ENERGY EFFICIENT COMMERCIAL BUILDINGS:

A STUDY OF NATURAL DAYLIGHTING IN THE CONTEXT OF ADAPTIVE REUSE

by

JOHN STEPHEN CROWLEY
B.A. UNIVERSITY OF NEW HAMPSHIRE 1976

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF ARCHITECTURE

at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 1982

Signature of Author ______________________
Department of Architecture
May 7, 1982

Certified by ______________________
Robert Slattery
Associate Professor of Architecture

Accepted by ______________________
Shun Kanda
Departmental Committee for Graduate Students

Energy Efficient Commercial Buildings: A Study of Natural Daylighting in the Context of Adaptive Reuse

By

John Stephen Crowley

Submitted to the Department of Architecture on May 7, 1982 in partial fulfillment of the requirements for the Degree of Master of Architecture.

ABSTRACT

Daylighting is a powerful design element which can have a dramatic impact on people's perception of space, physical and psychological well-being as well as a building's annual and daily energy requirements.

Understanding of the way daylight can penetrate a space, dramatize materials, create shadows and patterns, and is reflected and diffused gives an appreciation for light energy as a natural force.

Historic precedents, and the response of contemporary architecture to the problems and possibilities of daylighting demonstrate the changes in values, and attitudes about the role of natural light and ventilation as they have been constructed in the landscape over a period of centuries.

Three areas are investigated in considering the role of natural daylighting in the context of adaptive reuse. One is the historical evolution of atriums, their use as climate conditioners, as building form generators and as receptors of daylight. The second area is a qualitative and quantitative study of daylight. Topics explored are glazing location, diffusion and reflection elements, and psychological effects, impact on annual energy consumption and physical modeling. The third area of study is the development of a generic atrium piece which is the principal form and organizational generator of a design proposal for the reuse of a typical early 20th century warehouse building.

Thesis Supervisor; Robert J. Slattery
Title; Associate Professor of Architecture

ACKNOWLEDGEMENTS

I wish to take this moment to thank Zaurie who has so patiently supported me in a period of my life which is summed up as one of never-ending over commitment coupled with a sincere desire to learn.

I also wish to thank my close friends, colleagues, and professors who have so willingly given of their time and shared their experiences and knowledge during my four year engagement with M.I.T. Specifically, I would like to acknowledge and thank those individuals who have strongly influenced, in a positive and beneficial way, the direction of my life and career:

Charlie Wing, who first convinced me to think about buildings and energy;

Timothy Johnson, who has given invaluable guidance and inspiration while at M.I.T.;

Ralph J. Johnson, who has given me the opportunity to get direct experience with those issues of great concern to the American housing industry and who has so kindly enabled me to continue my work with the National Association of Homebuilders Research Foundation while completing this phase of my education;

to all those involved with the STAR Foundation who have provided me spiritual support and an outlet for healthy idealism and;

lastly, to Robert Slattery, Harvey Bryan and William Lam, who have advised, guided and helped to focus my energy and effort during the twelve months I have worked on this study.

The following is an excerpt from Louis Kahn's "Silence and Light" lecture given at the School of Architecture, Zurich. February 12, 1969.

"I turn to light, the giver of all presences; by will; by law. You can say the light, the giver of all presences, is the maker of a material, and the material was made to cast a shadow, and the shadow belongs to light."

"I did not say things yet made here, desire being that quality, that force, unmeasurable force, everything here stems from the immeasurable...but one can say, light to silence, silence to light, has to be a kind of ambient threshold and when this is realized, sensed, there is inspiration."

"A sculptor can make square wheels on a cannon to express the futility of war. Unfortunately, the architect must use round wheels if he wants to bring his stone from place to place. From this, you get the sense of that which tends to be in the market place, and that which never reaches the market place."

"I cannot speak enough about light because light is so important, however, actually structure is the maker of light. When you decide on a structure, your deciding on light. In the old buildings, the columns were an expression of light, no light, light, no light, light, you see. The module is also light - no light. The vault stems from it. The dome stems from it, and the same realization that you are relearning light...."

"Light has an order in the sense that is given by structure, and that the consciousness of the orders be felt."

INTRODUCTION AND OVERVIEW

Energy consumption in both new and existing construction has been the topic of much criticism, review, analysis, evaluation, and growing concern for the past eight years. Presently, it appears that the concern about energy consumption in buildings of both residential and commercial sectors is picking up momentum rapidly. The past five years have been filled with the disillusioning thought that cheap energy would cascade forth once again. However, after nearly a decade of hampered supplies and skyrocketing prices caused by inflation, OPEC price hikes and embargos, supply hoarding by multinationals, and lastly, a call for across-the-board deregulation by the omnipresent Reagan administration, the American public and specifically the building industry are beginning to view energy as a crucial issue for at least the next decade.

At present, annual energy costs equal the annual mortgage payment for some homeowners and commercial building owners. The importance of the buildings sector in national energy use is shown by the fact that 34% of the total United States energy consumption is used in residential and commercial buildings, accounting for 28 quads of energy in 1977.

Commercial buildings account for 31.4 billion square feet of floor space and are expected to increase 64% to 51.6 billion square feet by the year 2000. Commercial buildings are small warehouses, retail shops, offices, schools, hospitals, etc.

Preliminary indications suggest that for both new and retrofit applications, natural passive solar energy systems for heating, cooling, and lighting in commercial buildings can be cost-effective. Results for buildings in DOE's Passive Commercial Buildings Demonstration Program indicate nothing more than that a wide range of performance and cost can exist.

In this age of standardized buildings and mechanical heating and cooling, it seems to have been forgotten that climate-conscious design was once the norm. The focus of this thesis is twofold ; one, to explore, analyze and evaluate a series of natural energy systems addressing such forgotten issues as daylighting, shade control, ventilation, passive heating and cooling, thermal energy storage techniques, window treatments, and energy distribution in vernacular and contemporary buildings. Two, to develop and test an energy responsive design vocabulary in the context of adaptive reuse, focusing on the use of daylighting as a principal form generator.

Since the beginning of the industrial revolution and the migration to the cities that accompanied it, traditional architectural forms have been abandoned by one culture after another. The climate-sensitive building designs that had been developed prior to this period were not easy to adapt to cities and the growth of urban populations encouraged a standardization of architectural styles.

As modern architectural styles matured over the last century, natural energy considerations have come to play a non-existent part in the architects' program. Architect Richard Stein writes that "during the 1920's many of the most prophetic architects projected the form of the future as being freed from the rigorous demands of climate and orientation". The convenience of modern heating and cooling systems and the relatively low cost of fuels persuaded customers, architects, and builders alike that any concern about energy efficiency was a waste of time. This lack of attention to climate-sensitive design principles and construction techniques coupled with energy-intensive heating, cooling, and lighting techniques has proved costly. The fuel requirements of buildings have more than doubled between 1950 and 1970.

The past five years have brought about a new interest in climate-sensitive design principles and building techniques. Many foreign governments and the U.S. Department of Energy have funded extensive programs to examine the benefits of passive climate-sensitive strategies. Preliminary results and demonstration programs indicate substantial savings can be obtained through the implementation of strategies that have become nearly extinct in the building industry in the last century.

The integration of new technologies, age-old climate-sensitive practices and a commitment to relieving the banality of the current built environment, open an opportunity for the rediscovery of a regional architecture. An approach which embodies the best of the new materials and time proven techniques may result in a concern and commitment to improving our built environment that will overwhelm the frivolity of post-modernism.

Efforts to demonstrate potential benefits of natural energy systems have, for the most part, been carried out by the national laboratories, innovative engineers, and backyard inventors. Federally-funded demonstration projects have been largely responsible for the construction of a majority of buildings using "new" climate-sensitive strategies to reduce energy consumption. These projects have been predominantly engineered solutions to energy reduction with a low regard for architectural implications, e.g., narrow strip windows which fail to take advantage of natural daylighting opportunities or atrium spaces that make no provision for inhabitation.

The unadulterated engineered approach has frequently left an impression with users, architects, building owners and developers alike, that buildings utilizing natural energy systems and technologies are inherently restrictive in application, extremely complex in construction, costly, and aesthetically unpleasing to the beholding user. The reason for this sometimes appropriate impression is that laboratory-generated systems and analytical models, using simplistic proof-of-concept examples and engineering diagrams, are directly field-tested, demonstrated, and commercialized without equally extensive architectural analyses, evaluation, and design to enhance building-system integration and contextual compatibility.

The split-envelope concept is an approach to commercial building design which incorporates a variety of climate-sensitive natural energy technologies. The intent of this thesis is to transpose a family of these technologies into architectural form-making elements.

The split-envelope concept resulting in an atrium is a means to extend a building's perimeter and hence, habitable edge zone, while at the same time minimizing the structure's thermal exposure. The atrium is a powerful design element which can be used for daylighting, heating, and cooling commercial buildings.

Atrium spaces can be classified by use as well as physical definition. One type of use is the thermal buffer space. The buffer atrium typically houses circulation, restrooms, and other accessory functions that permit larger temperature swings than can be tolerated in areas of more sedentary use. As a buffer space the atrium may be effectively used for passive heating, cooling, and lighting, since greater environmental extremes are acceptable. In essence, this intermediate zone becomes a control device.

A second generic use is one in which the atrium is conditioned to standard comfort conditions, and normal functions of the building overlap into this space. For instance, in Wright's Larkin building, primary uses occur directly in the atrium. I will call this the habitable atrium approach. The habitable atrium requires more careful regard for thermal conditions than does the buffer atrium. I envision a habitable atrium to take on a life of activity similar to that which is demonstrated in Hertzberger's insurance building project Centraal Beheer.

The design of a habitable atrium space will be the primary emphasis of my investigation. In climates such as Boston which experience long cold winters, atriums offer the potential of providing a work environment that yields many more amenities than the constricted envelope approach to building design. The split envelope or atrium concept can effectively use natural energy systems to heat, cool, and light the workplace. Constricted approaches to building design require the use of artificial lighting at all times due to minimum use of glazing and are limited to the use of energy systems dominated by mechanical control.

The use of atriums and split envelopes is increasing and their role in reducing building's thermal and lighting requirements is in the early stages of documentation. The split envelope concept is a design element that, when included in the renovation of late 19th century and early 20th century mill or warehouse buildings, can greatly increase the structures' habitable edge, improve daylight levels, and define a conditioned enclosed space with outdoor-like qualities.

Atriums more commonly being used today in commercial office structures are of the buffer space type. Due to a variety of reasons, including conventional real estate pressures, often out-of-date code and zoning requirements, cost and lack of precedents, these buffer zones rarely interact with the zone that surrounds them. The form of the atrium space and adjacent zones can make the difference between a built zone that the users will joyfully inhabit and one that is rarely considered to be more than an extension of a corridor.

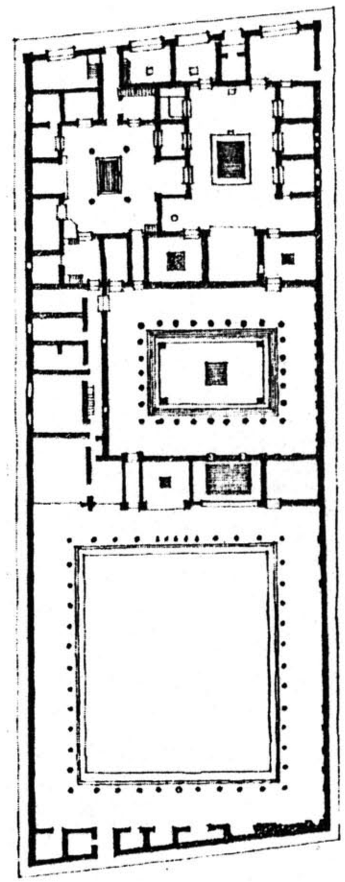
The hypothesis of this investigation is that a habitable atrium as a major design element can be integrated into the redesign of a 20th century factory building for commercial office use, and can be as much a part of the space which encloses it as a means to reduce the building's annual energy consumption.

This thesis centers around the approach of using an atrium space to extend habitable edge zones and minimize energy consumption in renovated late 19th and early 20th century mill and warehouse buildings. These structures represent a large retrofit office development market for the 80's, competitive with new construction.

The site for this project is an early 20th century warehouse building located at the Watertown Arsenal Complex in Watertown, Massachusetts. A building like this lends itself to the use of an atrium due to its great width and depth and almost perfect southerly exposure. This particular building is typical of many mill and factory buildings of old eastern industrial centers. It is hoped that the architectural attitude and vocabulary of forms developed through this exploration will be generalized to other buildings of similar physical configuration and climate.

Historically, numerous structures have been built in all regions of the world for a variety of purposes; one of these purposes is to provide human thermal comfort. It has been observed that many of these structures utilize atrium or courtyard configurations and thus seem to fit within the context of "Atria" as defined for use in this thesis. These historical architectural forms provide important clues to the function of contemporary Atria. This section of the thesis involves the investigation of known atrium designs of the past, in order to recover some of the lost technical secrets which may underline their functioning as effective thermal heating and cooling devices.

The Latin term "atrium" as used during classical times signified a courtyard, an open space, more or less centrally located in plan, around which were organized the rooms of the house. The atrium roof usually had inward-sloping surfaces which created a funnel or impluvium, that served to direct rainwater toward an opening at the center of the atrium roof, directly over a matching opening or basin in the floor leading to a cistern for rainwater collection. A further elaboration was the introduction of four or more load-bearing columns around the central



'HOUSE of the FAUN': Pompeii. C.2nd Century B.C.

Figure 1

basin, giving the effect of a small Greek portico. The atrium was often considered a principal room of the Roman house. Some wealthier Roman-built houses contained an atrium, located close to the entry, and a larger, colonnaded portico, "peristyle", located toward the rear of the house. With the passage of time, the definition of atrium was expanded, to refer to any private outdoor space located within a house or other building type, irrespective of its location, roof type, or rain harvesting potential.

In America, the atrium became a popular building type in commercial structures in the late 19th and early 20th century. Large glazed spaces caught the public's imagination with Paxton's Crystal Palace at Hyde Park in 1851 and Syndenham five years later. The later half of the 1900's was an era in which hundreds of notable atriums and glazed arcades were constructed both in America and Europe. The most notable include the recently preserved Cleveland Arcade (1890),Figure 2, the Bradbury Building (1893) in Los Angeles and the Milan Galleria (1860).

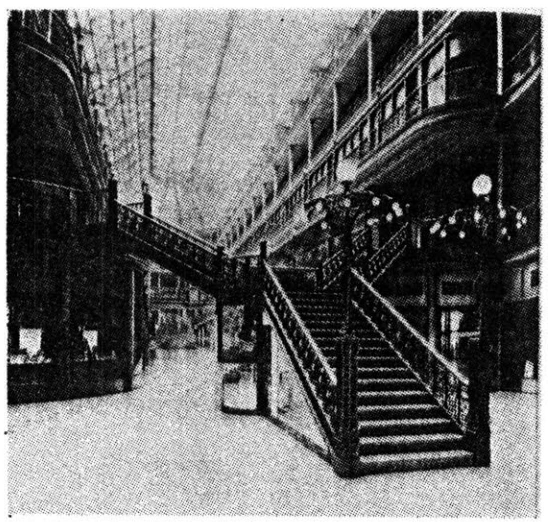


Figure 2

Frank Lloyd Wright saw the atrium as a romantic tool with which to fight the smoke, dirt and noise of industrializing America. Describing his 1906 Larkin building, he said "the superimposed stories, necessary to accomodate the required number of clerks, are all aired, lighted and unified by a big, open skylighted central court reserving the occupation of the interior, the character of family gathering, making the interior as a whole light, airy and beautiful altogether". (Figure 3)

"More and more, so it seems to me, light is the beautifier of the building". Frank Lloyd Wright

From his earliest designs on, Wright integrated light within the overall building concept, rejecting the hole-in-the-wall concept of the window. Unity Temple, a massive, textured concrete structure designed with light, displays how Wright allowed daylight to enter through high walls and ceilings. Wright describes designing the Unity Temple which captures his attitude about the role of daylight, "The room itself size determined by comfortable seats with leg room for four hundred people-was built with four interior free standing posts to carry the overhead structures. These concrete posts were hollow and became free-standing ducts to insure economic and uniform distribution of heat. The large supporting posts were located in plan to form a double tier of alcoves on four sides of this room. Flood these side alcoves with light from above: get a sense of a happy cloudless day into the room. And with this feeling for light the center ceiling between the four posts became skylight, daylight sifting through

Figure 3

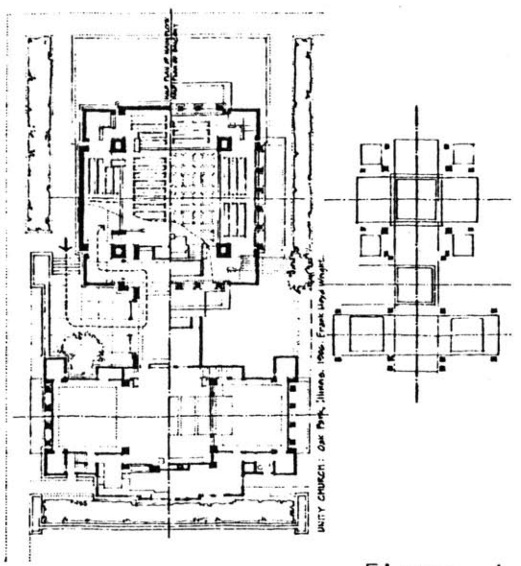


Figure 4

between intersections of concrete beams filtering through amber glass ceiling lights, thus the light would, rain or shine, have the warmth of sunlight." For Wright, it was by sunlit spaces that the human spirit could be elevated to the highest order. He once said, "The more we desire the sun, the more we will desire the freedom of the good ground and the sooner we will learn to understand it. The more we value light, the more securely we will find and keep a worthwhile civilization". Unity Temple may be termed, as defined in the introduction, a habitable atrium. (Figure 4)

Within the past five years, however, the meaning of the word as reflected in architectural and energy-oriented literature in the United States, appears to have been once more substantially modified. The current meaning of the word has been narrowed to describe a large-scale space enclosed by buildings; similar to 19th century department stores and hotels, whose primary purpose was to provide a center of focus or physical or visual access to other spaces within the building. Unlike their 19th and early 20th century predecessors atriums constructed over the last decade are inevitably sealed completely, are fully air conditioned and are intended primarily as a device that provides an activity center of maximum visual impact, and ensuring visual relief for the interiors of structures with extended floor areas.

In an extension of the meaning of "atrium", the word has also come into contemporary use to describe small-scale, attached greenhouses in residential or small commercial structures. Such structures are not unlike the glass houses which proliferated Western Europe and England at the turn of the century. This extension of the definition, of course, presents an even greater departure from the historical definition.

Only recently have architects begun anew to see the atrium in its original broader dimension, as having the potential for providing a wide range of environmental functions. This is not only in terms of its use as an activity center, or as a means of providing visual relief, but also as a powerful passive control device, specifically designed to improve a building's indoor thermal and luminous environment without increasing building energy consumption. A valuable source of information for this "new" approach to atrium use is the vernacular architecture predating the advent of "modern" closed-loop environmental control systems.

An approach toward determining the atrium purpose and environmental function is to examine the location and historical conditions under which atriums were first used. While the precise form in which the atrium or courtyard concept first appeared is likely to remain undetermined, it is hypothesized that the idea first evolved from a combination of three prehistoric prototypes: (a) cave dwellings; (b) encampments of nomadic peoples and (c) fenced compound dwellings of early farmers. Evidence relating to likely sources for the atrium has been reported in some detail from four areas of the world: North Africa, West Africa, Mesopotamia, and parts of Greece and Asia. These locations represent, for the most part, hot arid climates of the world. Except in the case of Mesopotamia, where archaelogical investigations provide the sole source of available information, reported information is based upon existing settlement patterns. These include primitive underground dwellings built around square and circular man-made craters open to the sky (North Africa and Asia), round huts joined by a wall which encloses a large courtyard (West Africa), and rectangular adobe huts located inside rectilinear earth berms (North Africa). Although different in outward form, these versions of the atrium concept appear to share a common climatic background, as well as a basically defensive rationale: defense either against human or animal intrusion, or against hostile climatic conditions.

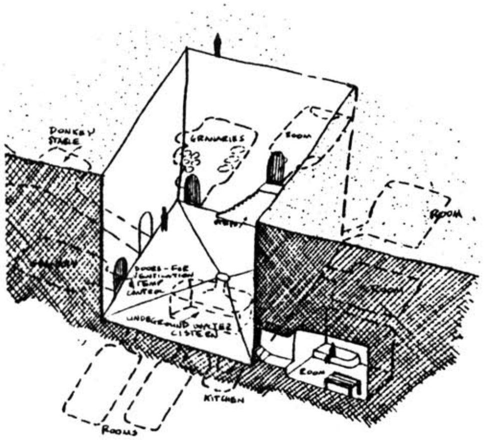


Figure 5

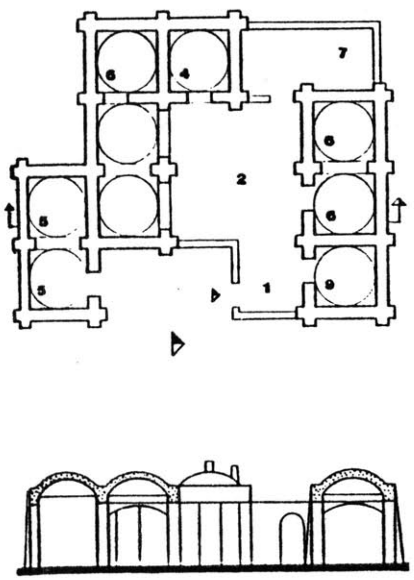


Figure 6

The foregoing evidence, and those inferences which reasonably can be derived from it, appear to warrant the conclusion that on a global basis arid regions are the major source area for the atrium concept. This suggests that a discussion of selected examples of Atria, from both historical and contemporary architecture, might be best organized on the basis of climate, rather than historical or geographical criteria. Thus, the evolution of the atrium is best categorized by hot arid, warm humid and temperate climates.

In tracing the evolution of each climate zone, a further subdivison can be made, (a) Atria of low effective sectional aspect ratio (height to width of shorter side <1.3) and (b) those of high effective sectional aspect ratio (height to width of shorter side >1.3).

Although the focus of this thesis investigation is temperate climates, a few observations about Atria characteristics in hot - dry and hot-humid climates will help to illustrate the value of examining historical vernacular examples.

Historically, atria began to appear with the emergence of the first cities and served as a central organizing element. There appear to be several reasons for this:

a. religious value of an earthly image of paradise,
b. increased privacy in a crowded social environment,
c. economic advantage of requiring only a limited amount of land,
d. atrium houses became recognized in the preindustrial world as the most effective means of modifying the hostile climate of the desert regions,
e. the atrium also provided private outdoor space. A source of natural illumination for surrounding rooms, shelter against dust and sand storms and welcome coolness to the deserts heat and a suntrap for the parts of the year when heat was required.

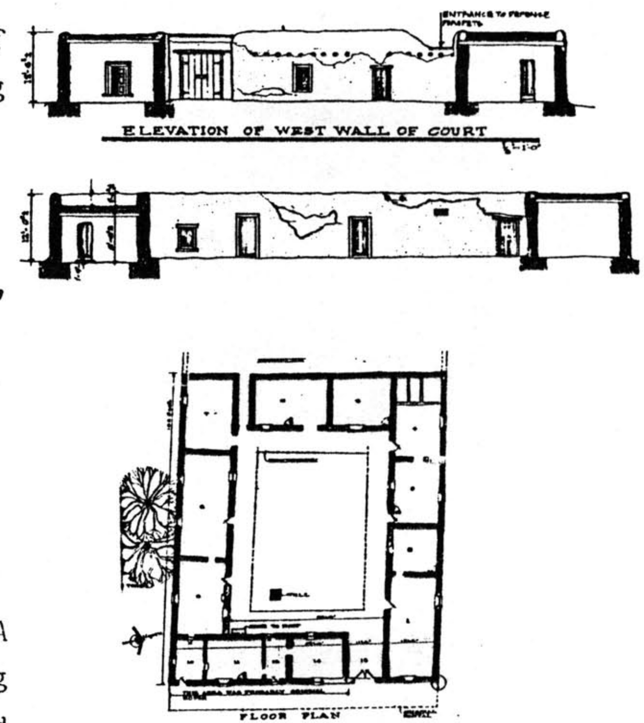


Figure 7

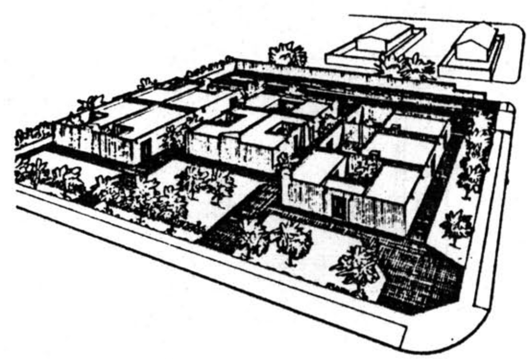
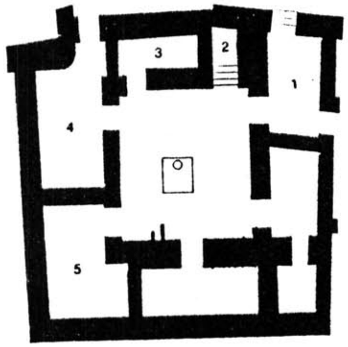


Figure 8

A review of the literature suggests that a low (<1.3) effective sectional aspect ratio type of atrium, usually one story in height, is characteristic of the hot-dry climate with relatively modest average summer time temperatures (50-70 degrees F). Examples of such shallow configurations include underground atrium dwellings of the

Matmata Plateau of Southern Algeria (Fig. 5), the domestic courtyard houses of the Souf Valley of Northeastern Algeria (Fig. 6), and the Spanish Mexican patio-centered adobe ranch houses of the Taos, New Mexico area (Fig. 7). A recent example is the Menlo Demonstration Townhouse Project in Tucson, Arizona. (Fig. 8).

The diurnal, buoyancy-driven process by which the atrium functions as a temperature regulator in a hot-dry climate was first analyzed in 1960 by D. Dunham, for the case of the traditional Arab courtyard house of North Africa. Both the courtyard and the flat roof surfaces of the rooms which surround it (especially their sunlit portions) radiate the heat they have gained during the day back to a clear cold night sky. As a result, the temperature of the thin film of air just above these surfaces will often drop below air temperature, particularly at night. High parapets along the building's exterior perimeter prevent the loss of this cool air. As long as the parapets on the



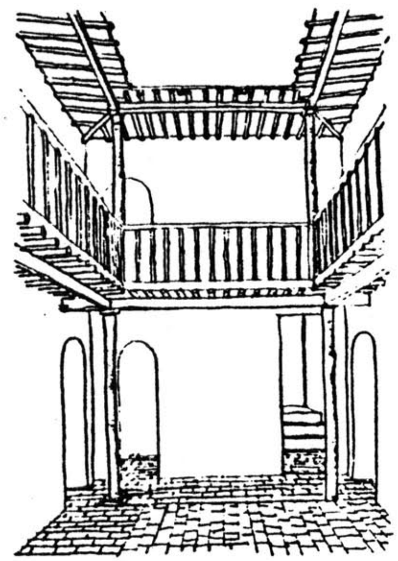


Figure 10

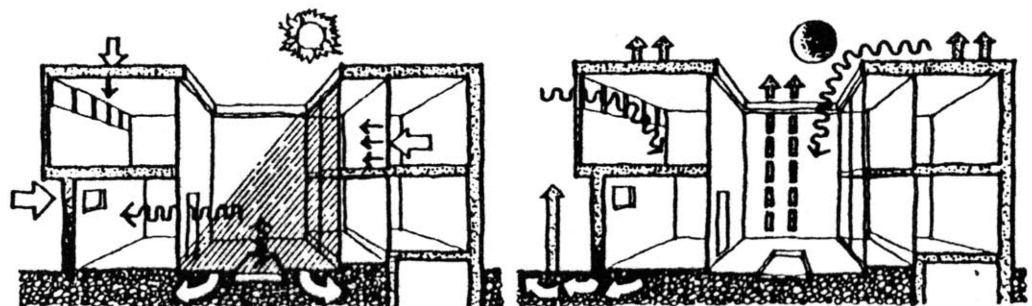


Figure 9

inner, or atrium, sides of roof surfaces are kept low, the accumulated cool air is able to sink by gravity into the courtyard below. (Figure 9).

Those examples from my literature search which turned out to have higher (>1.3) effective sectional aspect ratios appear to be characteristic of those portions of the hot dry climate with average summertime temperatures of 77-86 degrees F. Examples of such deep configurations, often two or more stories in height, include the earliest atrium house form known: the Sumerian Courtyard house of the Ur, on the Euphrates River from about 2500 B.C. (Fig. 10), the 15th century Moorish houses of Granada (Fig. 11), the Minoan Settlements of Crete (Fig. 12), the Oriental type of house of Baghdad (Fig. 13), the traditional urban courtyard house of Algeria's M'zab district, the early Ksars of Morocco, and the townhouses located in the Saharan oasis of Ghadames, in Western Libya (Fig. 14-15).

These deep atrium configurations function as temperature regulators. Two major features which differentiate these high aspect ratio atrium types help to maximize the "inverse stack effect" or "cool air collection process". The first feature is the greater height and the second is the presence of horizontal partitioning of the vertical shaft of the courtyard space into two or more superimposed

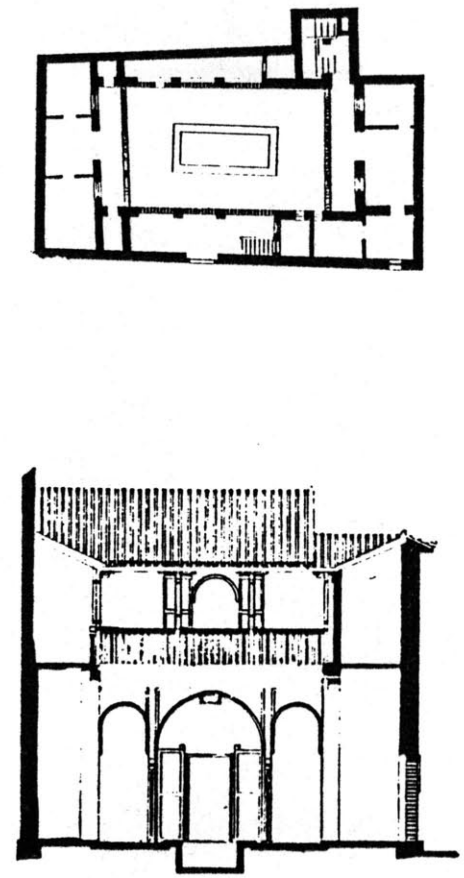


Figure 11

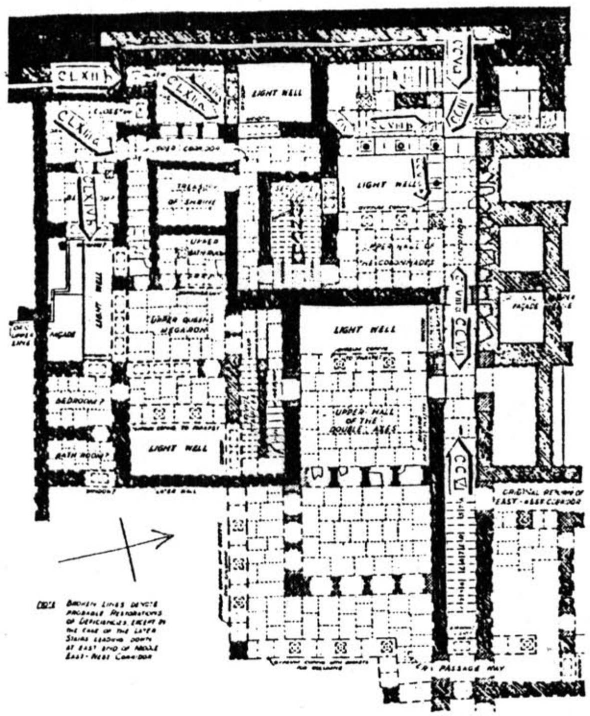


Figure 12

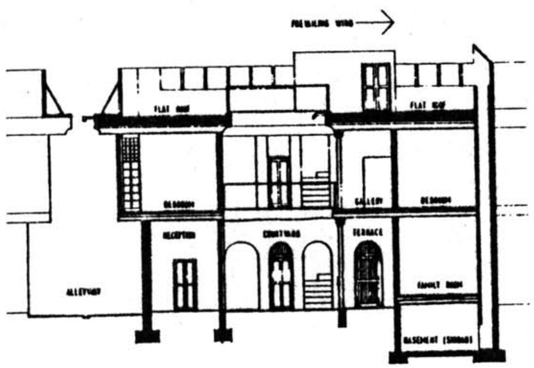


Figure 13

courtyards, connected only by an operable grilled opening. The lower room is used most often in the hot season as a thermal refuge. (Fig. 16) The grilled opening is sealed during the day and opened at night, allowing cool air from the upper atrium and roof top to flow downward to be collected inside the lower atrium. The upper atrium is used mostly in winter as it usually has its arcade oriented south and east to receive radiation during cool winter days.

WARM HUMID CLIMATES

The warm-humid climate atria examples reviewed, with one exception, were found to be low sectional aspect ratio. This trend appears to fit well with the desire in this climate region for courtyard designs which facilitate wind driven comfort ventilation. Despite low aspect ratios, solar shading can be accomplished through vegetation, verandas/porticos or other types of appropriate shade devices. Warm humid examples include a loosely-planned compound dwelling complex in Sekai, Northern Ghana (Fig. 17 and the Hotel Delicias in Puerto Rico (Fig. 18).

TEMPERATE CLIMATES

With few exceptions, all of the temperate climate atrium examples reviewed were of the low sectional aspect ratio, or shallow type. This is essentially the result which might be expected. The need for an atrium to operate as an efficient passive solar collector appears to be primary for a well designed courtyard in climates with moderate to severe winter seasons. Thus, a winter oriented open top atrium should be wide enough to receive low winter sun for a substantial number of hours per day. Such an atrium should also take into account the desireability for providing a wind shelter in climates with low temperatures and high winter wind velocities. Vernacular temperate climate examples reviewed include the single story Greek courtyard house (Figures 19-20) which typically surrounds an open courtyard on three to four sides and with porticos facing one or more sides of the court. This vernacular

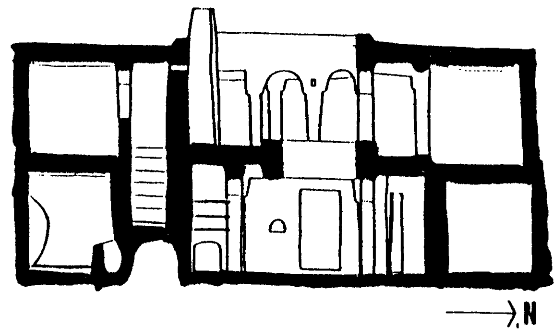


Figure 15

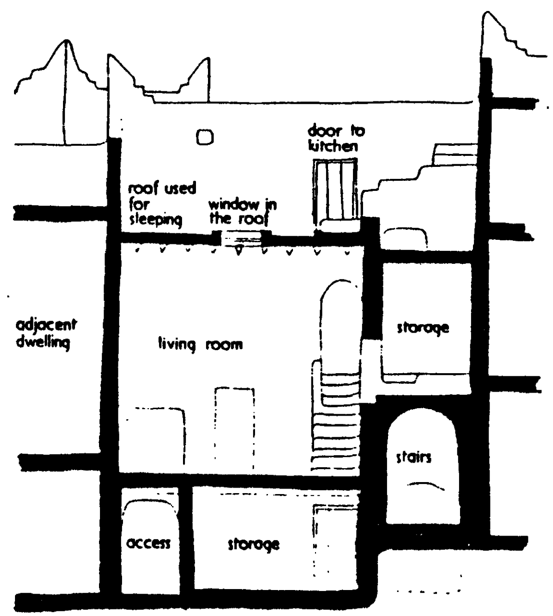


Figure 16

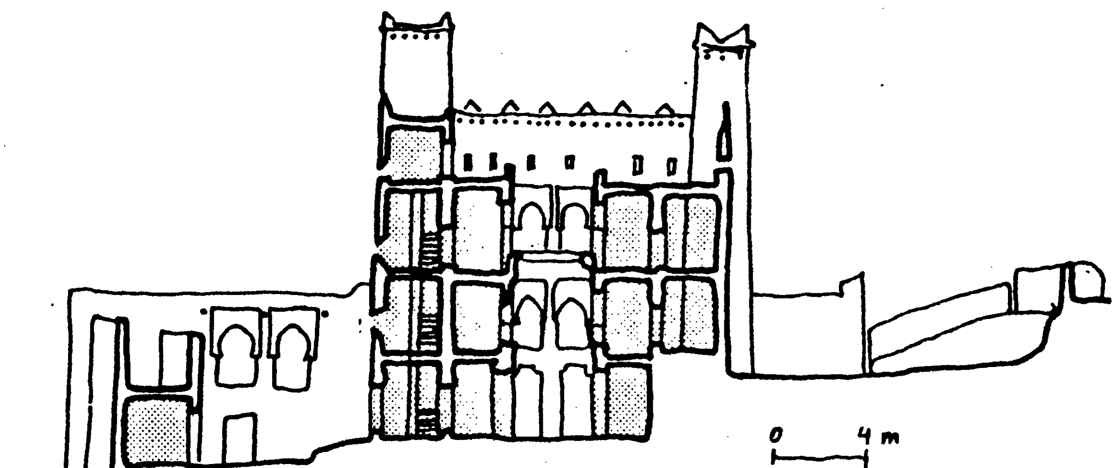
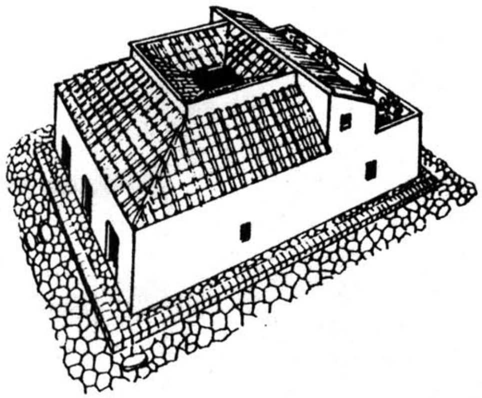
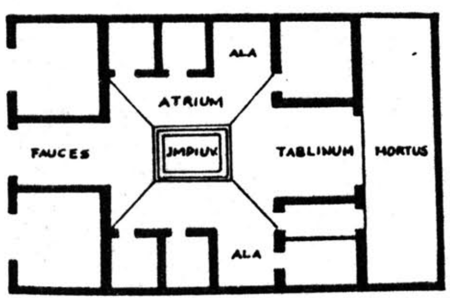


Figure 14





A typical old Roman house, Figure 19
4th-3rd centuries B.C.

Plan of the illustrated compound. *a.* Internal courtyard. *b.* Sheltered reception-sitting area facing the old market. *c.* Compound added for a second family. *d.* Ancestral shrine *g.* Granaries.

1. Compound owner's sitting room. 2. Compound owner's sleeping room. 3. Wives' rooms. 4. Wives' kitchens. 5. Sons' rooms. 6. Bathing enclosure. 7. Storerooms for granaries. 8. Sheep. 9. Chickens.

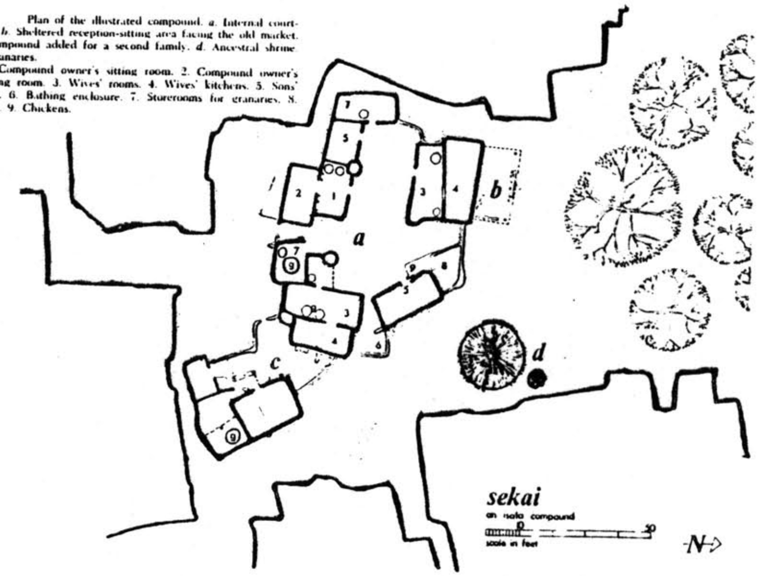


Figure 17

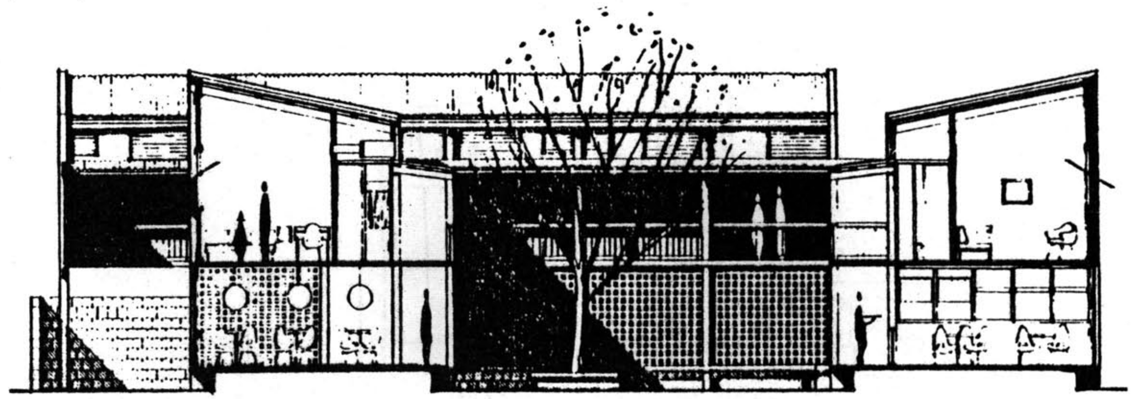


Figure 18

type was often constructed with a peristyle or row of columns surrounding the courtyard. It seems likely that the atrium with its impluvium, inward sloping roofs, offered a higher potential for promoting thermally induced ventilation than did the peristyle, particularly during the hot dry days of a Roman summer. Other vernacular examples include the atrium houses of Tunis and the compound dwellings of Peking (Fig. 21-22).

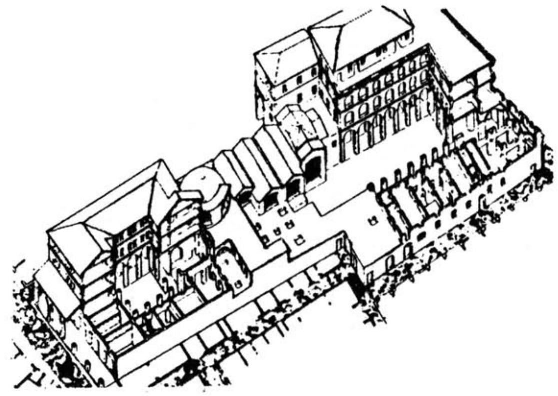


Figure 20

Architect designed open-top temperate examples include the Central Court of McKim, Mead and White's Boston Public Library (1888-1895), (Fig. 23-24) Jose Luis Serts own Cambridge patio centered home (1958), (Fig. 25) and S.O.M.'s Connecticut General Life Insurance Company building (1954-1957)(Fig. 26). Qualities shared by each of these examples are a low aspect ratio, meaning improved performance for daylighting and solar heating within the built spaces which surround them. While these examples do not appear to have been specifically designed for ventilative cooling, they each use deciduous trees which provide a canopy of summer shade.

