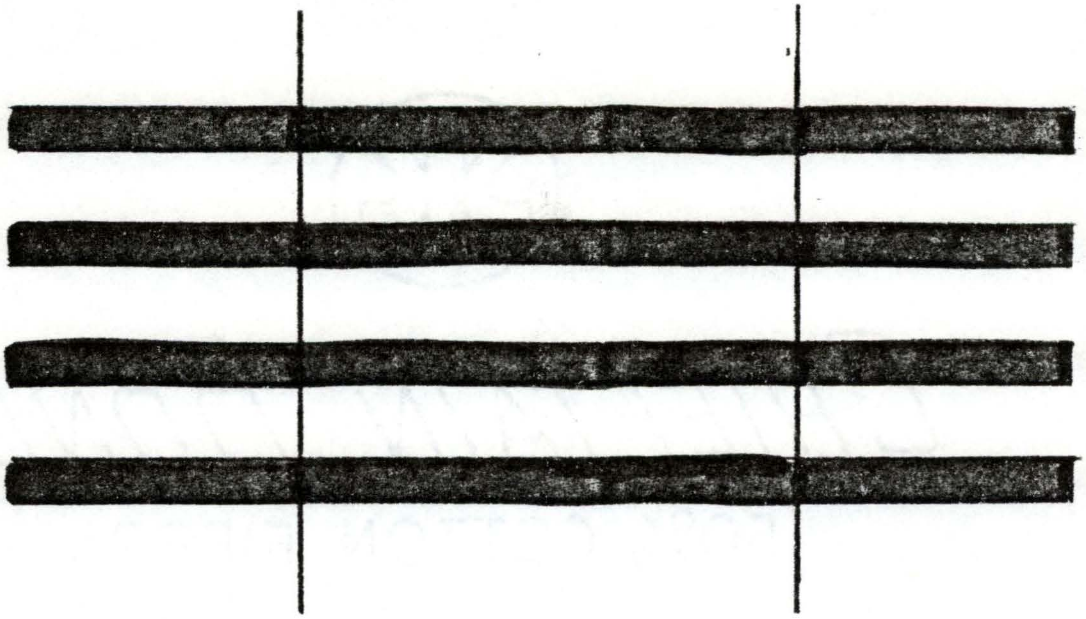
FIG. 10 BUILDING DESIGN CONCEPT

compared to other building shapes, the angled edges reduced the exposed surface area to such an extent, that the building was more energy conservative than the square plan tower.

For aesthetic reasons, it was desirable to emphasize the angled edges by running the glass down to the floor which results in 7 foot high glass on those edges. A conflict developed between the aesthetic desire and the resulting increase in energy consumption caused by the additional glass area. This was resolved by using more thermally effective one inch reflective thermopane on the 7 foot high glass area. The resulting "U" value was equal to the 4 foot high standard insulated reflective glazing it replaced (see fig. 11).

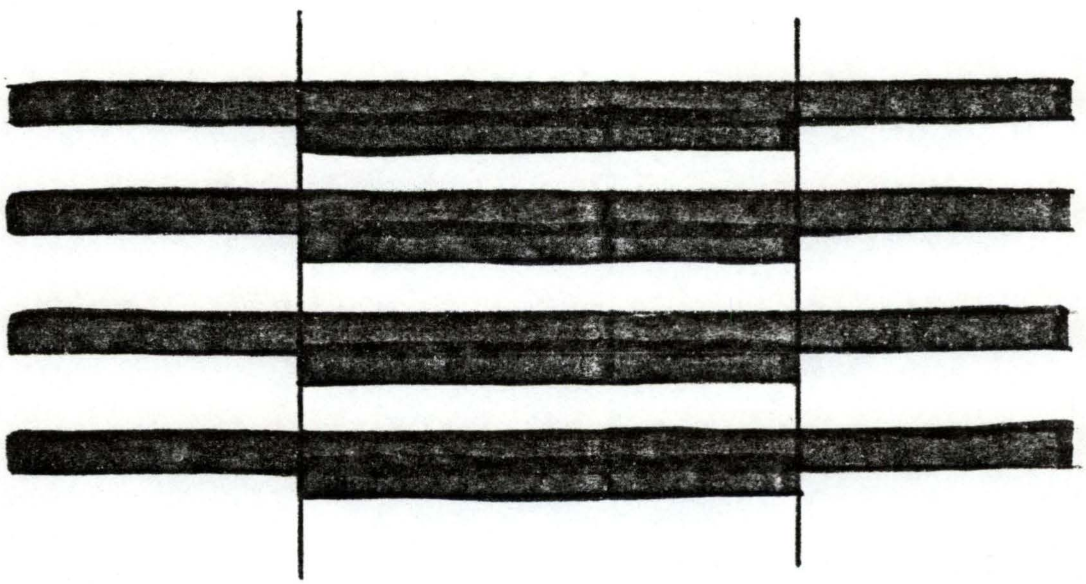
The average annual energy consumption was calculated and compared with the average energy consumption of similar buildings in the Philadelphia area. Figure 12 shows that the designed building consumes an average of 21,580 BTU/ sq. ft./yr.. This figure does not include the energy necessary for fans, pumps, and elevators, and does not include provisions for computer equipment rooms.

The mechanical systems (HVAC, lighting, vertical transportation) were designed on a general level. Mechanical systems can become much more energy efficient from good control. For an office building of this size, it is assumed that some form of computer control would be employed. The exact degree of control would depend on the economics of a particular system, but the low cost of computers presently would probably allow a fairly extensive system. Computer control would determine the HVAC requirements, control outdoor air intake, adjust fan speeds, regulate temperatures, and start up and shut down the



U value of 4' high std. reflective glazing

EQUALS



U value of 7' high 1" reflective thermopane

FIG. 11

	sq. ft.	BTU/s.f./yr.	KWH/s.f.	OIL gal/s.f.
Phila.	1,149,732	90,061	26.4	.6
"	182,830	102,734	30.1	.68
"	864,800	219,800	64.4	1.5
"	900,000	168,504	49.4	1.1
Reg. Avg.	———	65,000	19	.43
Nat'l. Avg.	———	64,000	18.75	.43
New Fed. Std.	———	55,000	16.1	.37
Design	874,200	21,580	6.3	.14

FIG. 12 COMPARATIVE BUILDING ENERGY CONSUMPTION

building when required. Although individual control may be highly desirable, it is usually expensive and becomes inefficient when systems are set at high levels during working hours and not turned off at the day's end.

