ECONOMIC AND DESIGN ANALYSIS OF DAYLIGHTING A COMMERCIAL TOWER IN A HOT AND HUMID CLIMATE

by

ROBERT F. ROSCOW

B.A. Duke University

1972

Submitted in Partial Fulfillment
of the requirements for the
Degree of
Master of Architecture
at the
Massachusetts Institute of Technology
June 1981

Signature of Author..
Department of Architecture
May 8, 1981

Certified by......
Harvey Bryan, Assistant Professor
of Building Technology,
Thesis Supervisor

Accepted by......
Associate Professor Sandra C. Howell,
chairperson Departmental Committee for
Graduate Students

ACKNOWLEDGEMENTS TO:

my parents for an infinite amount of
patience,
Harvey, for keeping me on track and a
lot of ideas,
and Bill Upthegrove for two extra hands
and oft' needed smile.

A destiny that leads the English to the Dutch is strange enough; but one that leads from Epsom into Pennsylvania, and thence into the hills that shut in Altamont over the proud coral cry of the cock, and the soft stone smile of an angel, is touched by that dark miracle of chance which makes new magic in a dusty world.

Each of us is all the sums he has not counted: subtract us into nakedness and night again, and you shall see begin in Crete four thousand years ago the love that ended yesterday in Texas.

The seed of our destruction will blossom in the desert, the alexin of our cure grows by a mountain rock, and our lives are haunted by a Georgia slattern, because a London cutpurse went unhung. Each moment is the fruit of forty thousand years. The minute-winning days, like flies, buzz home to death, and every moment is a window on all time.

Thomas Wolfe, LOOK
HOMEWARD, ANGEL,
New York, 1929.

Figure 1.

ECONOMIC AND DESIGN ANALYSIS OF DAYLIGHTING A COMMERCIAL TOWER IN A HOT AND HUMID CLIMATE

by

ROBERT F. ROSCOW

Submitted to the Department of Architecture
on May 8, 1981 in partial fulfillment of the
requirements for the Degree of Master of
Architecture

ABSTRACT

A forty story commercial office tower in Tampa, Florida was redesigned for daylighting. The methods are outlined and results illustrated. A cooling load comparison is done to determine the economic feasibility of such a strategy. It was found that the smaller cooling plant and greater perimeter office space could offset the increased building expense. Energy savings were also significant, especially for cooling.