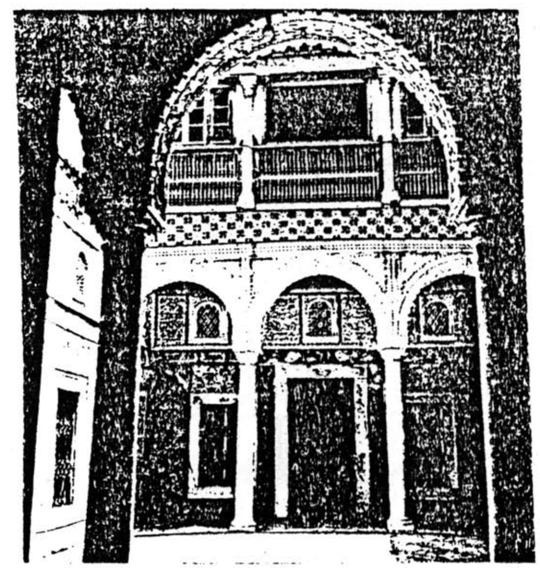


Figure 21

The decision to investigate historical vernacular atrium was made in an attempt to glean from them characteristics that are appropriate for inclusion in the development of an atria design vocabulary applicable to the generic

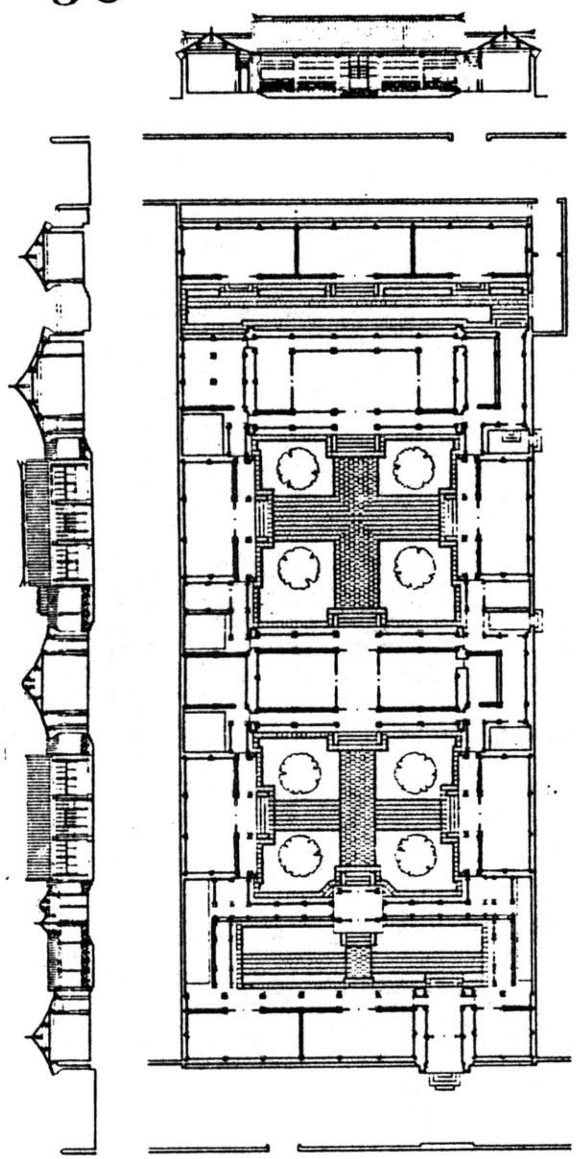


Figure 22

building type configuration (small exterior surface area to volume ratio) being studied in this thesis exploration.

As previously mentioned, the interior atrium has become, once again, architecturally popular in recent years for a variety of reasons including realities of the marketplace, in large part due to developers who believe atrium buildings are a good sell; architects have selected them for inclusion in their decisions because of romantic ideals about freedom of movement and both have been led to believe, rightly or wrongly, that atriums are a quick-fix energy saving device that also sells buildings. As one Houston developer put it, "You can put up a small atrium office building on a poor site and still have atmosphere."

Energy conservation and/or passive heating and cooling are commonly given as justifications for the utilization of glass enclosed courtyards, partially or fully enclosed by built volumes and comprised of a wide variety of glazing combinations ranging from large expanses with top lighting only to opaque roofs and vertical or sloped glazing. These attempts by architects and engineers to reduce a building's annual energy consumption often neglect to evaluate the atrium's orientation on the site, make adequate provisions for natural ventilation, seasonal and daily shading, and control of atrium temperature stratifi-

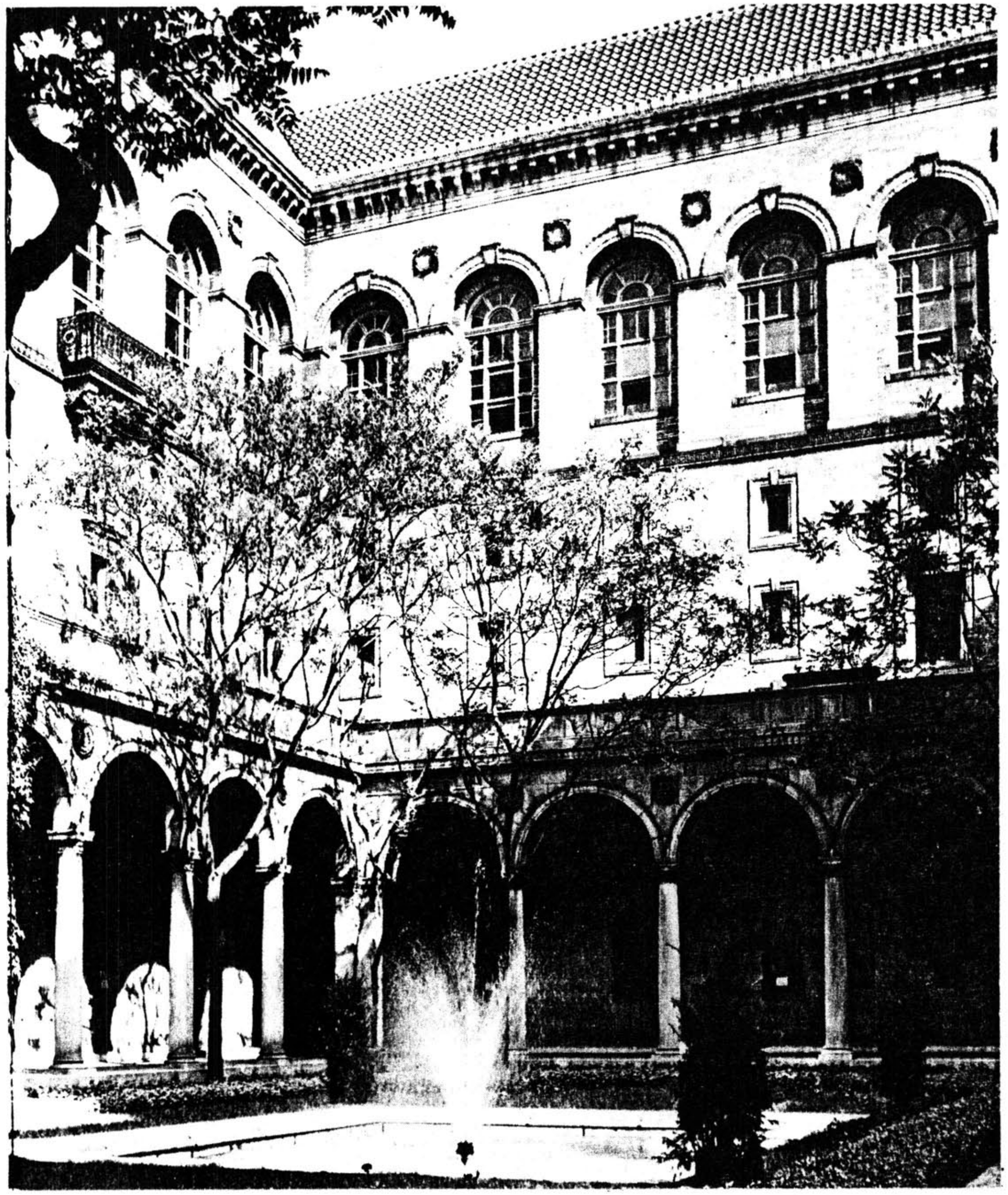


Figure 24

CHARLES MCKIM'S BOSTON PUBLIC LIBRARY

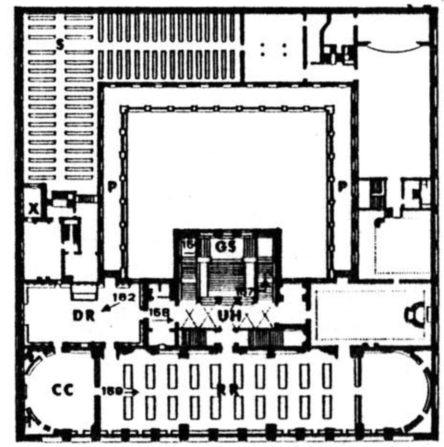


FIGURE 154. Boston Public Library. Plan at the level of the main reading room: grand staircase (GS); vaulted upper hallway at the head of the grand staircase (UH); main reading room (Bates Hall) (RR); alcove originally containing the card catalogue (CC); original delivery room (DR), with murals by Edwin Austin Abbey (now housing the card catalogue); terrace porch (P) atop the garden arcade (now closed to the public); (X) the point at which the book trolley originally deposited books from the stacks, whether for home borrowing or for use in the main reading room.

AMERICAN BUILDINGS AND THEIR ARCHITECTS

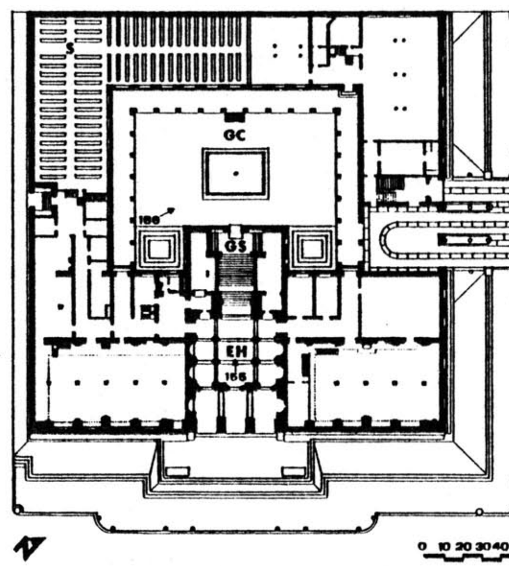


FIGURE 153. Boston Public Library. Plan of the entrance floor: entrance hallway (EH); grand staircase (GS), with Puvis de Chavannes' murals on the walls; garden court (GC), with fountain and surrounding colonnade; stacks (S). Numbers on this and the following plan indicate vantage points for the sequence of illustrations which follow.

Figure 23

cation. Designers also often overlook the design of diffusion elements to balance atrium daylighting levels, increase daylight penetration into adjacent spaces and control glare. The result of failing to carefully consider each of these design parameters, and thus take an integrated design/technology approach, is an atrium environment requiring excessive mechanical conditioning year round.

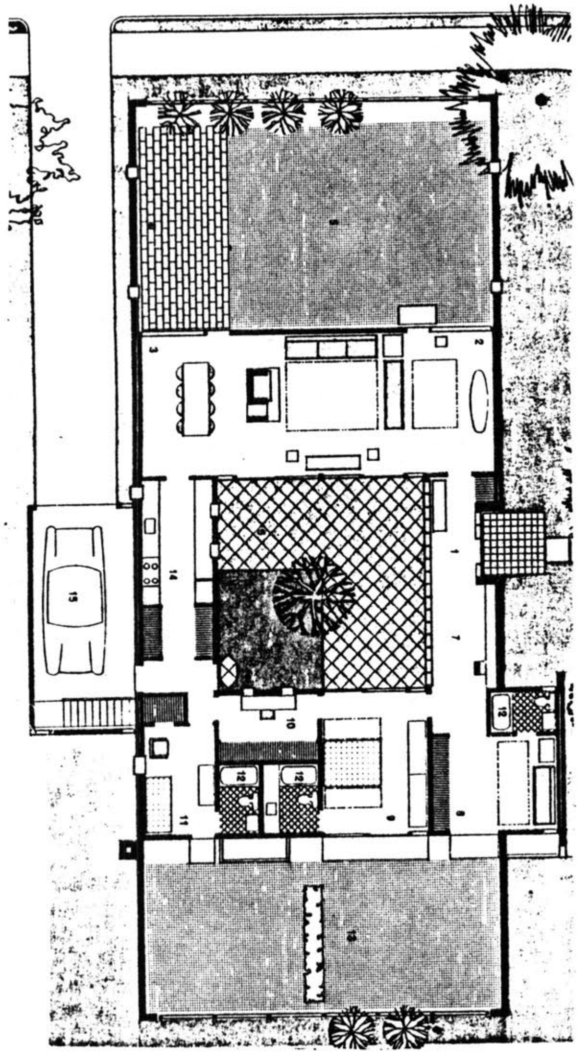


Figure 25

The balance of this section is comprised of example enclosed atria and corollaries such as clerestory, and large aggregations of side and top light glazing systems, which demonstrate many principles of good energy conscious design in temperate climates such as Boston, Massachusetts.

Principles which bear directly upon the form and function of an environmentally responsive atrium include but are, of course not limited to the following:

- Orientation of the space(s) and requisite glazing location.
- Roof and exterior closure forms which direct daylight to the floor level.
- Elements which will direct daylight from the atrium to adjacent zones.

- Enclosure systems that will provide shading and glare control to facilitate maintenance of thermal comfort.
- Natural and wind driven ventilation provisions to facilitate convective cooling.
- Diffusion elements to balance atrium lighting levels.
- Materials and colors which help to internally reflect and diffuse daylight.
- Materials which will provide an acoustically comfortable atrium space.
- Effective sectional aspect ratio of <1.3.
- A means to minimize atria temperature stratifiction.
- Preconditioning of make-up air to assist the mechanical heating and cooling function.
- Heat collection and storage. Location of thermal mass to facilitate absorption of winter solar radiation.

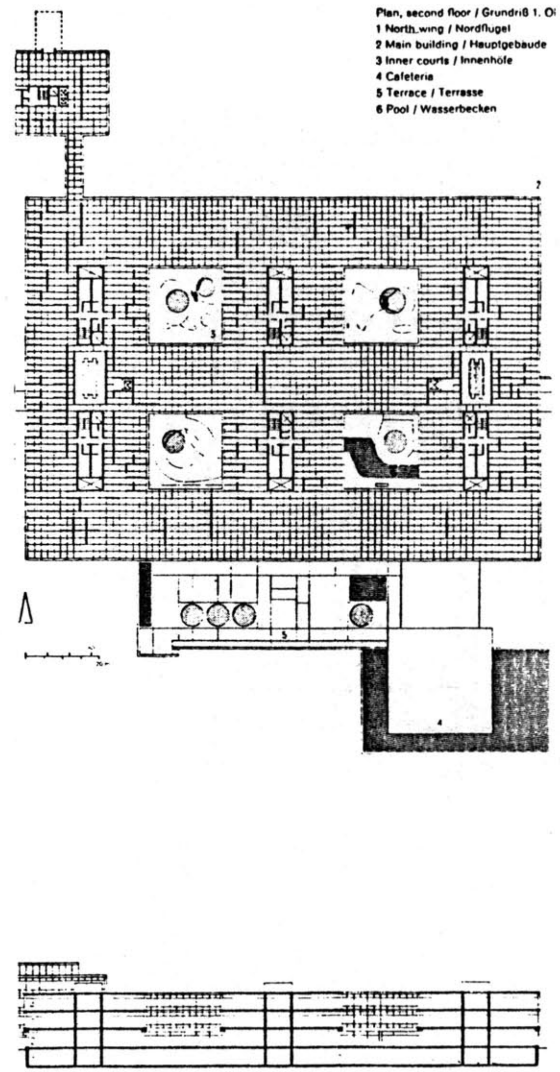
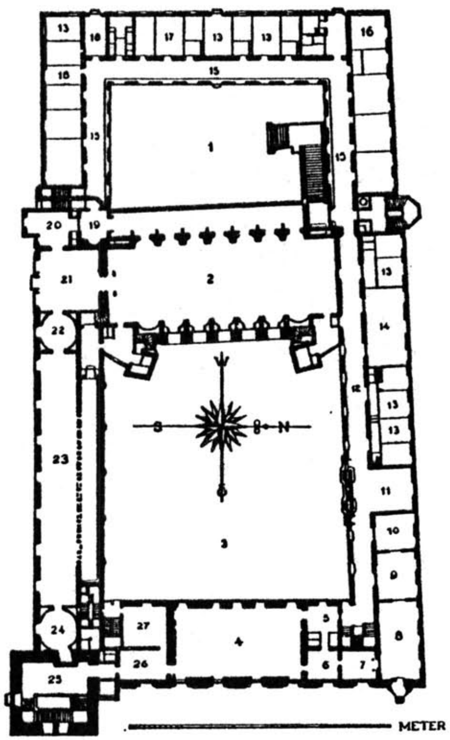


Figure 26

Ragnar Ostberg: Stockholm City Hall (1908-1923)

THE BLUE HALL AND THE COUNCIL GALLERY



The Stockholm Town Hall. Plan of the main storey on the first floor, comprising the Council Passage with the office rooms surrounding the Blue Hall and the Council Storey, and the State Apartments round the Great Court.

1. Blue Hall. 2. Golden Chamber. 3. Great Court. 4. Council Chamber. 5. Boudoir. 6. Library. 7. Presidency Chamber. 8. "Stora Kollegiesalen". 9. "Lilla Kollegiesalen". 10. Chairman. 11. Council Hall. 12. Council Corridor. 13. Aldermen. 14. Brávalla Chamber. 15. Council Passage. 16. Chancery. 17. City Accountant. 18. Attendants' Room. 19. Sea-shell. 20. Blue Chamber. 21. Three Crowns Chamber. 22. Circle. 23. Gallery. 24. Oval. 25. Vaulted Stairway. 26. Smaller Conversation Room. 27. Larger Conversation Room.

Figure 27

There are many examples of atriums in which the entire ceiling is one large skylight. The open ended uninterupted influx of natural light of such a configuration produces a shadowless interior; forms tend to appear flat and texture is diminished.

"This can be seen in Copenhagen City Hall which has two courts - an open one and glass-roofed one, though you would expect the light in both places to be very much the same, there is an amazing difference." Rasmussen.

The glass covered hall renders the interior dull and virtually lifeless. Ostberg visited the Copenhagen City Hall while designing the Stockholm project to assess the daylighting quality. His project is comprised like the Copenhagen building, of an open and enclosed court. (Figure 27-28)

His study resulted in a hall in the Stockholm building with an opaque solid ceiling instead of an entirely glass roof. Three sides of the ceiling rest on a widebank of vertical windows. The floor of the hall is three and one-half stories below which creates an atrium space with high side lighting. High side lighting gives good light distribution, deep penetration and the incoming horizontal light highlights and enhances the surface texture. Horizontal light entering high in the hall creates a range of light intensities across the space producing a variety of shadows which give a dynamic quality to the hall. The walls and floor of the hall are constructed of masonry which absorbs the incoming solar radiation almost immediately. The hall is connected to the adjacent spaces with a series of large arches and grilled openings which enables air to move freely. These openings also allow light to be borrowed from the hall by surrounding spaces generating a rich variety of shadow, reflection and textural imagery. (Figures 29-30) The sectional aspect ratio is slightly less than 1.3 which allows winter sun to penetrate deep into the hall. The high side lighting while allowing winter sun penetration minimizes summer penetration. A wide shelf at the base of the window bank helps to diffuse and reflect incoming sunlight during both summer and winter seasons.

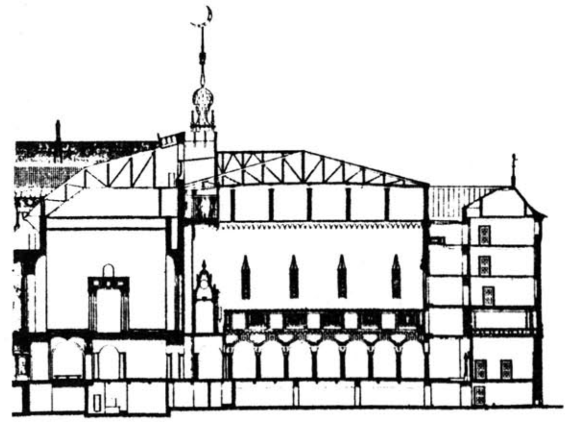


Figure 28

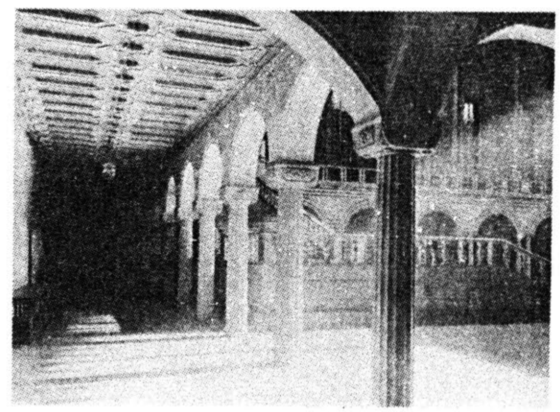


Figure 29

"It was originally intended that the brickwork of this hall - the halls of which are made solely of machine made brick - should be finished off and lined in a blue tint. Hence the name. But when the masonry work was completed, the fine red colour of the brick stood out so well we were loath to change it.... The blue hall owes much of its

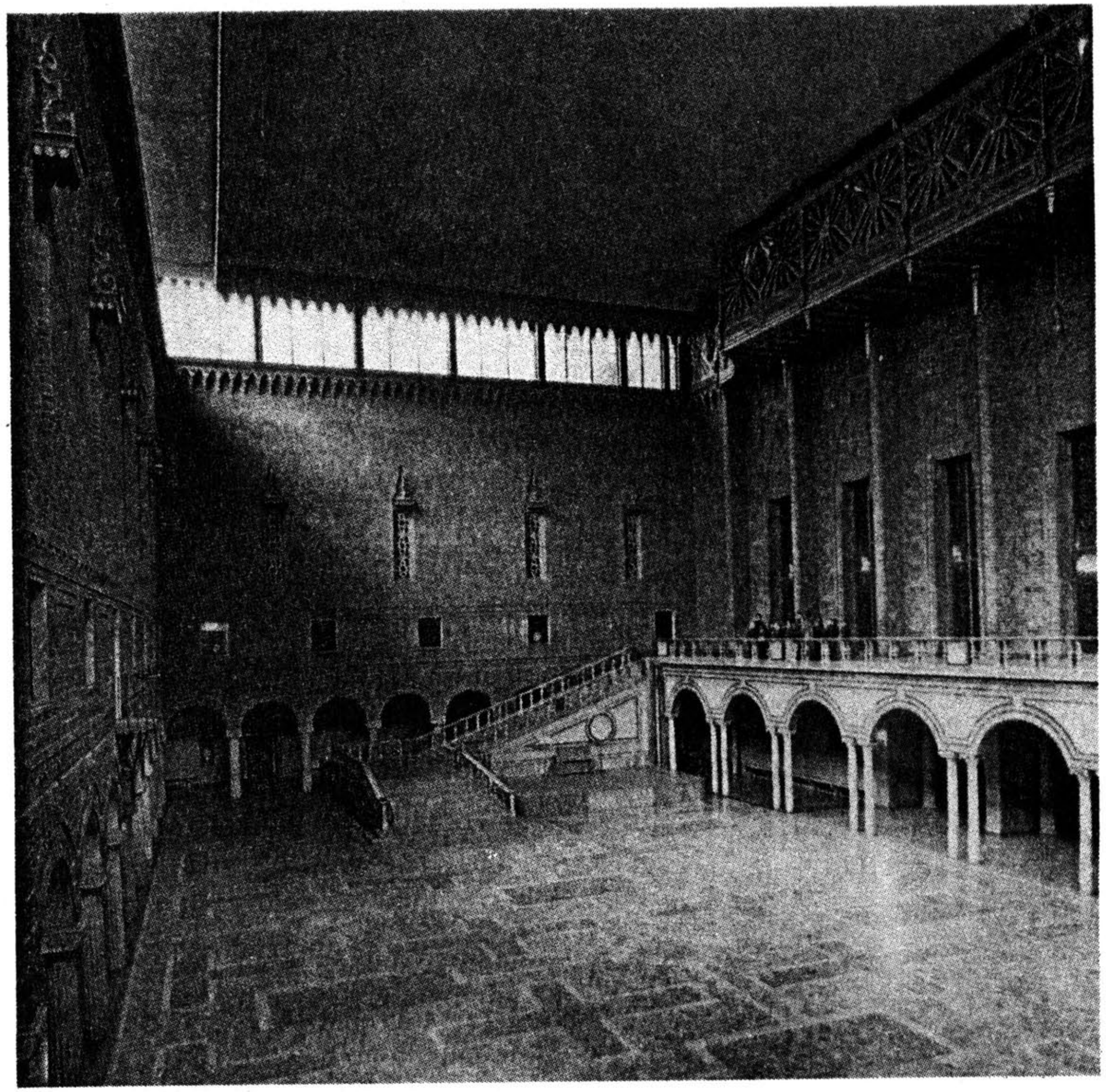
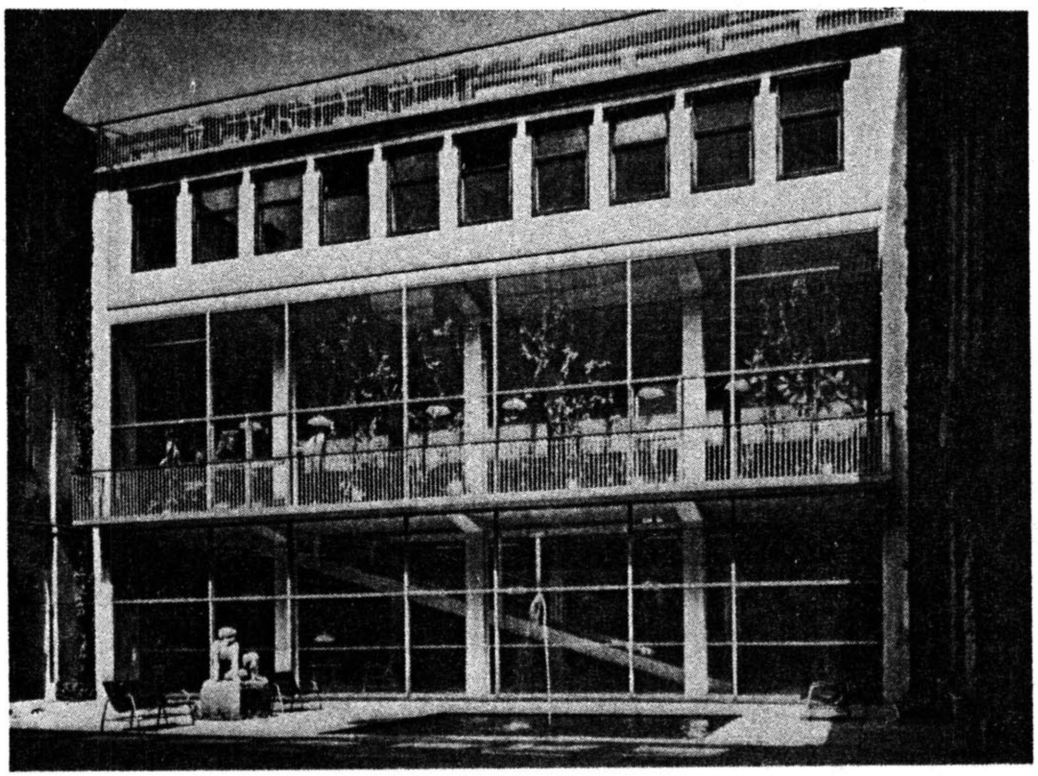


Figure 30

charm to the lighting. The light falls slantwise through horizontal windows running immediately below the roof, giving the effect of a vibrating sheaf of rays. Moreover, three of the walls are so placed that the sun cast its beams upon them, bringing out the colour and producing irridescent effects." Ragnar Ostberg. (Page 38 The Stockholm Townhall)

Figure 31



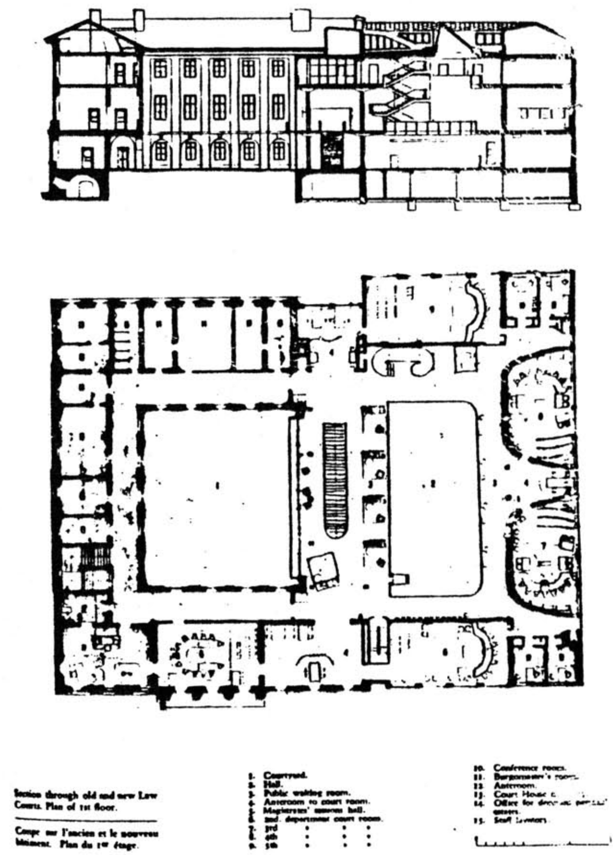
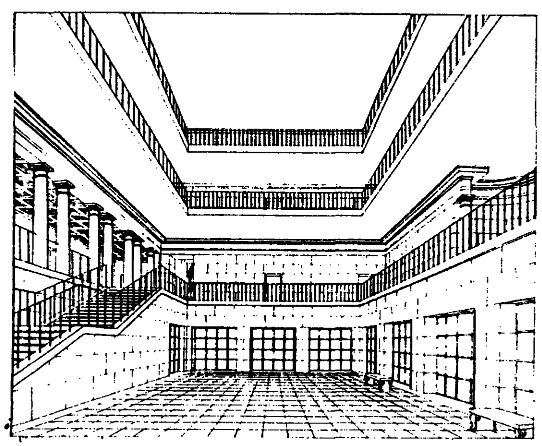


Figure 32

E. G. Asplund: Gotenburg Law Court Addition (1934-1937)

Asplund's City Hall project like the Copenhagen City Hall, organizes the space around an open and closed court or atrium space. (Fig. 31) Asplund has chosen to connect the two by glazing the wall of the closed court that faces the open court. The large windows which face the outer court, a potential source of intense glare-producing daylight, employ a variety of architectural elements to diffuse and soften the incoming light. (Figures 31-32) These elements are deep light-colored rounded double steel columns set back a few feet from the glazing, a screen of plantings just inside the glazing, a balcony overhanging the first level foyer, light-colored mullion bars and light-colored wall surfaces in the adjacent open courtyard.



The vertical wall of glass is supplemented with a roof mounted clerestory monitor that brings diffuse horizontal light into the back of the three story space resulting in a light quality that acts to highlight the physical materials within the space. (Figure 33) The principle demonstrated is one that creates a dynamic physical space through contrast. The light entering through the vertical wall is brighter and provides a view to the open court beyond creating a visual and luminous experience for people walking or lingering in the atrium. The light from

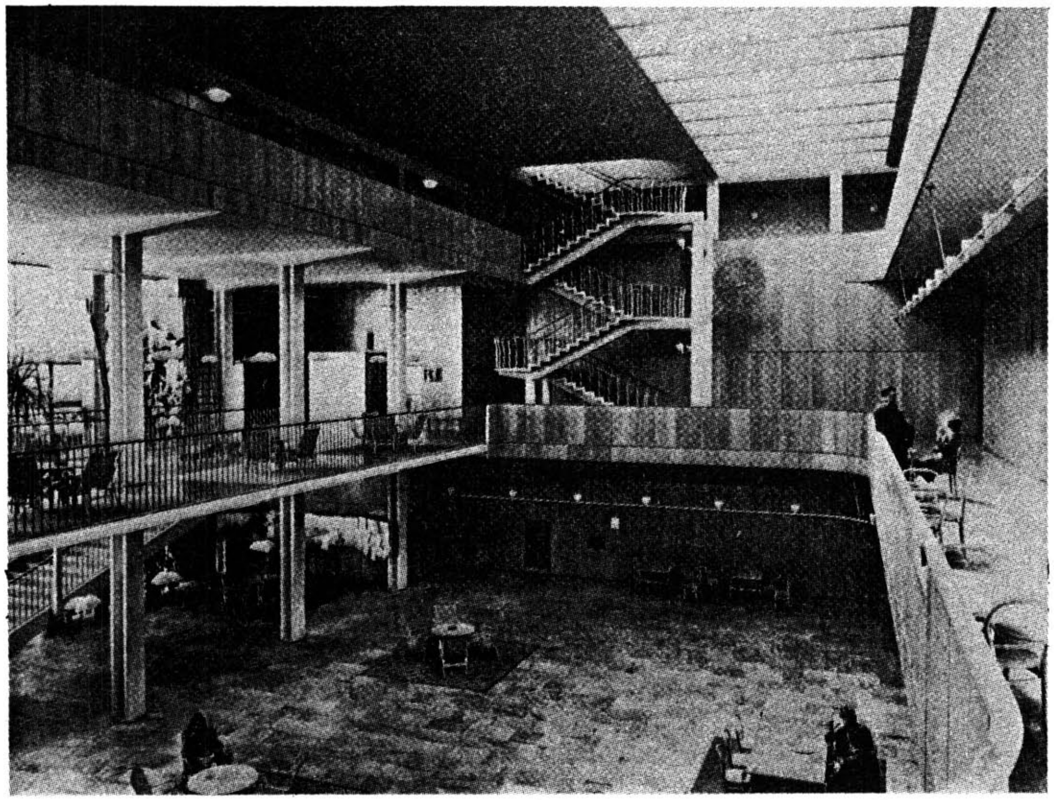
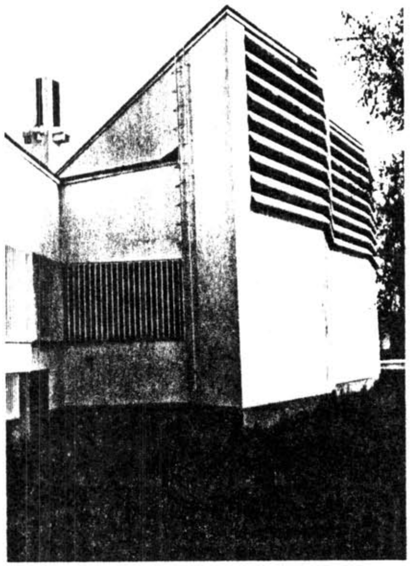


Figure 33

the clerestory is a softer diffuse light, together the two sources build a gradient of light and shadow. The horizontal nature of each luminous source highlights both relief and texture.

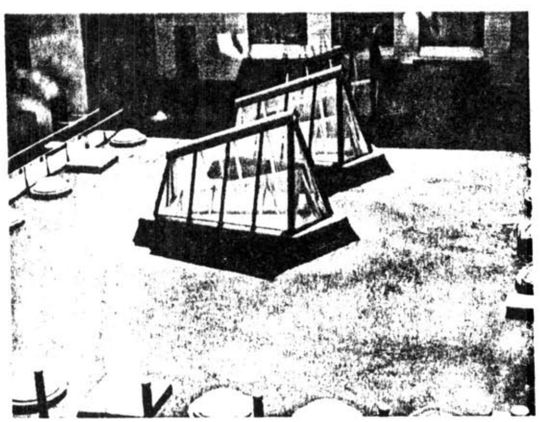
The use of light colored matte finish materials on the ceiling and many of the vertical surfaces acts to further diffuse and reflect incoming light, reducing the brightness ratio between inside and out and reducing the possiblity of reflective glare.



The aspect ratio of this space approximates the desired 1.3 height to depth ratio observed in numerous vernacular examples.

Alvar Aalto: Multiple Projects

Aalto is no doubt one of the great masters of daylighting design and there is an enormous amount of information that can be learned from studying his work. It has occurred to me from time to time during this thesis exploration, as I keep coming back to study his many projects in which he so eloquently expresses the magic of light, that I could have devoted my entire research to studying and gaining a greater understanding of his vast experience.



In his early career, Aalto studied the work of both Ostberg and Asplund and no doubt learned a great deal about the positive manipulation of light through such works as the Stockholm City Hall and Gotenburg Law Courts.

Aalto clearly understood the distinction between lighting requirements for the winter and summer and developed a system or vocabulary of daylighting elements that are utilized in all his buildings. Rooftop lighting, clerestories, screened windows and lighting scoops are clearly made to play the role of major design elements in his work. They are used to accent and highlight places, to denote movement from place to place programmed activity space or to punctuate activities along a path or a hinge of activity. Light is always carefully evaluated in relation to the human functions it helps to illuminate. Aalto displays a keen ability in his work to put light where he wants it - where it enhances the visual experience and assists the user in his or her luminous requirements. His spaces are replete with patterns of sunlight, shadows, and reflected light, always combined with one another, providing in a qualitative sense, just the right amount of light to enjoy the experience of his beautiful use of materials. (Figure 34-35)

Figure 34

An important point about his buildings is that from the exterior one can virtually "read" what is within the skin. (Figures 36-37) The exterior forms have a direct relationship to the interior spaces. Windows, for example, are never arbitrarily placed into the facade, but are designed to allow light to enter the building exactly where it is wanted and needed by the building user. Aalto expresses his attitude toward light in an article appropriately titled "Between Humanism and Materialism".

Figure 35

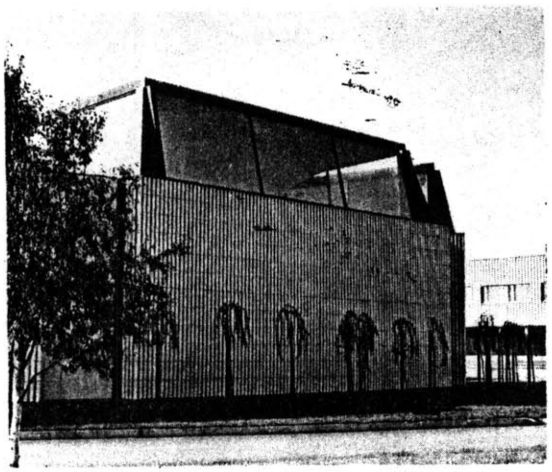


Figure 36

"Not only the increasing mechanization of our age but also our activities remove us further and further from real nature. We see how nature is destroyed to some extent by the construction of roads. If we look carefully we can find similar phenomena in all fields of our profession. We have created for example, better and better forms of artifical lighting. The electric light of today is much more convenient than oil lamps or wax candles of grandfather's day. But is this light really of better quality than that obtained from those older sources? It is in fact no better at all. Nowadays, in order to be able to read a book at some distance from the light source, we use a bulb of 60-80 watts, whereas our grandparents managed with two candles. We are using more light for the same activities because the physical and psychic qualities of light itself are no longer satisfactory. It is the same everywhere."

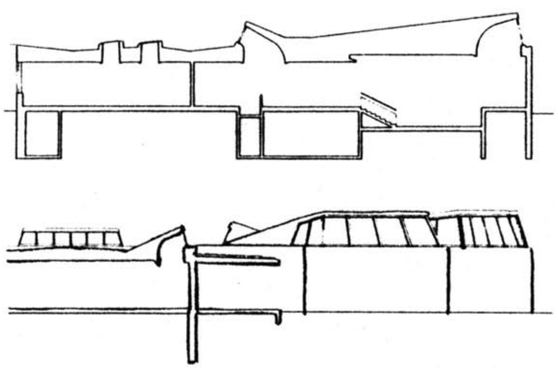
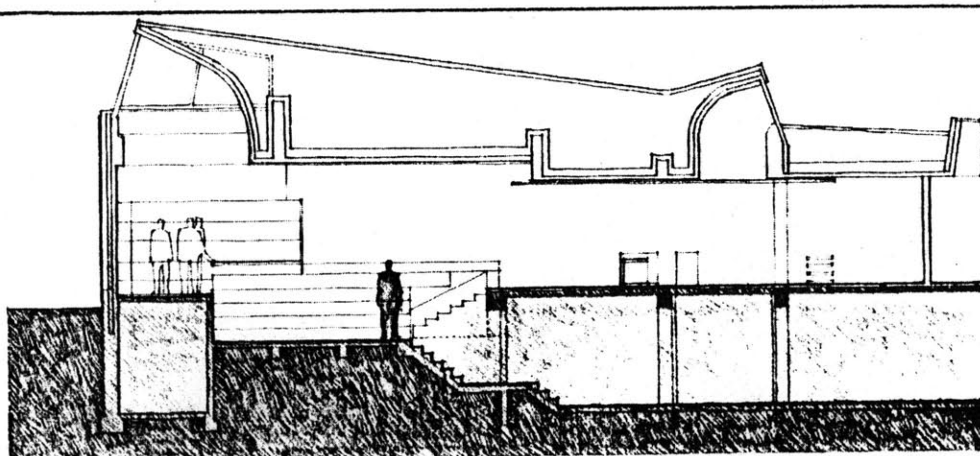
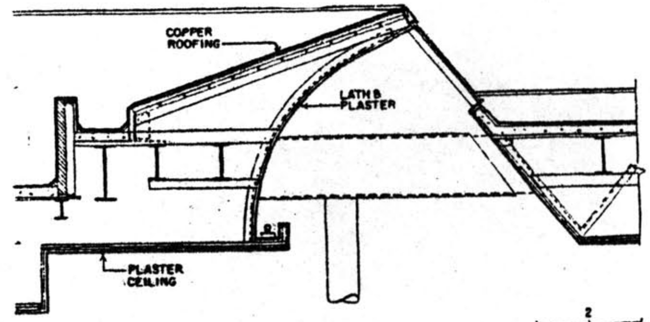


Figure 37

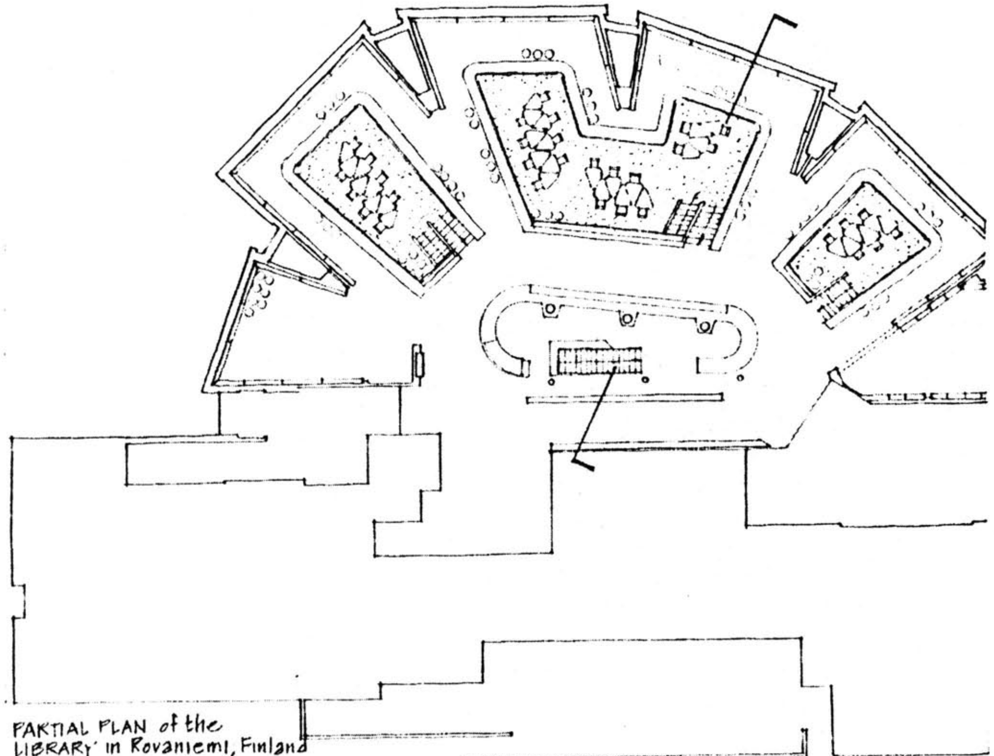
Aalto's sensitivity to the needs of the building user can be summed up in his approach to the design of a hospital room at the Tuberculosis Sanatorium in Paimio, Finland. "When I received this assignment I was ill myself and was therefore able to make a few experiments and find out what it is really like to be ill. I found it irritating to lie horizontal the whole time as like moths around a lamp, my eyes were drawn to the electric light located in the



PARTIAL SECTION through the Library in Rovaniemi.