The HVAC distribution system chosen is a single duct, variable volume, constant temperature system. This is considered to be one of the most energy efficient distribution systems available. All the ducts and the return air plenum in the ceiling are insulated with 1/2 inches of fiberglass to prevent unwanted heat loss or gain of the conditioned supply air. Return air is channeled through the luminaires to recover heat generated by them. This prolongs the luminaires' life and increases their efficiency.

The mechanical plant must provide year round cooling to counteract the heat gain from the occupants and lighting. Several energy conserving features are designed to allow efficient operation. Outdoor air is first passed through a dry desiccant bed to dehumidify it permitting the electric chiller to simply reduce the air temperature. In most buildings, excessive energy is used by the chiller to condense the moisture out of the air, dehumidifying it, and then reheating it to a comfortable temperature. The chiller also charges a chilled water storage tank at night to take advantage of off-peak utility rates. The chilled water stored would then be used to cool the next day's air. Waste heat from the occupied space (from lights and people), and from the condenser coils of the chiller charges a phase change material heat storage tank. The phase change material would be a eutectic salt which can absorb large quantities of heat in a relatively small space compared to water or air storage. The stored heat would be used to recharge the desiccant beds and/or to preheat the hot water supply for the building. The stored heat could also be used to humidify winter air.

The type of lighting used will depend on the type of office layout, and the individual tenant. High intensity discharge (HID) lamps are the most energy efficient lamps available, however, some have a considerable color correction problem and can create some unattractive results. It would be recommended that some form of task/ambient lighting system be used. Task lighting in any office is highly efficient since it focuses higher light levles only on the area required. At the perimeter areas, it might be possible to reduce lighting levels by using photocells to shut off ambient light sources when daylight levels are sufficient. Despite its energy savings however, the slight changes in light direction and quality as the daylight fluctuates could be too distracting to workers.

The elevators for the building were selected to carry approximately 12% of the building's total population in 5 minutes during morning peak hours. The size and speed of the elevators should be as small and as slow as possible without causing excessive wait time. The reduction of numbers of elevators, and slightly longer wait time increases the elevators' efficiency since it carries near its capacity more often, reduces the core size, and reduces elevator costs. Double deck elevators, which have a high degree of energy efficiency, were considered, but the extra space required for a double deck lobby interfered with the need to provide as much commercial space as possible in the mall area. In addition, further energy could be saved by turning off some elevators during non-peak hours.

After all of the factors presented here were evaluated, the following design resulted.

Architectural Response

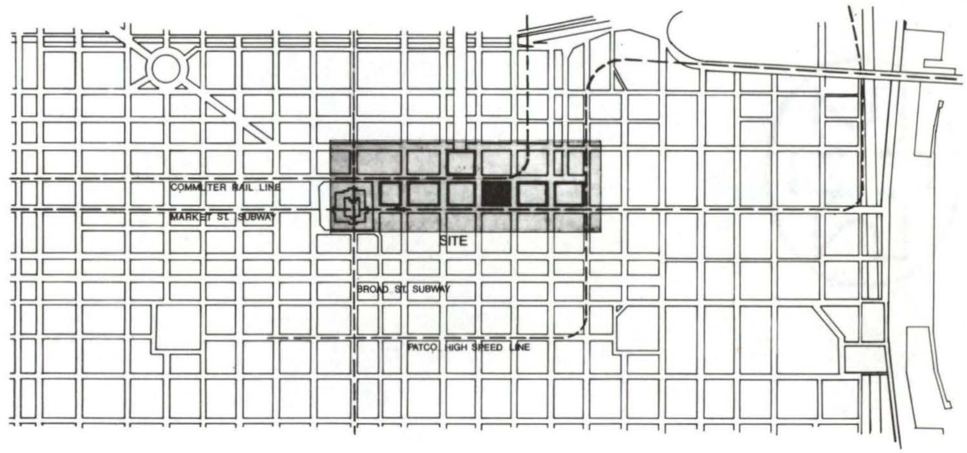
6

AN ENERGY CONSCIOUS HIGH RISE OFFICE BUILDING

PHILADELPHIA, PA.