Thesis Supervisor: Harvey Bryan

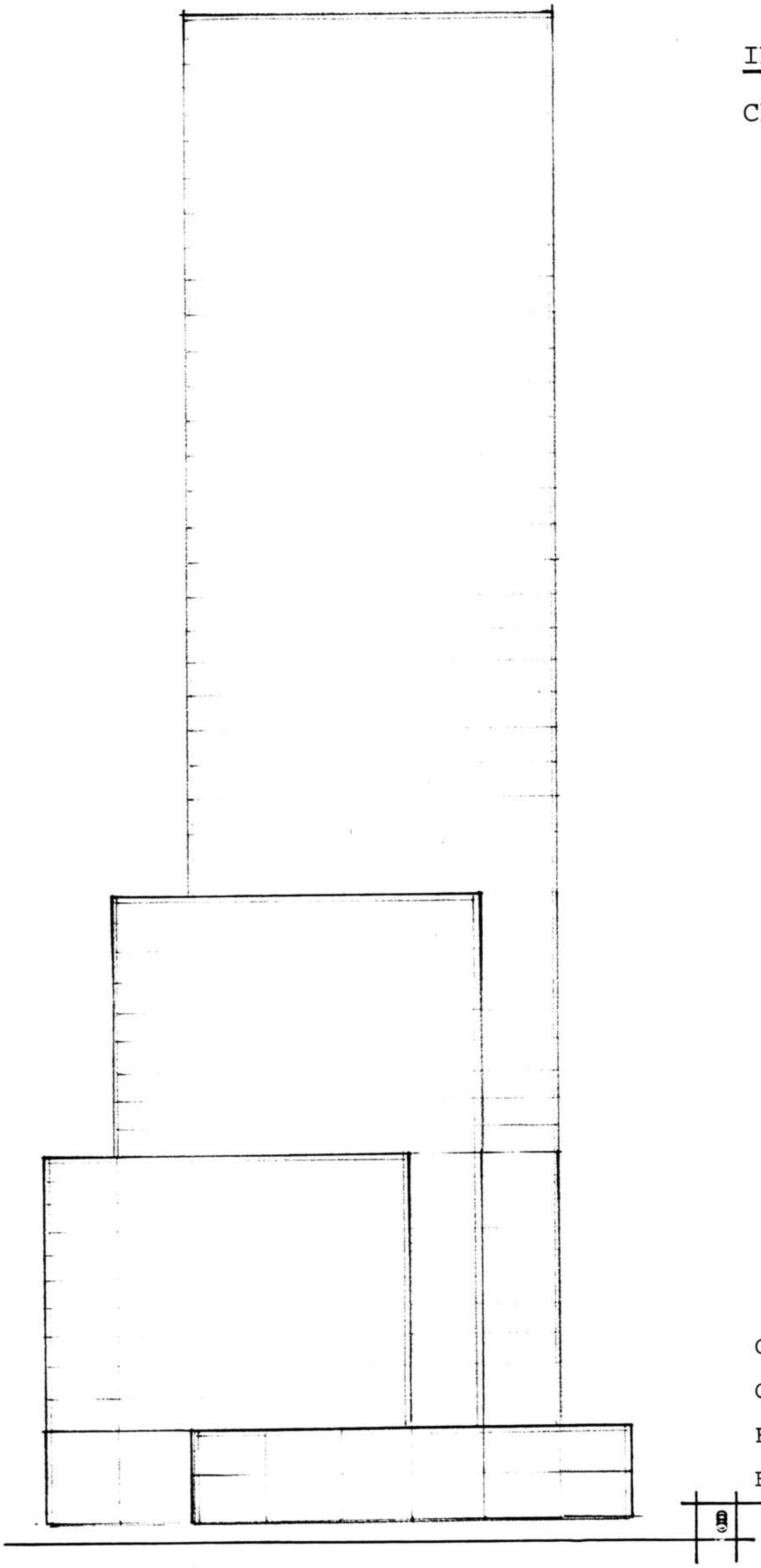
Title: Assistant Professor of Building
Technology

TABLE OF CONTENTS

TABLE OF CONTENTS continued

INTRODUCTION

Chapter One



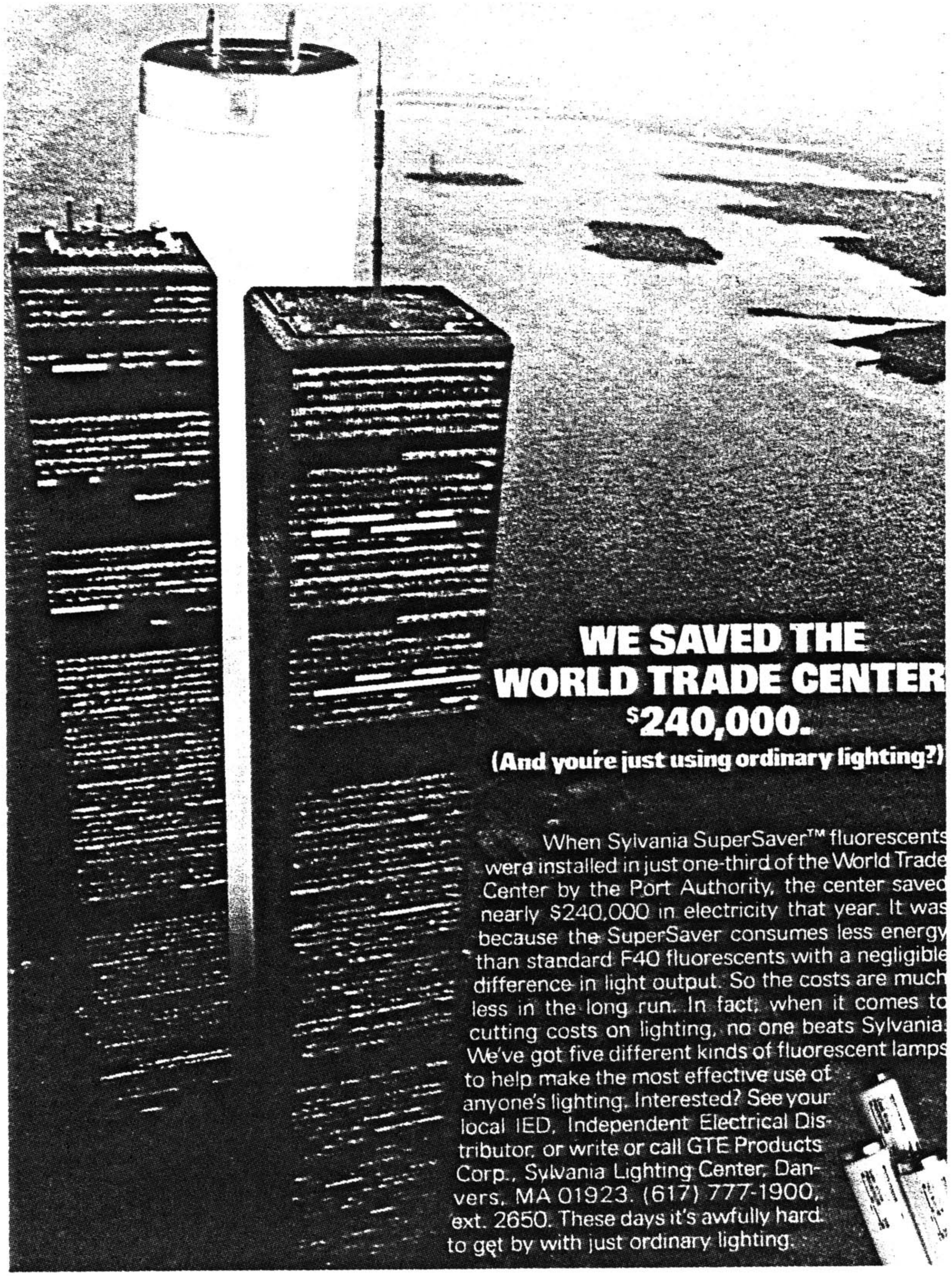
One Tampa City
Center, Welton
Becket Associates
Figure 2.