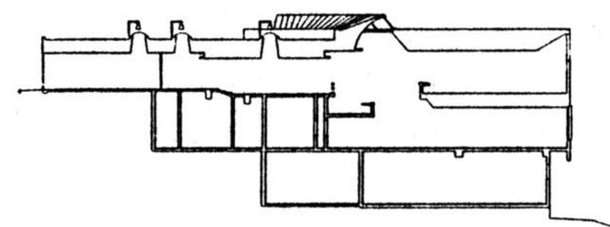
SKYLIGHT DETAIL



PARTIAL PLAN of the
LIBRARY in Rovaniemi, Finland
1968
Alvar Aalto

Opposite:
General view, showing
reading room

1 Cross section through
reading room
2 Reading room, showing
clerestory lighting



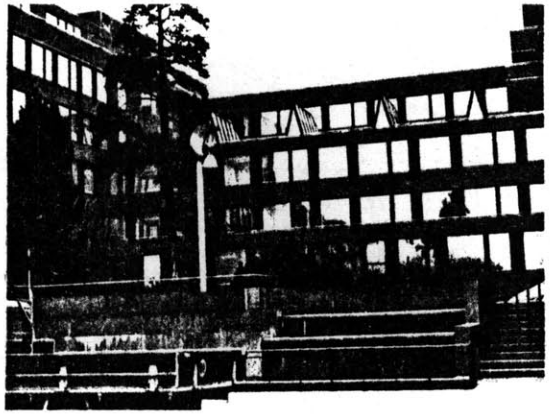


Figure 39

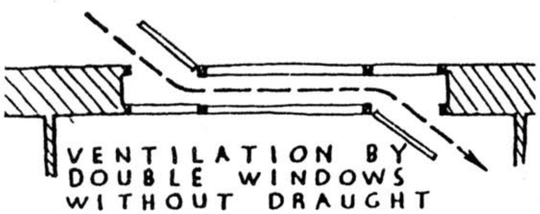
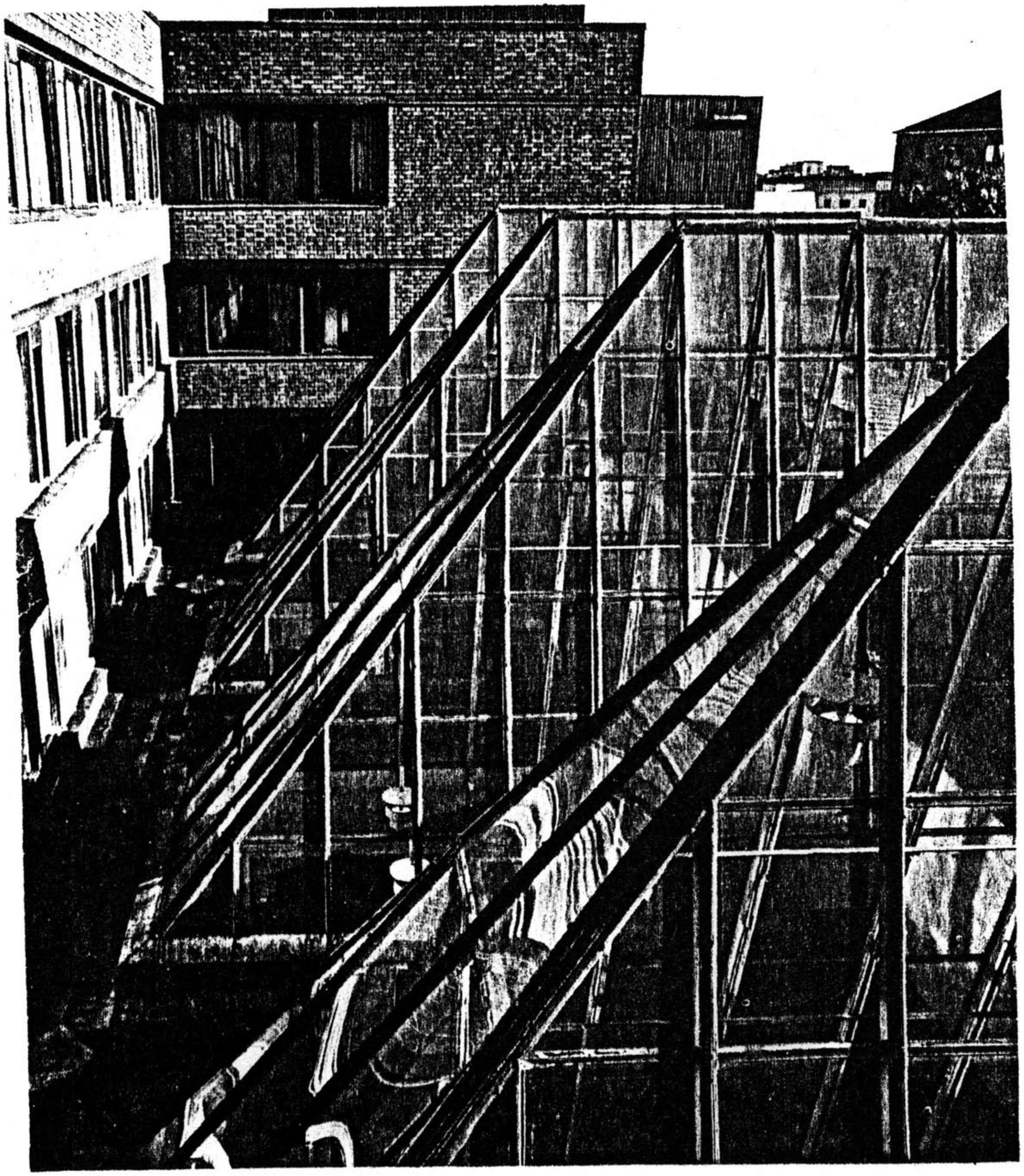


Figure 38

center of the ceiling". Aalto's solution was to provide a small moveable task light and windows designed to enable the patient to have visual contact with the outdoors in either a horizontal or upright position. The window is protected by a large overhang not to allow direct sunlight to cause discomfort to the patient. An operable double glazed window system has two benefits, one it increases the resistance to heat loss resulting in a higher mean radiant temperature than singular glazing which was used almost exclusively at the time, and secondly, provides draughtless natural ventilation. (Fig. 38)

The National Pension Bank Headquarters building in Helsinki is a large, four story volume ringed with offices. The triple-glazed skylights that project two and one-half stories above the roof and far below the ceiling are used in a conscious attempt to create a sunny, warm indoor environment in the harsh Finnish climate. (Figures 39-40) Because each of the skylights is canted and rises from a one story coffer, light is diffused and reflected from near vertical surfaces above the ceiling before entering the building's interior spaces. It is then bounced off reflective, white walls. The result is a shadowless light without glare.

The three crystaline skylights floating above the three



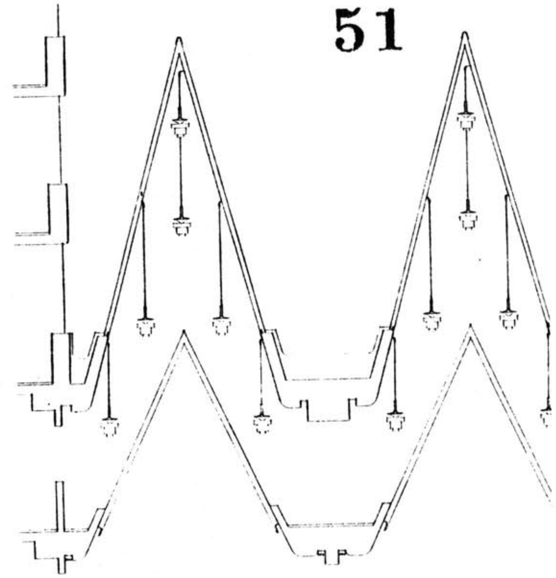
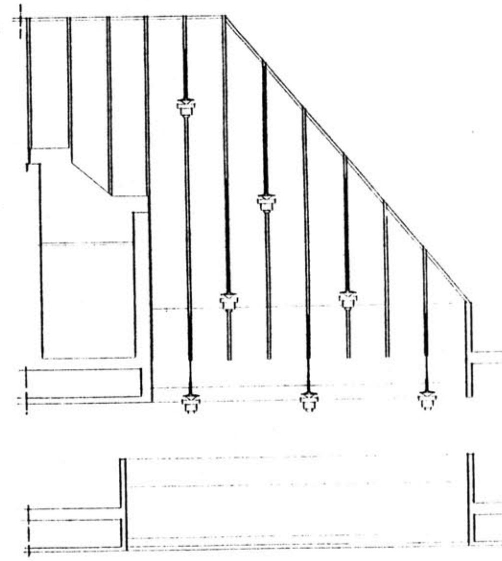


Figure 40



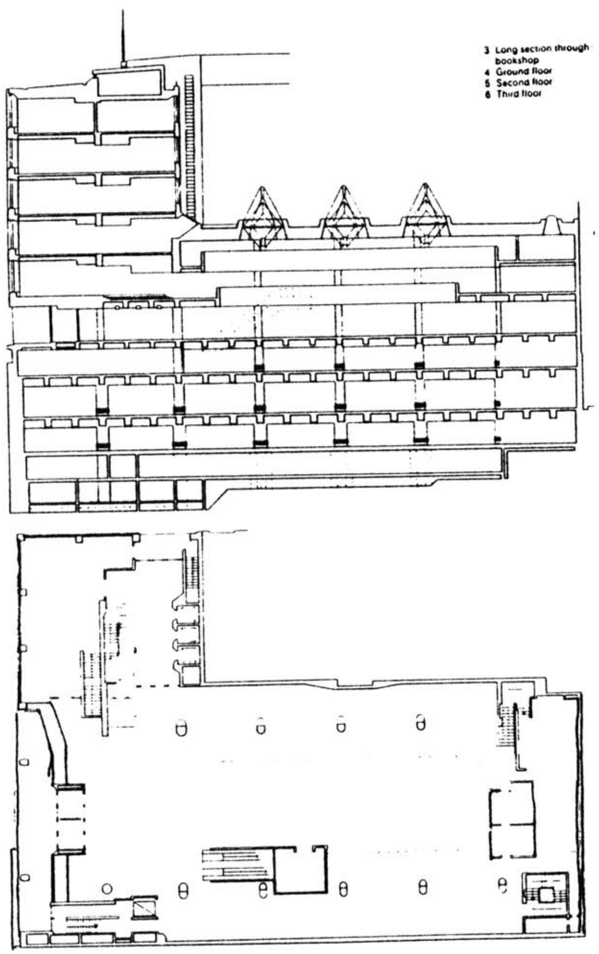


Figure 41

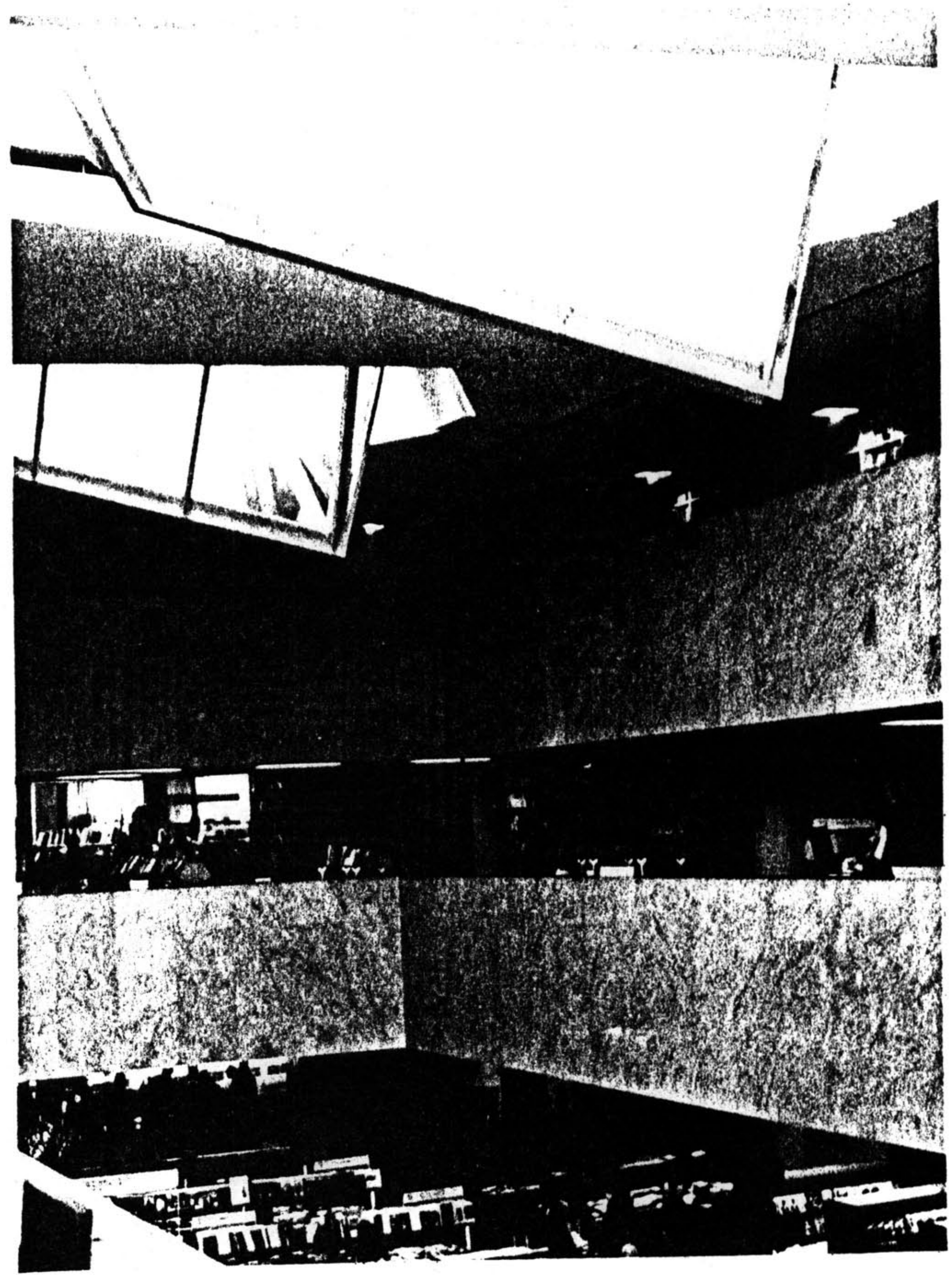
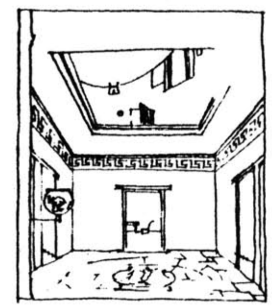


Figure 42

story bookstore at the Polytechnic Institute at Otanjemi utilizes a similar concept to the pension bank scheme. (Figure 41-42). The walls of the book store are clad in reflective white marble to diffuse the light entering through the skylights.

P. D. Pearson suggests in his book Alvar Aalto and the International Style that, Aalto following his 1924 journey to Italy became fascinated with the classical atrium. He further states that the idea is clearly expressed in his early study for a home for his brother, although not included in the final construction.(Fig. 43) The atrium came to be a major form determining element in many of Aalto's buildings. "By hollowing out and stepping the residual solid, Aalto creates a multiplicity of surfaces through which light may be brought into the building". (Steven Groak notes on responding to Aalto's buildings). ' The cutaway volume creates a richness and a system of light sources within the built field that form a central theme throughout Aalto's work and career.'



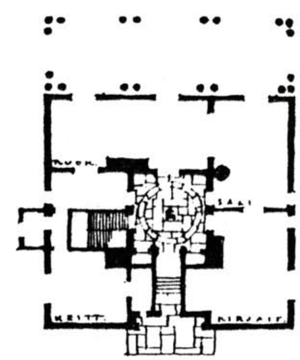


Figure 43

Aalto's use of the screen is as nearly widespread in his buildings as skylights, clerestories and atriums. Two important characteristics of the screen should be noted: 1. they are most often vertical and 2. they are usually flush with the surrounding wall surface unless part of the

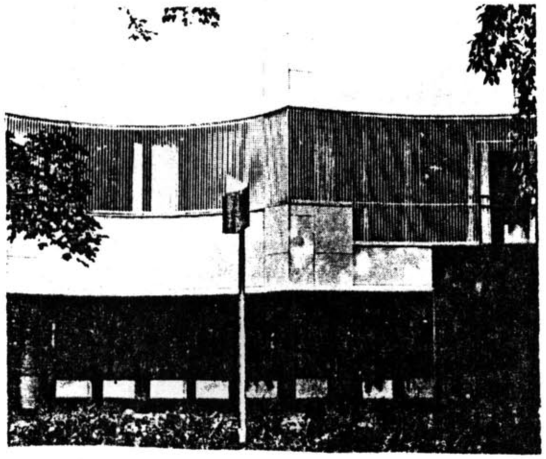


Figure 44

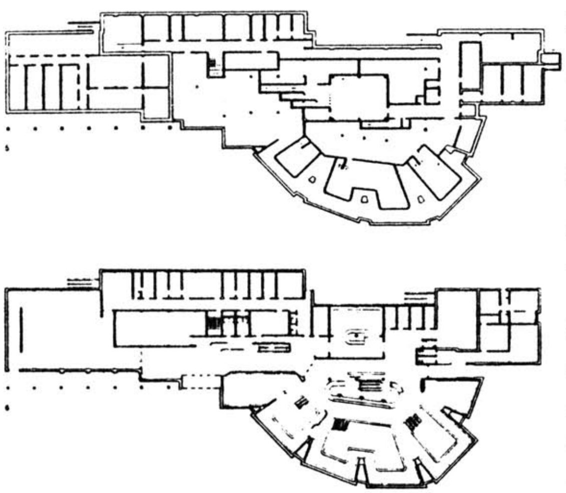
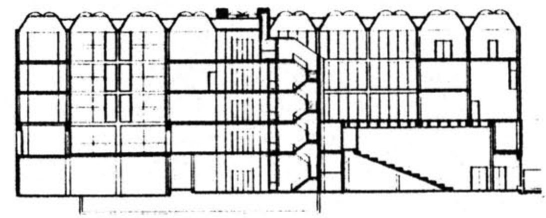


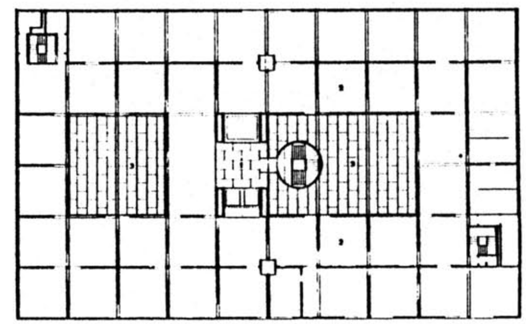
Figure 45

surrounding wall surface and then they stand out from the wall plane. The screens constructed of a variety of materials throughout his work are most often light in color to reflect and diffuse daylight into the building. The screen provides a reprieve from the direct rays of the sun which often create glare at the use-plane and, hence, being externally located reduce interior summer heat gain. (Figure 44)

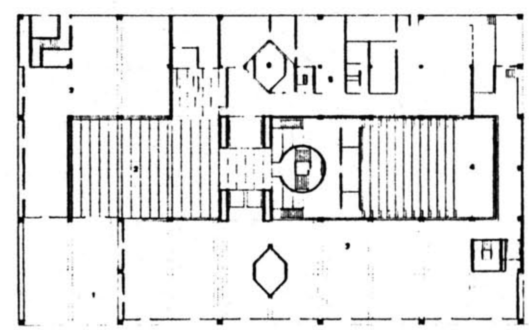
Helsinki is the general area in which a number of Aalto's buildings are constructed, and it is interesting to note his predominant use of vertical glazing placed high in the space to be illuminated in order to capture the nearly horizontal rays of the sun and to maximize its penetration. Helsinki is located at 60 degrees north latitude and on the winter solstice the sun does not exceed 10 degrees altitude. Due to the generally low altitude of the sun throughout the year and short number of hours the sun is above the horizon each day, Aalto's placement of glass and often the building shape respond to the path of the sun across the sky to allow for the greatest amount of daily illumination into the building. (Figure 45) Windows for Aalto seem to be devices for bringing light into the building and not so much for giving views to the exterior. Hence, the use of top and side-lit atria without side views. It is important to note that, Aalto in all of his projects having an atrium or courtyard type space, respects the vernacular-based effective sectional aspect ratio of temperate climates. This configurational relationship of the height to shortest side facilitates deep penetrations of light in northern latitudes. Aalto couples this design guideline with a family of light-diffusion elements which have a strong impact on both the users visual field and the organization of the spaces surrounding the light emitting source. It appears, for me, that Aalto's preoccupation with light is demonstrably a generative source of his conception of space and enclosure.



Section



Fourth-floor plan



Street-level plan

Figure 46

LOUIS KAHN: YALE CENTER FOR BRITISH ART AND STUDIES 1969-1974

Louis Kahn had a preoccupation with light similar to Aalto's. For Kahn the building was a "natural light fixture". The role of light in his work is best summed up in his statement that "We were born of light. The seasons are felt through light. We only know the world as it is evoked by light, and from this comes the thought that material is spent light. To me natural light is the only light, because it has mood--it provides a ground of common agreement for man--it puts us in touch with the eternal."

The British Center embodies many of Kahn's concerns. Dark on the outside, the building explodes with light on the inside. A system of skylights brings light into the galleries on the top floor and, in two courts, brings this light down into the heart of the building. (Figure 46) Although horizontal skylights are used in this climate where the direct sun could produce harmful and uncomfortable interior conditions for both artwork and visitors, Kahn has used a combination of deep structural concrete coffers and exterior fixed louvres placed above the skylights to reflect and diffuse the light entering the building. (Figure 47)

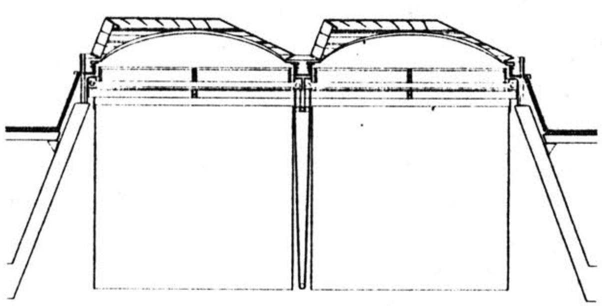


Figure 47

ALBERT KAHN: PACKARD MOTOR CAR COMPANY 1911

Kahn practiced in Detroit from 1896 until his death in 1942 and was uncontestably a pioneer in the area of industrial factory design. In his hundreds of projects designed for the automobile and glass industry, there is a keen sense of the environmental forces which impact the workspace. Kahn designed factory spaces having high ventilated volumes and long span deep trusses which became the framework for light and ventilation. (Figure 48)

One interesting result of the configuration of the enclosing envelope was that the total wall height available for light and ventilation exceeded the height of the building itself. Expressed in terms of building height, 52 percent of the wall could be opened for ventilation and 70 percent was glazed. His use of inward sloping opaque roof sections work to diffuse and reflect light and provide enhanced ventilative cooling from increased height and distance from inlet to outlet. Equally interesting are the lines drawn in the section of the Packard forge shop depicting paths of light and venti-

Figure 48

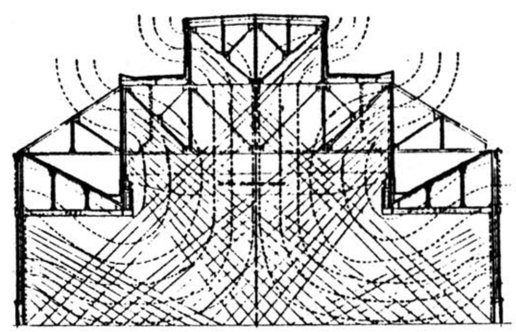
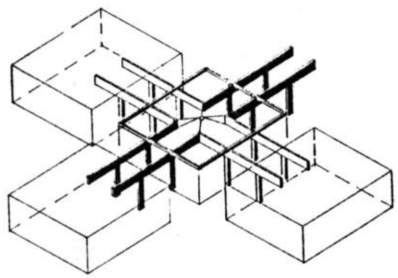
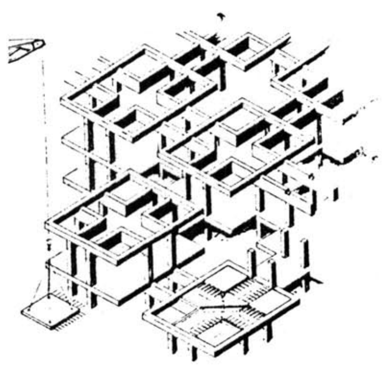
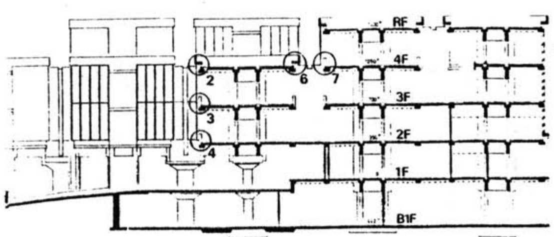


Figure 49





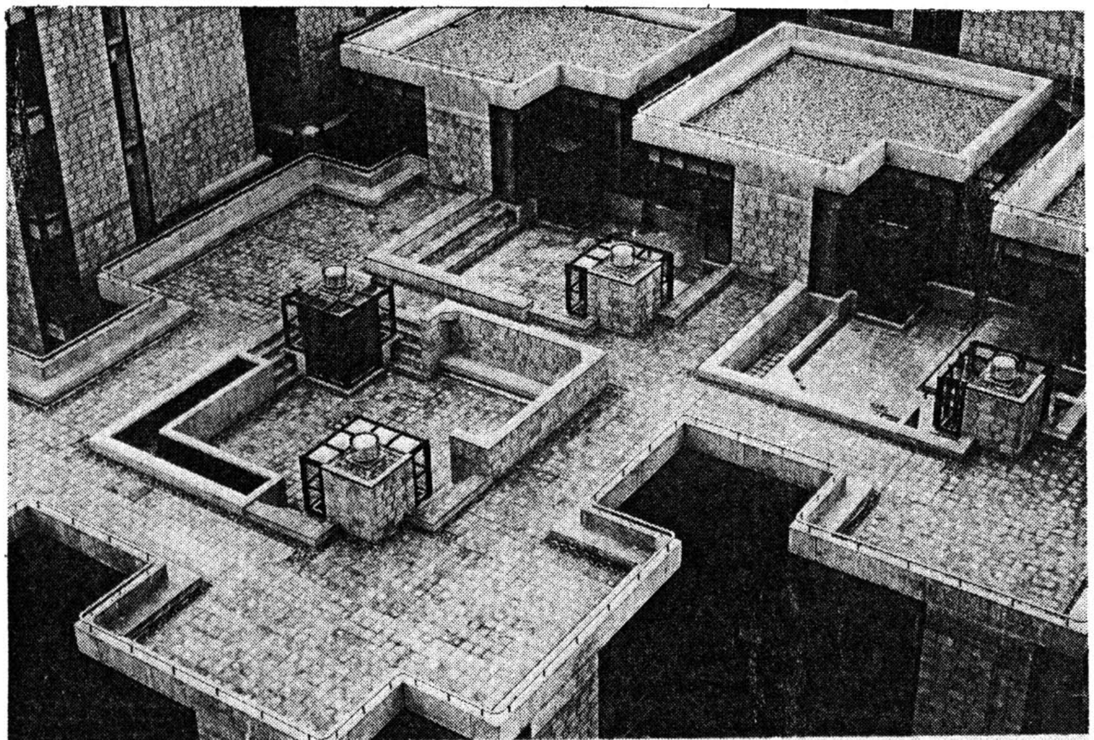


lation. (Figure 49) Although they are not entirely scientific or accurate, they do provide evidence of Kahn's conscious concern for qualities of light and air. It also appears the truss frame extending beyond the glazing may have been intended to support a seasonal shade device. Judged from photographs, the light quality in his buildings appears to be excellent. However, summer over-heating may have been a problem in some of his projects. Not unlike Louis Kahn's Yale Center for British Studies, Albert Kahn often used deep structural concrete beams to diffuse and reflect light to the work plane.

HERMAN HERTZBERGER: APELDOORN OFFICE BUILDING (1974)

For Hertzberger, small atriums, light wells and skylights form the connective tissue in this significant alternative approach to office design. Small interior atria are surrounded by workstations, lounges, coffee areas, offices and movement paths. (Figure 50) A collection of one, two and three-story atria maintain a large degree of openess within the building to facilitate human interaction.

A unique skylight system coupled with masonry-enclosed vertical ventilators bring a diffuse but dim light to the building. (Figure 51) A range of closure materials steming from opaque masonry blook to transparent glass



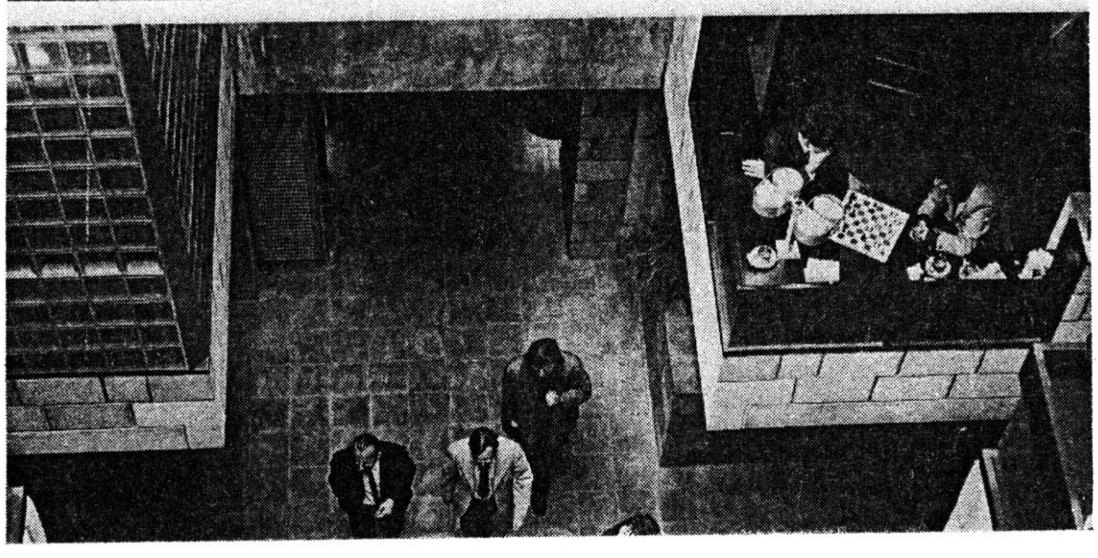


Figure 51

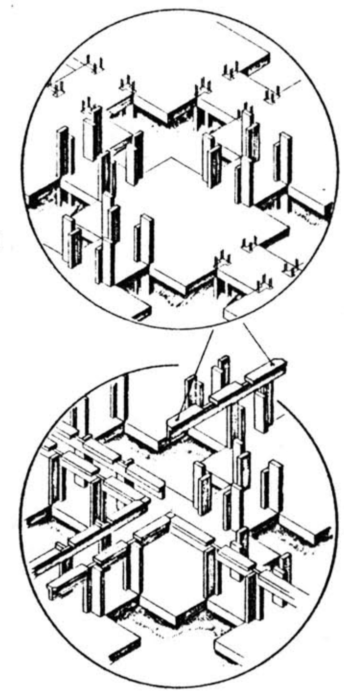


Figure 50

block to metal-framed panels and low walls provide the necessary degreees of privacy needed by the building's users.

In several studies on small-group ecology, Sommer (1961,1965,1967) has shown how seat location influences participation rates, and how different seat arrangements are associated with cooperative, competitive or coacting behaviors. Other studies (Sommer 1961; Hearn 1957; Becker 1962) have shown the effect of office layout on friendship formation, autonomy, performance feedback and communication. This relatively small but accumulating body of research evidence suggests a strong relationship between performance, organizational effectiveness and the physical setting. (Figure 52) Clearwater (1980), for example, using self-reported measures of productivity found that environmental satisfaction, environmental functional quality and ability to concentate correlated significantly with self-reported measures of productivity. Although this type of data need be treated with caution it does demonstrate that employees may use characteristics of the physical environment as a basis for justifying performance.

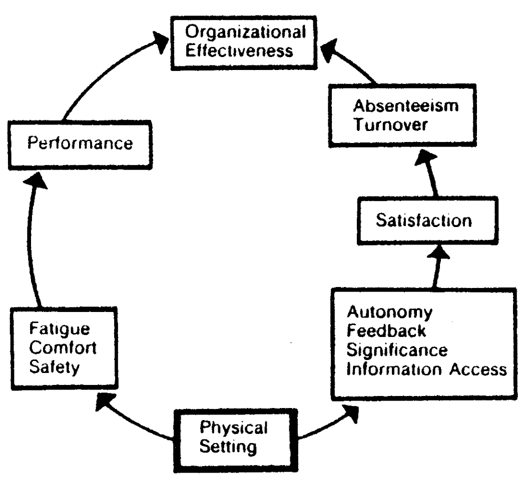
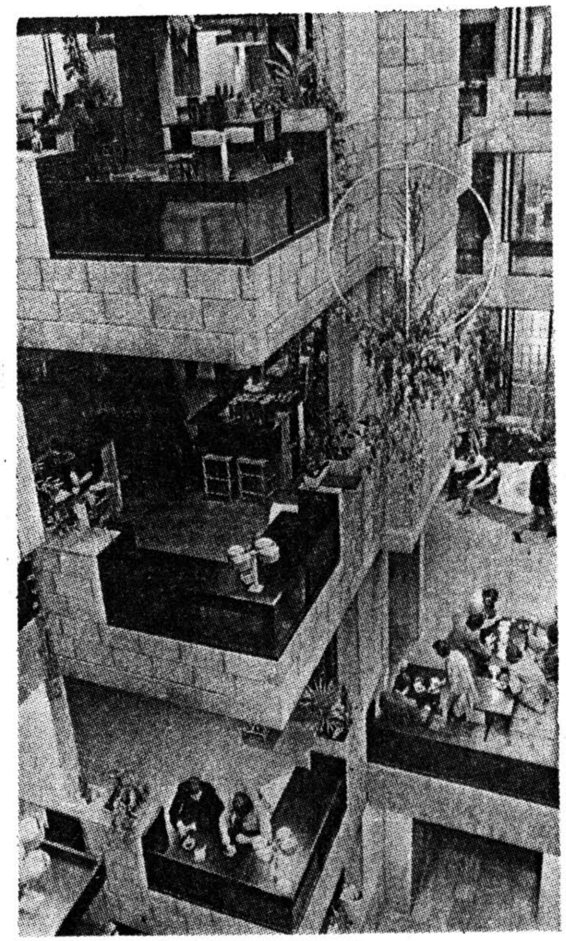


Figure 52

Assessing the relationship between aspects of a proposed physical design and identified programatic needs is very difficult. Hertzberger's office design for the Centraal Beheer Insurance Company is a significant departure from the conventional American approach to office landscape design. The result with respect to worker job satisfaction and hence decrease in absenteeism and increases in individual productivity has not been conclusively assessed. But, according to observations of the architect and impartial visitor's, the Centraal Beheer approach has been termed a successful non-hierarchial work environment.



The project attempts to demonstrate an integration of daylighting, and a collective work habitat--the focus of this thesis investigation. Unfortunately, the major criticism by visitors to the building is one of gloom--not enough light! Hertzberger appears to have not provided adequately scaled openings for daylight to penetrate his skylights to the workspaces below. In addition, many of the atria paths tend to be very deep, narrow and canyon-like making it difficult for daylight to reach the floor. Dark trim and floor coverings tend to diminish reflection adding to visitors perception of gloom.

The building, while not an example of a well-executed daylighted office building, does embody an attitude and approach to an office environment that provides a strong reference for this thesis investigation.

ENERGY EFFICIENT CASE STUDIES EMPLOYING DAYLIGHTING, PASSIVE SOLAR HEATING, VENTILATIVE COOLING AND CONSERVATION

Recently the Department of Energy has sponsored a series of demonstration programs with the objective of determining the economic benefits of an energy conscious approach to architectural design. Two projects selected from the many funded follow comparing the projected computer simulated energy consumption of each building first as conventionally designed and second with the energy reduction strategies applied. The purpose of presenting these cases is to demonstrate the potential savings that are realizable in a design solution which synthesizes architecture, a sensitivity to the seasonal environmental forces which impact the building and innovative technologies.

COLORADO MOUNTAIN COLLEGE, GLENWOOD SPRINGS, COLORADO
PETER DOBROVOLNY, ARCHITECT
THERMAL TECHNOLOGY CORPORATION, SOLAR DESIGN

The Colorado Mountain College building houses the Glenwood Springs Community Education Center on the first two floors, with the central administration offices on the third floor. The building occupies 31,870 gross square feet and houses an average of 150 visitors at one time.

The average climate is relatively sunny and dry year-round, with warm to hot days and cool nights in the summer. The winter days are sunny and cold, with very cold nights.

A critical element in the program was that many of these classes and activities be arranged in an unstructured open fashion to encourage intermingling with public spaces providing an education center which displays community education.

An intuitive approach was used by the designers to establish the general spatial arrangement of the building and an assumption was made that heating was the overriding energy problem. In retrospect, the designers indicated that their design approach was "overly intuitive", pointing out that cooling and daylighting were given less than adequate predesign consideration. The spatial arrangement of the building was determined by considering the compatibility of the spaces with each other, their times of use, and their heating, cooling and lighting requirements. Activities least disturbed by passersby and those which can occasionally expand into the atrium were located on the ground level. Classrooms needing more

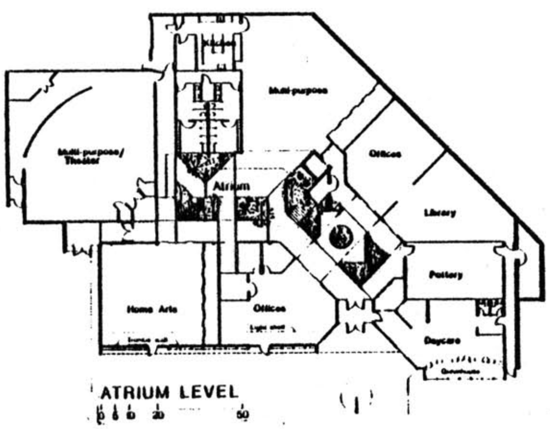


Figure 53

seclusion were located on the second level, while administrative offices were located on the third level where, due to its primarily day-use functions, it has access to daylighting and solar gain. Night classes and activities needing little light were located either to the north side or in the interior section of the building, where internal loads could provide heating. (Figure 53)

The desired energy end-use savings established during pre-design process were roughly:

Heating	60-80%
Cooling	80-100%
Lighting	40-60%
Hot water	40-60%

ARCHITECTURAL RESPONSES TO REDUCING ENERGY CONSUMPTION (Figure 54)

HEATING

The designer's heating strategy was to utilize a long, unobstructed south facade which employs a combination of direct gain, Trombe walls and water walls. By establishing the amount of glazing as 15% of the floor area, to achieve 60-80% savings on heating, it was deter-

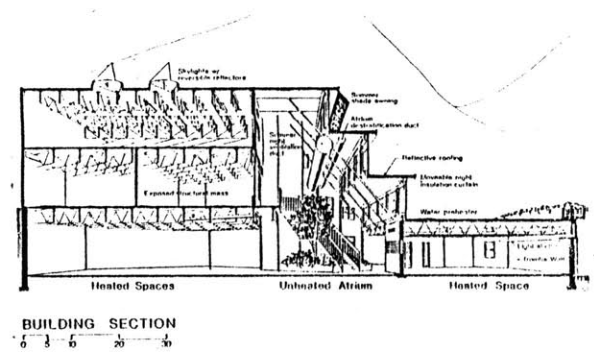


Figure 54

mined that a central heating plant would not be required. Small fan-coil units and electric baseboard heaters were chosen to meet the minimal back-up needs.

COOLING

By using fan-flushing at night virtually all of the cooling needs can be met by forced ventilative cooling. The most modest scheme - 4 hours of night ventilation at 5 ACH will reduce the auxiliary cooling requirement by 50%, while 8 hours at 10 ACH will all but eliminate all of the auxiliary cooling needs. Simulations were performed at LBL using the BLAST code. Any auxiliary that may be required will be met using evaporative cooling units.

THERMAL MASS

A steel frame structure was chosen because of reduced cost and time to errect over a concrete frame. Five inch concrete floor and roof slabs are used throughout with vertical concrete walls at the ground levels, which step up the hill side to the third level offices on the northeast side. The mass was left exposed for use in both passive heating and ventilation cooling.

ATRIUM/SUNSPACE

The atrium will be allowed larger temperature swings than adjacent occuped spaces. Although infrequently encountered, the extremes in the atrium were simulated to be 48 degrees F and 84 degrees F. A gas fired furnace will raise the lower extreme to 55 degrees F during the day and 45 degrees F at night. In addition, doors and operable windows of adjacent spaces may remain closed if the atrium is too cold, or if the spaces are too warm during the winter, the doors and windows may be opened to increase the comfort of both spaces.

DAYLIGHTING

Spaces needing glare-free light utilize Trombe walls for thermal storage with light shelves above. A number of other solutions exist to using a Trombe wall for glare reduction as can be observed in the previous examples. Light entering the atrium through stepped vertical clerestory monitors is reflected and diffused to adjacent spaces to the north by light shelf type roof pieces (reflection occurs from the top and bottom of these pieces.) The third floor offices utilize skylights with reversible reflectors to provide ambient daylighting. (Figure 54) The overall daylighting design approach

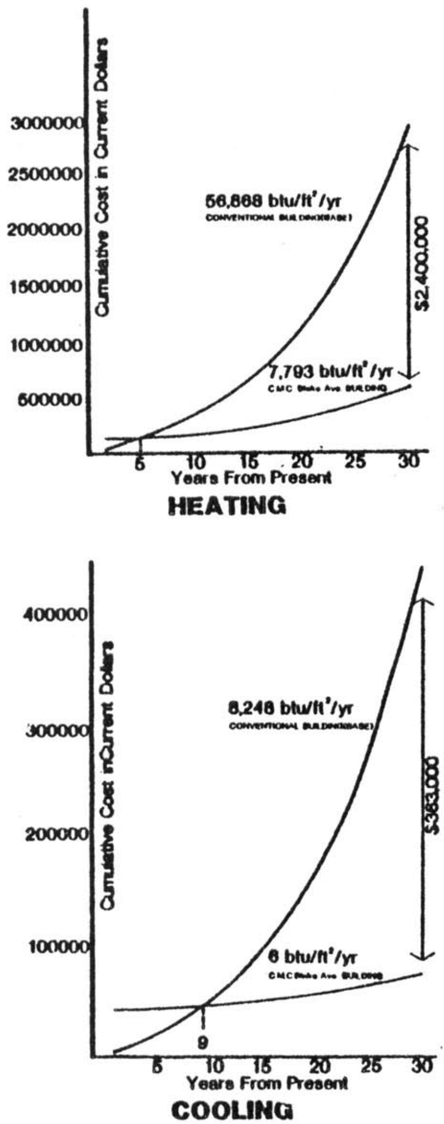


Figure 55

appears to over emphasize quantity at the expense of quality. Recent comments by the architects express regret for not more carefully evaluating reflected glare, brightness ratios and other subtle qualative aspects of the daylighting design.