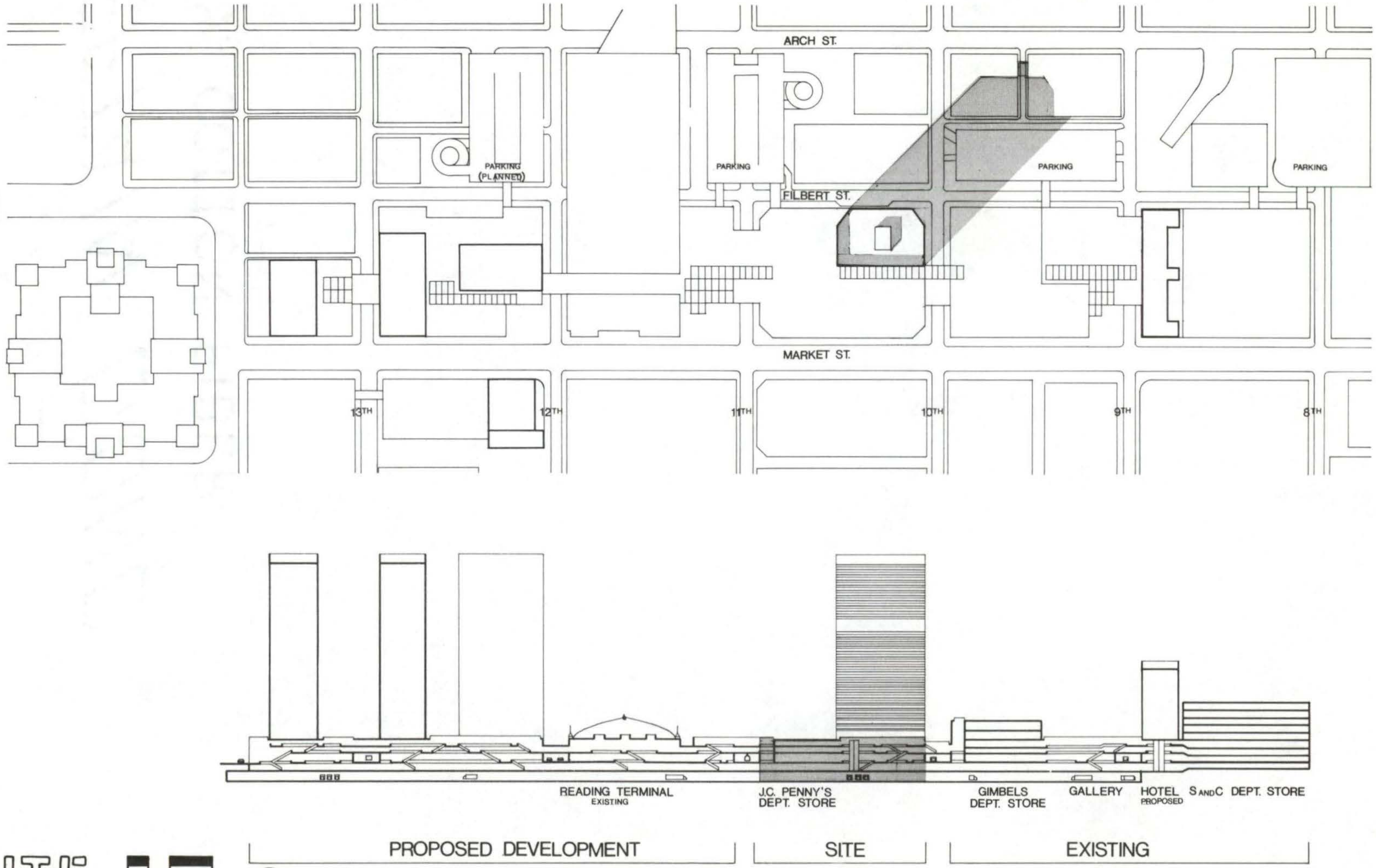
A TERMINAL PROJECT SUBMITTED TO THE FACULTY OF THE COLLEGE OF ARCHITECTURE, CLEMSON UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARCHITECTURE

PHILADELPHIA



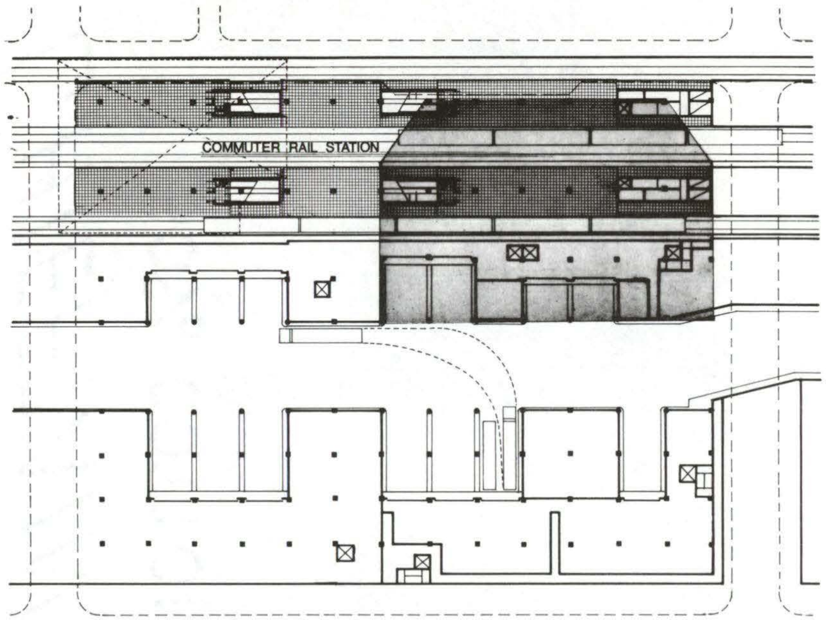
CENTER CITY

SITE LOCATION

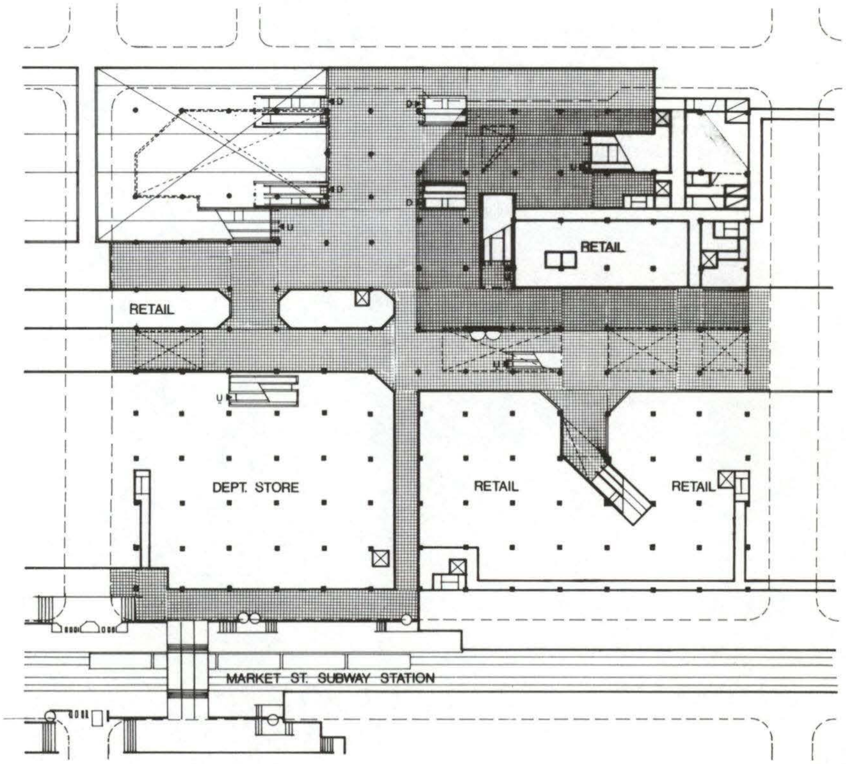


SITE

0 50 100 200



TRUCK LEVEL



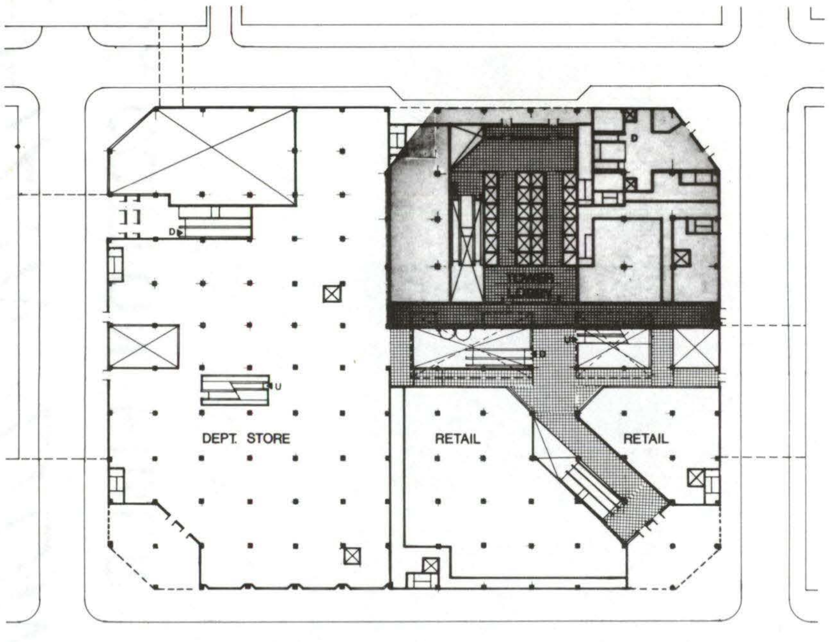
MALL LEVEL

OPEN TO ABOVE

OPEN TO BELOW

TRUCK & MALL LEVEL PLANS

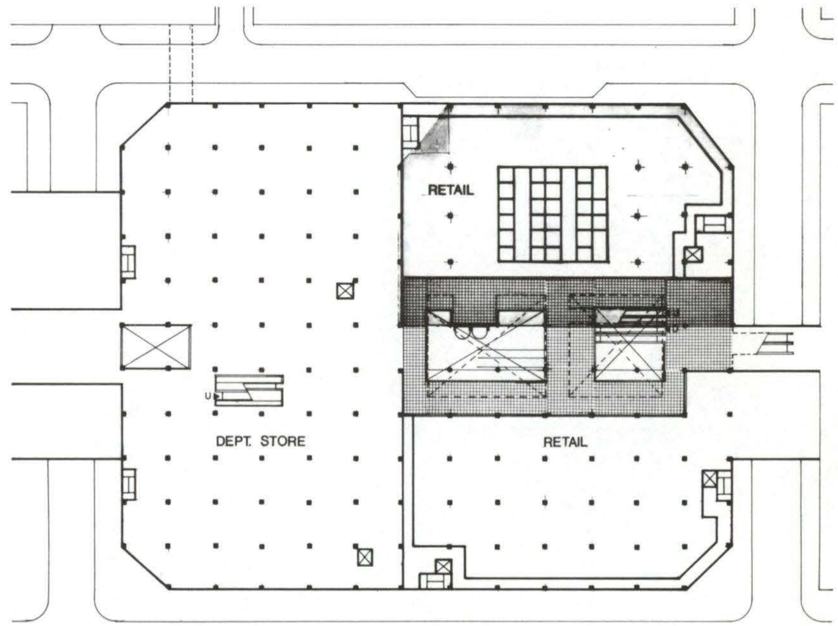
0 16 32 64



STREET LEVEL

OPEN TO ABOVE