Although the tall commercial tower has become commonplace in the world's major cities, it is of relatively recent origin. The technologies which made it possible did not evolve until the turn of the century: most notably the elevator, high strength steel, and later air conditioning systems. Not least among these new technologies though less obvious was the invention of the electric light and concomitant power generation plants. A growth in urban centers consequently emerged at a rate never before thought possible. Figure one illustrates the impact. The accretion of buildings on Boston's Beacon Hill built over a couple of hundred years stand in marked contrast to downtown's commercial towers built in the last twenty years. Many of these amazingly enough have as much floor area as Beacon Hill itself.

Many feel that this development was far too rapid and overlooked man's basic needs: abstracting technology and attendant architecture out of the realm of serving man but rather corporate images and symbols. The energy crisis now gives a physical and quantitative basis to this criticism and hopefully one which can become qualitative as well. In the following pages a method is developed for daylighting these towers with F.A.R.'s approaching twenty to not only save energy but, more importantly, produce a qualitatively better environment. Perhaps it might also define one path to the "proper forms" of which Reyner Banham speaks which can produce an architecture "...as convincing as the millenial architecture of the past."[1]

---

[1] Reyner Banham, THE ARCHITECTURE OF THE WELL-TEMPERED ENVIRONMENT, London, 1969, p. 289.



WE SAVED THE WORLD TRADE CENTER $240,000.

(And you're just using ordinary lighting?)

When Sylvania SuperSaver™ fluorescents were installed in just one-third of the World Trade Center by the Port Authority, the center saved nearly $240,000 in electricity that year. It was because the SuperSaver consumes less energy than standard F40 fluorescents with a negligible difference in light output. So the costs are much less in the long run. In fact, when it comes to cutting costs on lighting, no one beats Sylvania. We've got five different kinds of fluorescent lamps to help make the most effective use of anyone's lighting. Interested? See your local IED, Independent Electrical Distributor, or write or call GTE Products Corp., Sylvania Lighting Center, Danvers, MA 01923. (617) 777-1900, ext. 2650. These days it's awfully hard to get by with just ordinary lighting.

Figure 3.
PROGRESSIVE ARCHITECTURE, Dec. 1980, p. 100.