ARTIFICIAL LIGHTING

The exposed ceiling system, including structural mechanical and electrical elements are painted white. Fluorescent light fixtures are designed to provide glare-free indirect lighting. Two levels of lighting can be selected by manual switching.

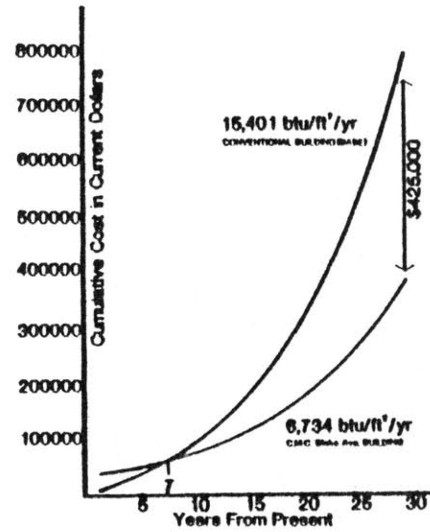
CONSERVATION

Automatically operated night insulation was recommended by the designers, the 26.1 MMBTU's it saves annually will amortize the $26,750 investiment only over the long term - 15 to 20 years. It is seriously questioned whether the system has an operating life in a public building of greater than 10 years. Screens with an 80% shading factor will cover the south windows during the summer to reduce solar gains. R-40 insulation has been specified for the roofs and R-25 for the walls.

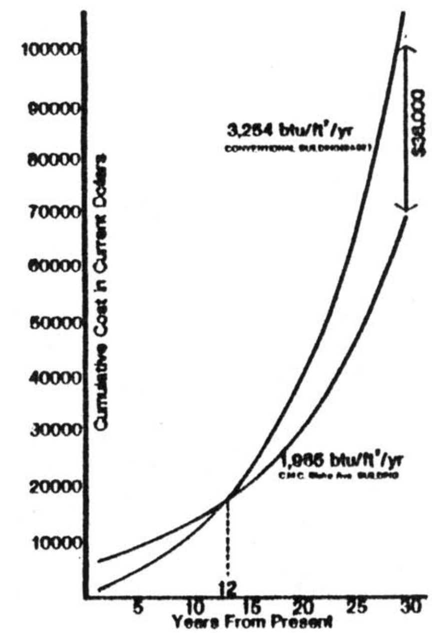
HOT WATER

Hot water will be preheated passively in black-painted tanks suspended in the atrium and exposed to direct sunlight.

It is observed from the data presented in the graphs produced from data provided from BLAST simulations, that substantial annual savings can be realized. (Figure 55) However, many of the options selected by the designers require substantial capital costs such as the automatic night insulation, Trombe walls and solar hot water. Of the options selected by the designers, those that seem most practical for realistic consideration are increased insulation levels, natural daylighting, exterior shade devices, ventilative cooling and management controls. It is odd the designers choose electric heating as the auxiliary fuel when gas is also being used in the building and at a price currently five times less than electricity. Hence, the savings predicted for heating and hot water are somewhat optimistic being based on electrical resistance rates.



LIGHTING



HOT WATER

MT. AIRY PUBLIC LIBRARY
J.N. PEASE ASSOCIATES, ARCHITECT
ED MAZRIA AND ASSOCIATES, SOLAR CONSULTANTS

The library is located in downtown Mount Airy, North Carolina, within close proximity to cultural events, shopping and government offices. The site slopes to the south and has a stand of mature deciduous trees on its north side. (Figure 56) The climate is generally mild and moderately humid. The proposed program emphasizes the unhampered circulation of visitors staff and handicap users. The building has a total gross enclosed floor area of 13,450 square feet.

The owner, (City of Mount Airy) is interested in the building's long term performance and is not only committed to an energy-saving building but is also interested in setting an example to further encourage utilization of renewable energy and conservation. Figure 57) compare the end-use energy consumption and costs of three buildings of similar size and configuration to the newly designed Mt. Airy Library.

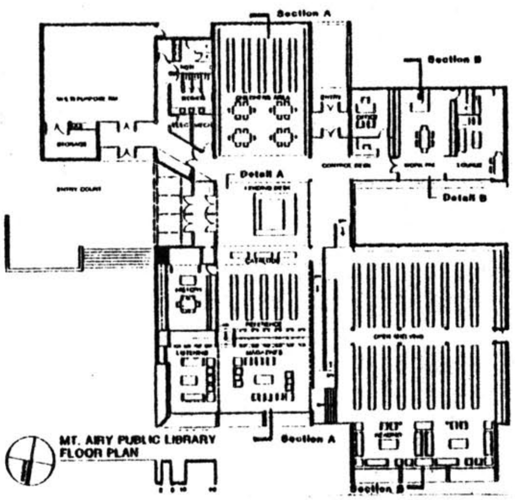
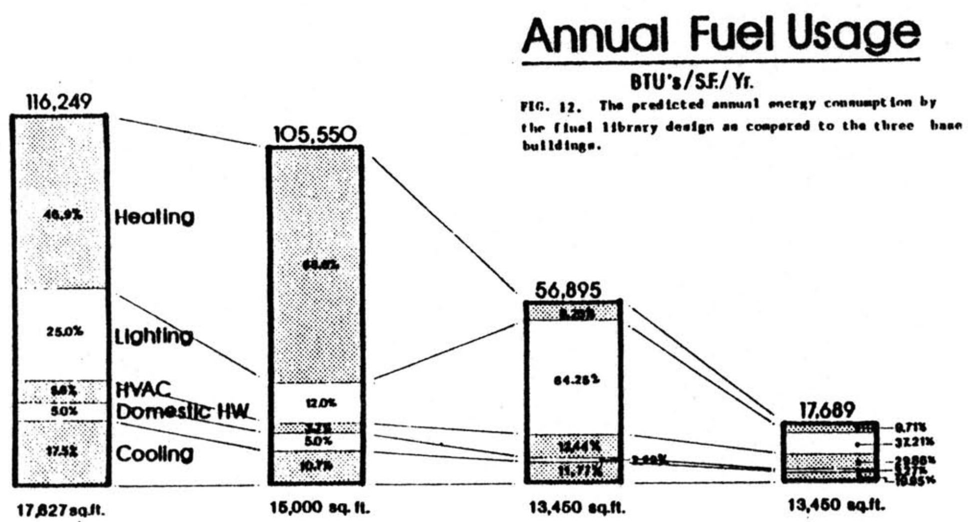


Figure 56

The Municipal building is 17,207 square feet and was constructed in 1978. The Elkin Library is 15,000 square feet and was built in 1969. The 13,450 square foot non-


Annual Fuel Usage
BTU's/S.F./Yr.
FIG. 12. The predicted annual energy consumption by the final library design as compared to the three base buildings.
116,249
Heating
25.0%
Lighting
HVAC
5.0%
Domestic HW
Cooling
17,827 sq.ft.
105,550
12.0%
5.0%
15,000 sq. ft.
56,895
64.28%
13,450 sq.ft.
17,689
13,450 sq.ft.

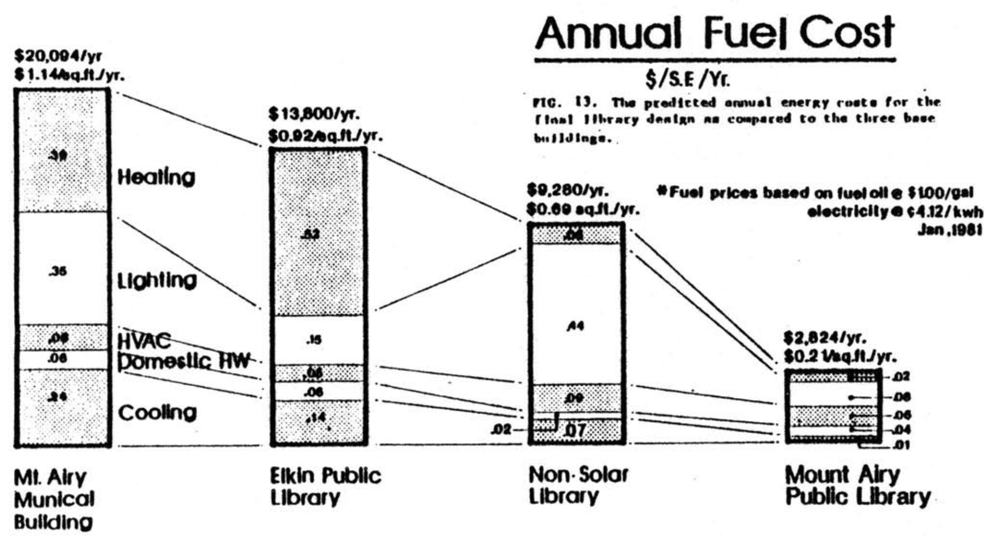
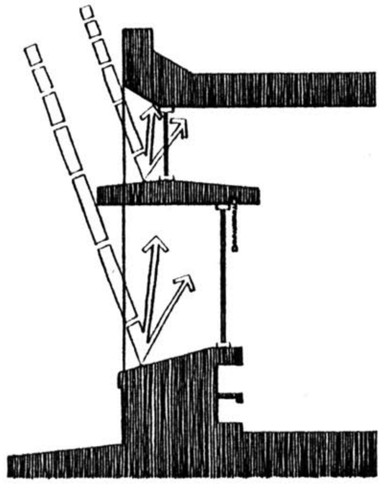

Annual Fuel Cost
$/S.F./Yr.
FIG. 13. The predicted annual energy costs for the final library design as compared to the three base buildings.
$20,094/yr
$1.14/sq.ft./yr.
Heating
.36
Lighting
HVAC
.06
Domestic HW
Cooling
$13,800/yr.
$0.92/sq.ft./yr.
.53
.15
.06
.14
$9,280/yr.
$0.69 sq.ft./yr.
.44
.09
.02
.07
#Fuel prices based on fuel oil @ $1.00/gal
electricity @ ¢4.12/kwh
Jan, 1981
$2,824/yr.
$0.21/sq.ft./yr.
.02
.06
.06
.04
.01
Mt. Airy Munical Building
Elkin Public Library
Non-Solar Library
Mount Airy Public Library

Figure 57



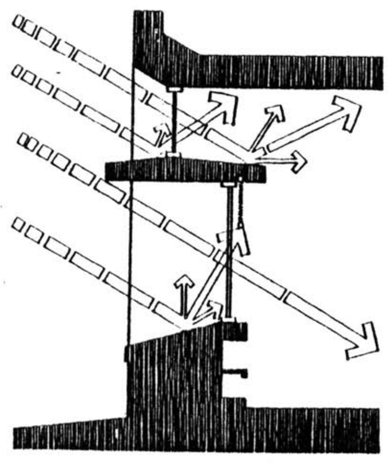


Figure 58

solar library is the same design as the Mount Airy building substituting conventional architectural responses for the passive solar amenities. These amenities include exterior shading treatments on the south and west glazings, clerestories and light shelves. (Figure 58) In addition, the non-solar library performance prediction was arrived at using less internal mass and carpet rather than quarry tile over the concrete floor slab. The predicted energy consumption for the non-solar and solar building were determined using the ECAL computer analysis model. It was assumed that air to air heat pumps were used for both auxiliary heating and cooling needs. Water-to-air heat pumps were rejected due to the corrosiveness of the water in the area and environmental problems with dumping heated water into the city sanitary/storm sewer system.

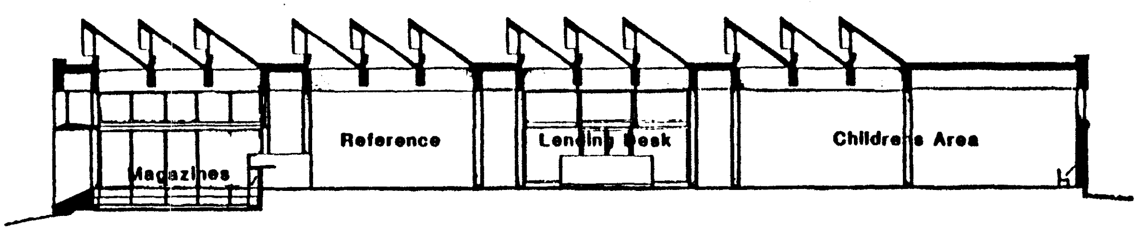
The final building design, according to the design team, evolved incrementally from one basic design rather than a selection from schematic alternatives. The energy related architectural responses and requisite energy reduction strategies are as follows:

LIGHTING

South-facing clerestories are arranged to provide daylighting (Fig. 59) to those areas farthest from the view windows since they have the highest potential electric lighting demand. Reading and staff areas are located next to south windows which employ a light shelf to block direct sunlight at the building edge-zone and to reflect and diffuse it into the building. Calculations show that the combination of view windows and clerestories reduce the energy consumption of artificial lighting by 82 percent. The installed task lighting and ambient artificial lighting (fluorscent) for night time use is 1.5-2.0 watts per square foot.

HEATING

Estimated heating costs were reduced by 63% compared to the non-solar library due to winter solar heat gain from south-facing glass. The total south-facing glas area is the equivalent of 17% of the total floor area. Trombe walls proposed by the designers were eliminated from the final design because of low cost effectiveness.



SECTION A

Figure 59

COOLING

Summer window shading with light shelves and overhangs, using trees to shade east and west sides of the building light colored roof and walls, and natural ventilation all contribute to an estimated 47% reduction in cooling costs relative to the non-solar referenced building. This also allowed a first-cost savings on cooling equipment, since the capacity required was reduced from 37 to 32 tons.

CONSERVATION

Heat pumps are zoned by activity area which can be activated by library staff prior to occupancy. During unused periods the spaces will be allowed a wider temperature fluctuation.

Airlocks are used at all entries to the building to reduce infiltration and interior glass partitions divide use zones within the building.

Double glazing is used throughout the building and 2-3 inches of rigid insulation is used on the exterior side of the solid masonry walls and roofs to reduce conductive and radiant losses. Solid grouted masonry walls are exposed on the inside, together with a quarry tile covered concrete floor and exposed steel and concrete roof to provide the building's thermal mass, thus reducing diurnal temperature swings. The energy reduction strategies designed into this building have increased estimated construction costs over the non-solar library by 15.9% or $217,000. The total projected cost for the building is $1,367,000. The energy design cost was $57,521, nearly 25% of the incremental cost for all energy reduction strategies.

Life cycle costs were not performed for this building but estimated first year energy savings is reported to be approximately $6,000.

It is obvious such an incremental cost for energy savings alone is not an economical design based upon conventional developer wisdom and logic. Therefore an optimum mix strategy needs to be developed between incremental costs, reductions in peak and base energy usage, demand changes and, savings in overall annual operating costs. Issues of social costs, power shortages, regional independence and security may also be entered into the optimum-mix equation to arrive at a design solution which fulfils the client and user's needs.

SOME QUALITATIVE AND QUANTITATIVE CONTRIBUTIONS OF DAYLIGHTING

As experienced inside a building, daylight indicates changes with respect to time in the visual environment, changes particularly in intensity and color, which are affected by the size, shape and location of the window, by the time of the day, by the time of the season, by the weather, and by obstructions or screening outside the building. Natural lighting provides positive directional effects within a room, these too change with time.

Sunlight is one of the most important cosmic forces in our existence, as it tunes us to the rhythm of our planet. Primitive people greeted the daily rebirth of the sun with rituals and worship. It was at the heart of the Taoist religion of China. As an ancient writer said, "The Tao... which is revealed by the sun's course through the heaven's is also revealed inside Man's heart." Light is an important synchronizer.

Civilizations dating back at least to the Egyptians worshipped the sun, and had a fundamental 'awareness' of light and dark. Much use was made of reflecting materials in Egyptian statues and obelisks, the latter often being tipped with gold to catch the sun's first rays. Pyramids were faced with white limestone to sparkle from great distances. The shadows cast by these monuments to the past helped to delineate time of year, month and day - a spiritual, proverbial, built sundial.

Cathedrals, temples and churches throughout time have been designed to be receptors of both natural and spiritual light. Procopius described the great Church of Santa Sophia in Constantinople when it was completed in the 6th century as so 'singularly full of light and sunshine (that) it appears not so much to be lit from the sun without, as from some heavenly light within'. The daylight enters from quite small windows, 40 in all, around the rim of the dome. It is this technique that causes Procopius to go on to say that the dome ' does not appear to rest on a solid foundation but to cover the place beneath as though it were suspended by the fabled golden chain'. (Figure 60)

The Gothic period which followed the Byzantine, when the Santa Sophia was built was one of great structural innovations in which the window was one of the most important determining factors. Flying butresses permitted virtually the whole wall of cathedrals such as York, Westminster Abbey, etc. to be liberated from acting as load bearing elements, to become 'structured lace' divided into smaller elements for the support of translucent and transparent

Figure 60

materials. Church windows not only let in sunlight to create warm luminous environments during the day but told stories as well by means of stained glass. The interior surfaces, and materials of the Renaissance churches acted to model and reflect the light.

Architects such as Balthasar and Dominikus Zimmermann created buildings during the Renaissance in which the plan forms were curved and shaped specifically to produce a magic form of daylight. In Balthasars' church of the Fourteen Saints, light is used like a waterfall splashing against the white and gold surfaces of the interior, creating contrast, shadow and internal changes which reflect the external environment.

Since the birth and development of artificial lighting, beginning with gas lighting in the 19th century, there has been a continued increasing disconcern for sensitive daylight and artificial lighting design by the architect. Any review of lighting from 1950 onwards must take account of a gradually increasing inter-relationship between artifical and natural sources. The degree of dependency clearly varies from buildings where daylighting tends to dominate as in the works of Aalto, to those such as new offices where permanent systems of artificial lighting are installed and the role of the window is in serious question.

One does not need a research program to know that sitting in a well daylit room with all its variety is pleasurable, a different measure of experience from a room without a view out, or one intolerably broken up by the pattern of wall perforation, or glazing bars, or one which is diminished by external obstruction or modified in tone or color by low transmission glass.

The human body has a capacity for adaptation, particularly in vision, and a need to exercise that capacity: perception itself depends on a degree of change. Changes of light with time are of a natural order. Throughout history, until around 1950, natural daylighting determined the building form and artificial light was added, but since 1950 such an observation is no longer valid. In fact, there are hundreds of examples in the United States alone where the opposite conceptual approach has been selected. Artificial illumination should be considered, as this thesis demonstrates in the Watertown Arsenal Case Study, a supplement and complement to daylight.

Artificial light has unique and important qualities of being independent of time of day or external conditions, is available at the touch of a switch, can be made available at any point in a building that electricity can be fed, is easily controlled and directed and lastly, is available in a wide range of colors and intensities. But despite these variations the unique difference between artificial and natural lighting sources is the fundamentally static quality of the former and the dynamic variety of the latter.

At a quantitative level energy is certainly one of the justifications for a recently renewed interest in daylighting for both its lighting and heating characteristics. The most frequent argument is that daylight can offset large electrical demands for artifical lighting systems. This may be true if the artificial lighting system is responsive to daylight conditions. Numerous daylit buildings have artificial lighting systems that are designed and operated with no regard for daylight contributions to interior space illumination, resulting in little if any energy savings. Although daylight may provide a more pleasant workspace in this situation,it will not reduce energy consumption unless people turn off the lights. Daylight design may result in lower levels of installed lighting, but its greatest energy contribution is that it allows people to turn off the lights.

Steven Selkowitz, at Lawrence Berkeley Laboratories is concerned that if designers and engineers justify day lighting on the basis of reduced electrical demand alone, predicted improvements in artifical systems will make comparative daylight energy savings appear insignificant Task/ambient lighting systems are now available that operate in the range of 1.0-1.5 watts per square foot of installed power. Projected improvements in electronic ballasts, fluorescent lamps and controls will further reduce electrical demand.

'With these types of changes, lighting electrical demands could be reduced from 7.5 to a range of 1 to 3 kilowatt hour per square foot per year. The 1 to 2 kilowatt-hour per square foot per year achieved with daylighting is less impressive from an energy savings alone in this context.'

Selkowitz does make an argument for daylighting however, that is not easily compromised by advanced artifical systems. It relates to peak power demands. Peak power demands are a critical issue for utilities, and lighting loads often coincide with peak heating and cooling loads. Charges for peak power can represent a significant fraction of a building's total electric bill. Many utilities have implemented rate structures to penalize peak power consumption. The significance of peak power demand can be seen in the following example.

Consider an office building in which half of the total energy load results from lighting. Assuming that one third of the usable floor space is close enough to a window to benefit from daylighting the maximum potential savings is one-third of the electrical demand for lighting, or 15 percent of the total demand. Under summer peak conditions typical cooling loads amount to 5-10 watts per square foot of which 3 watts represents lighting. If the lights can be turned off in 33 percent of the building, power consumption is reduced by 1 watt per square foot which also reduces the cooling requirement by one-half a watt per square foot. This results in a total savings of 1.5 watts per square foot, or approximately 10 to 20 percent of the building's peak power demand.

HEALTH, DAYLIGHT AND ERGONOMICS

A strong case for greatly increased attention to the use of natural light in buildings relates to biological, physiological and psychological well being. A growing body of research strongly indicates that daylighting and full spectrum artificial lighting is of great beneficial importance to the human body, and may have important consequences for productivity, absenteeism, and overall job satisfaction in the workplace.

There are several well known processes going on in the human skin which depend on the photochemical effects of ultraviolet radiation (UV). UV radiation is usually considered to be in the wavelength range between 100 and 400 nanometers which is for convenience broken into three bands, UV-A, ranging from 400-315 nm, UV-B, ranging from 315-280 nm, and UV-C from 280-100 nm.

Radiation in the ultraviolet A range passes through most types of glass and produces nearly no Vitamin D or reddening of the skin (erythema). Radiation in the UV-B range has both an erythemal and pigmenting effect on the human skin and also forms the Vitamin D in the body. However, ordinary window glass as well as reflective and heat absorbing types used commonly in office buildings absorbs essentially all radiation in the B range. "Considering the fact that millions of persons work behind glass, underground or in window-less environments, travel to work in closed vehicles and venture outdoors only in the early morning and late evening, when UV radiation is minimal, this situation might be regarded as serious."[1]

In addition, incandescent lamps emit very small amounts of UV radiation and the radiation emitted by flourscent lamps is usually absorbed by the fixtures on which they are

Some non-visual effects on man of different kinds of radiation.

Radiation	Notation	Wavelength nm*	Effects on man
Ultraviolet	UV-C UV-B UV-A	100-280 280-315 315-(400)	Actinic effects on skin, Erythema, Production of vitamin-D, General physiological effects
Visual	Violet Blue Green Yellow Orange Red	380-436 436-495 495-566 566-589 589-627 627-780	Entrainment of circadian rhythms, Activation of pineal organ, Endocrine and autonomic effect, Influence on nervous arousal through reticular activation, Effect on performance and fatigue, Cognitive, emotional and behavioural correlates, Dermo-optic perception?
Infrared	IR-A IR-B IR-C	780-1400 1400-3000 3000-1.000.000**	Heating effect on skin, Vasodilation, Influence on body temperature and metabolism, Effects on behaviour, Sensations of cold, heat and pain

* nanometer = 10^{-9} meter

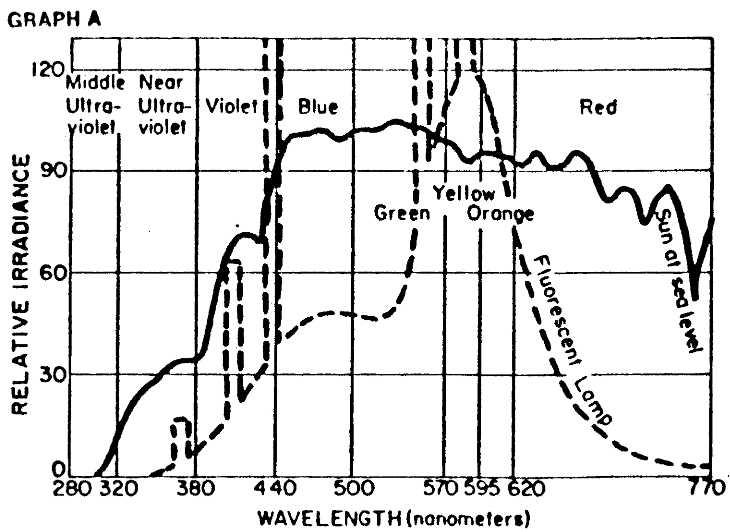
** 10^{6} nm = 1 millimeter

Figure 61

mounted. Consequently, many people in northern climates get very little exposure to radiation in the B-range, especially during the winter.[2] Vitamin-D is an important hormone in the body, it acts on the intestines to facilitate absorption of dietary calcium. If one drinks a glass of milk it does not necessarily follow that the calcium in the milk will be able to pass from the gut into the blood stream, and become available to the bones and the other tissues of the body.[3] Left to their own devices the intestines are rather inefficient absorbers of dietary calcium, but Vitamin D helps markedly.[4]

Adults who fail to consume adequate calcium, or to absorb enough of this compound because they lack Vitamin D, develop a disease known as Osteomalacia.[5] Recent studies show that if normal, healthy adults remain indoors for several months, i.e., during the long Boston winter, and are exposed to their customary artificial light sources, which provide little UV light, so little Vitamin D is synthesized within their skin that calcium absorption is impaired.[5] Exposing such people to other light sources designed to provide some UV in the B range can correct this.

Wurtman[6], et al, states that the amount of time necessary to provide an individual with adequate daily exposure would be equivalent to the radiation that would fall upon a resident of Washington, D.C. who took a daily 15 minute walk outdoors at lunchtime in midsummer. Several studies reviewed indicate the existence of a rather delicate balance between UV radiation exposure and the intake of Vitamin D^2 and D^3.[7]

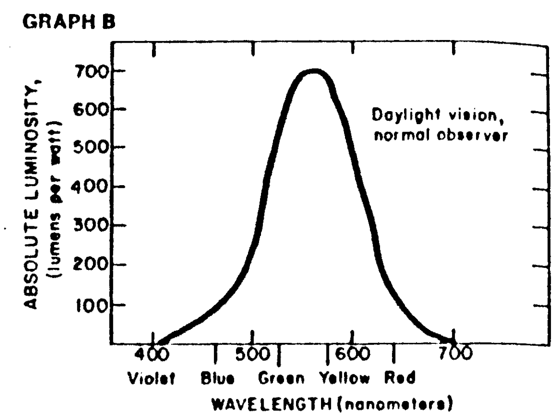


GRAPH A

The spectrum of the sun at sea level is shown in the heavy lines in the accompanying graph. The fluorescent lamp characteristic, in dotted lines, is seen to be radically different. This difference is of a vital nature, related to the effects of fluorescent lighting on health of plants and animals, including man.

Illumination from "cool white" fluorescent lighting is weak in just that region in which light emission from the sun is strongest (the spectral region to which the eyes of countless generations of humankind have been adapted).

Incandescent lamps give poor illumination in the entire blue-green half of the spectrum, the part to which the eyes have their best response (over the band of wavelengths from 500 to about 650 nanometers). Fortunately, fluorescent lighting can be modified by engineers and physicists to produce illumination closely resembling that of sunlight.



GRAPH B

Response of human eye to light of wavelengths from 400 to 700 nm.

Figure 62

In experiments on hamsters and cotton rats it was shown that the nature of illumination had a profound effect on the incidence of dental cavities.[8] These results were followed up in a study comparing the influence of different lighting conditions on the incidence of cavities in two windowless classrooms near the beginning and end of the year. Children supplied with cool-white flourscent lighting developed significantly greater number of dental cavities than those children exposed to full spectrum lighting.[9] It should be noted that definite conclusions should not be drawn from the results of these few studies, but they do indicate several possible effects of varying the spectral radiation range.

Another direct effect of UV-B radiation is its capacity to destroy circulating bilirubin in premature infants. Bilirubin is a breakdown product of the hemoglobin released when red blood cells die after their 120-day lives. In adults the bilirubin is normally destroyed in the liver. However, adults with liver disease, such as hepatitis, or newborn infants whose livers are not yet mature, bilirubin is not destroyed and its accumulation within the body causes the skin to become yellow. Bilirubin cells are fat-soluble and tend to collect in pockets within certain portions of the brain in infants resulting in neuronal destruction. Studies in England, Russia, Brazil and the

United States have amply confirmed that exposing newborn jaundiced babies to natural light is a very highly efficient treatment for bilirubin. The indirect effects of light include its capacity to generate the raw material for vision, on sexual maturation, on the pineal gland and biological rhythms. For a more detailed account of these effects, I refer you to papers by R. J. Wurtman, Professor of Endocrinology and Metabolism in the Department of Nutrition and Food Science at M.I.T. or to the annotated bibliography prepared by the Swedish Building Research Council titled The Non-Visual Effects of Light.

Numerous studies indicate that UV radiation might also have effects of a general physiological nature, including a lowering of pulse rate, a fall in blood pressure, changes in skin temperature, and metabolic rate, in reaction time and general activity level, as well as an improvement of health conditions and resistance to certain kinds of infection.[10] Sigmund[11] for instance, reports a considerble reduction of visual reaction time to optical stimulations in healthy adults and children three weeks after UV irradiation. Zamkova and Krivitskaya[12] were able to demonstrate that UV-irradiated students had a shorter reaction time to light and sound, a lower fatigability of the visual receptor, and improved working capacity. The improvement of academic standing in the experimental class is probably also connected with these favorable shifts.

In a study by Lykken and Olsson[13] on children in Swedish day-care centers, a clear-cut correlation was demonstrated between duration of outdoor activity and a resistance to infection of the respiratory passages.

A three-year study by Larson[14] of small school children in Michigan, USA indicates that students attending a windowless school have a higher absenteeism rate than those attending a daylighted school.

Wurtman provides an interesting personal statement about the role of natural daylight in a 1973 article written for "Progressive Architecture", "It seems reasonable that the light sources to which we expose people should not deviate markedly from the lighting environment under which people evolved in nature. The fragmentary data now available suggest that working under such natural conditions significantly decreases visual fatigue, and may also increase productivity. I, for one, would worry somewhat about keeping my children under, let us say, pure green light, or, of more immediate concern, yellow sodium light, even if it can be shown that the brightness indices of such lights are greater than that of existing broad-spectrum light sources. I suspect that all one can do is hope that new information about biological effects of light accumulates as quickly as possible, and that such information is applied on a continuing basis in the design of light sources."

In a report published in "Lighting Research and Technology" in 1976, author Belinda Collins summarizes a series of studies relating to the psychological reaction to windows. She concludes that acceptance of a windowless space is governed by the characteristics of the space itself. She indicates that although few studies have actually assessed individual reaction to a windowless office, there appears to be a widespread opinion that people do not like to work in windowless offices.[16]

Ruys[17] questioned 139 female employees in five buildings containing windowless offices in Seattle, Washington. Almost 60% of the subjects were the sole occupant of an office; only 5% occupied an office with more than three people. Almost 45% of the interviewees thought their offices were large enough and almost 90% believed the lighting levels to be adequate. Despite general satisfaction with their workspaces, about 90% expressed dissatisfaction with the lack of windows, and almost 50% thought that the lack of windows affected them or their work adversely. The interviewees gave the following reasons for disliking their windowless offices:

1. no daylight
2. poor ventilation
3. inability to know about the weather
4. inability to see out and have a view
5. feelings of being 'cooped-up', isolation and claustrophobia; and
6. feelings of depression and tension.

Ruys found that the presence of such factors as access to a nearby window, bright lights or warm colors, did not alter the workers dislike for a windowless environment.

Sommer[18] noted numerous similar complaints about conditions in underground offices. He was struck by the frequency with which employees hung landscape pictures and posters on walls to become surrogate windows. Dislike of the windowless situation seemed accentuated because interviewees knew that executives had large offices upstairs with beautiful views.

A number of investigators have attempted to quantify the most acceptable size and shape for fenestration using scale model simulation techniques. Ne'eman and Hopkinson[19] found that subjects could consistently define a minimum acceptable window size. Results obtained revealed that distance from the window, window height and visual angle all effected the subjects judgement of acceptable size. View type proved critical, with subjects preferring wider windows for nearby views than distant views. The researchers explained that near views demand more attention and need a wider aperture to be seen in full, while distant views, having less detail and subtending a smaller angle, require a smaller window. They observed that for 50% of the subjects the smallest window size acceptable indicated a window occupying about 25% of the window wall. The window wall had to be increased to 35% to satisfy 85% of the subjects.

A similar study by Keighley20 investigated preferences for a window wall in a small scale open-plan office, he found that subjects selected windows that were wider than tall. They also tended to locate the sill somewhat below eye level. Satisfaction was greatest for windows which occupied 30% of the window wall. Percentages of the wall less than 20% were seen as extremely unsatisfactory by the subjects. These findings correlate well with those of Ne'eman and Hopkinson. Unfortunately, the scale models used in each study prohibit examination of the dynamic qualities of the exterior view, however, they do indicate strongly that there are window sizes which are too small to be acceptable.

It has become evident through my search into the disciplines of photobiology, environmental psychology, sociology, and industrial psychology there is an enormous amount of factual and circumstantial data and results, that is almost never considered in architectural practice or education. Thus, one finds a gap between research conducted in related and unrelated disciplines and the transfer of that knowledge into the profession engaged in the design of the built environment.

It occurs to me that a great deal of this 'factual' information would be valuable to architects in persuading a client to accept an office design solution that may have a higher first cost but a substantial financial return through increased worker productivity, decrease in absenteeism, greater job satisfaction and a reduction in annual energy costs.

For example, take an office worker making an annual salary of $20,000, who occupies 100 square feet of work space, thereby creating a payroll cost of $200/square foot/year, which helps to put things in perspective when prioritizing design options. Where a savings in annual energy costs of 50% would generate a savings on the order of $1.00-1.50/

square foot/year, an increase in worker productivity of 2% would result in increased revenues to the employer on the order of $4.00/square foot/year. To further extend this argument, if the average salary for all workers in a building with 50,000 square feet of actual workspace were $20,000/year, the annual payroll would total $10,000,000. A 2% average increase in productivity resulting from an improved work environment would generate a $200,000 increase in profits annually to the respective employer. Whereas, a 50% savings in annual operating costs, assuming a reduction from 150,000 BTU/square foot/year to 75,000 BTU/square foot/year, would result in a savings to the employer of approximately $85,700, assuming a gross conditioned space of 65,000 square feet (50,000 square feet work space and 15,000 circulation) and an electric rate of six cents per kilowatt hour. A building design that accomplishes both may have a combined equivalent return of roughly $280,000 per year. The point of this simplified comparison is to demonstrate the need for better communication between research and practice - as well as demonstrating some of the potential value of an office design based on human/worker well-being and satisfaction rather than the typical minimalist attitude of most American developers.

This review of the psychological and physiological reactions to a variety of luminous conditions is to be regarded not as a finished product but as a starting point for a better understanding of the impact on the human body of light and color.

As many of my classmates, I too, began this thesis investigation with numerable aspirations and expectations of what was to be accomplished. And, like my colleagues, have been engaged in a continual distillation and refinement process over the past weeks to assemble a body of coherent information, messages and, a few facts from the vast sources investigated and knowledge acquired through this experience. The intent and purpose of this section is to portray through words and drawings the application of atria and daylight design philosophies, principles and strategies discovered in my research and exploration.

As described in the introduction, the hypothesis of this investigation is that a 'habitable' atrium as a major design element can be sensitively and systematically integrated into the redesign of an early 20th century warehouse building. The atrium, a primary spatial organization component, source of natural illumination, a means to view the world beyond, and a variable aperature for emitting solar radiation and facilitating natural ventilation is the focus of this design proposal. This thesis explores an approach of using small atria to extend a building's habitable and most-marketable edge zone and to bring daylight into otherwise artificially illuminated zones of the building that would ordinarily have no relationship to the dynamic external environment.

The turn of the century warehouse structure represents a potentially significant office development market for the 1980's, competitive with new construction. The conceptual thinking from which this study evolved was an observation that a significant number of late 19th and early 20th century industrial buildings are often destroyed to make space for new speculative office parks. A decision to demolish and rebuild is often made on the basis that buildings, like the particular type being studied in this proposal, lack clear marketable amenities.

Warehouses and mill buildings constructed at the turn of the century and early 20th century were usually comprised of a concrete or steel frame with masonry infill. These structures may be characterized as having a very small exterior surface relative to enclosed volume, resulting in large floor areas with no relationship to the external world. Obviously, these characteristics are well-suited for warehouse applications. However, when addressing the prospects of adaptive reuse, developers find it difficult to visualize a marketable solution for the expansive interior zones of such a building.

The following design proposal presents a framework approach for developing existing warehouse and mill complexes into commercial leasehold office type uses, using daylighted atria as a principle form generating component. This thesis has been truely a study of light, first and foremost, leading to its integration and synthesis in the context of this design proposal.

Building Site

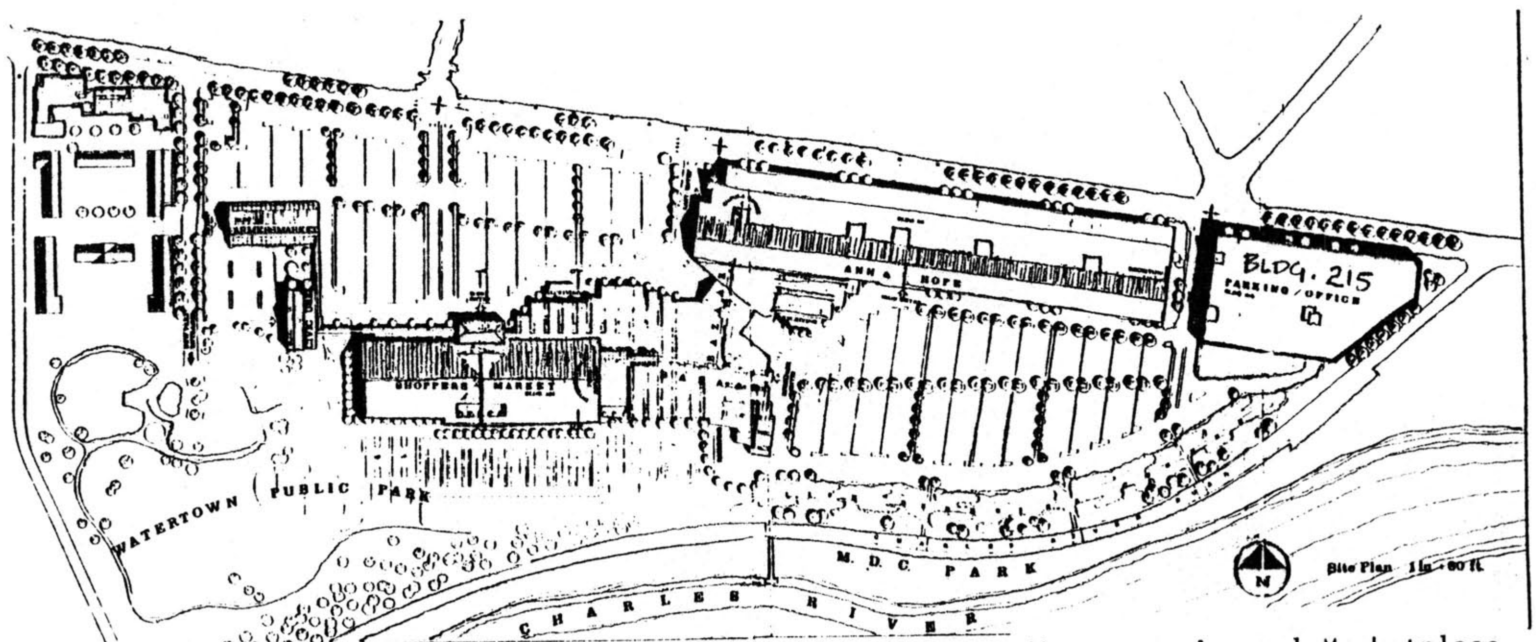
The building selected for this redesign proposal is one that would enable me to develop a conceptual design methodology that could be extended to a multitude of building types with similar characteristics. These characteristics are low rise, large bulk, a relatively small surface area to volume ratio, concrete or steel frame and slab construction, located in an area ripe for retail and commercial development and a site that had a reasonable southerly exposure.

A number of turn of the century and early 20th century warehouse and mill complexes were examined ranging in location from the Boston waterfront area to outlying areas such as Clinton, Lowell and Lawrence. The building selected is a non-descript large three-storey warehouse located at the Watertown Arsenal Complex. This particular building was chosen because it represents a generic frame construction industrial building with relatively minor site constraints. It should be emphasized that the thrust of this study is upon the development of a building's interior edges and consequently, many site specific issues have been intentionally left unaddressed.

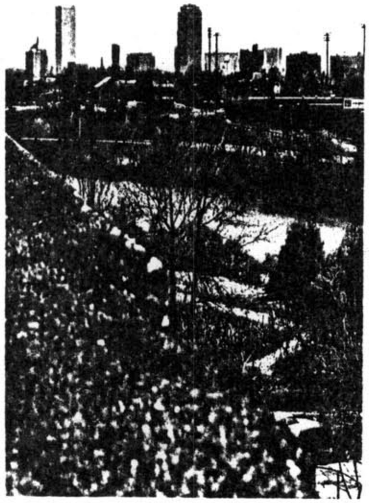
As its name connotes the Arsenal is a retired military installation, in fact, the oldest munitions storage depot in the United States. The Arsenal was transferred from the General Services Administration to the City of Watertown a number of years ago. The City has recently embarked on a mixed-use development track for the entire parcel.

The 38 acre parcel is located five miles west of Boston and extends in an east-west direction along the Charles River. The orientation of the long axis of nearly all existing structures at the Arsenal, including the one studied in this proposal, is roughly 15 degrees west of south. Therefore, making the exploration of daylighting and passive solar heating most feasible.