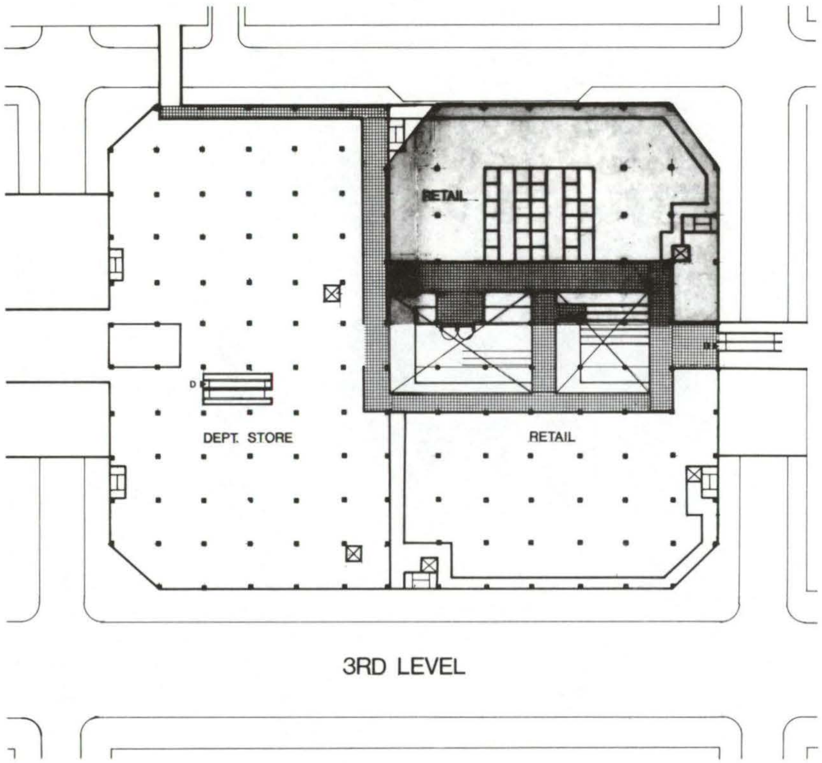
OPEN TO BELOW

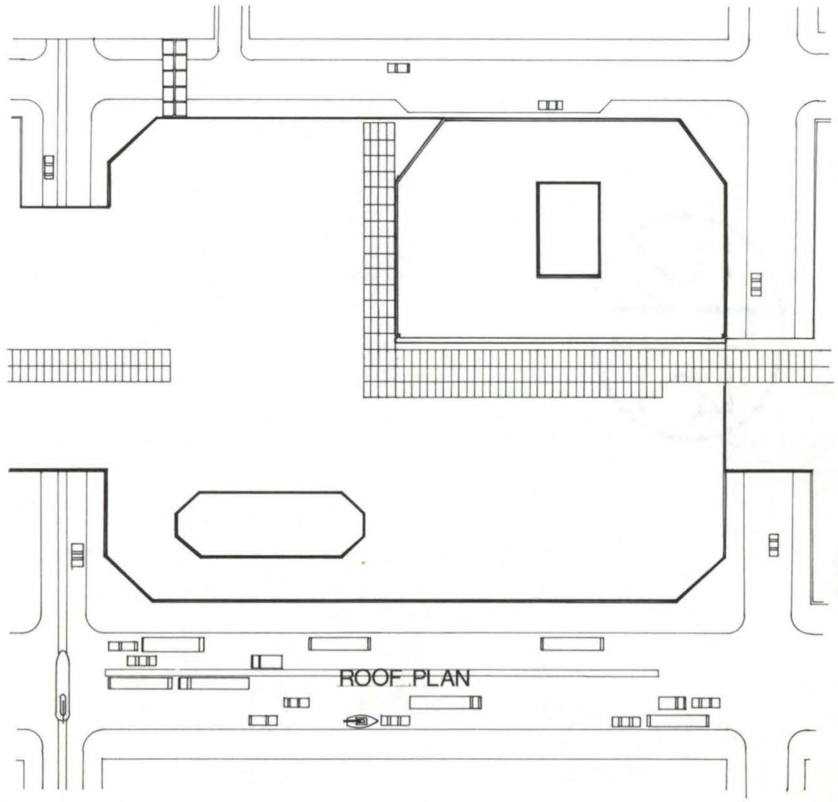


2ND LEVEL

STREET & 2ND LEVEL PLANS

0 16 32 64





OPEN TO BELOW

3RD LEVEL & ROOF PLAN

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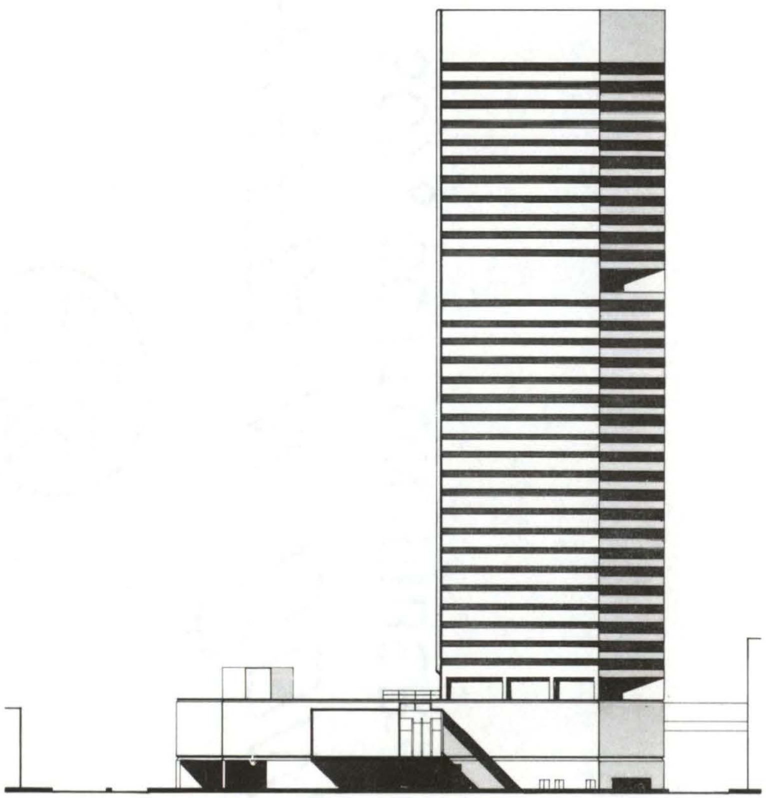
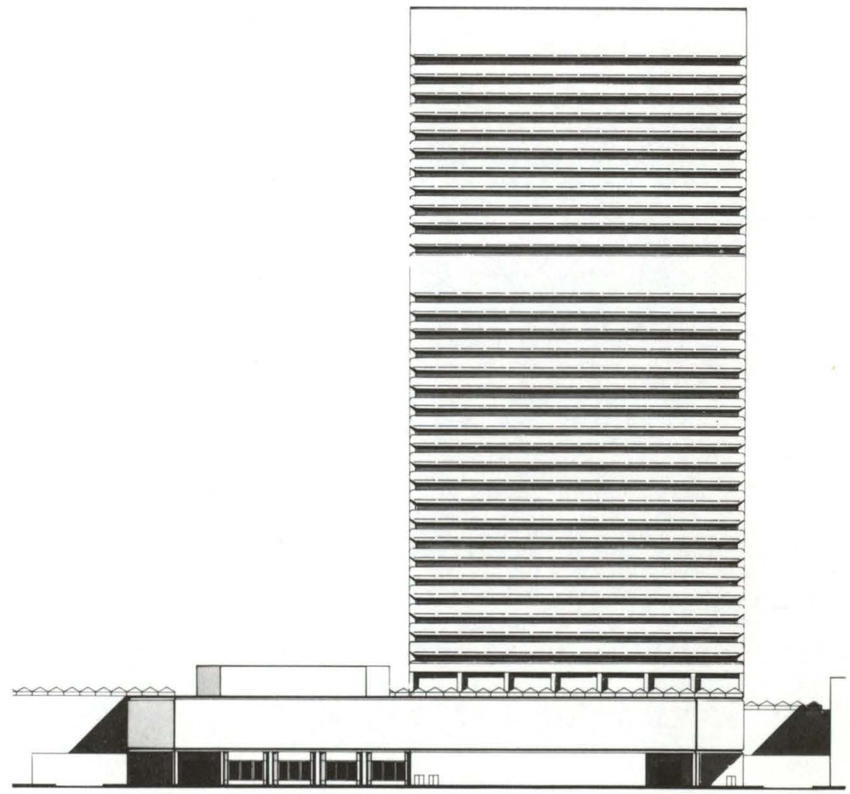
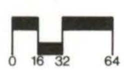