One is tempted to utter, " So what." Perhaps some miracle tube will be developed; but probably not until the New York Port Authority has paid through the nose for every million square feet of floor (roughly twenty-three acres per million square feet) needing artificial light. A better approach would have been to design the World Trade Center in the beginning to optimize natural light which is after all free. Architects from the Egyptians on seem to have had no problem understanding this point. And they did "big stuff" too.

The paradox of the present situation symbolized by the World Trade Center is that given the electric light and therefore the capability to light buildings at night; we somehow arrived at a one-hundred story cave architecture. We have in effect in much of our new architecture closed the options inherent in the electric light. We did not expand our experiences with it but rather contracted them to monotonous, uniformly lighted dropped ceilings necessitated by huge floors stacked one on the other around some sculptural, not architectural, principle.

The resultant of this myopic process has been tower architecture consuming huge quantities of energy not only to operate the lights but also dissipate the heat generated by them. Chapter Three will show the magnitude of this problem. One should find it very odd or counter intuitive that we cool New York towers in the dead of winter!

The program for One Tampa City Center and the Welton Becket designed tower have been used in this thesis as a base for comparison of a daylighted and normally lighted tower. The program required the design of eight-hundred thousand square feet of commercial office space on roughly a one acre site in downtown Tampa, Florida. One Tampa City Center represents an extreme test of daylighting since there are no alternatives but to use a tower because of the high F.A.R. (approximately eighteen) and exposing large areas of fenestration to the hot and humid Florida climate can cause immense cooling problems.

The process outlined generates what one might term a schematic or first pass at the final form. It is not by any means a final design but more a reference and direction for design.

Although the process is described linearly; it obviously did not occur in such a manner or without regard to other restraints and architectural problems. I have tried to at least mention some of these problems; since they are so critical in the design of such vertical structures where one continuously finds oneself making many decisions simultaneously.

A typical upper-level floor of the tower designed by Welton Becket was analyzed initially to estimate the worst case cooling load. This figure is usually used to size air-conditioning equipment and serves as a good base for comparison of alternative designs.

The design temperatures and procedure were obtained from the ASHRAE HANDBOOK 1977 FUNDAMENTALS published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. of New York City.

The floor plan dimensions were one-hundred twenty-five by one-hundred twenty five composed of twenty-five foot square bays.

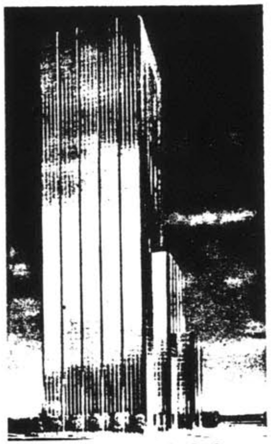

ONE TAMPA CITY CENTER, TAMPA, FL
ARCHITECT WELTON BECKET ASSOCIATES

Figure 4.

PROGRESSIVE ARCHITECTURE, Dec. 1980, p. 52.

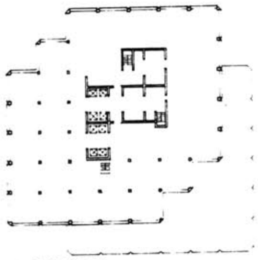

ONE TAMPA CITY CENTER

Figure 5.

op. cit., p. 52.

COOLING LOAD CALCULATION PROCEDURE^2

Table 1 Procedure for Calculating Space Design Cooling Load—Summary of Load Sources and Equations