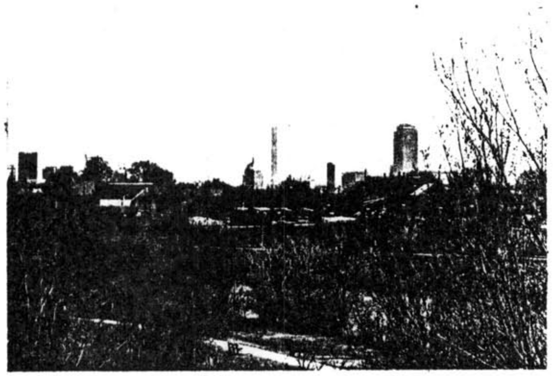
The Watertown Arsenal Markets, as it is now called, is to be comprised of four major retail markets totaling over 100 shops and stores linked together by a landscaped pedestrian street. A shoppers market, bazaar, farmers market and large anchor store, Ann and Hope, comprise the four retail centers. 36 units of market and 156 units of subsidized housing are nearing completion on the west end of the parcel. The Watertown Public Park and M.D.C. Charles River Park extends the entire length of the site immediately to the south along the River. The most easterly located building on the site, number 215, (even its name is non-descript) has been designated for commercial office and parking uses. Building 215 is the focus of this proposal. It is a three-storey rectangular



Watertown Arsenal Marketplace



View of Charles River Looking Southeast



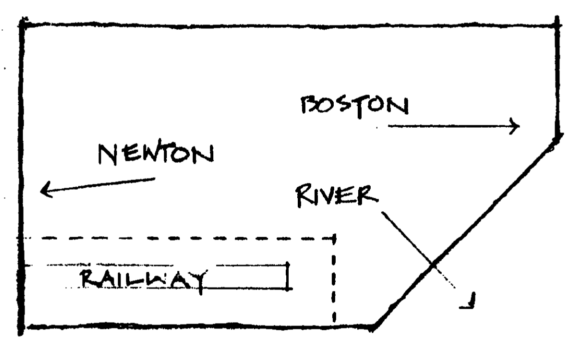
View of Boston looking southeast.

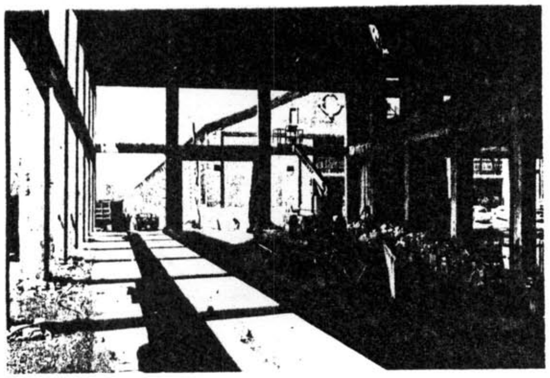
building with the southeast corner removed. The building system is a typical concrete mushroom slab with a 20'0 o.c. column spacing and masonry, brick, and glass infill. Its most recent use has been for the storage of building materials and automobiles. The original use was for the storage of heavy armorment such as tanks and weapons carriers. Consequently, the original design called for a live floor-load capacity of 650 pounds per square foot.

The original design, anticipating needs for additional space was engineered to allow for at least one additional level to be added in the future. Clearly, the building is extremely over engineered for the live loading experienced in an office application, therefore, it is entirely feasible to consider the addition of two floors if a need can be demonstrated.

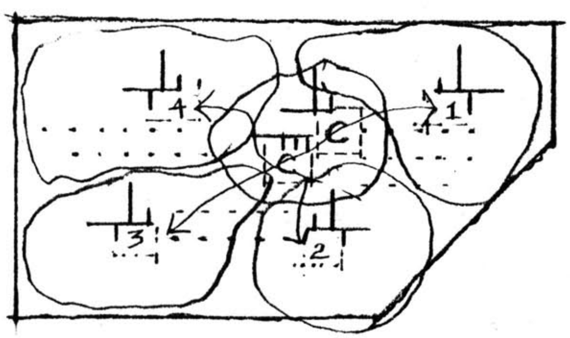
The building measures 440'0 feet in length - along a basically east/west axis - and 240'0 feet in depth. The site slopes to the southeast toward the parkway and river, creating space for a lower level that occupies approximately one half the total area of the floor above, and has a floor to ceiling height of 14'0. The first level has a floor to ceiling height of 18'0 and the second level is 14'0. A two-storey space extends horizontally from the south west corner to the south east corner and vertically from the first level to the roof. This space is the location of a railroad siding that provided enclosed loading and off-loading of military hardware.

Building 215, located at the east end of the Arsenal Market Complex, has commanding views of the Charles River and beyond to the skyline of Boston. These views are predominantly south and east. Views to the west include the expansive Arsenal itself and the treed suburbs of Newton. The addition of workspace on the existing roof could make this valuable amenity quite profitable for the building owner in terms of higher quality rental space. It would also provide a need for sites within the expansive building that introduce vertical access to these 'rooftop development pods'. By expanding such vertical access zones to the roof, a small atrium can be generated to bring daylight into the central core of the building. If operable glazing were used to enclose the atrium, a mechanism for natural ventilation would also be provided. The introduction of an air recirculation device may be logical to minimize temperature stratification in the small atrium and distribute warmed air to surrounding zones or the inverse - to exhaust excessive internal gains through the top of the atrium. In the summer, such a system with proper controls, could be used to bring cool night air into the building to cool the expansive concrete





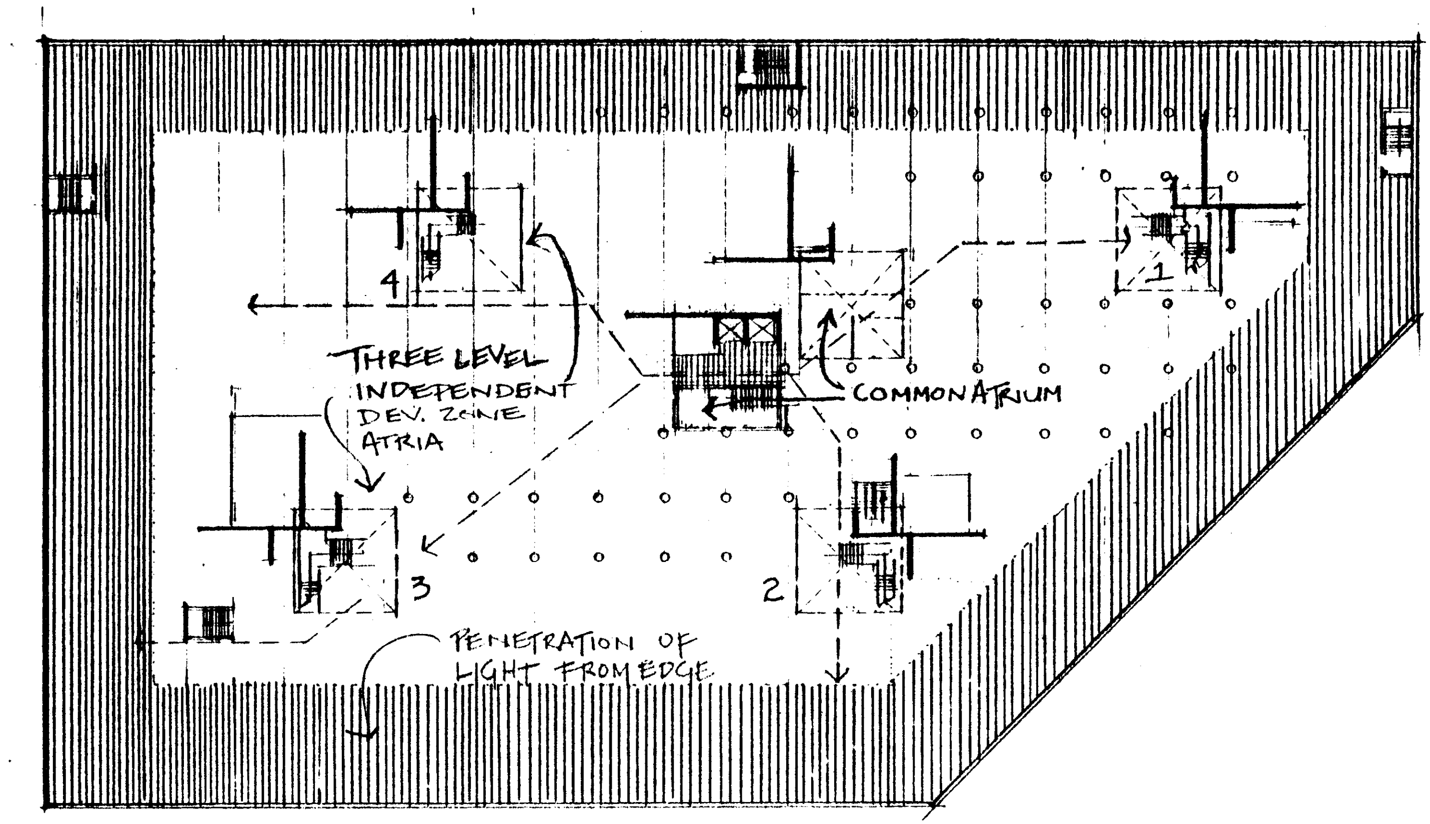
View of Two Storey Space



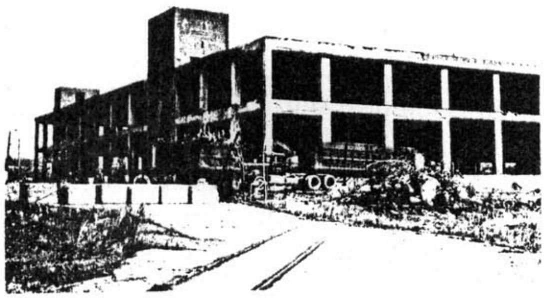
frame and slab which would act to temper the environment during daily occupied hours. This concept is often termed as forced air ventilative cooling. The atrium zone, with careful attention to seasonal shading and glare control, acts as an effective thermal control device while facilitating access to one of the building's most marketable physical amenities - the view. Equally important is the daylight that penetrates the atria to illuminate the interior sections of an otherwise dark, undesirable rental space. The psychological importance of the link established with the outside, through the atrium from the core of the building as described earlier in this study, plays a vital role in employee job satisfaction, productivity and attitude about the general workspace environment.

General Building Organization

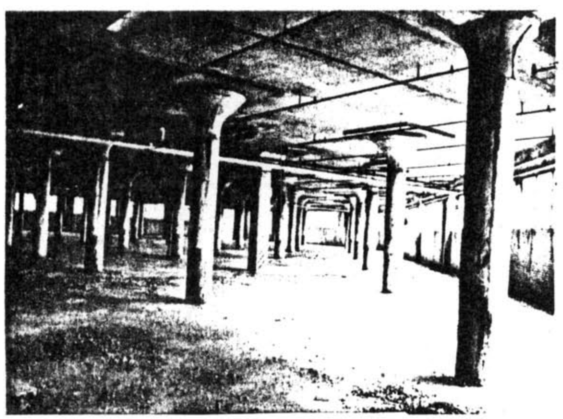
Building 215 is organized into four major independent development zones each of which may be subdivided or added to in a variety of ways to provide a large measure of flexibility in meeting the specific space requirements of prospective tenants. Each independent development zone shares an edge on a short interior spine. The spine connects each of the development zones to a common atrium space daylighted from above with clerestory and/or fixed-louvred daylighting monitors. The shared atrium contains



Second Level Plan Depicting Four Development Zones; Major Access; Central Atrium; Footprints; and Zone of Light at the Edge



Exterior of southwest corner.



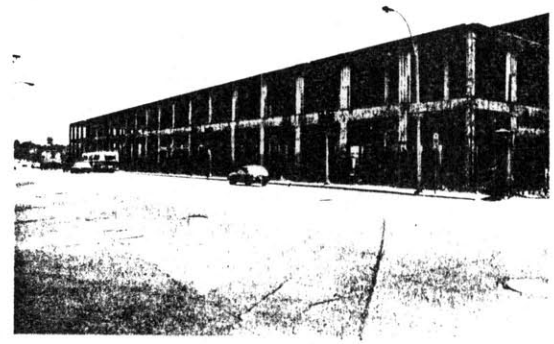
View Along Southeast Edge

the building-wide reception area, entry vestibules, cafeteria, principle stairs and elevators which provide easy and direct access to the parking garage at the lower and first level; to the primary access level at the second floor and rooftop development pods which overlook the central "public" enclosed atrium space.

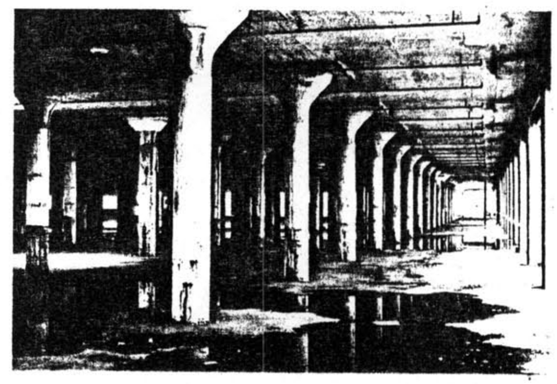
Each of the four independent development zones is organized around a glazed courtyard-type atrium space - which forms the heart of the leasehold spaces. The courtyard atrium forms a collective focal point for each development zone and together with the 'public' atrium court organize a sequence of daylighted spaces and experiences throughout the building.

The location of the atria was determined by studying in physical and graphical models, the penetration of light from the edge of the building and from a variety of atrium glazing configurations. Results indicated that a network of atriums, one in each development could be deployed such that a majority of the buildings' workspaces would be within 30-40 feet of a natural light source. The high ceilings allowed for exceptionally good light penetration and a workspace distance of 30-40 feet from an edge seems to allow those working in the building to have strong visual connection with the outside.

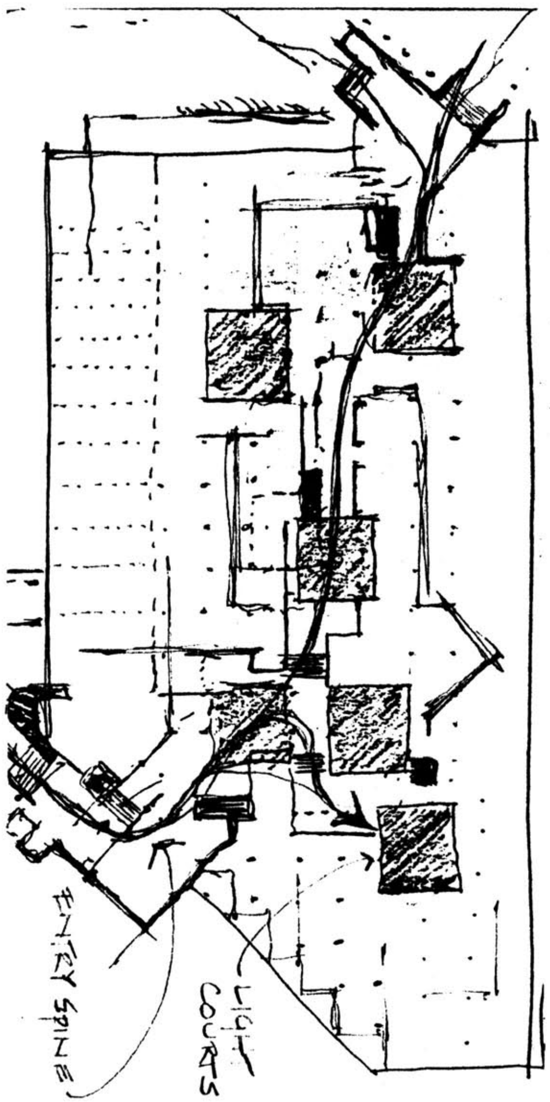
In a building like 215 with ceiling heights of between 14 and 18 feet excellent daylight illumination can be achieved fifty feet from the building's edge - which is an important virtue in a structure that is 240 feet deep. The assumption has been made in this proposal that an exposed mechanical system is used and integrated with it is the artificial ambient lighting system. Such an approach will visually and spatially define the ceiling zone from the room zone, thus psychologically minimizing the potential negative effects of the building's high ceilings. Lowered ceilings are used in private offices, bathrooms and similar small spaces where a greater level of intimacy, afforded by a lower ceiling, is desirable. Primary mechanical and electrical trunks are located above these spaces.The open framework defined by the mechanical and electrical systems will also provide a horizontal continuity and important visual reference plane throughout each development zone. The ceiling zone reflectance is assumed to be 80%, wall partition reflectance 70% and floor reflectance 35%. Areas within the building which are greater than forty feet from a daylight source - slack space - have been reserved for uses either not requiring daylight or where daylight and a fluctuating thermal environment may have undesirable effects - such areas include storage, computer facilities, copy centers, special-use conference rooms, circulation and restrooms.



North elevation after infill has been removed leaving exposed concrete frame.



Interior view along north edge.



Sketch of Path Through the Building - Early Concept

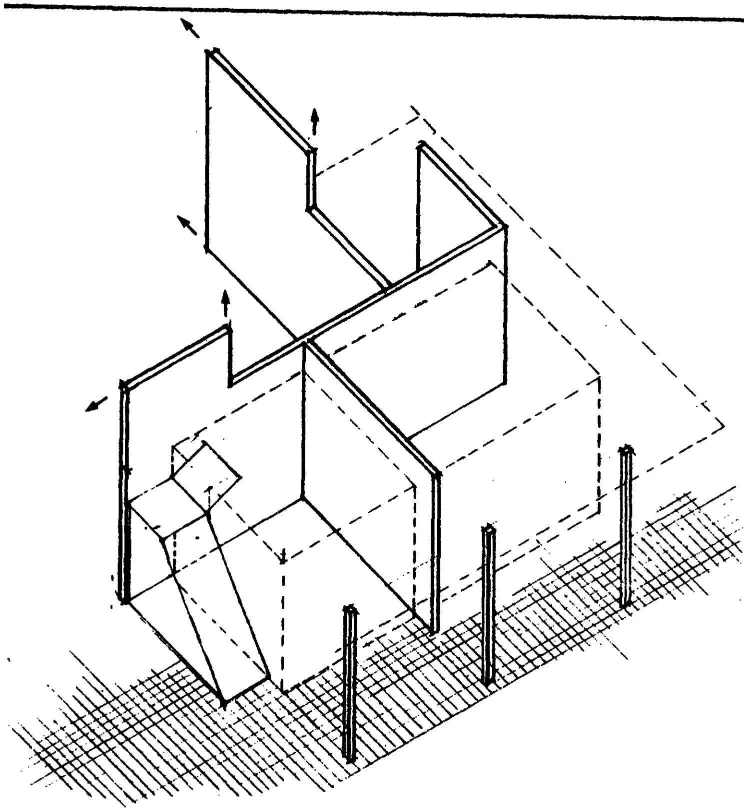
The shadowed and darker zones of the building are regarded with comparable importance to the daylighted areas because without such an expression of contrast, one tends to lose an appreciation for the dynamic quality and character of daylight. Thus, uniformity of light levels throughout the building has not been a necessary criteria of a well lighted environment for this exploration.

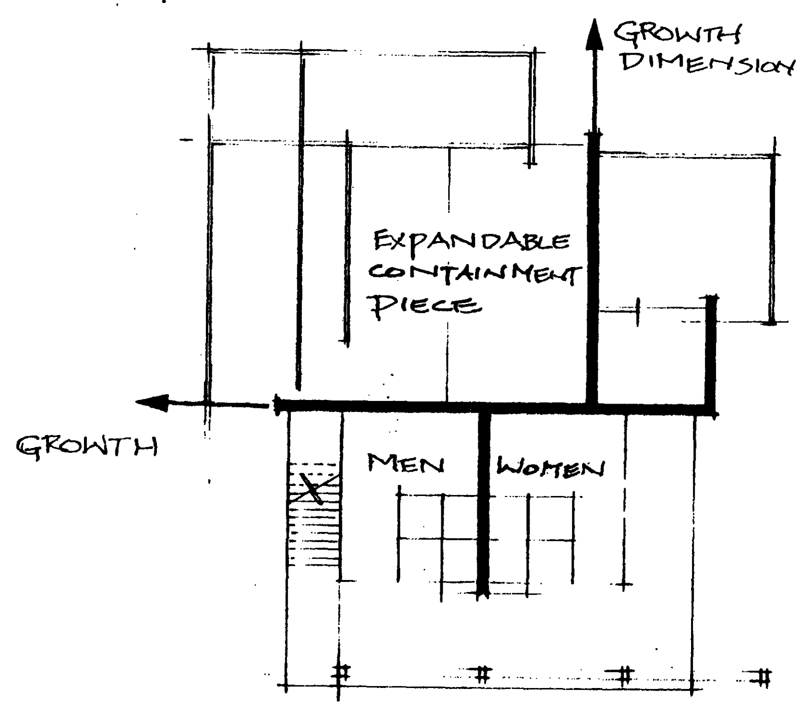
Courtyard Atrium Development

A range of atrium sizes were explored throughout the course of this investigation from simple light-wells to large 'ceremonial' atria, comparable to those done by Portman et.al.

Neither end of the range seemed appropriate or desirable in either architectural or economic terms for this application. The scale of historical vernacular courtyard atria, influences of Asplund and Aalto and the non-heirarchical approach adopted by Hertzberger in the Centraal Beheer building have led me to develop an atrium space with qualities of each of these important references.

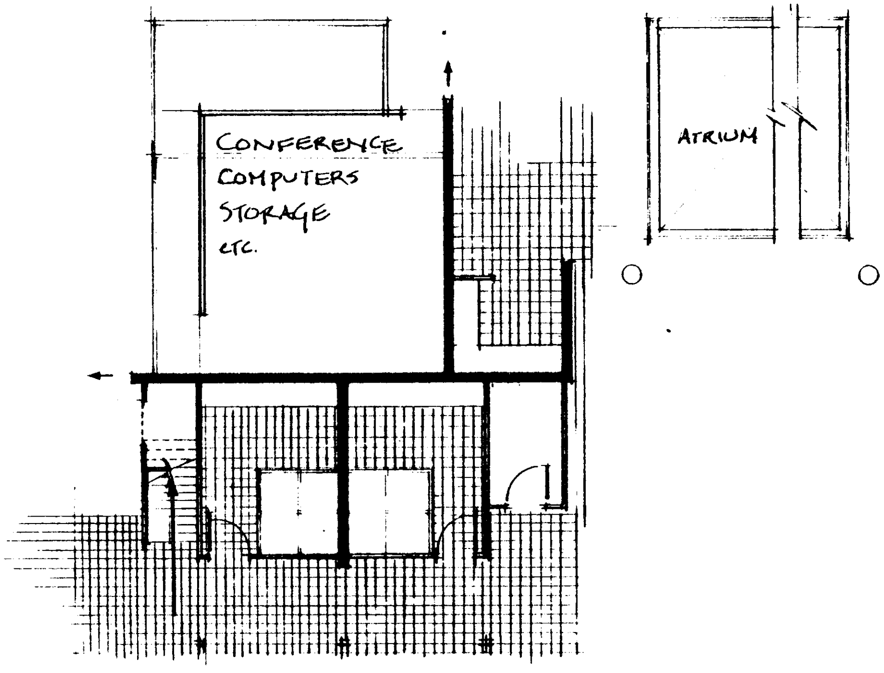
The atrium developed in this proposal has three primary components - the core piece or footprint; a development

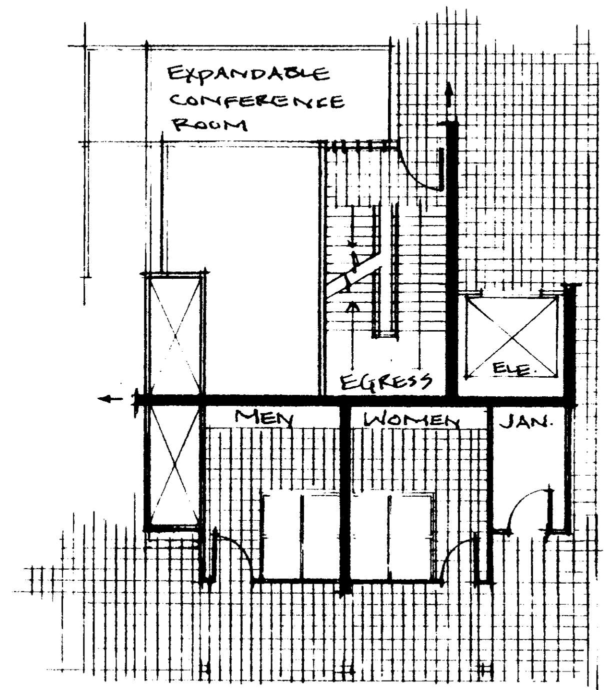




Generative Footprint Charactertistics

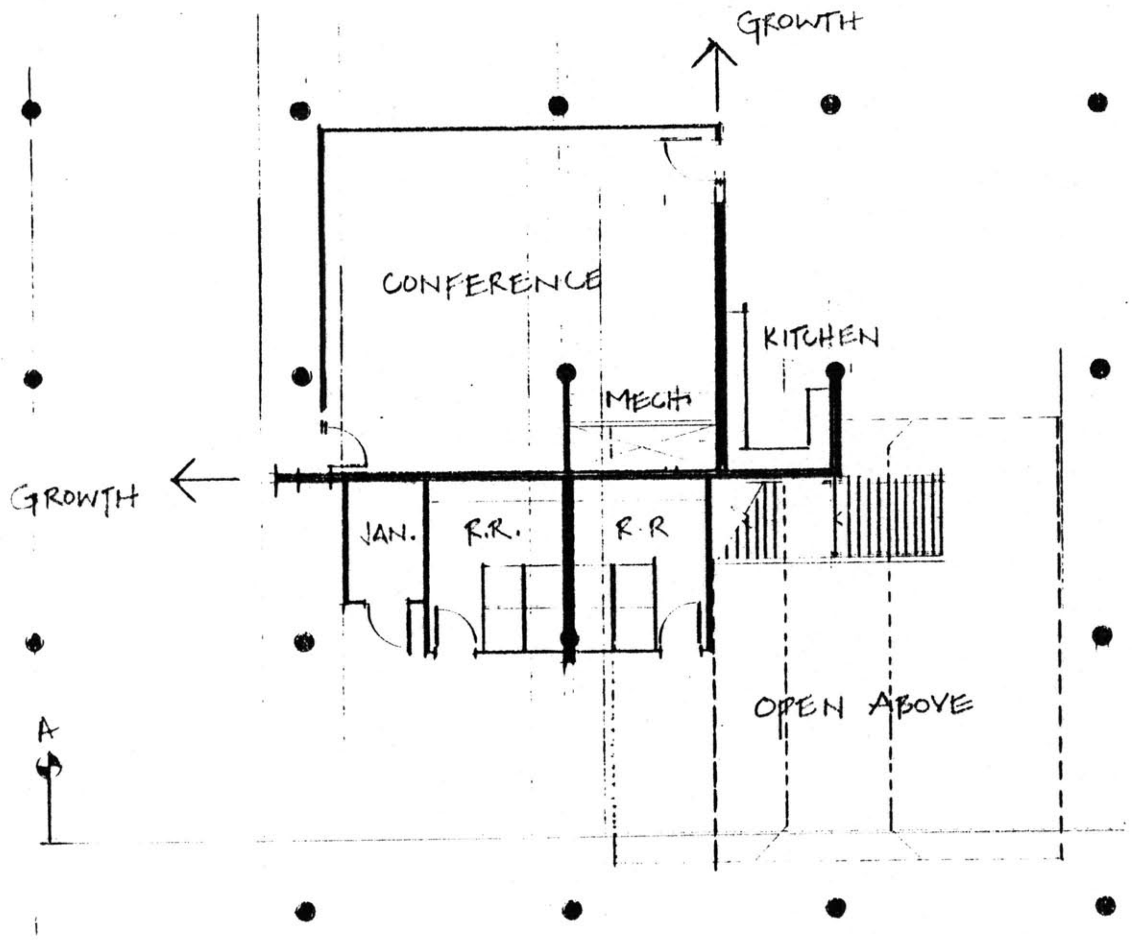
- Masonry
- Wet Core
- Vertical Mechanical Risers
- Luminous Source to Adjacent Spaces
- Circulation around -'a rock in a field'
- Establishes Vertical Continuity in Atrium
- Privacies Within
- Extendable Horizontally/vertically
- Egress



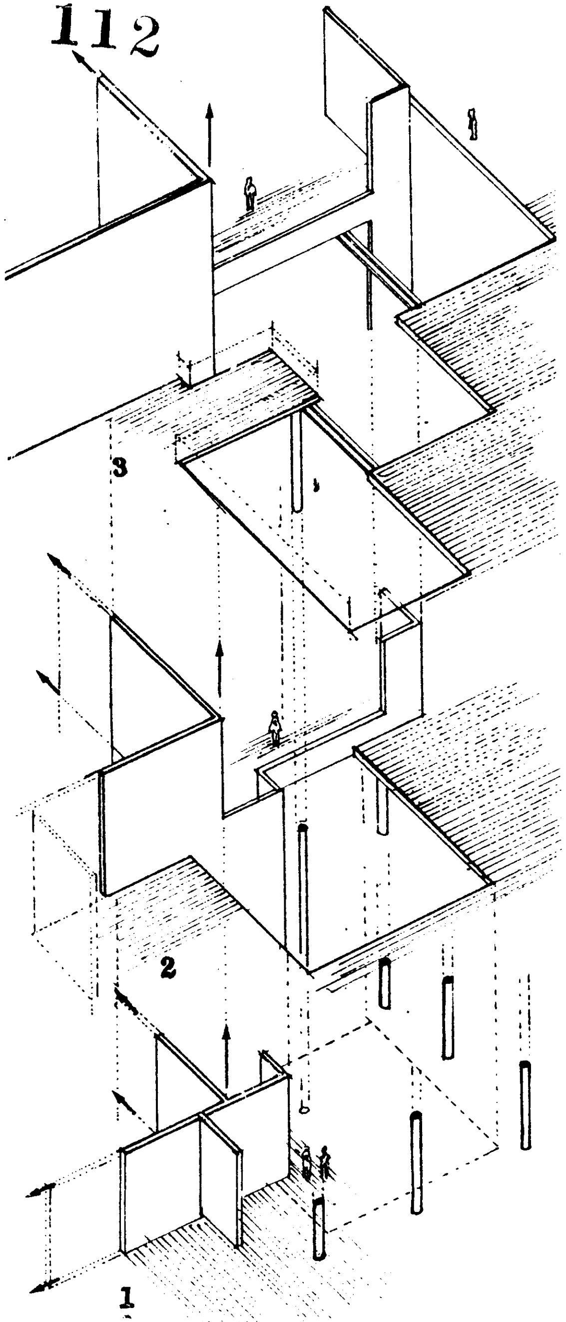


Two Footprint Options

pod that is added to the existing roof accessed through the atrium and; the glazing system. Fundamental to these components is the relationship of light, materials and movement.



Typical Atrium Footprint at Access Level



The core 'footprint' piece is constructed of masonry and extends vertically from the second level through to the roof. At each level the footprint is extendable horizontally in two directions to provide a 'support' from which to build conference rooms, offices, etc. The two growth directions are perpendicular to each other - the angle formed between these directional elements creates a containment zone which can be infilled with programatic functions desiring a sizeable degree of privacy. The foot-print is the site for each development zone's primary wet core and vertical mechanical and electrical runs. Bathrooms, kitchenettes and other uses needing water and sewage service have been designed as integral parts of the core piece.

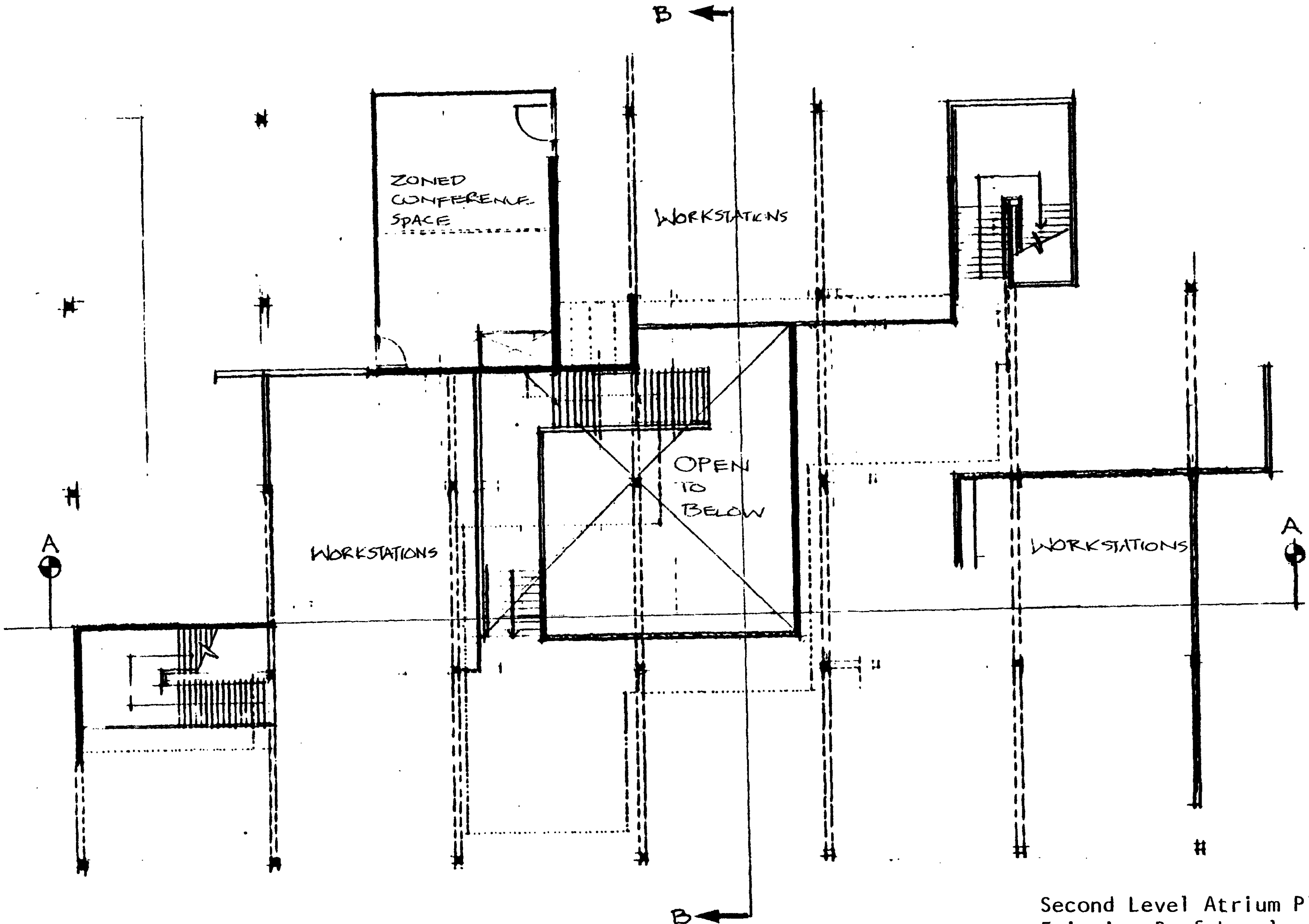
This piece can optionally house fire stairs, elevators, conference space, copy centers, etc. The footprint by extending vertically through the roof provides a base from which to build the skylight monitors. In addition to providing vertical and horizontal continuity in the atrium, the core acts as a luminous source by virtue of daylight being reflected and diffused from its surface to adjacent atrium spaces.

The footprint constructed of masonry units provides additional thermal mass to the atrium to mediate diurnal temperature swings. The core provides a partial definition to the atrium territory and anchors it within the development zone. Additionally, this component helps to spatially define the light and shadow, and contributes to elaborating the dynamic interplay between these two form-giving characteristics.

An extendable development pod is the second component of the atrium. This pod is made by cutting a hole in the existing roof. The hole is made by removing the equivalent of four bays resulting in a thrity-two foot square hole. One column is removed and the beam bands are preserved on the four sides of the opening.

Offices are added to the existing roof surrounding the atrium and extending approximately sixty feet in each direction from the center of the atrium. A steel frame and concrete slab structure is added to the roof and it extends upward one level above the roof. Thereby creating a three-storey atrium at its deepest part.

The third level of the atrium also extends approximately sixty feet from the center of the atrium in each direction. The third level atrium edge is extended to

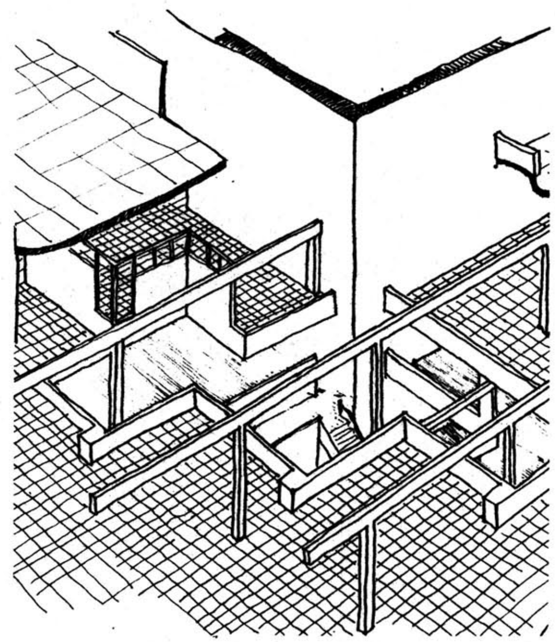


Second Level Atrium Plan -
Existing Roof Level

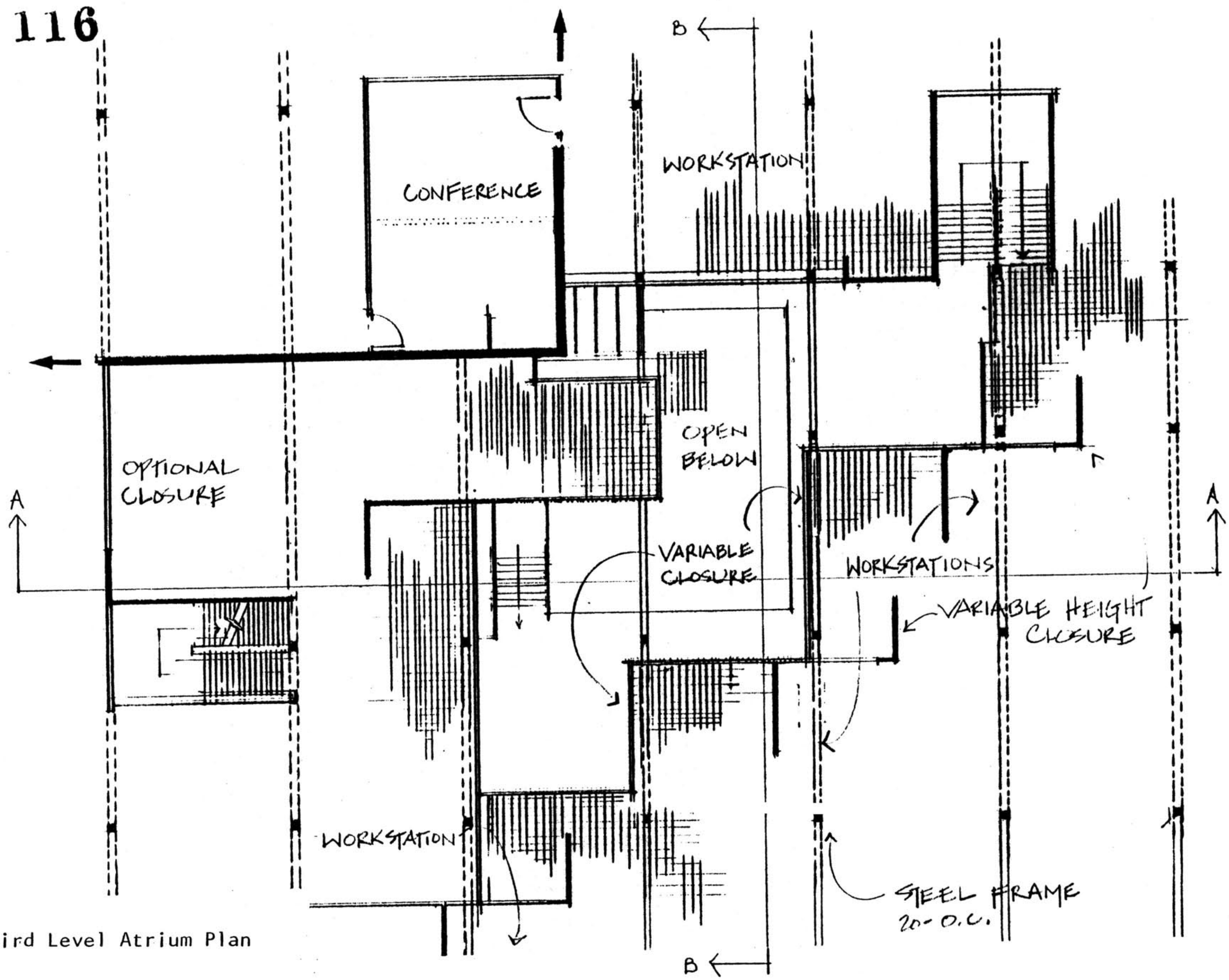
generate a greater number of work stations along the edge; to provide more light to the levels below; respond to the diagonal at the building's edge and reinforce the diagonal movement of the primary circulation through the development zones to the centrally located and commonly shared atrium.

The development pod can be optionally extended across the roof to meet additional space requirements of leasehold tenants. As the 'foot print' core extends vertically through the atrium, water, mechanical and electrical chases are available at each level above the main access level.

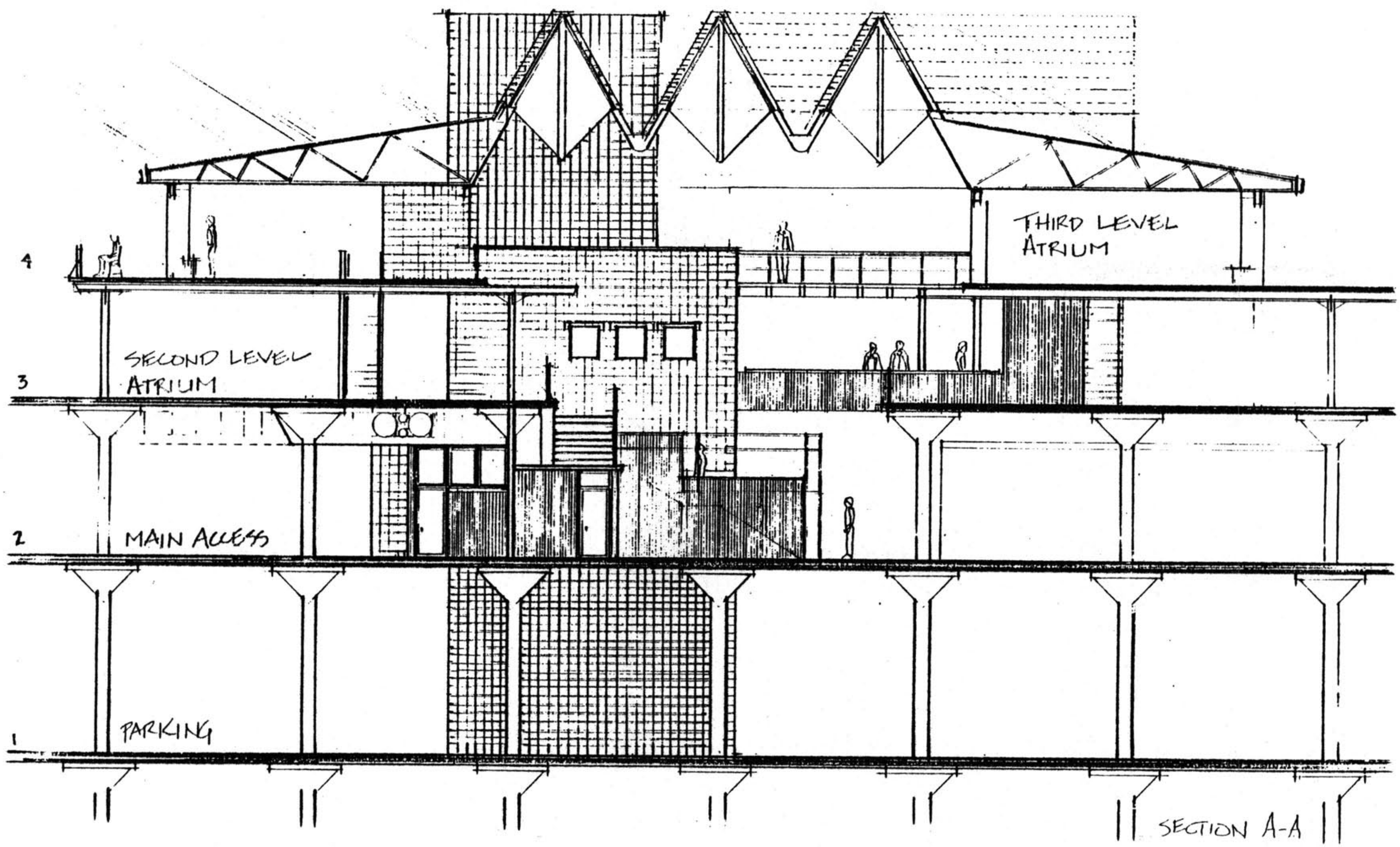
It is envisioned that the edge of the atrium would be a variable closure system, such that some workstations would have a greater degree of acoustical and visual privacy while still benefitting from a strong visual connection to the outdoors. Therefore, the range of closure that might be used would be a simple open railing; a closed railing; a low wall; a five foot partition - glazed or opaque or; a full height partition with selectively located transparencies to provide light and view.