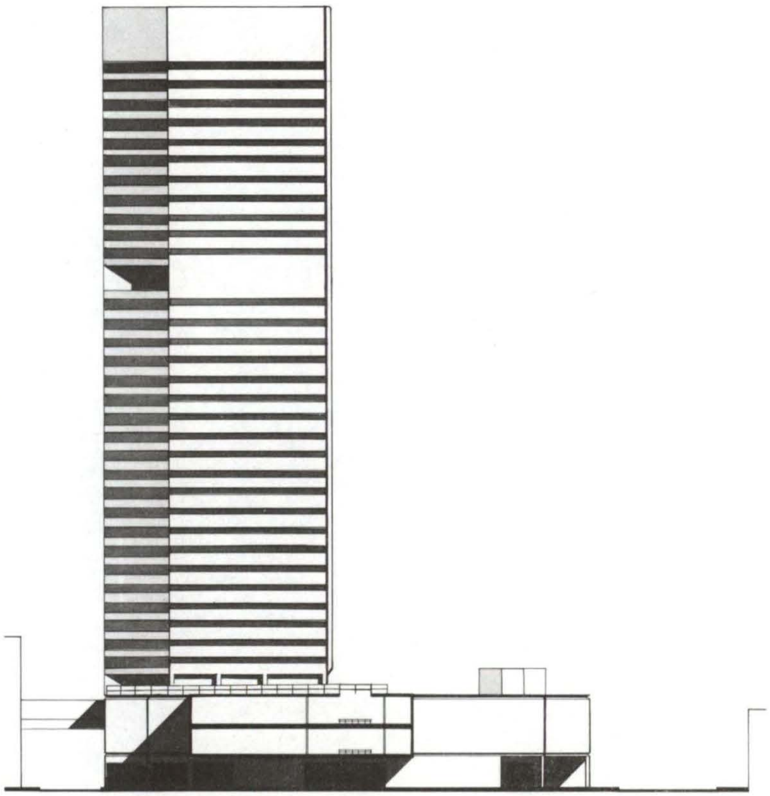
EAST



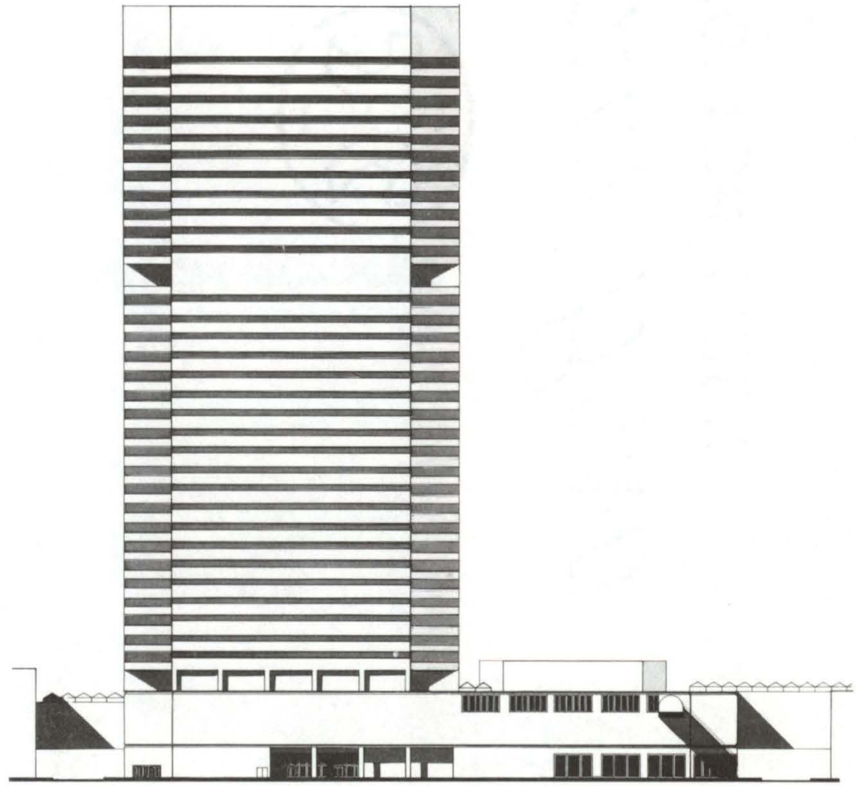
SOUTH

ELEVATIONS





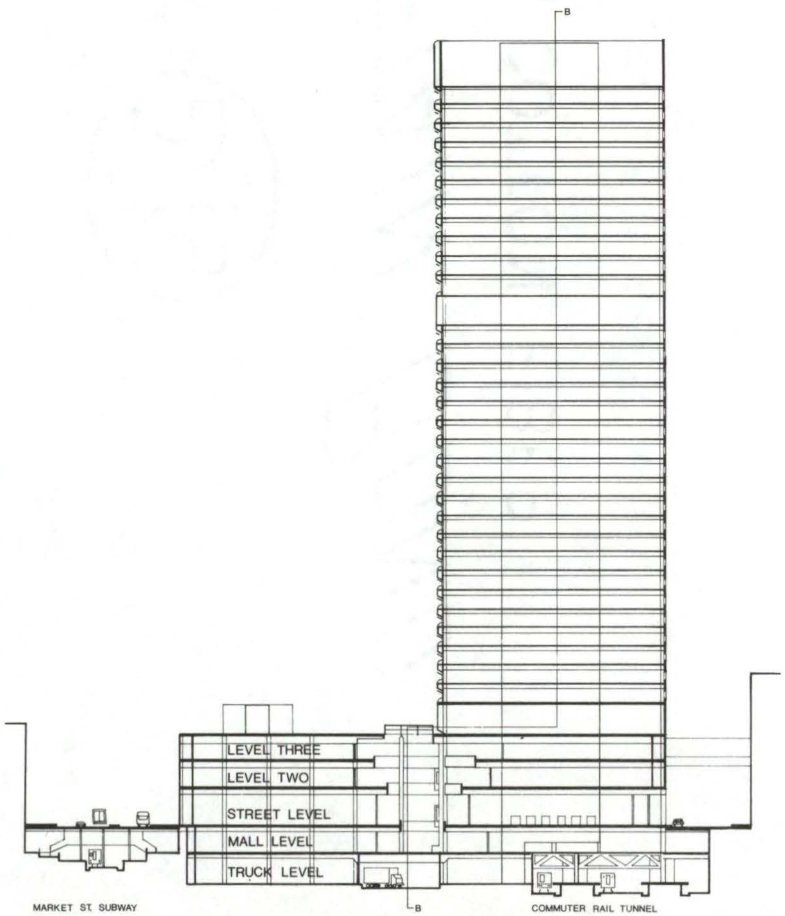
WEST



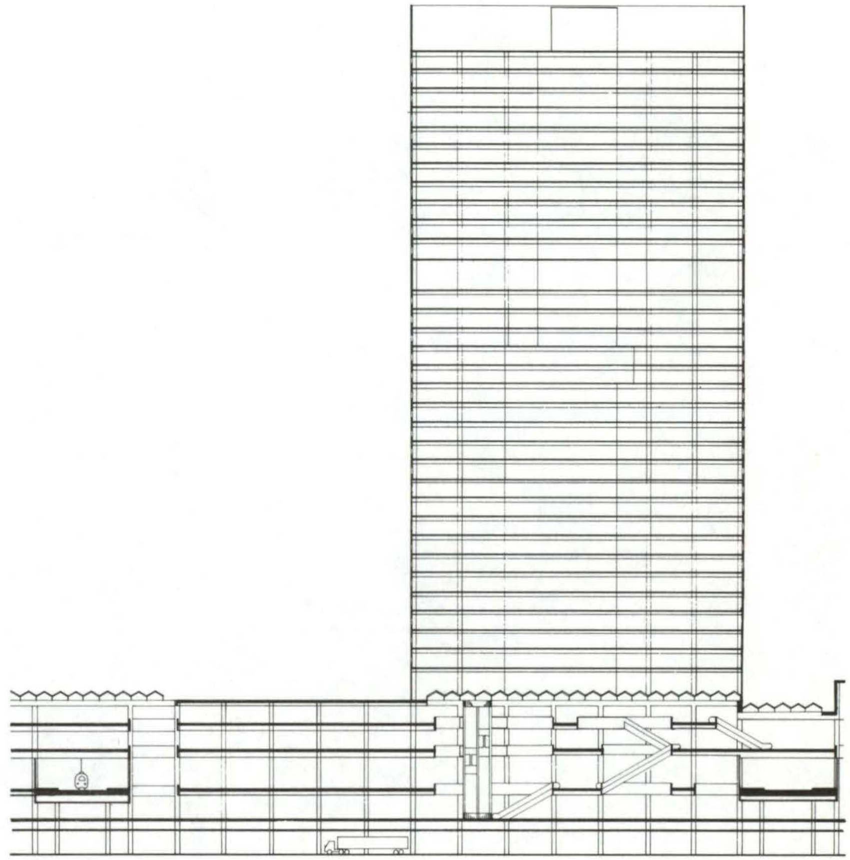
NORTH

ELEVATIONS

0 16 32 64

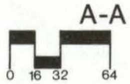


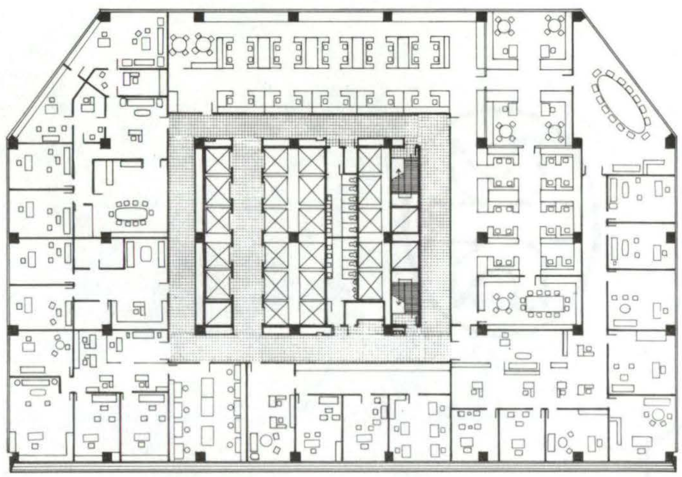
A-A



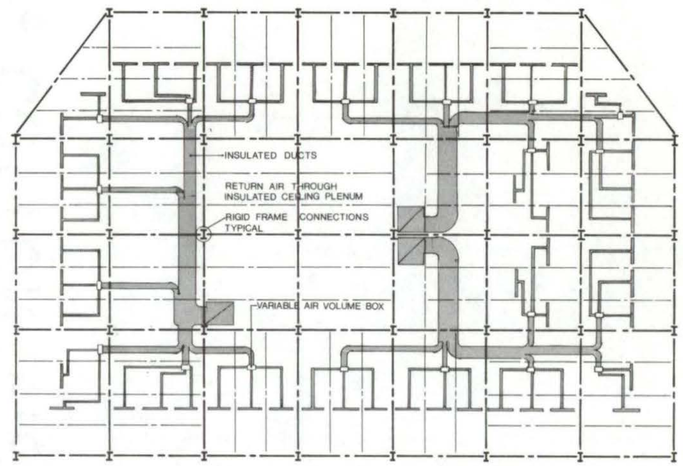
B-B

SECTIONS

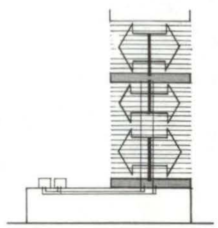




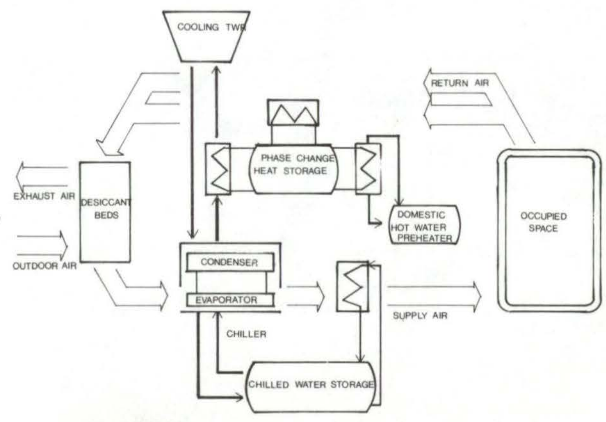
TYPICAL OFFICE FLOOR



STRUCTURAL, MECHANICAL SYSTEMS

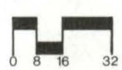