Load Source	Equation	Reference, Table, Description
External Roof	$q = U \times A \times \text{CLTD}$	Chapter 22-Design Heat Transfer Coefficients—Table 3 and 4 Area Calculated from Architectural Plans Table 5—Cooling Load Temperature Difference at Base Conditions for Roofs Note 4—Correction for Color of Exterior Surface Note 2—Correction for Outside Dry Bulb Temperature and Daily Range Note 2—Correction for Inside Dry Bulb Temperature Note 1 & 5—Application for Latitude and Month
Walls	$q = U \times A \times \text{CLTD}$	Chapter 22—Design Heat Transmission Coefficients—Tables 3 and 4 Area Calculated from Architectural Plans Table 6—Wall Construction Group Description Table 7—Cooling Load Temperature Difference at Base Conditions for Wall Group Note 3—Correction for Color of Exterior Surface Note 2—Correction for Outside Dry Bulb Temperature and Daily Range Note 2—Correction for Inside Dry Bulb Temperature Note 1 & 4 Application for Latitude and Month
Glass Conduction	$q = U \times A \times \text{CLTD}$	Chapter 22 or Chapter 26-Type of Glass and Interior Shading if Used Area—Net Glass Area Calculated from Plans Table 9—Cooling Load Temperature Difference for Conduction Load Through Glass Note 1—Correction for Outside Dry Bulb Temperature and Daily Range Note 1—Correction for Inside Dry Bulb Temperature
Solar	$q = A \times \text{SC} \times \text{SHGF} \times \text{CLF}$	Area—Net Glass Area Calculated from Plans Chapter 26—Tables 28, 33, 34, 35, 36, 38, and 40 Shading Coefficients for Combination of Type of Glass and Type of Shading Table 10—Maximum Solar Heat Gain Factor for Specific Orientation of Surface, Latitude and Month Table 11—Cooling Load Factor with No Interior Shading Table 12—Cooling Load Factor if Interior Shading is Used
Partitions, Ceilings, Floors	$q = U \times A \times \text{TD}$	Chapter 22—Design Heat Transmission Coefficients—Tables 3 and 4 Area Calculated from Architectural Plans Section 5.0—Design Temperature Difference
Internal Lights	$q = \text{INPUT} \times \text{CLF}$	Input Rating from Electrical Plans or Lighting Fixture Data Tables 13 & 14—Coefficients "a" and classification "b" for Type of Fixture, Installation, Air Supply and Return and Room Furnishings and Construction Table 15—Cooling Load Factor Based on Total Hours of Operation and Time Note 1—Correction for Schedule of Operation of Cooling System
People Sensible	$q_s = \text{No} \times \text{Sens. H.G.} \times \text{CLF}$	Number of People in Space Table 16 or Chapter 8—Sensible Heat Gain from Occupants Table 17—Cooling Load Factor for People—Based on Duration of Occupancy and Time from Entry Note 1—Correction for Density of Occupants
Latent	$q_l = \text{No} \times \text{Lat. H.G.}$	Table 16 or Chapter 8—Latent Heat Gain from Occupants

COOLING LOAD CALCULATION PROCEDURE continued

Appliances		
Sensible	$q_s = \overline{\text{HEAT GAIN}} \times \text{CLF}$	Tables 18 & 19—Recommended Rate of Heat Gain-Sensible Heat Table 20—For Use with Hood Table 21—For Use without Hood
Latent	$q_l = \overline{\text{HEAT GAIN}}$	Tables 18 & 19—Recommended Rate of Heat Gain—Latent Heat (Without Hood) Set Equal to Zero When Hood is Used Over Appliances
Power	$q = \overline{\text{HEAT GAIN}} \times \text{CLF}$	Eq 21, 22, or 23 using Tables 22 and 23 or Manufacturer's Data Table 21
Ventilation & Infiltration Air		Ventilation and Infiltration Air, Standard CFM Inside-Outside Air Temperature Difference, deg F
Sensible	$q_s = 1.10 \times \text{CFM} \times \Delta t$	
Latent	$q_l = 4840 \times \text{CFM} \times \Delta W$	Inside-Outside Air Humidity Ratio Difference, lb H_2O/lb Dry Air
Total	$q = 4.5 \times \text{CFM} \times \Delta h$	Inside-Outside Air Enthalpy Difference, Btu/lb of Dry Air
Adjustment Factor		Fraction of Input Energy Lost to the Surroundings; Applied to all External and Internal Loads Except Ventilation and Infiltration Air.
	$F_c = 1\text{-}0.02\,K_t$	Eq 31

DESIGN WEATHER DATA[3]

TABLE 1 CLIMATIC CONDITIONS FOR THE UNITED STATES[a]