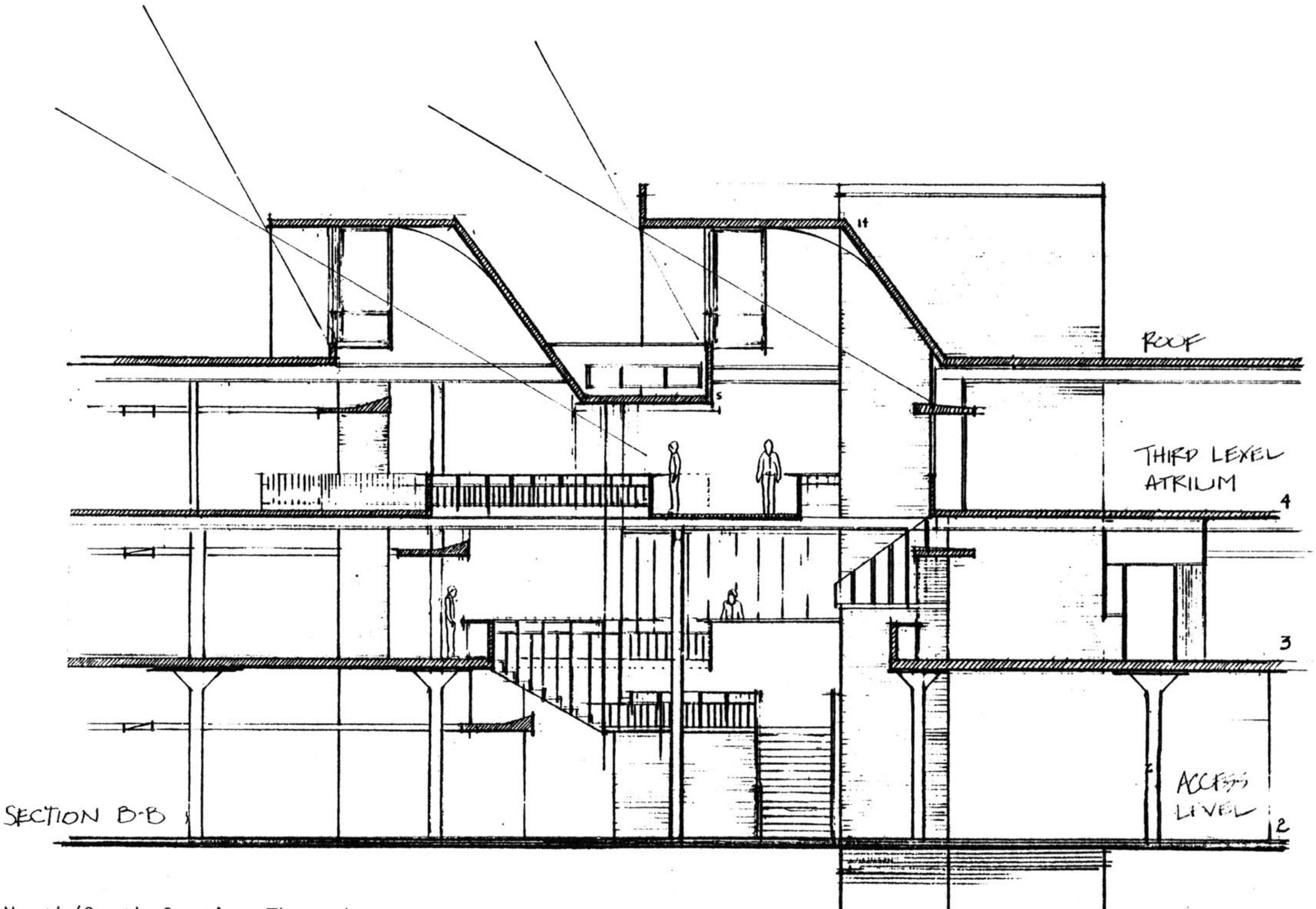
The third component of the atrium is the glazing system which encloses the space and protects it from the natural



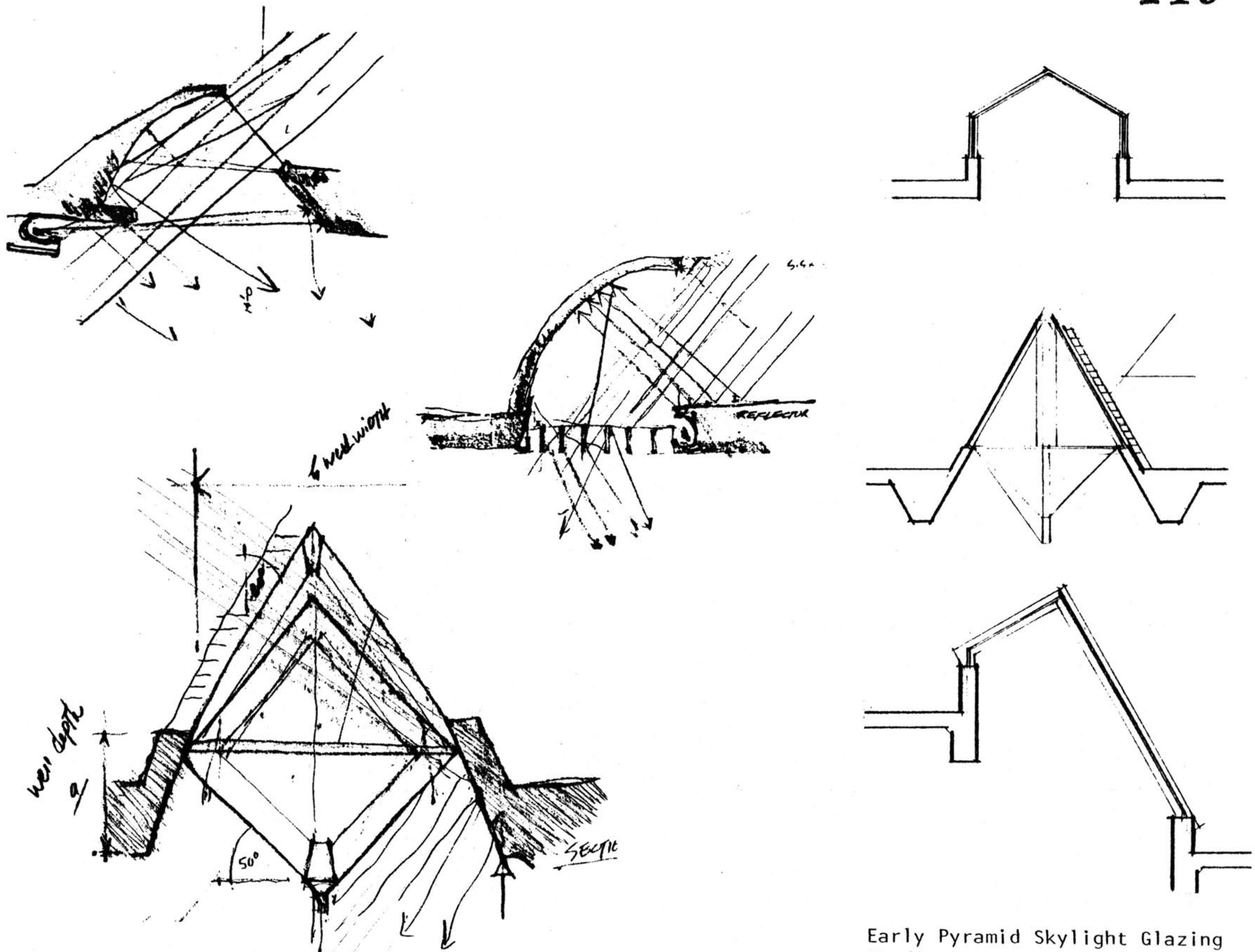
Third Level Atrium Plan



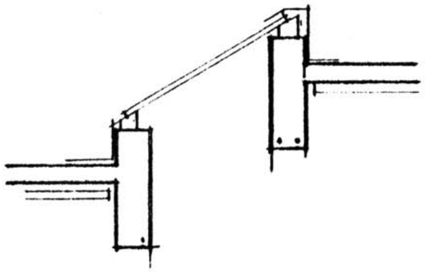
East/West Section Through
Independent Development Zone
Atrium Depicting Rotated Skylight
Section

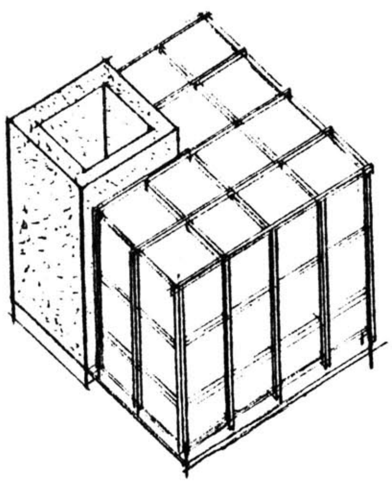


North/South Section Through
Independent Development Zone
Atrium Depicting Clerestory
Monitor Scheme



Early Pyramid Skylight Glazing Studies





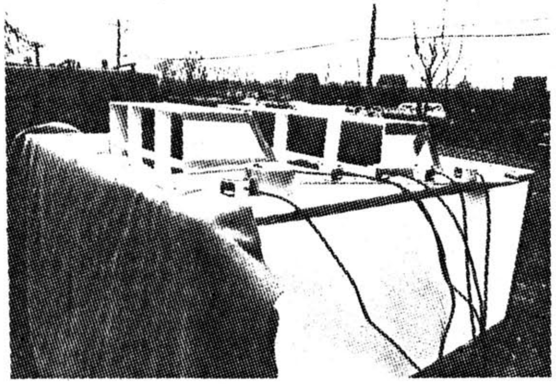
elements. From a number of top lighting designs investigated, two were further developed and tested using a one-half inch scale model of the three level atrium and adjacent spaces extending fifty feet from the center in each direction.

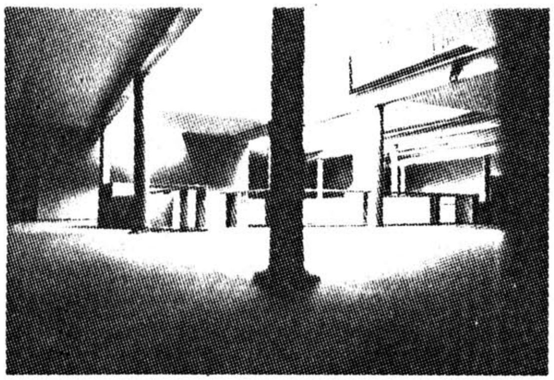
The two systems tested were both long rectangular configurations that reinforce the direction of movement within the building, and site to best capture south and north light while ameliorating east and west exposure. The first system studied was a pyramid shaped device in section with fixed louvres located outside the glazing on the south side of the skylight system. The fixed louvres were designed with a cut off angle of 50 degrees to control summer heat gain and allow for direct solar penetration in the winter months. The pyramid skylight system has a view of the entire skyvault and thereby emits diffuse radiation from the north as well as south. The louvres are painted white to diffuse and reflect incoming sunlight and to control reflected glare. The east and west ends of the louvre system are intended to have a combination of operable shaded glazing and mechanical ventilators to enhance stack effect ventilation.

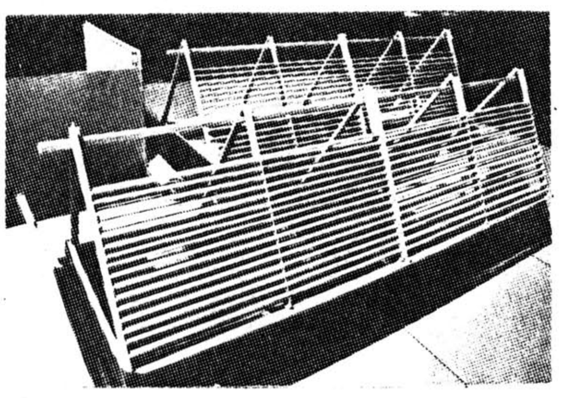
The glazing for this system can be placed in a variety of ways. First, it can follow the slope of the pyramidal frames toward the sky. A second glazing unit could project into the space to form a triple or quadruple glazed diamond shaped section. The diamond shaped system would project into the visual field of the building occupants, thus enhancing their architectural experience of the space. See Aalto's Pension Building and Bookstore at Otanjeni. Another reasonable approach to glazing the louvred skylight system would be to use flat or bubble glass located above a splayed coffer. This approach would reduce the exposed glazed area and benefit from the solar control offered by the louvre system as well as the diffuse light from the sky vault.

The second toplighting system investigated was a double bank of clerestory monitors with comparable horizontal roof aperature area to the louvred system. However, this approach only sees half as much of the sky vault. The clerestory windows were studied with and without a fixed overhang for shading.The overhang has a 50 degree cut off angle. It is envisioned that ventilation could be provided through a combination of operable glazing and mechanical ventilators.

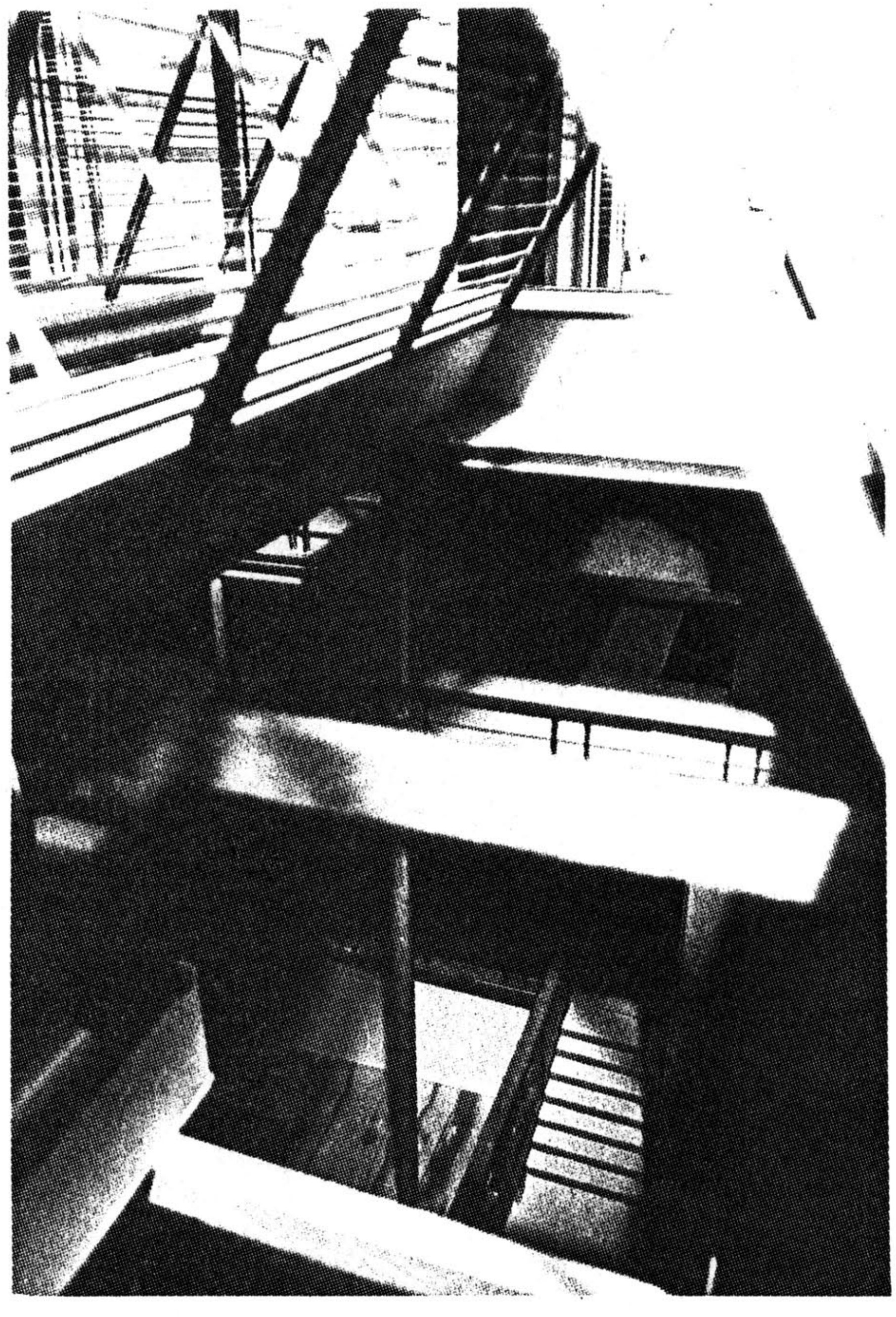
Data was collected for both overcast and sunny day conditions for each of the glazing systems, using a six channel light meter. One sensor was used to read ambient

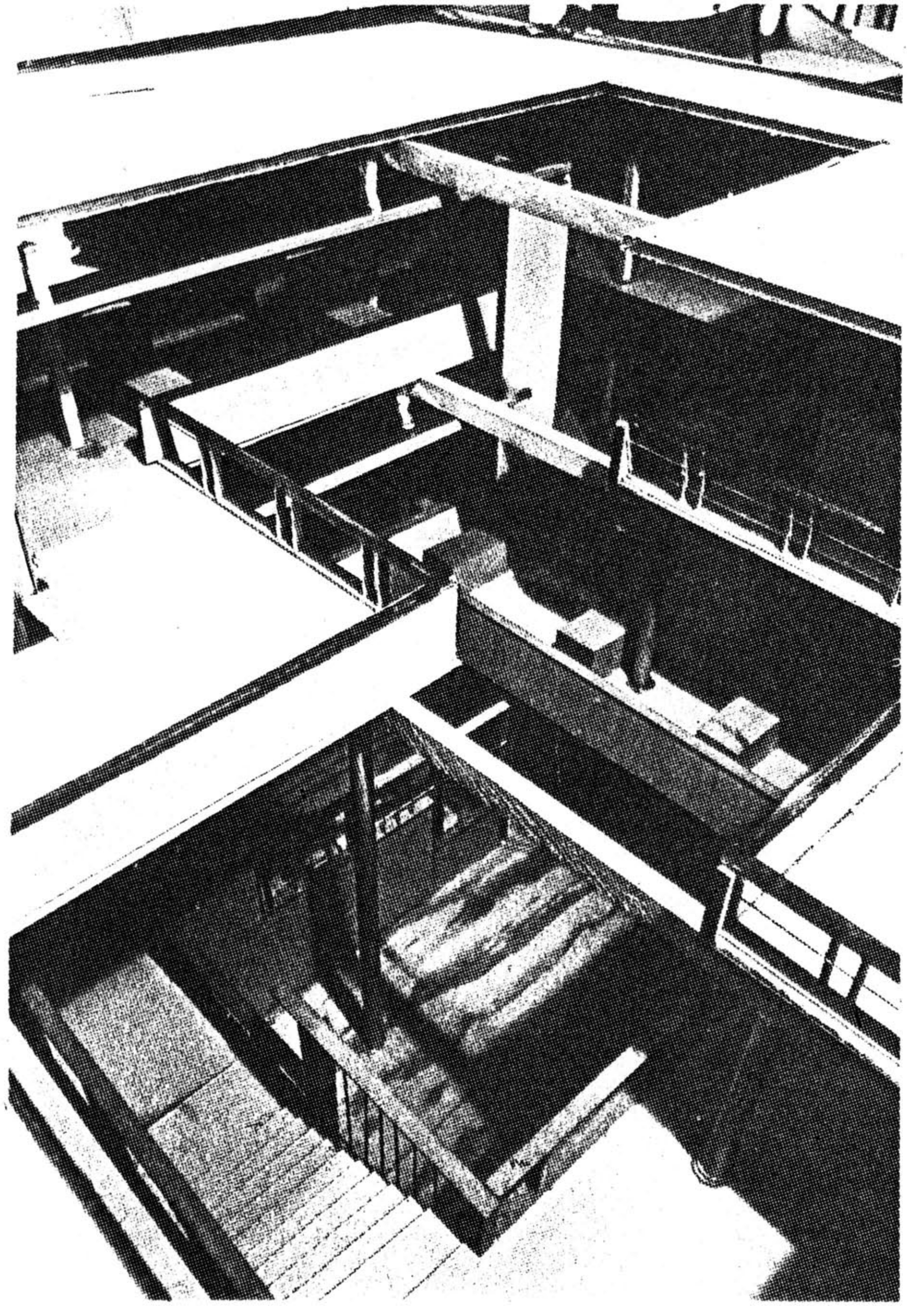


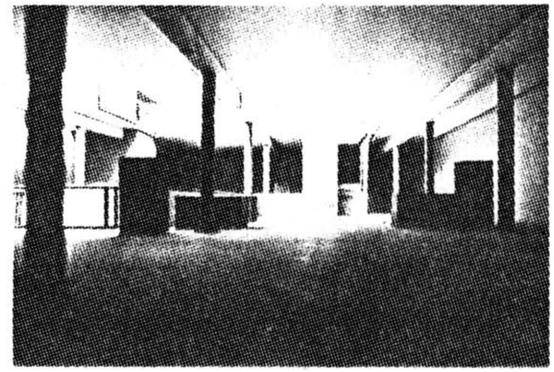


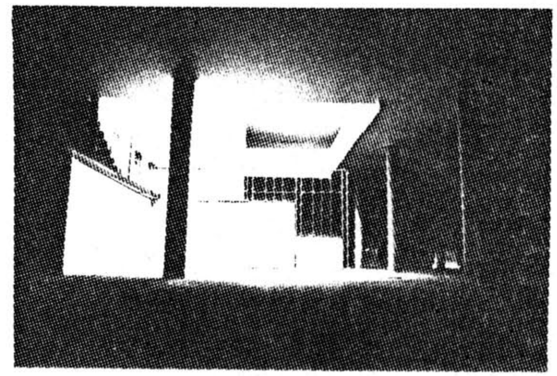


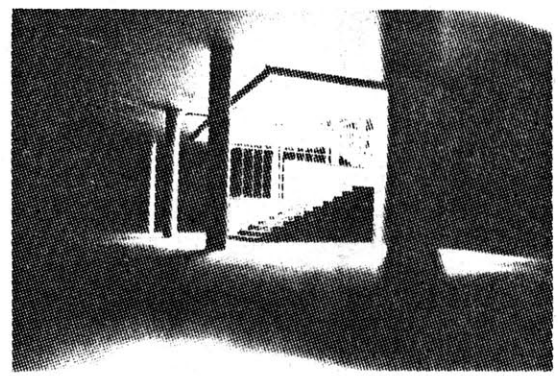
Lighting Model Photographs





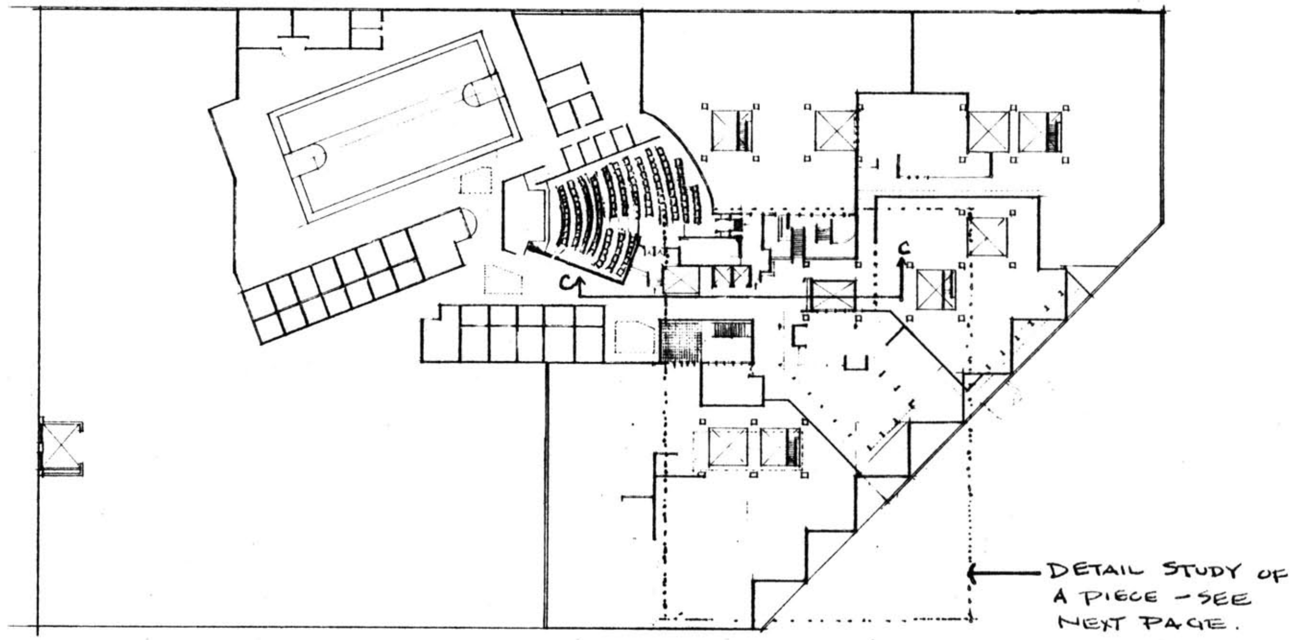




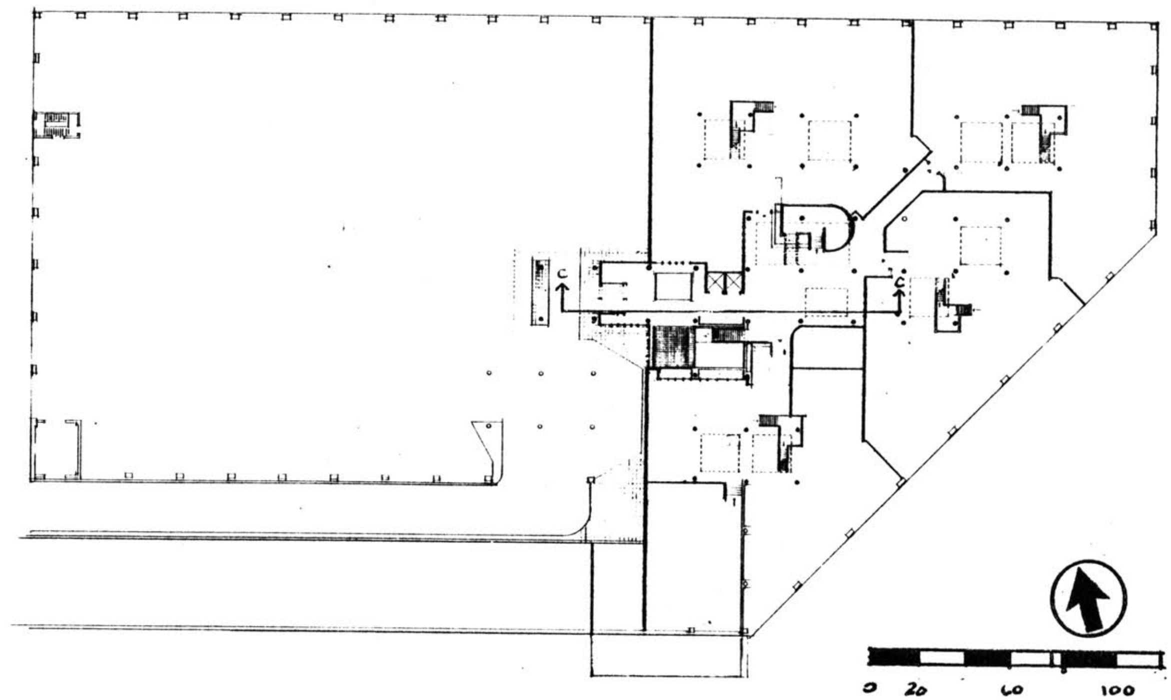


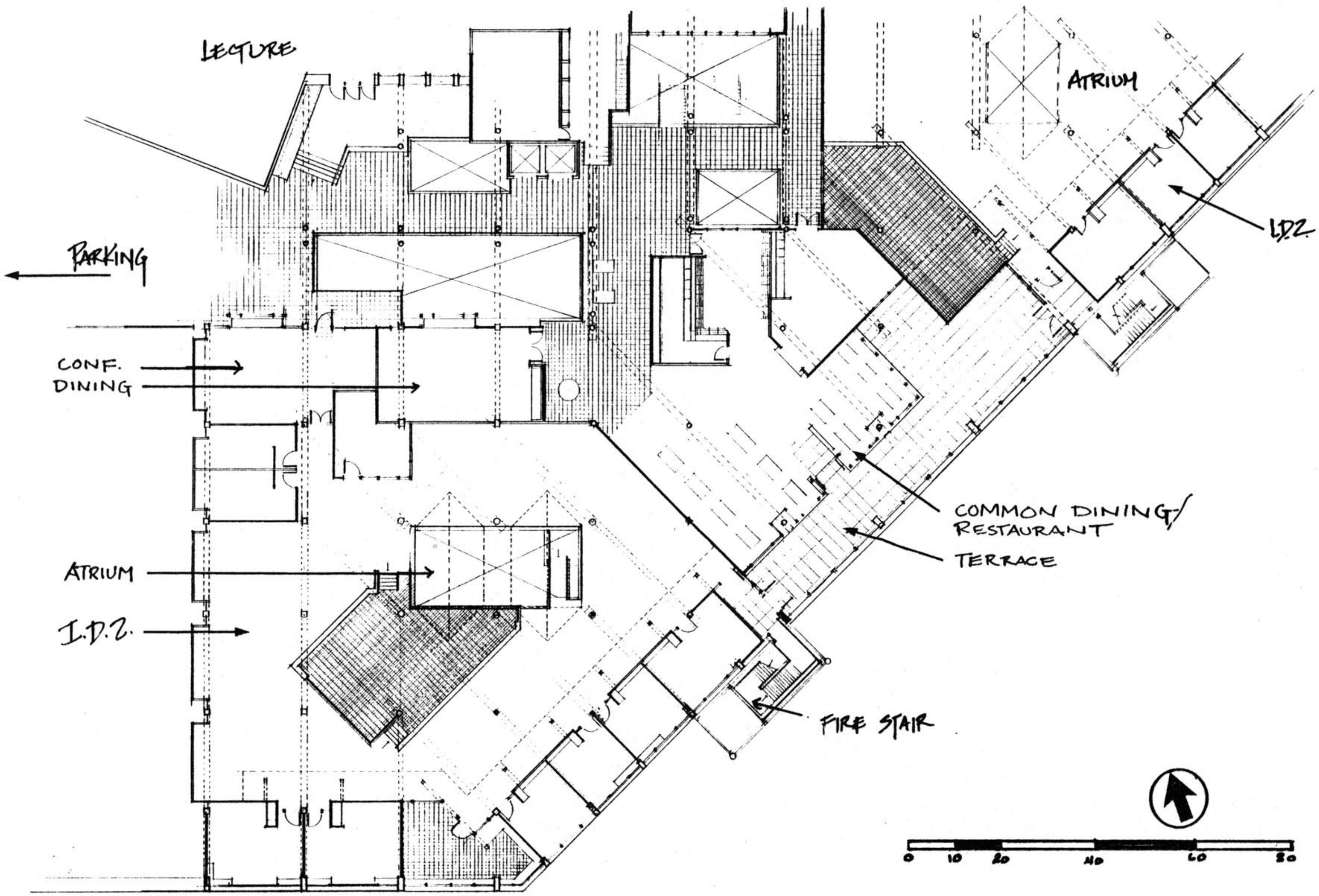
Lighting Model Photographs

SECOND LEVEL - Main Access
Early study depicting Four Independent Development Zones (I.D.Z.) Each zone is two storey's in height, totaling 15,000 square feet of lease-hold space. Each floor is within the I.D.Z. is connected vertically by a two storey atrium. Parking is located in basement, first level and one-half of level two, the Main Access Level. Each I.D.Z. shares an edge with a common 'public' daylighted atrium.

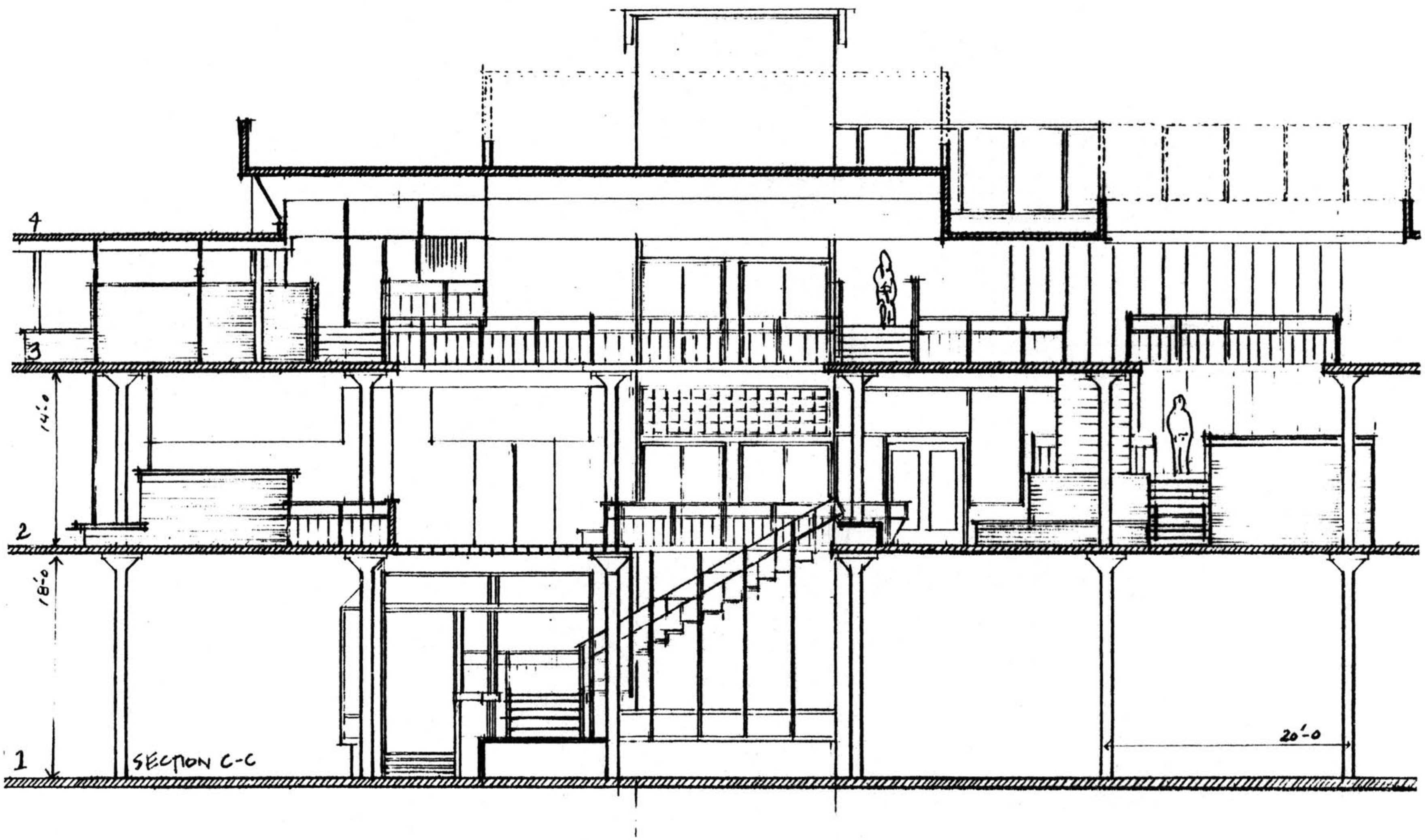


THIRD LEVEL contains the upper 7,500 square feet of each I.D. Z. as well as a common dining center which overlooks the Charles & Boston to the South-east; a lecture hall for 2000 people which is for training seminars and corporate meeting functions; a small health club with basketball and racket ball facilities and; lastly, option-al expansion space to the west on the existing roof.

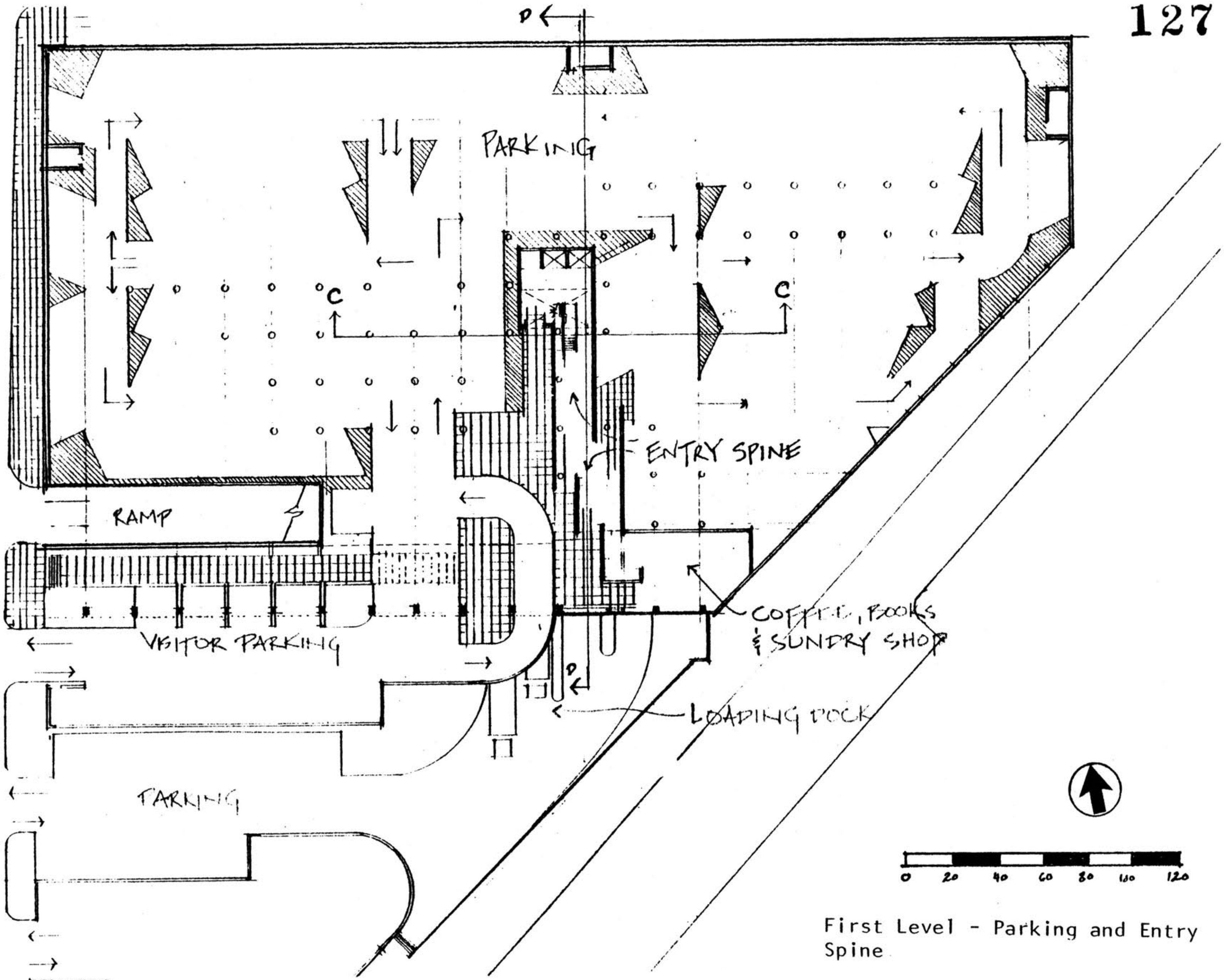




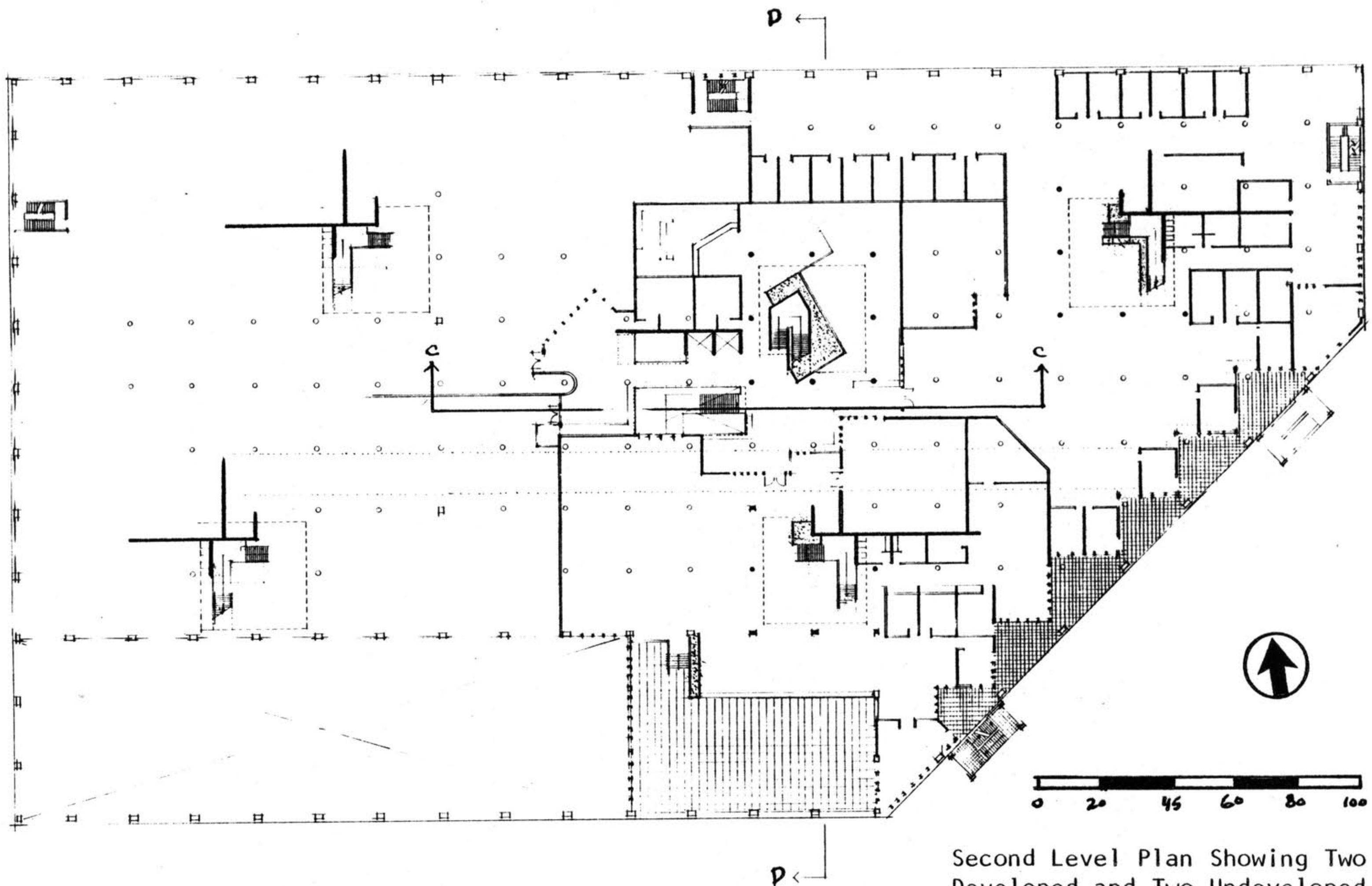
An Early Study of a Piece at the Third Level



Section Through Common Atrium

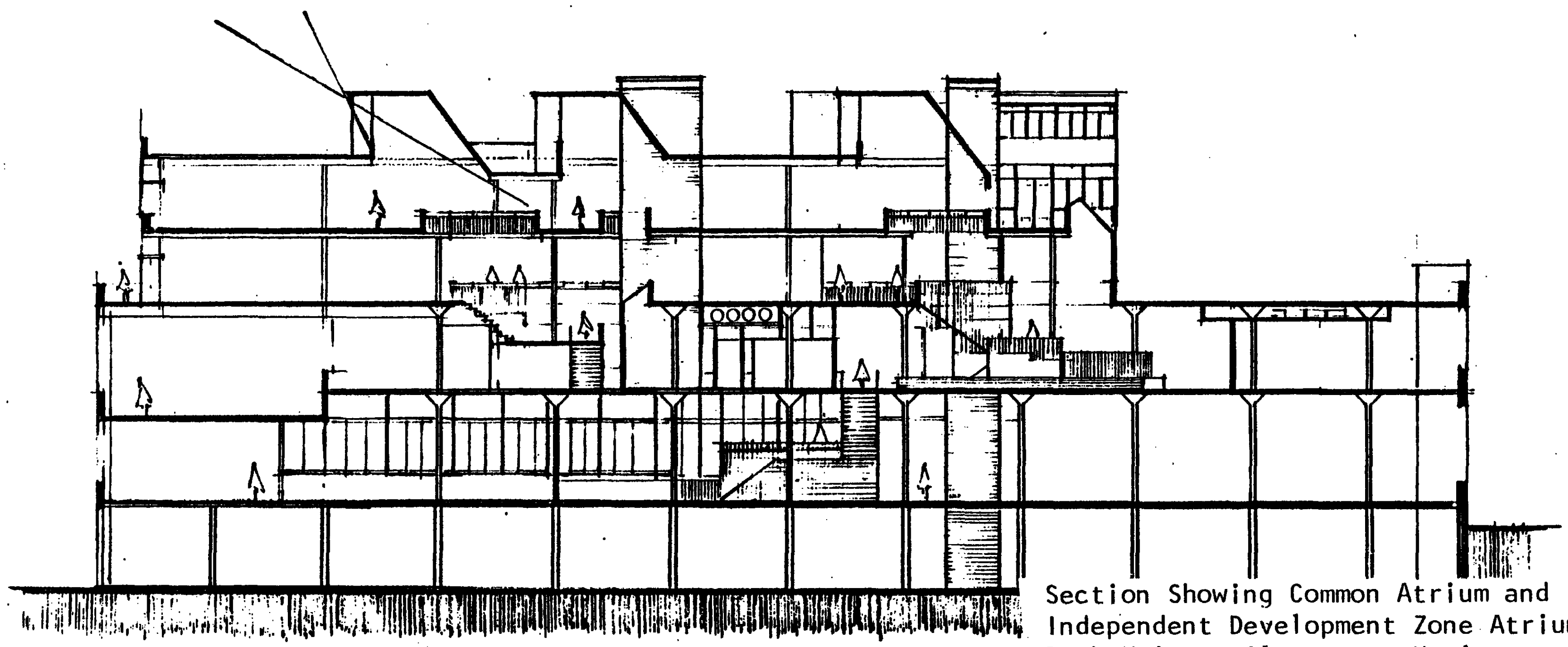


First Level - Parking and Entry Spine



Second Level Plan Showing Two Developed and Two Undeveloped Zones horizontal sky luminance and five sensors were used to measure lumination levels throughout the three storey atrium and surrounding spaces. The model comprises a 100' x 100' plan area with the atrium roughly at its center.