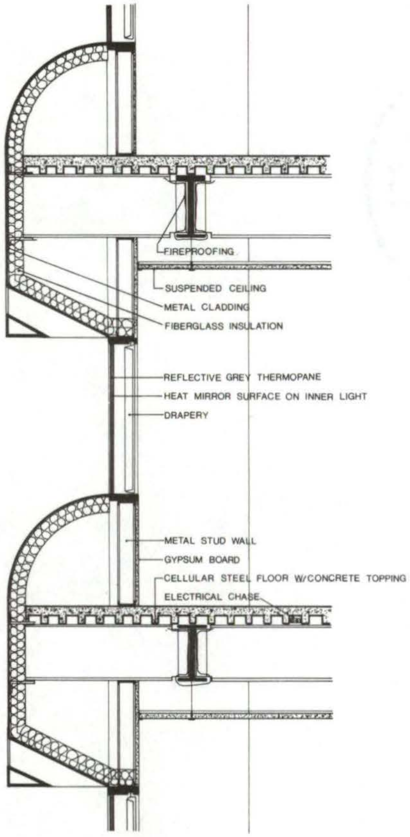
VERTICAL MECH. DISTRIBUTION



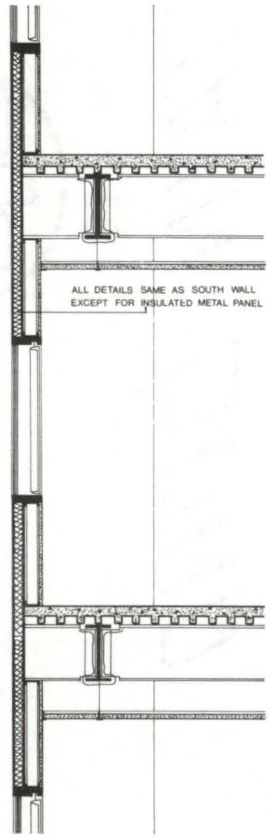
MECHANICAL SYSTEM SCHEMATIC

TYPICAL FLOOR MECHANICAL & STRUCTURAL PLANS

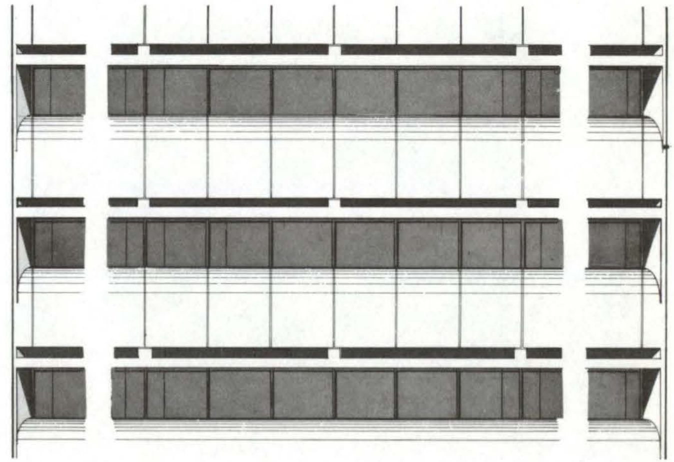




SOUTH WALL

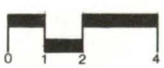


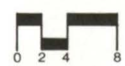
EAST WALL



SOUTH FACADE

DETAILS





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Special thanks to the following for furnishing information by mail, telephone conversation, or personal interview.

Architectural Research Corporation, Livonia, Michigan

Dow Chemical Company

Prof. David M. Egan, P.E., Clemson University

Mr. Dwight Jones, Ms. Merrill Scogin, Mr. William Viehman, Heery & Heery, Architects & Engineers, Inc., Atlanta, GA

Mr. Roger Lewis, Bower, Fradley, Lewis And Thrower Architects, Philadelphia, PA.

Libby-Owens-Ford Company

National Solar Heating and Cooling Information Center, Rockville, MD

Otis Elevator Company

Philadelphia Redevelopment Authority

Mr. Cal Thomson, Cope, Linder, and Wallmsley Architects, Philadelphia, PA

Mr. Noel Tyson, Mitchell and Giurgola Associates, Philadelphia, PA