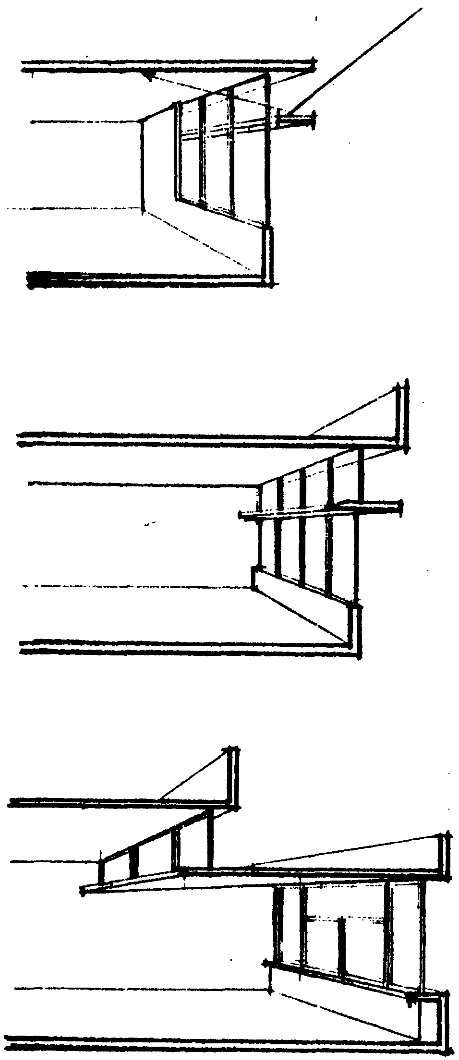
The overcast measurements were normalized and converted into daylight factors. These values were then placed on one-eighth inch plans and also plotted in section in order to make comparisons between the toplighting schemes at each level of the atrium. For the variations that measurements were made, the louvre system clearly provides



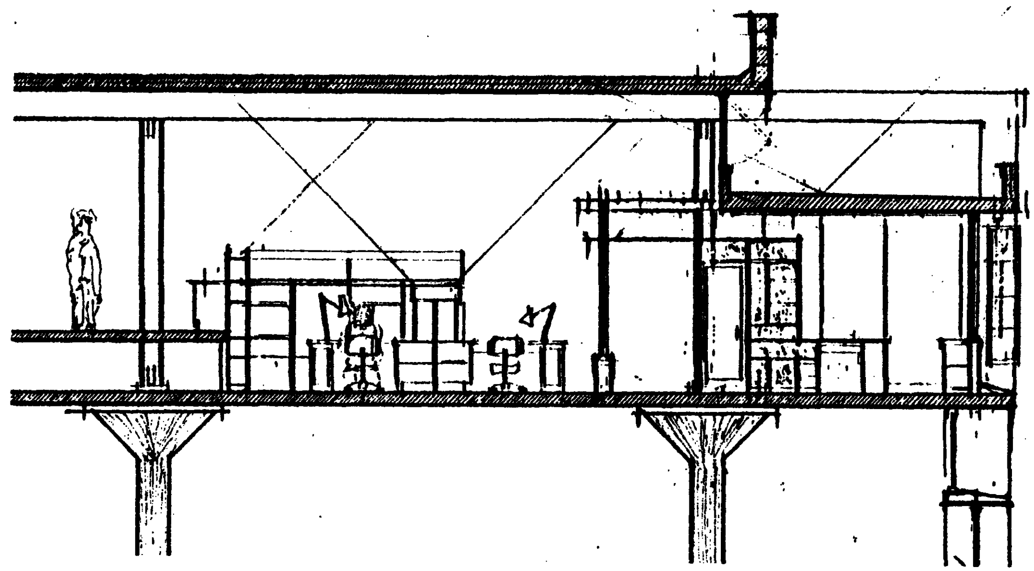
Section Showing Common Atrium and Independent Development Zone Atrium Both Using a Clerestory Monitor better illumination throughout the atrium and adjacent workspaces. See Appendix A for comparisons of daylight factors and foot candle readings at each level surrounding the atrium.

The clerestory system could be measurably improved if the fixed overhang was removed and replaced with a seasonal operable device.

An interior light shelf was examined at the second and third levels of the atrium's north side. As can be seen from the graphs, the mirror surfaced light shelf proved to be beneficial at the second level and a potential liability at the third level. Although the light shelf

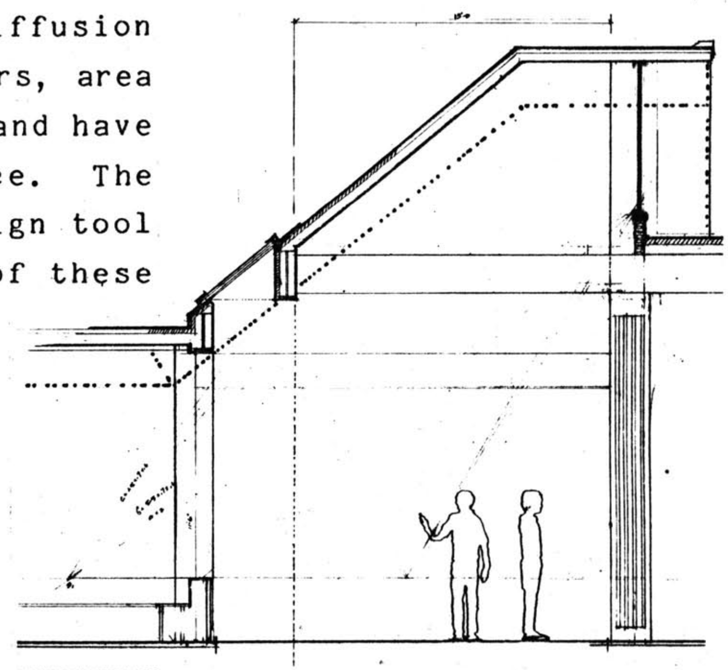


Edge Study for Roof Pod Development Space



alters the foot candle distribution at the edge, thus reducing the brightness ratio, it does not measurably increase the depth of light penetration into adjacent spaces.

The data taken from the louvred system indicates that ambient illumination needs can be met up to 40 feet from the edge at the third level, 30 feet from the edge at the second level and 20 feet from the edge at the first level of the atrium. The lighting model study has helped tremendously my understanding of the relationship between the quantitative and qualitative character of daylight. The influence of material, texture and color, diffusion elements such as the fixed louvres and deep coffers, area of glass, and orientation can be very dramatic and have great consequences upon the finally built space. The lighting model has proved to be a valuable design tool with which to study the dynamic relationship of these variables.



Study of Clerestory that Admits Light from Two Sides

Conclusion

To summarize, this design proposal attempts to illustrate that an early 20th century warehouse structure can be redesigned for use as an office building using daylight as a principal organization and form generator. The importance of this investigation lies not in the specific design proposal presented, but in the transferability of this design methodology. The method being the development of a footprint or in this case, a generic atrium comprised of three principal parts, which can then be used to organize a framework from which individual tenants can expand. The generic atrium piece could be extended to organize frameworks or supports for residential, shopping and industrial buildings. The method is not necessarily limited to buildings with large bulk, a variation on the proposal developed in this thesis might be an atrium piece located at the edge of a building with a more modest depth. Hence, establishing a direct relationship to the external environment, which introduces a new set of design opportunities and problems.

The atrium piece may be viewed in the abstract as a small neighborhood center - comprised of the basic infrastructure pieces which remain over time as the surrounding pieces grow and change, responding to the changing needs of its residents.

Existing codes and current thinking indicate that windows are undesirable from an energy perspective. In this thesis, I have attempted to present an argument for building designs that counter these relatively recent legislative mandates and conventional thinking about energy conservation with evidence showing that windows have a number of beneficial impacts, particularly in reducing lighting electrical use. Other promising ways of saving energy in large buildings include: off-peak cooling, ventilation, more efficient artificial lighting systems and more efficient HVAC systems and controls.

This study further demonstrates that atria and natural light have been a powerful and vital architectural element throughout history with a myriad of psychological, physiological, and cultural implications.

It is hoped that those who read these pages gain a clearer understanding of the significance of daylighted environments and a heightened sensitivity to their luminous environments.

Appendix A

This Appendix contains a summary of the results from physical daylight studies of the atrium described in the design proposal description section and calculated daylight illumination gradients at the building edge for overcast skies.

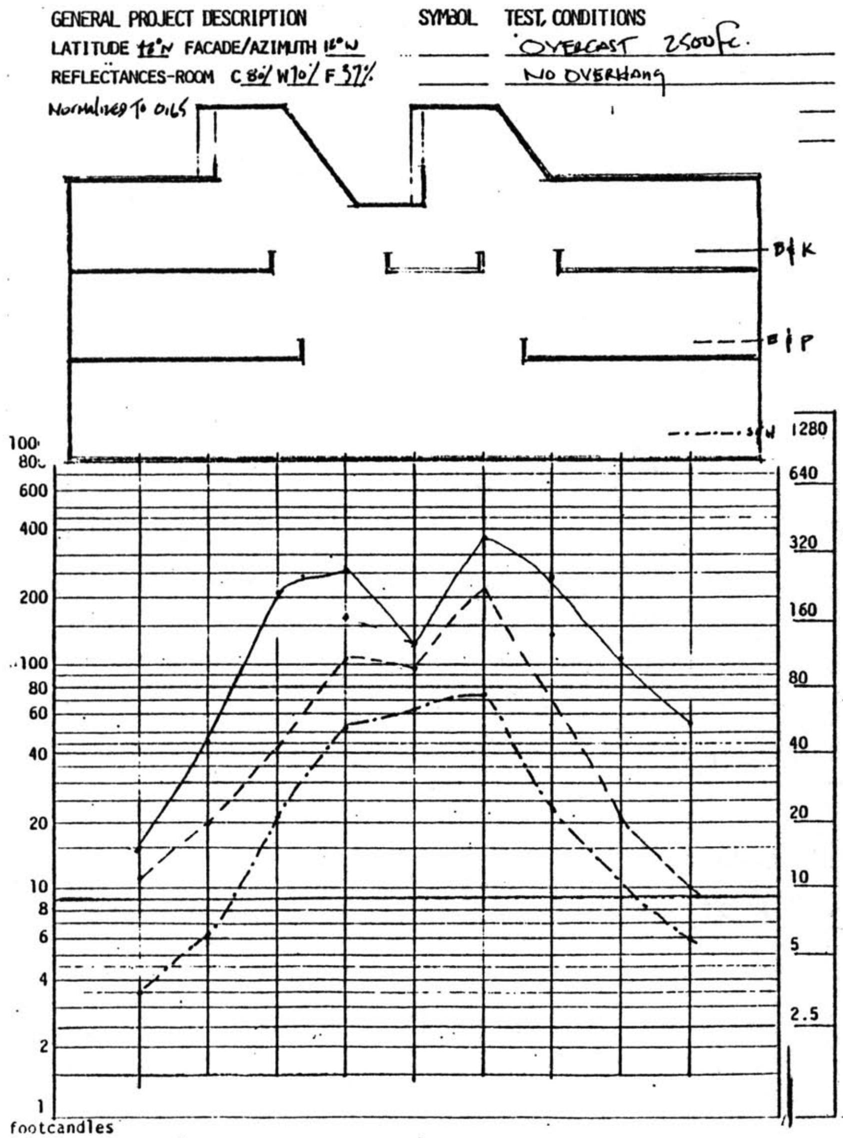
Typical vertical section graphs are presented for each level of the atrium and keyed to the plan drawings also located in the Appendix. Due to the asymmetrical nature of the atrium, each graph should be examined with respect to its location on the plans. The sectional graphs are keyed to twenty data plans comprised of a total of 96 discrete data points. The data plans are designated by letters A through T.

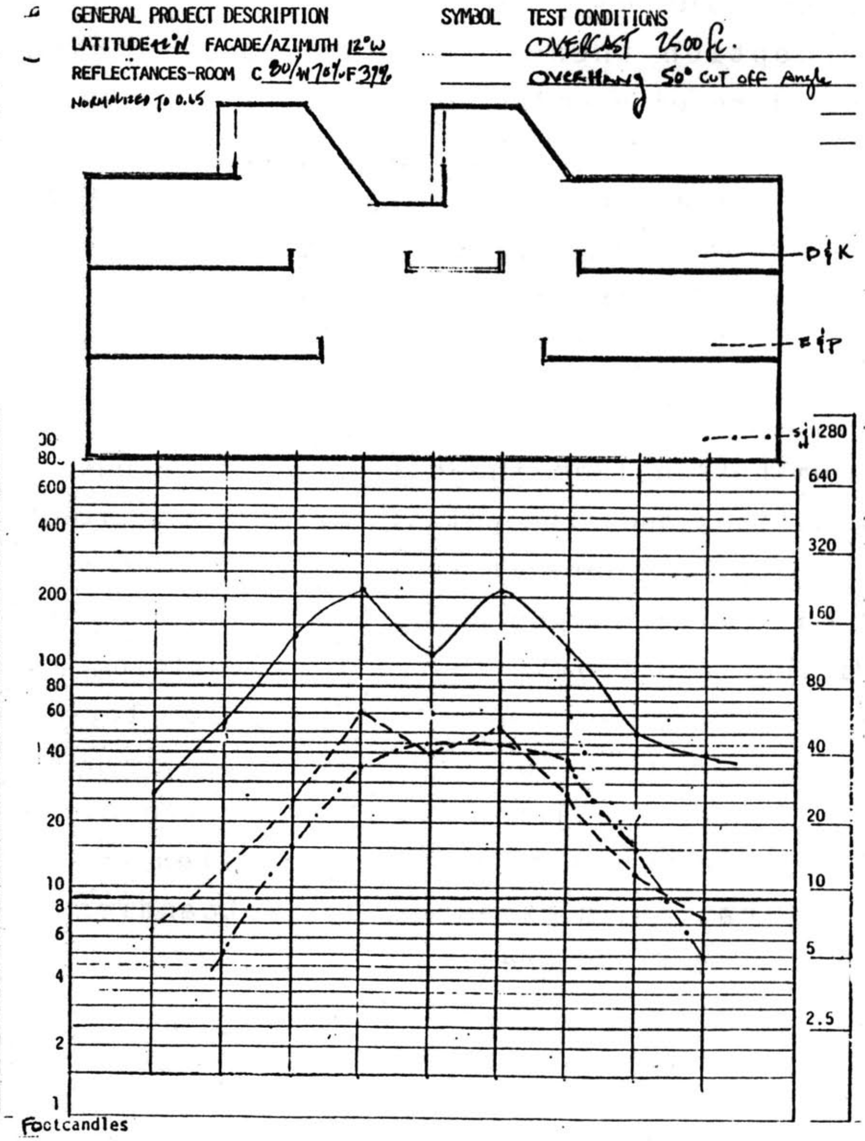
Data presented in the sectional graphs is presented in footcandles for two toplighting configurations for sunny and overcast sky conditions. Data in the plan drawings is presented in daylight factors for the two toplighting configurations tested under overcast skies. The daylight factor is defined as the ratio of interior illumination from the sky (excluding the sun). All data presented has been adjusted to account for glass transmission and maintenance factor. A correction factor of 0.65 was used throughout.

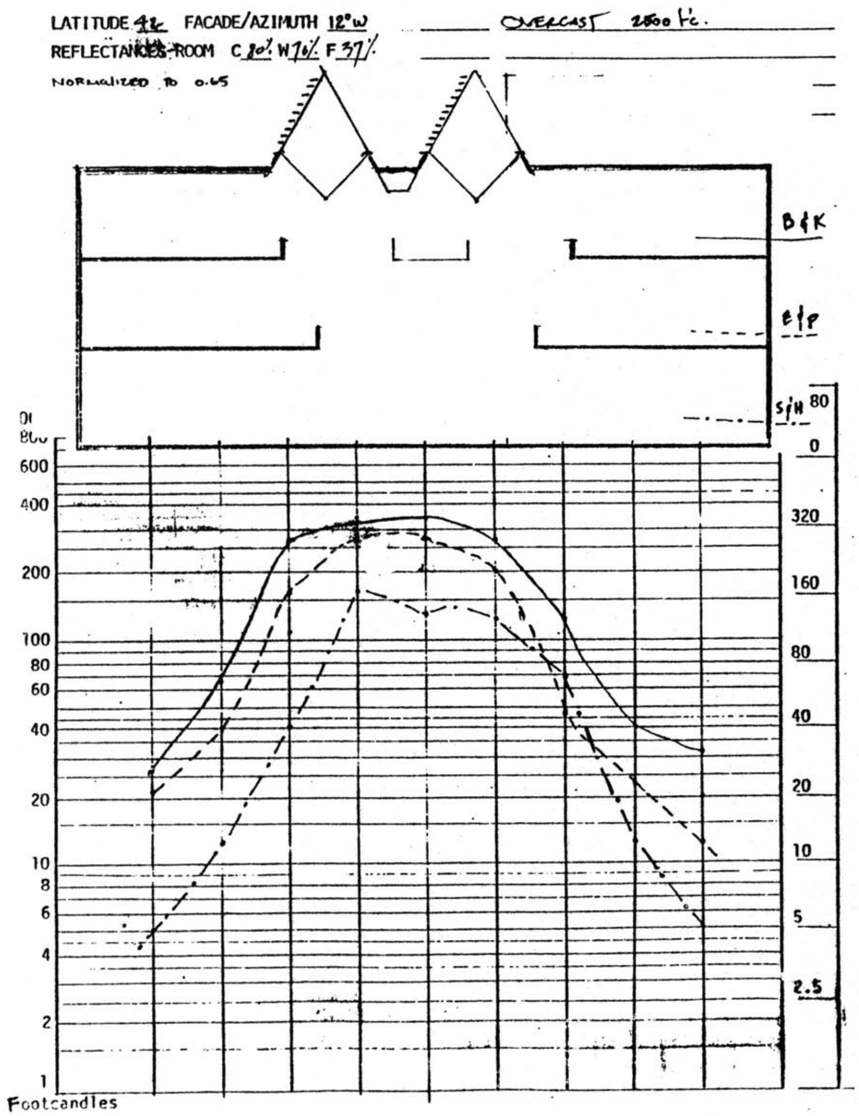
All test data has been normalized, since exterior light levels fluctuate regularly. Though invisible to human perception these fluctuations are large enough to interfere with model measurements.

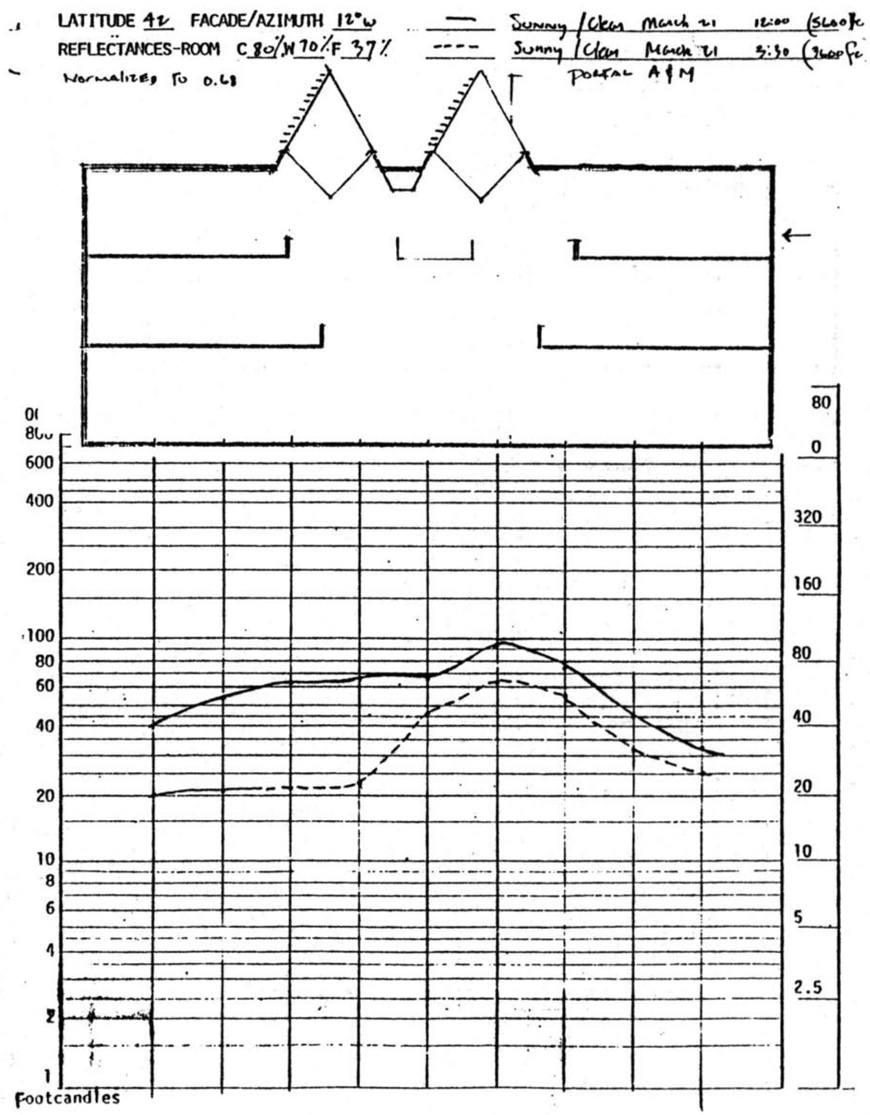
All data was recorded using a Vactec Model 3107 light meter and six Vactec Model 3117 cosine corrected photometric sensors.

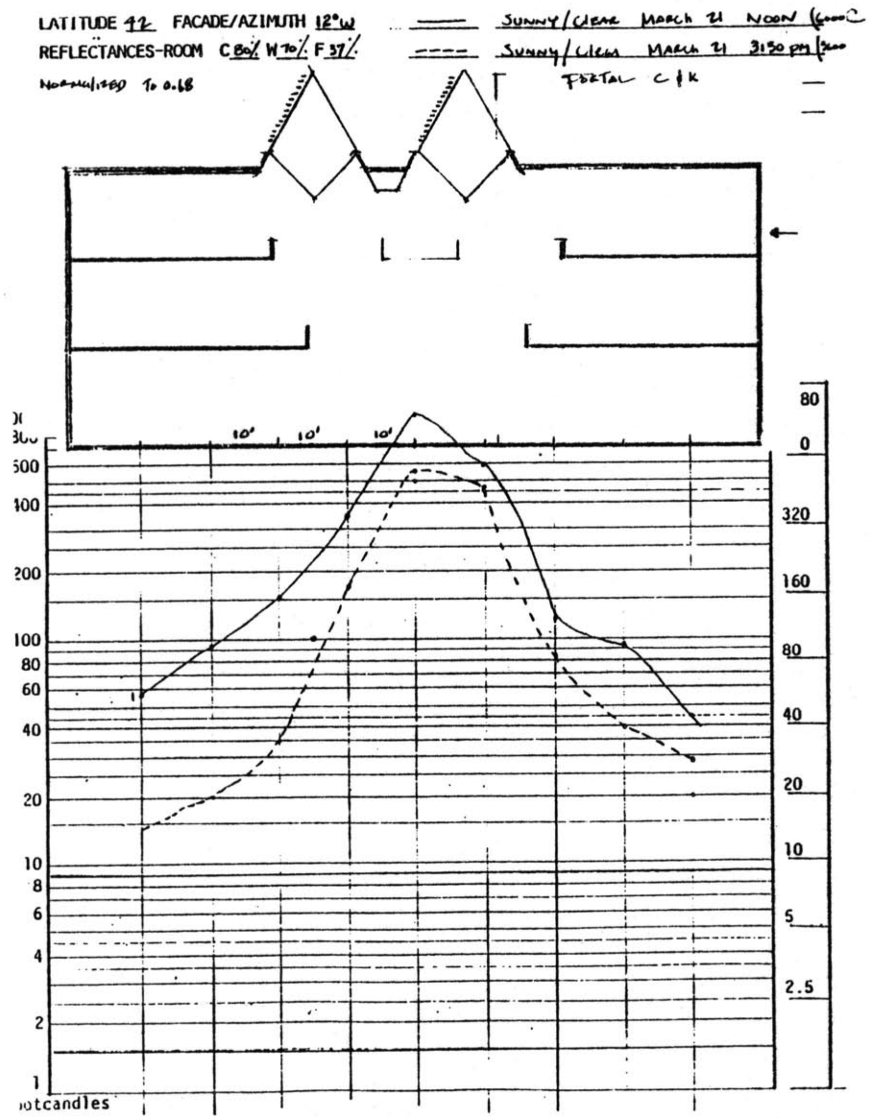
Based upon the atrium model studies, calculation of illumination from the building's edge under overcast sky conditions and extrapolation of clear sky data from model testing by others it is estimated that on a clear sunny day in March having a sky luminance of 5600 footcandles (diffuse and beam), that 75% of Building 215's leasehold and common spaces have illumination levels equal to or greater than 40 footcandles. This is based on a total floor area of 204,900 square feet. An overcast day with a sky luminance of 1500 footcandles provides interior illumination in excess of 40 footcandles for 57% of the building's floor area.

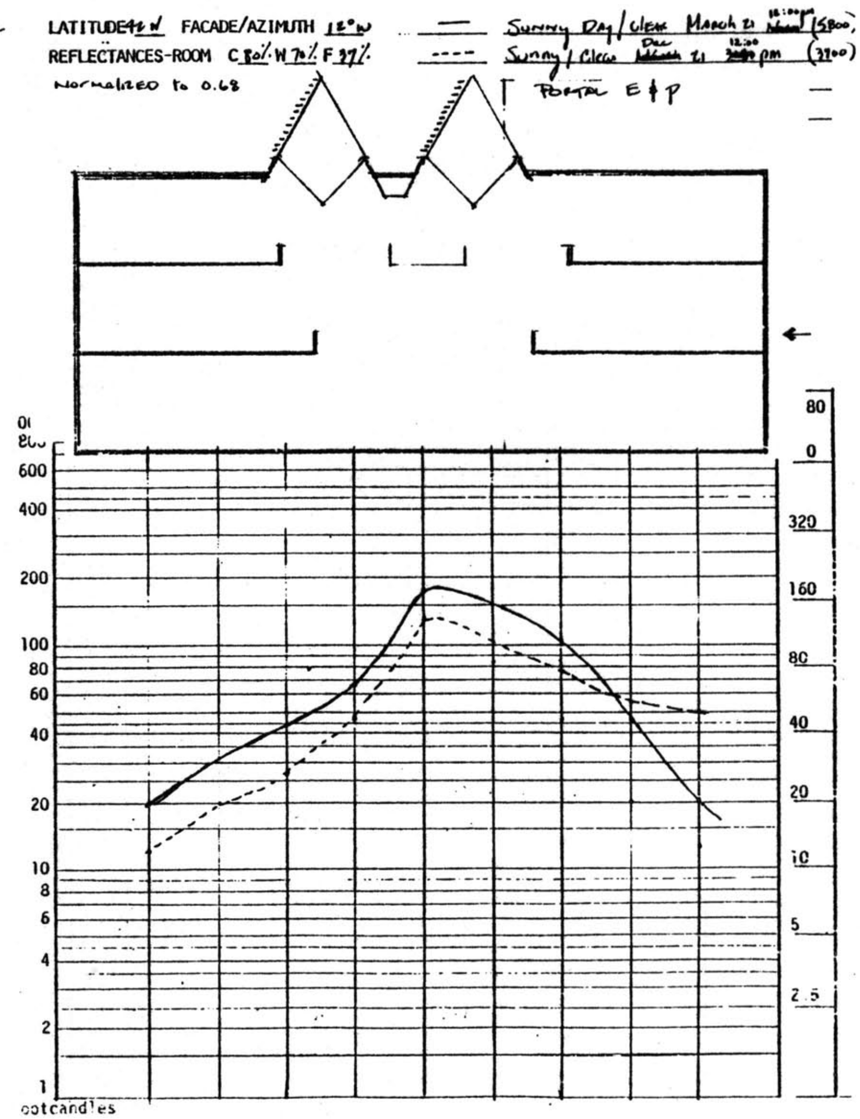

GENERAL PROJECT DESCRIPTION
LATITUDE 42°N FACADE/AZIMUTH 12°W
REFLECTANCES-ROOM C 80/ W 70/ F 37%
Normalized To 0.65
SYMBOL
TEST CONDITIONS
OVERCAST 2500fc.
NO OVERHANG
D & K
E & P
S & W
footcandles

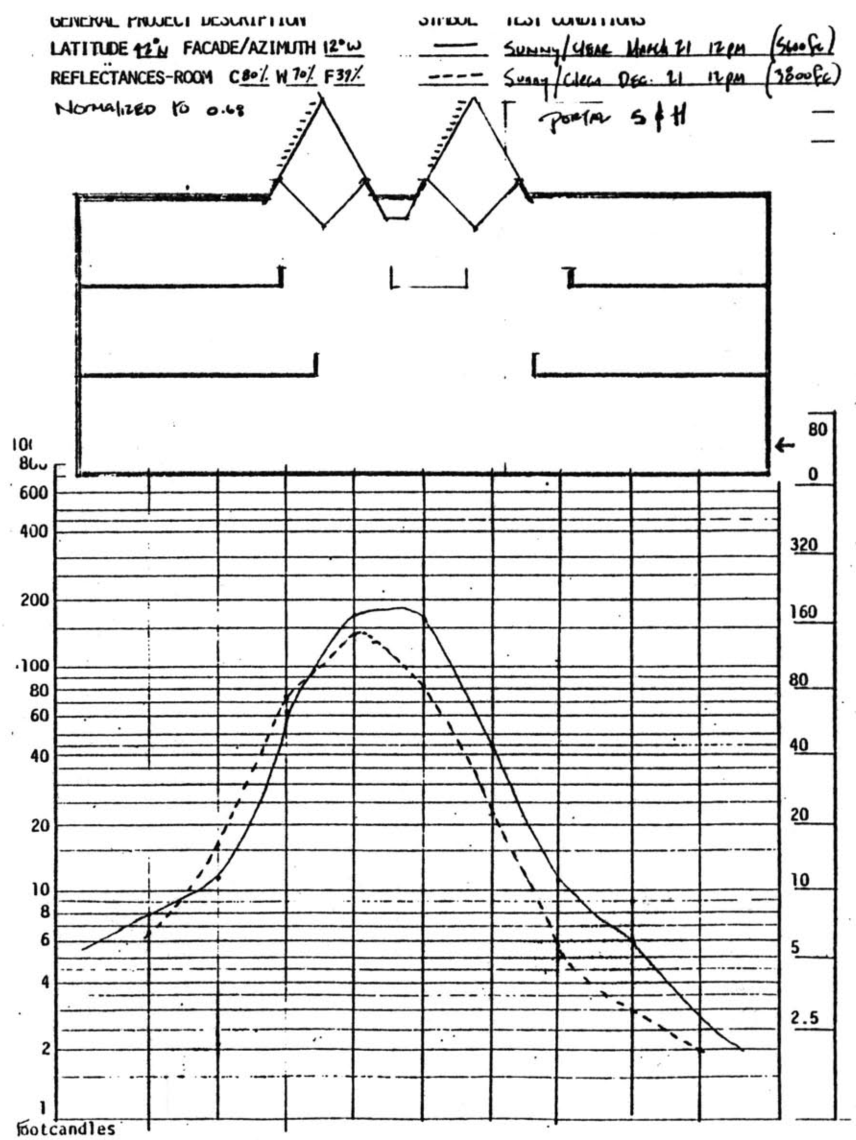

GENERAL PROJECT DESCRIPTION
LATITUDE 42°N FACADE/AZIMUTH 12°W
REFLECTANCES-ROOM C 80/W 70/F 37%
Normalized To 0.65
SYMBOL
TEST CONDITIONS
OVERCAST 2500fc.
OVERHANG 50° CUT OFF Angle
D & K
E & P
S & W
Footcandles


LATITUDE 42 FACADE/AZIMUTH 12°W
OVERCAST 2500 fc.
REFLECTANCES-ROOM C 80% W 70% F 37%
NORMALIZED TO 0.65
B&K
E&P
S&H
Footcandles


LATITUDE 42 FACADE/AZIMUTH 12°W
REFLECTANCES-ROOM C 80% W 70% F 37%
Normalized to 0.68
PORTAL A&M
Footcandles


LATITUDE 42 FACADE/AZIMUTH 12°W
REFLECTANCES-ROOM C 80% W 70% F 37%
Normalized to 0.68
Sunny/clear March 21 Noon
Sunny/clear March 21 3:30 pm
PORTAL C & K
10' 10' 10'
600
400
200
100
80
60
40
20
10
8
6
4
2
1
80
0
320
160
80
40
20
10
5
2.5
otcandles


LATITUDE 42 N FACADE/AZIMUTH 12°W
REFLECTANCES-ROOM C 80% W 70% F 37%
Normalized to 0.68
Sunny Day/clear March 21
Sunny/clear 21 pm (3900)
PORTAL E & P
600
400
200
100
80
60
40
20
10
8
6
4
2
1
80
0
320
160
80
40
20
10
5
2.5
otcandles


GENERAL PROJECT DESCRIPTION
SYMBOL
TEST CONDITIONS
LATITUDE
FACADE/AZIMUTH
REFLECTANCES-ROOM C80% W70% F39%
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
footcandles
80
0
320
160
80
40
20
10
5
2.5

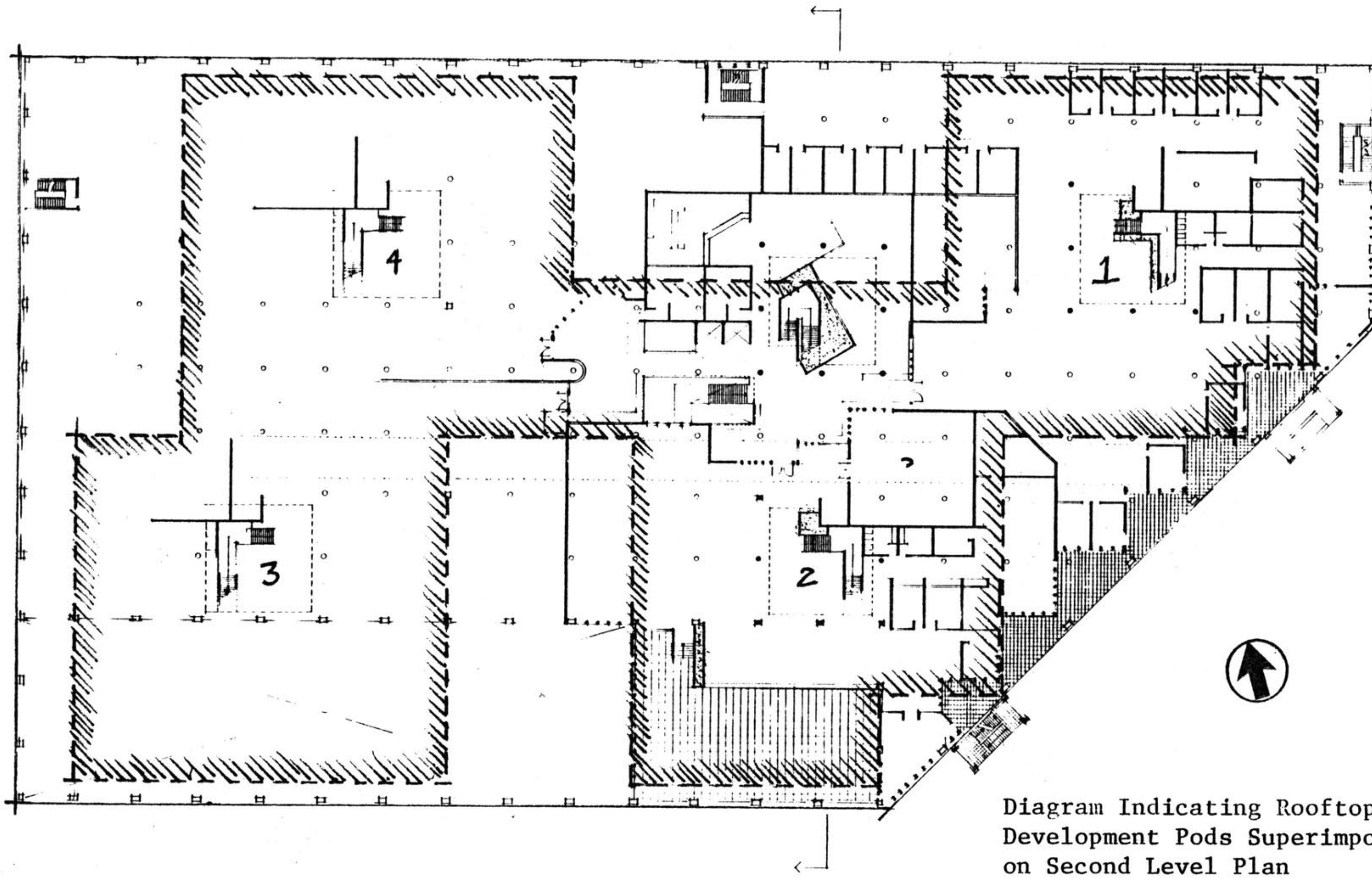
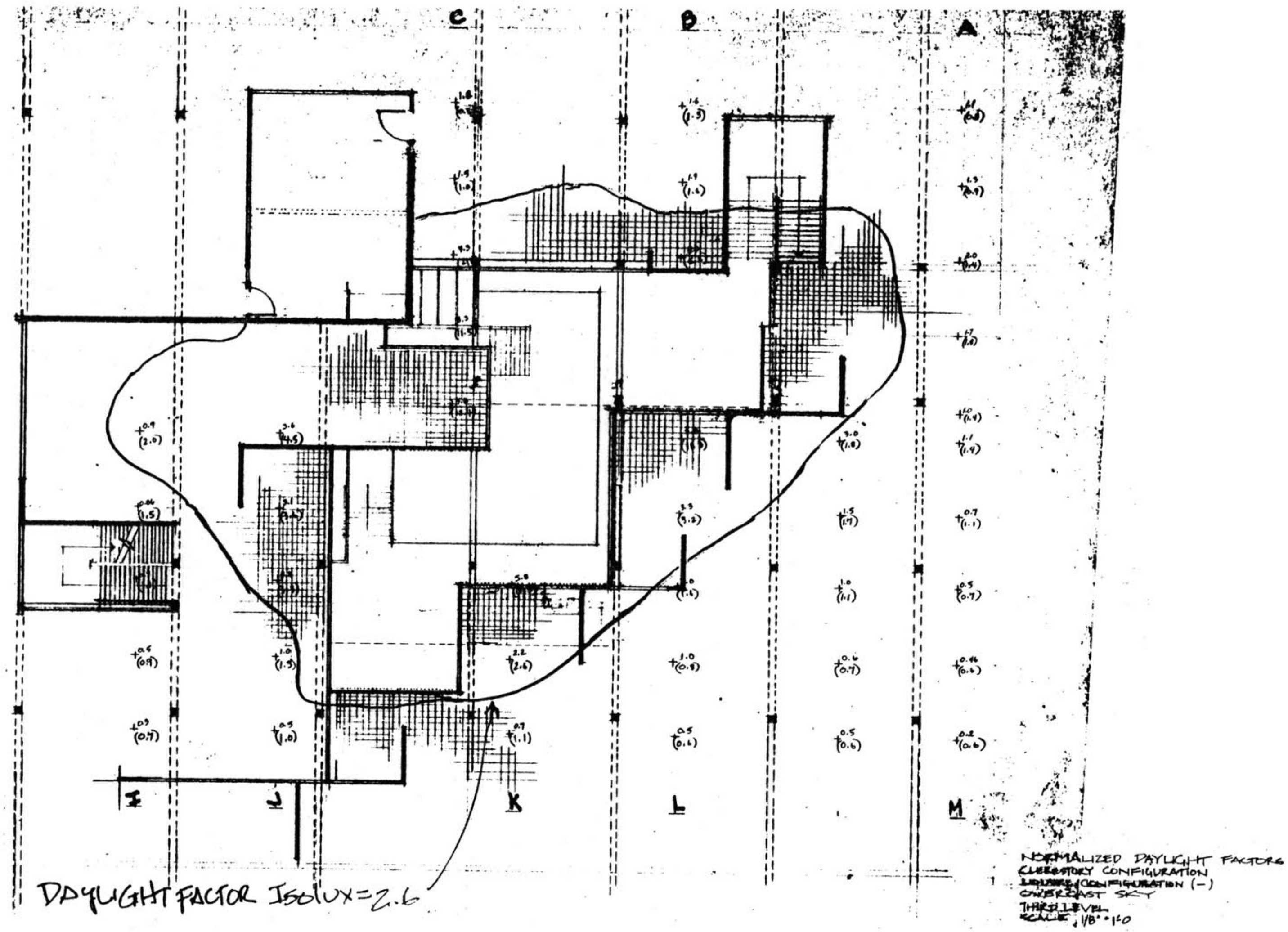
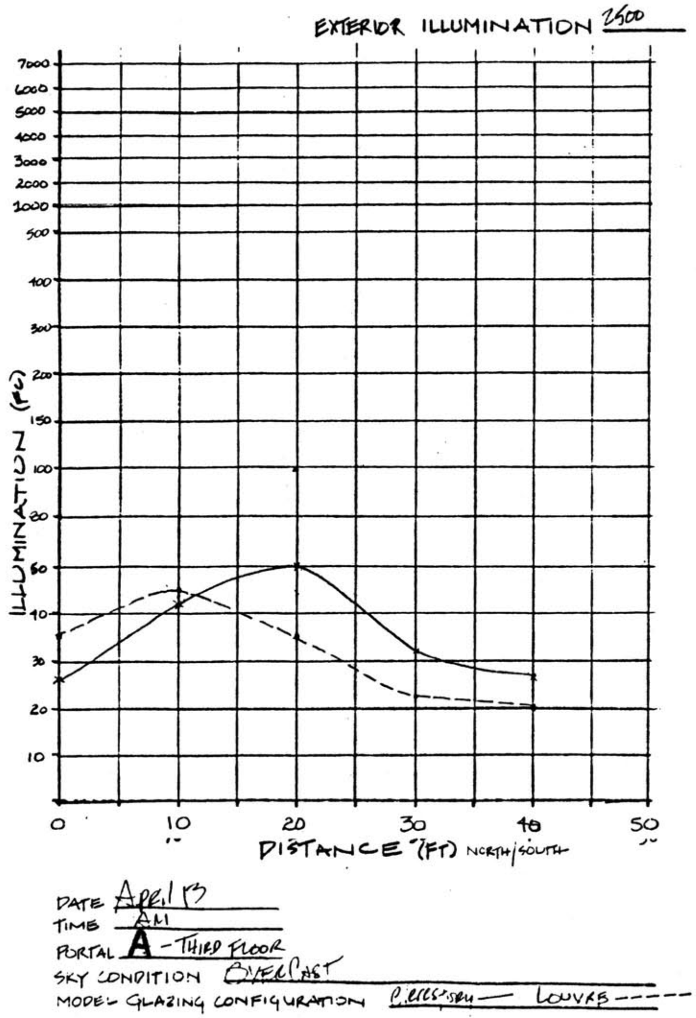
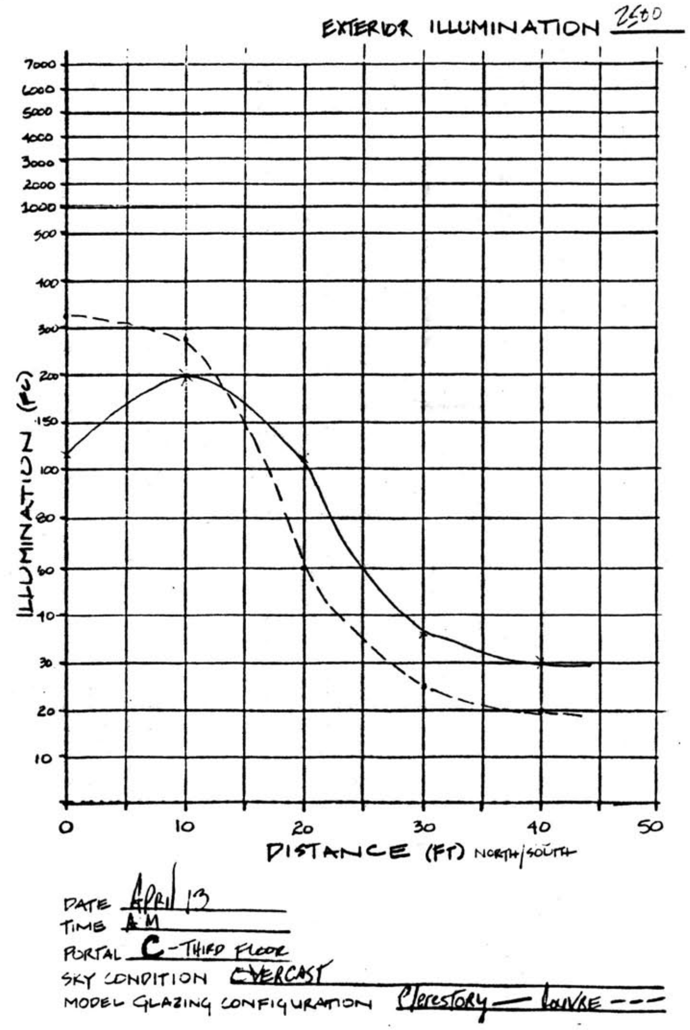


Diagram Indicating Rooftop Development Pods Superimposed on Second Level Plan

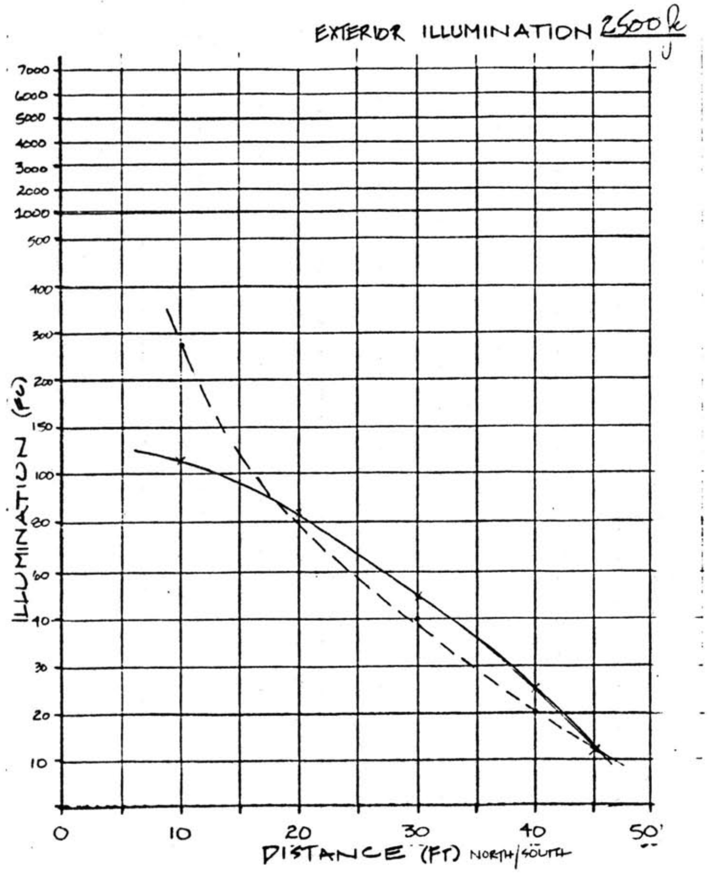

C
B
A
I
J
K
L
M
DAYLIGHT FACTOR ISOLUX=2.6
NORMALIZED DAYLIGHT FACTORS
CLERESTORY CONFIGURATION
CONFIGURATION (–)
OVERCAST SKY
THIRD LEVEL
SCALE 1/8"=1'-0



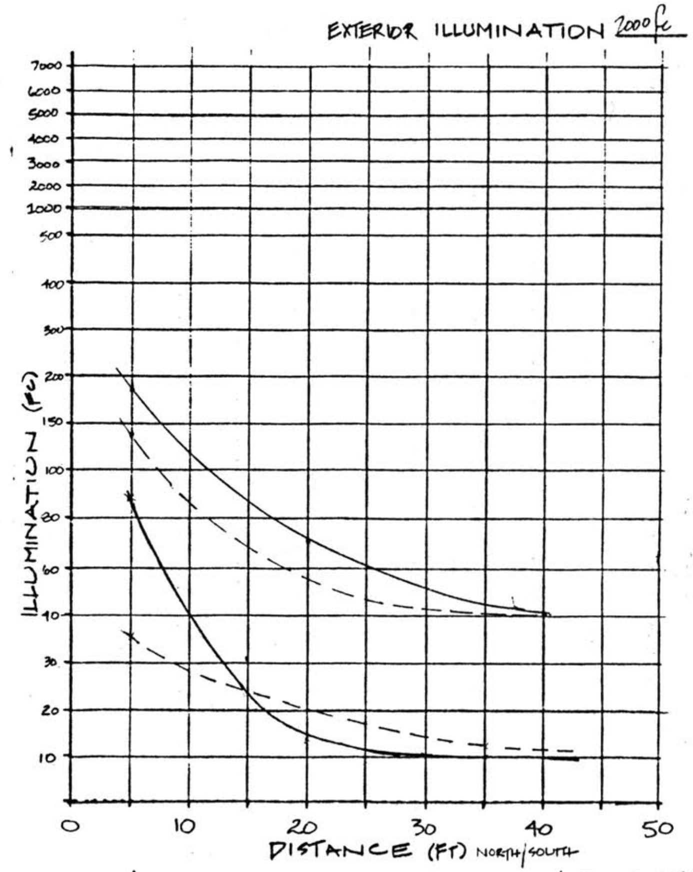
EXTERIOR ILLUMINATION 2500
ILLUMINATION (FC)
7000
6000
5000
4000
3000
2000
1000
500
400
300
200
150
100
80
60
40
30
20
10
0
10
20
30
40
50
DISTANCE (FT) NORTH/SOUTH
DATE April 13
TIME AM
PORTAL A - THIRD FLOOR
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory — LOUVRE -----



EXTERIOR ILLUMINATION 2500
ILLUMINATION (FC)
7000
6000
5000
4000
3000
2000
1000
500
400
300
200
150
100
80
60
40
30
20
10
0
10
20
30
40
50
DISTANCE (FT) NORTH/SOUTH
DATE April 13
TIME AM
PORTAL C - THIRD FLOOR
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory — Louvre ---

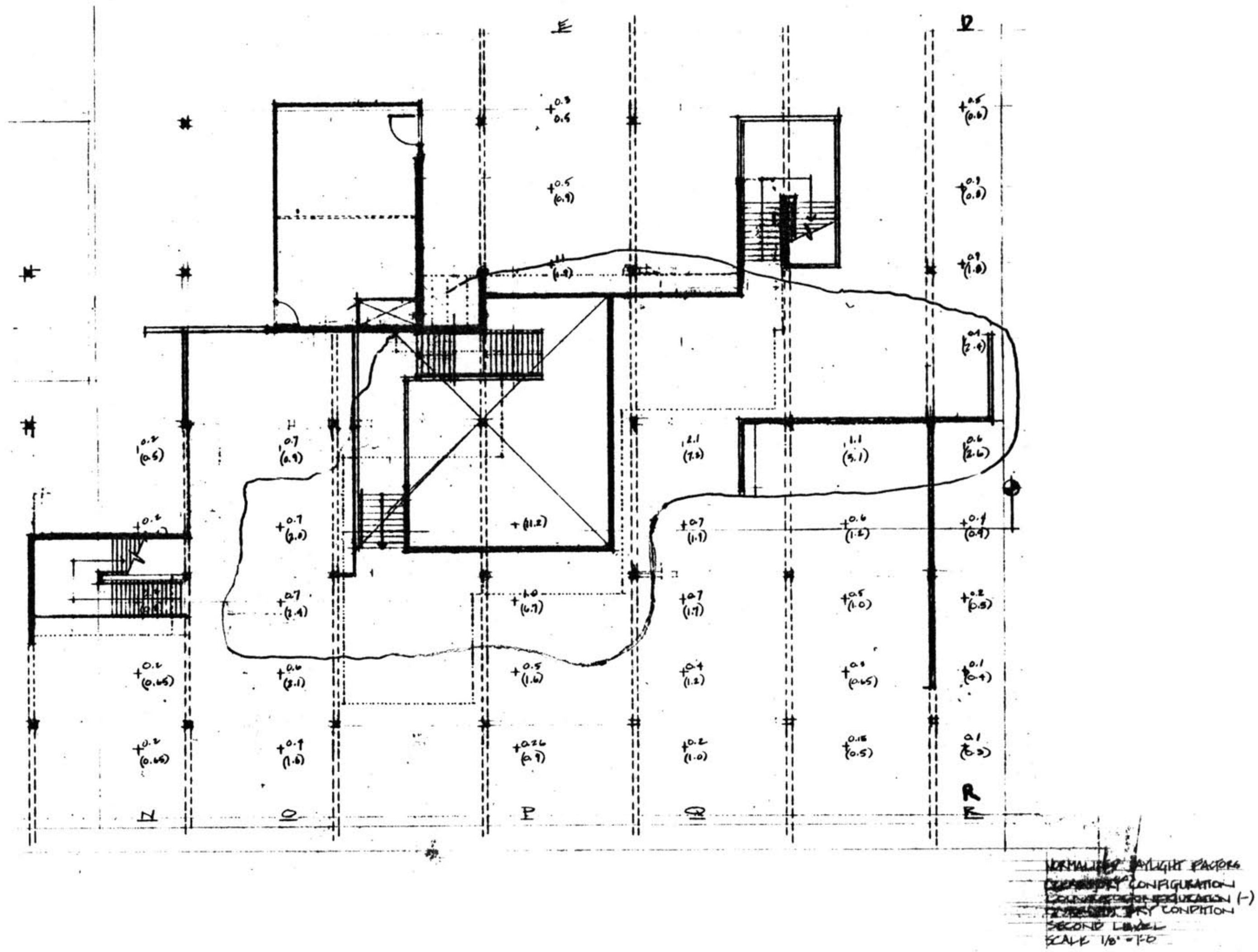


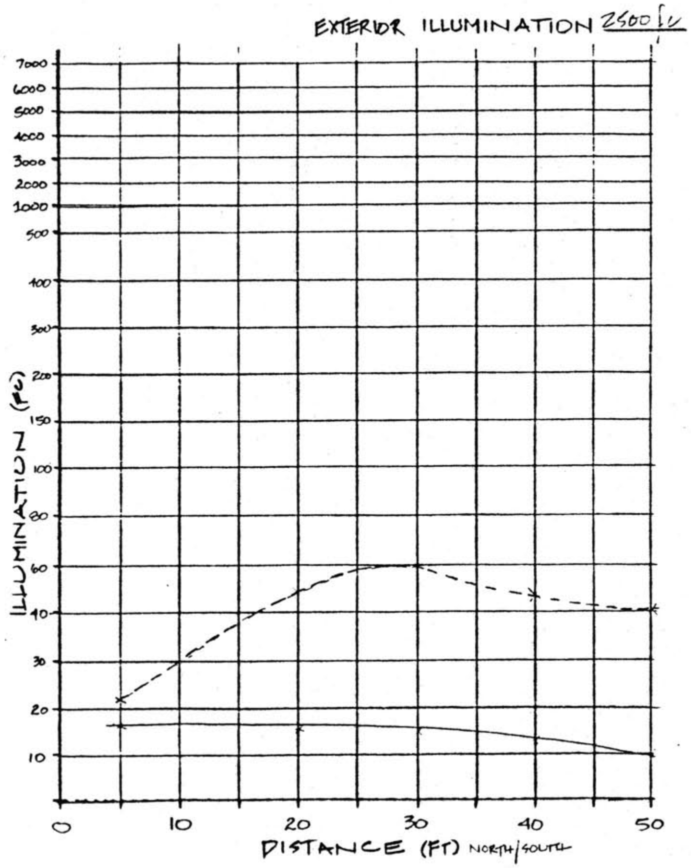
DATE April 13
TIME A.M.
PORTAL THIRD FLOOR L- NORTH TO SOUTH FROM CENTER OF ATRIUM
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre ----



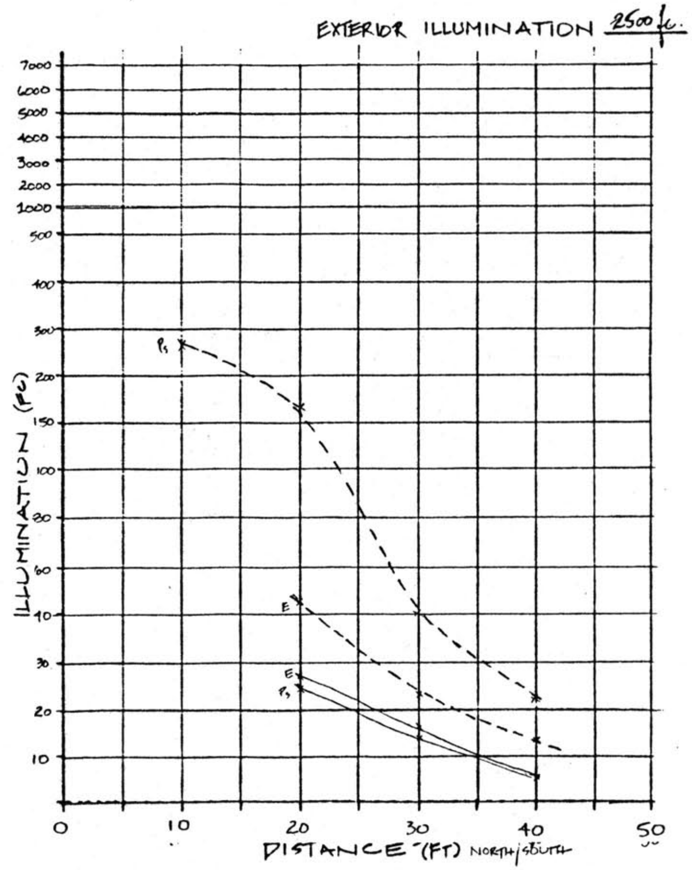
—— w/o interior light shelf
– – – w/ interior light shelf

DATE April 13
TIME AM
PORTAL B E
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Floor 3 Clerestory B-1
Floor 2 " "

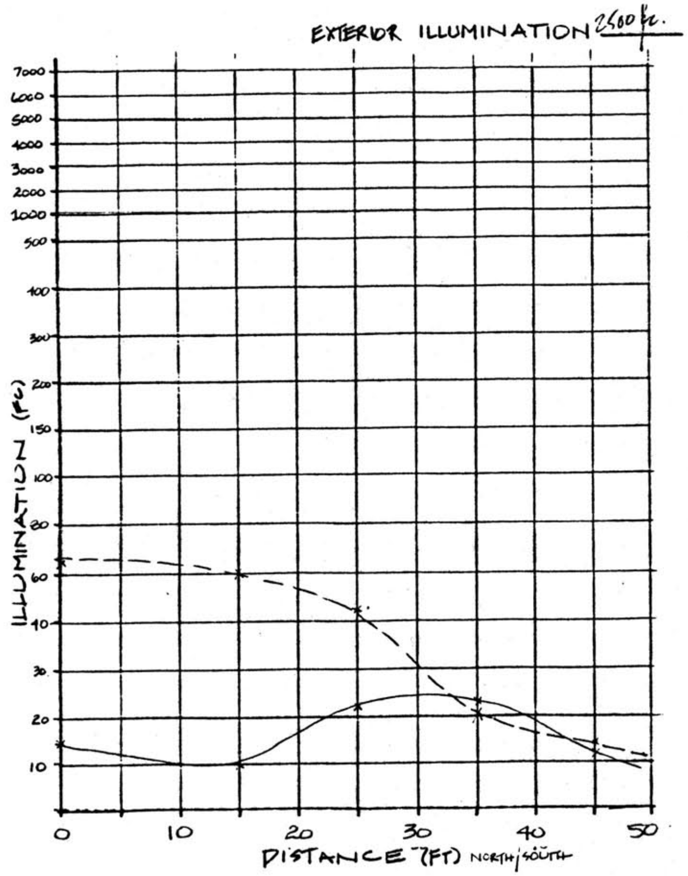

N
O
P
Q
R
CONFIGURATION
SECOND LEVEL
SCALE 1/8" = 1'-0



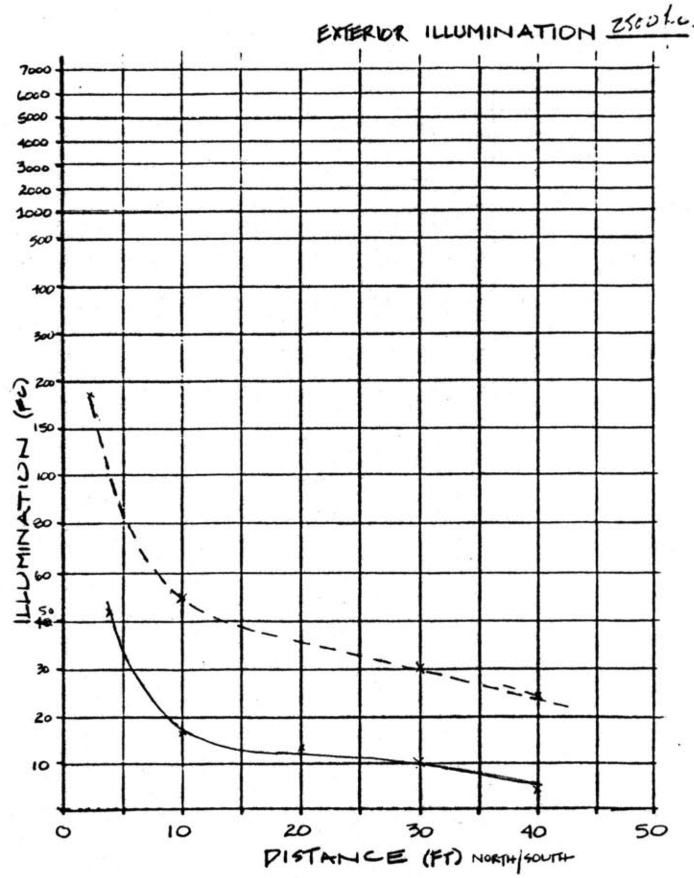
DATE April 13
TIME A.M
PORTAL O SECOND FLOOR
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre - - - -



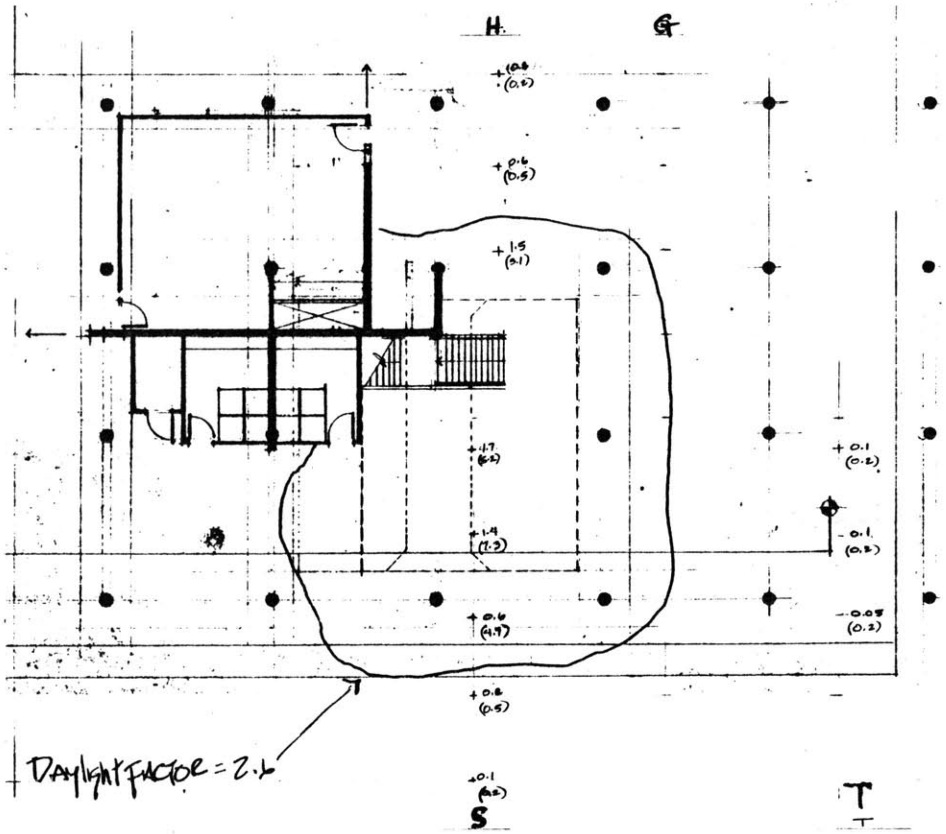
DATE April 13
TIME A.M
PORTAL P, E - SECOND FLOOR
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre - - - -



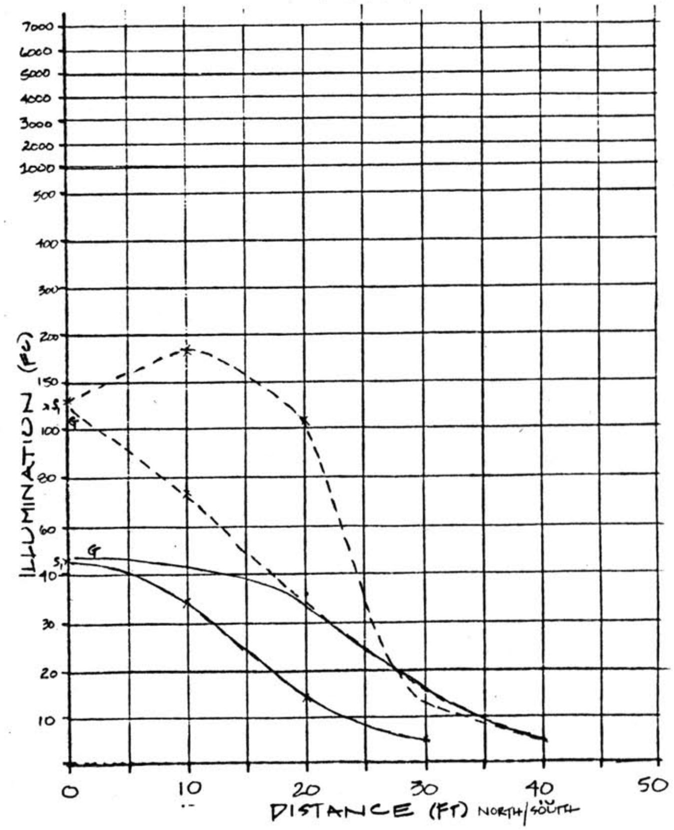
DATE April 13
TIME AM
PORTAL D - Second Floor
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre - - - -



DATE April 13
TIME AM
PORTAL Q - Second Floor
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre - - - -



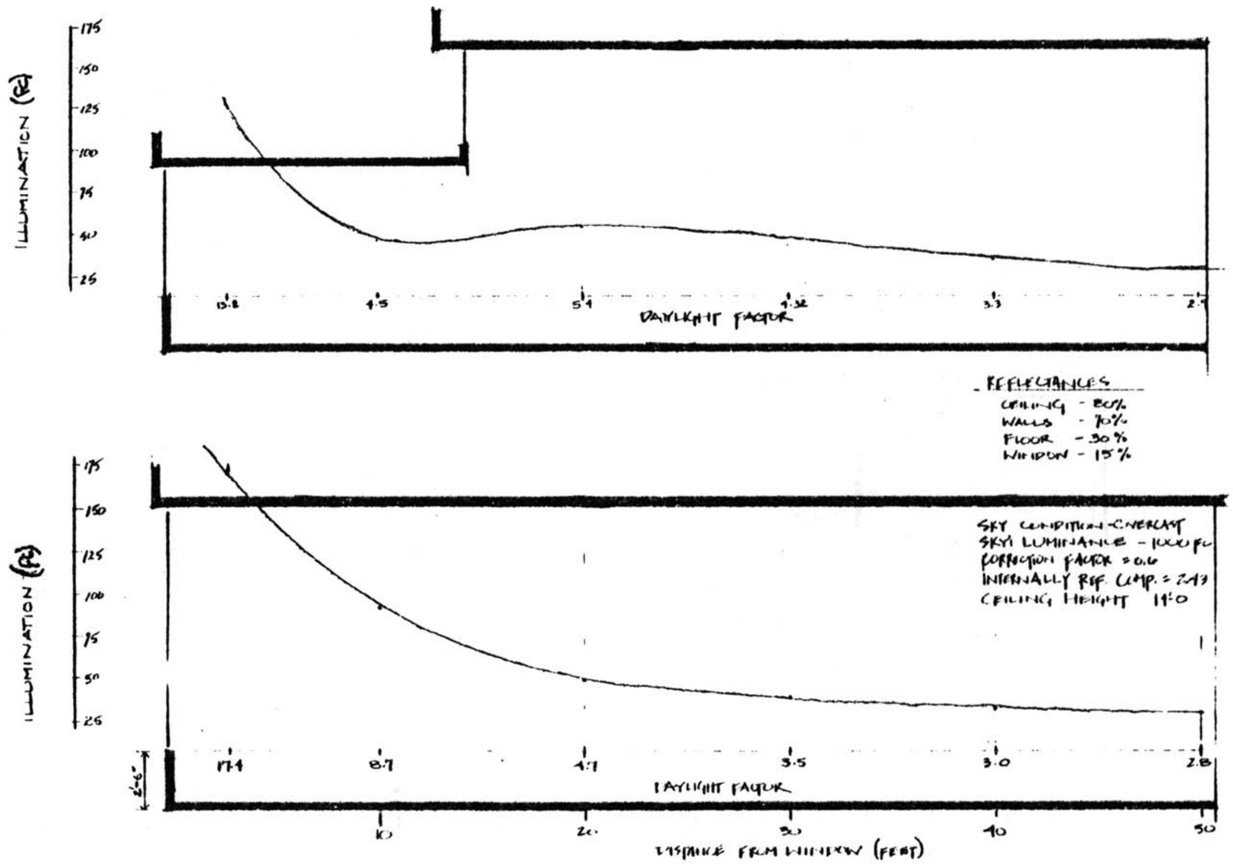
EXTERIOR ILLUMINATION 3600 fc



DATE April 13, 1982
TIME A.M.
PORTAL S: north to South G, south to North — 1st Floor
SKY CONDITION OVERCAST
MODEL GLAZING CONFIGURATION Clerestory —— Louvre - - - -

~~NORMALIZED DAYLIGHT FACTORS~~
~~CLERESTORY CONFIGURATION~~
~~LOUVRE CONFIGURATION~~
~~OVERCAST SKY~~
~~FIRST LEVEL~~
~~SCALE 1/8" = 1'0~~

These sections illustrate the illumination gradient under overcast sky conditions for two proposed building edge treatments. The first has a stepped roof at the edge to control the brightness ratio, reduce the incidence of glare, enhance daylight penetration, provide a view of the sky to people working in the building's interior, and potentially natural ventilation if operable sash is used. The second is clear, unobstructed glazing. Extrapolation from model studies by M.C. Lam Associates indicate that under clear sky conditions illumination levels of 40fc can be achieved 60 feet from the edge of south-facing facades. The British Research Station (BRS) daylight protractors* were used to estimate the sky component and the internally reflected component (IRC) was calculated using the following formula:



$$IRC = \frac{0.85w}{A(1-R)} (CRfw + 5Rcw)\ \%$$

w = glazed area

A = total area of internal surfaces

c = function of sky luminance distribution and obstruction angle of any exterior building. In this case c = 39 for no obstruction.

Rfw = average floor reflectance and those parts of wall below the plane of the mid-height of the window.

Rcw = average ceiling reflectance and those parts of the wall above the plane of the mid-height of the window.

* Reference: Hopkinson, R.G., Daylighting, W. Heineman LTD, 1966. Chapters 4,5,12,16.

Illustration Sources

1. House of Faun, Pompeii, 2nd Century B.C. from Architecture: Form Space and Order by F. D. K. Ching.

2. Cleveland Arcade from Passagen

3. Larkin Building Atrium, F. L. Wright Memorial Foundation, AIA Journal, July 1979, pg. 52.

4. Unity Temple, AIA Journal, June 1979.

5. Matmata Plateau, South Tunisia, Architects Yearbook XI, Elek Books, London, 1965.

6. Urban Communities of Algerian Sahara, Ekistics 227 October 1979, pg. 255-258.

7. Taos Adobes, Bunting, G. Museum of New Mexico Press, 1964.

8. Menlo Park Demonstration Houses, Brochure 1975.

9. The Courtyard House as Temperature Regulator, The New Scientist, Vol. 8, September 8, 1960, pg. 663-666.

10. History of the House, Putnam's Sons, 1971, pg. 32.

11. Buildings, Climate, Energy. Markus, T. A., Pitman Publishing, London 1980, pg. 154-160.

12. Minoan Settlement Plan, Le Grand Palais de Knossos by Jacques Raison, Roma, Edizioni, 1969.

13. Al-Azzawi, S. H. "Oriental Houses in Iraq" Shelter and Society, Praeger 1969, pg. 91-102.

14. Abdulak, S. and Pinon, P. "Maisons en pays Islamiques" L'Architecture d'aujourd'hui, Paris, No. 167, May/ Jeune 1973.

15. Evans, M. Housing, Climate and Comfort. Architectural Press, 1980, pg. 104-106.

16. Donnadieu, C. and P. Didillon, H and J. M. Habites de desert, Les Maisons Mozabites, A & R, 1977, pg. 75-77.

17. Prussin, L. Architecture in Northern Ghana, University of California Press, 1969, pg. 77.

18. Fernandez, J. A. Architecture in Puerto Rico, 1965, pg. 116-117.

19. Brown, F. E., Roman Architecture, Braziller, 1961, pg. 14-15.

20. Ibid.

21. Revault, J. Palais et Demeures de Tunis, Centrale National de la Recherche Scientific, Paris, 1971, pg. 45-59.

22. Blaser, W. Courtyard Houses in China, Tradition and Present, Birkhausen, 1979, pg. 5-8.

23. Jordy, W. H. American Buildings and Their Architects, Vol. 3, Doubleday and Company, 1972, pg. 350, 351, and 371.

24. Ibid.

25. Bastlund, K. Jose Luis Sert/Architecture, City Planning, Urban Design, Praeger, 1967, pg. 141-144.

26. Danz, E. Architecture of S.O.M. 1950-1962, Praeger 1963, pg. 65.

27. Ostberg, Ragnar. The Stockholm Town Hall, P. A. Norstedt and Sones, 1929.

28. Ibid.

29. Ibid.

30. Cornell, E. Ragnar Ostberg, Byggmastarens, Forlag, Stockholm, 1965, pg. 159.

31. Wrede, Stuart. The Architecture of E. G. Asplund, M.I.T. Press, 1980, pg. 150.

32. Ibid. pg. 153.

33. Holmdahl, G. Gunnar Asplund, Architect, Stockholm, 1950, pg. 161.

34. From slide by Bradley Shotola.

35. From slide by Bradley Shotola.

36. Alvar Aalto, Monograph 4, Rizzoli, New York, 1978.

37. Ibid.

38. Draghtless Window Detail, Architectural Review, Spring 1940.

39. Pension Building Photo by Bradley Shotola.

40. Pension Building, George Baird, Alvar Aalto.

41. Polytech Library Section, Alvar Aalto, Monograph 4.

42. Polytech Library Interior photo by Bradley Shotola.

43. Alvar Aalto, Monograph 4, pg. 22.

44. Alvar Aalto, Monograph 4, pg. 79.

45. Rovaniemi Library Plan, Alvar Aalto, Monograph 4, pg. 56.

46. Lobell, John. Between Silence and Light, Shambhala, Boulder 1979, pg. 111.

47. Progressive Architecture, September 1973, pg. 85.

48. Hildebrand, G. Designing for Industry, The Architecture of Albert Kahn, The M.I.T. Press, 1974, Figure 11.

49. Ibid, Figure 18.

50. A & U, Vol. 8, August 1979.

51. Ibid.

52. Becker, Franklin D. Workspace: Creating Environments in Organizations, Praeger Publishers, 1981, pg. 88.

53. SERI, Building Case Studies, Unpublished document.

54. Ibid.

55. Ibid.

56. Ibid.

57. Ibid.

58. Ibid.

59. Ibid.

60. Mango, Cyril. The Mosaics of St. Sophia at Istanbul, J. J. Augustin Publishers, 1962, pg. 1.

61. Non Visual Effects of Colour and Light, Annotated Bibliography by Rikard Kuller, pg. 236.

62. Consumers Research, August 1979, pg. 28.

Footnotes

1/ Kuller, R. Non Visual Effects of Light and Colour, Swedish Building Research Council, 1981.

2/ Ibid.

3/ Wurtman, R. J. "Biological Effects of Light", Progressive Architecture, September 1973. Pg. 79-81.

4/ Ibid.

5/ Ibid.

6/ Neer, R. M., Davis, T.R.A., Walcot, Koski, Schepis, Thorington and Wurtman. "Simulation by Artificail Lighting of Calcium Absorption in Elderly Human Subjects". Nature, 229, Pg. 255-257.

7/ NonVisual Effects of Light and Colour, Pg. 17.

8/ Feller, R. P., Edmonds, E. J. Shannon and Medsen. "Significant Effects of Environmental Lighting on Carrier Incidence in the Cotton Rat". Proceedings of the Society for Experimental Biology and Medicine, 145. Pg. 1065-1068.

9/ Mayron, L. W., Ott, J. N., Amontree, E. J. and Nations. Carrier Reduction in School Children Applied Radiology. Nuclear Medicine, July/August 1975.

10/Non Visual Effects of Light and Colour, Pg. 17.

11/Sigmund, R. Die Wirkung Ultravioletter Strahlen Aug die Reaktionszeit des Menschen, 1956. 101, 623-629.

12/Zamkova, M. A. and Krivitskaya, E. "Effect of Irradiation by Ultraviolet Erythema Lamps on the Working Ability of School Children". Gig i Sanit, Vol.31

April 1966. Pg. 41-44.

13/ Lykken, K. and Olsson, N. Utevistelse ger daghemsbarn lagre franvaro i'oli, 671 00 Arvika.

14/ Larson, C. T. "The Effect of Windowless Classrooms on Elementary School Children". Architectural Research Laboratory. Department of Architecture, University of Michigan, 1965.

15/ Wurtman, "Biological Effects of Light", Progressive Architecture, September 1973.

16/ Hopkinson, R. G. and Collins, J. B. The Ergonomics of Lighting, MacDonald 1970.

17/ Ruys, Windowless Offices, Masters Thesis, University of Washington, 1970.

18/ Sommer, R. Tight Spaces and How to Humanize Them, Prentice Hall, New Jersey, 1974.

19/ Ne'eman, E., and Hopkinson, R. G. "Critical Minimum Acceptable Window Size, A Study of Window and Design and Provision of a View". Lighting Research and Technology, Vol. 2, 1970. Pg. 17-77.

20/ Keighley, E. C."Visual Requirements and Reduced Fenestration in Buildings - A Study of Window Shapes." Journal of Building Scinece, Vol. 8, 1973. Pg. 311-320.

Bibliography

Aalto, Alvar. Synopsis Painting, Architecture Sculpture. Birkhauser Verlag, Basel and Stuttgart, 1970.

AIA Journal. "Natural Light", September 1979. Pg. 49-92.

AIA Journal. "Those Proliferating Atria", July 1979. Pg. 50.

AIA Journal. "Energy, Human Ecology and Urban Design", January 1981. Pg. 72.

Alexander, Christopher. A Pattern Language, Oxford Press, 1977.

Architectural Monographs. Alvar Aalto, Rizzoli Academy Edition, 1978.

Architectural Record. "Building Types Study", August 1981. Pg. 41.

A&U #75 "Herman Hertzberger", March 1977.

Baird, George. Alvar Aalto, Thames and Hudson, 1970.

Collins, Belinda. "Review of the Psychological Reaction to Windows", Lighting Research and Technology, Vol. 8 #2 1976.

Cresti, Carlo. Alvar Aalto, G. C. Sansoni, 1975.

Danz, Ernst. Architecture of Skidmore Owings and Merrill 1950-1962, Praeger, 1963.

Davis, Sam. Designing for Energy Efficiency, DOE Grant DE F603 80 GS 22004, 1981.

Flavin, Christopher. Energy & Architecture, World Watch Paper #40, November 1980.

Hildebrand, Grant. The Architecture of Albert Kahn, The M.I.T. Press, Cambridge, 1974.

Hix, John. The Glass House, The M.I.T. Press, Cambridge, 1974.

Holmdahl, G. Gunnar Asplund, Architect, Stockholm, 1950.

Hopkinson, R.G. Daylighting, Heineman, London, 1966.

Jordy, William. American Buildings and their Architects, Vol. 3, Doubleday and Company, 1972.

Kuller, Rikard. Non Visual Effects of Light and Colour, Swedish Council for Building Research, 1981.

Lam, M. C. The Effects of Light on Health, A Review and Assessment. The Bureau of Human Ecology, Ottawa, Ontario Canada, 1976.

Luce, G. G. Bodytime, Physiological Rhythms and Social Stress, Pantheon Books, Random House.

Ludlow, A. M. "The Functions of Windows in Buildings", Lighting Research and Technology, Vol. 8 #2, 1976.

Matthews, S. and Calthorpe, P. "Daylight as a Central Determinant of Design", AIA Journal, Vol. 23 #11, 1979. Pg. 86-93.

Östberg, Ragnar. The Stockholm Townhall, P.A. Norstedt and Sones, Pub. 1929.

Ott, J. N. Health and Light, Simon and Schuster, 1973.

Ott, J. N. Light, Radiation and You, Devin-Adair, 1982.

Otto, Christian. Space into Light, The Churches of Balthasar Neumann, The M.I.T. Press, Cambridge, 1979.

Phillips, Derek. "Space, Time and Light in Architecture", Lighting Research and Technology, Vol.7 #1, 1975.

Present Value - Constructing a Sustainable Energy Future, California Energy Commission.

Rasmussen, S. E. Experiencing Architecture, The M.I.T. Press, Cambridge, 1962.

Rodgers, N., Ballinger, J. and Dunkerly, "An Analysis of Innovative Methods in Natural Lighting", Architectural Science Review, June 1979.

Ronner, H., Jhaveri and Vasella, A. The Complete Works of Louis I. Kahn 1935-1974. Institute for the History and Theory of Architecture, The Swiss Federal Institute of Technology, Zurich 1977.

Ternoey, Steven, et al. "Energy Efficient Commercial Buildings", Proceedings 5th National Passive Solar Conference, 1981.

Werde, Stuart. The Architecture of Erik Gunnar Asplund, The M.I.T. Press, Cambridge, 1980.

Wurtman, R. J. "The Effects of Light on the Human Body", Scientific American 233 #7, July 1975.

Wurtman, R. J. Biological Implications of Artificial "Illumination" presented at the National Technical Conference of IES, September 1968.

Wurtman, R. J. Biological Considerations in Lighting Environments, Progressive Architecture, September 1973.