						Winter[d]		Summer[e]						
Col. 1	Col. 2		Col. 3		Col. 4	Col. 5		Col. 6			Col. 7	Col. 8		
State and Station	Latitude[b]		Longitude[b]		Elevation[c]	Design Dry-Bulb		Design Dry-Bulb and Mean Coincident Wet-Bulb			Mean Daily Range	Design Wet-Bulb		
	°	'	°	'	Ft	99%	97.5%	1%	2.5%	5%		1%	2.5%	5%
FLORIDA														
Belle Glade	26	4	80	4	16	41	44	92/76	91/76	89/76	16	79	78	78
Cape Kennedy AP	28	3	80	3	16	35	38	90/78	88/78	87/78	15	80	79	79
Daytona Beach AP	29	1	81	0	31	32	35	92/78	90/77	88/77	15	80	79	78
Fort Lauderdale	26	0	80	1	13	42	46	92/78	91/78	90/78	15	80	79	79
Fort Myers AP	26	4	81	5	13	41	44	93/78	92/78	91/77	18	80	79	79
Fort Pierce	27	3	80	2	10	38	42	91/78	90/78	89/78	15	80	79	79
Gainesville AP (S)	29	4	82	2	155	28	31	95/77	93/77	92/77	18	80	79	78
Jacksonville AP	30	3	81	4	24	29	32	96/77	94/77	92/76	19	79	79	78
Key West AP	24	3	81	5	6	55	57	90/78	90/78	89/78	9	80	79	79
Lakeland CO (S)	28	0	82	0	214	39	41	93/76	91/76	89/76	17	79	78	78
Miami AP (S)	25	5	80	2	7	44	47	91/77	90/77	89/77	15	79	79	78
Miami Beach CO	25	5	80	1	9	45	48	90/77	89/77	88/77	10	79	79	78
Ocala	29	1	82	1	86	31	34	95/77	93/77	92/76	18	80	79	78
Orlando AP	28	3	81	2	106r	35	38	94/76	93/76	91/76	17	79	78	78
Panama City, Tyndall AFB	30	0	85	4	22	29	33	92/78	90/77	89/77	14	81	80	79
Pensacola CO	30	3	87	1	13	25	29	94/77	93/77	91/77	14	80	79	79
St. Augustine	29	5	81	2	15	31	35	92/78	89/78	87/78	16	80	79	79
St. Petersburg	28	0	82	4	35	36	40	92/77	91/77	90/76	16	79	79	78
Sanford	28	5	81	2	14	35	38	94/76	93/76	91/76	17	79	78	78
Sarasota	27	2	82	3	30	39	42	93/77	92/77	90/76	17	79	79	78
Tallahassee AP (S)	30	2	84	2	58	27	30	94/77	92/76	90/76	19	79	78	78
Tampa AP (S)	28	0	82	3	19	36	40	92/77	91/77	90/76	17	79	79	78
West Palm Beach AP	26	4	80	1	15	41	45	92/78	91/78	90/78	16	80	79	79

---

2. ASHRAE, ASHRAE HANDBOOK 1977 FUNDAMENTALS, New York, 1978, p. 25.3.
3. op. cit., p. 23.5.

RESULTS OF COOLING LOAD CALCULATION (15,625 SF AREA):

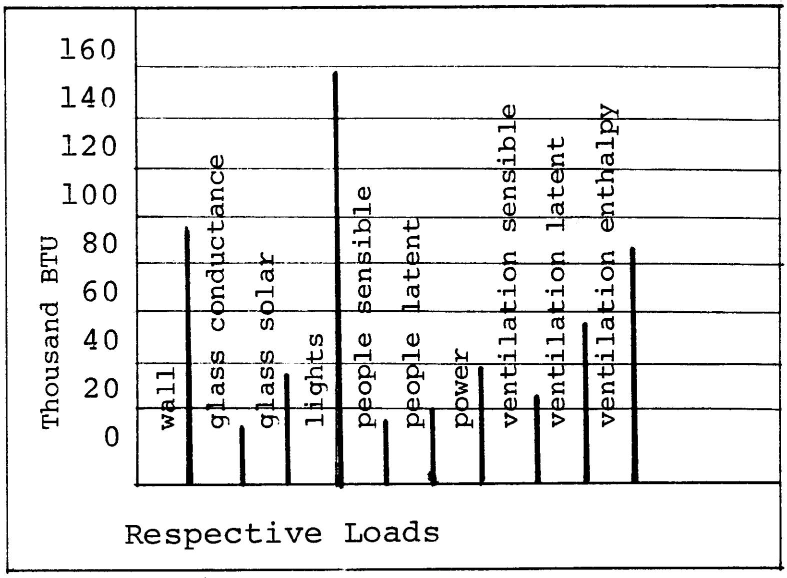


Figure 6.

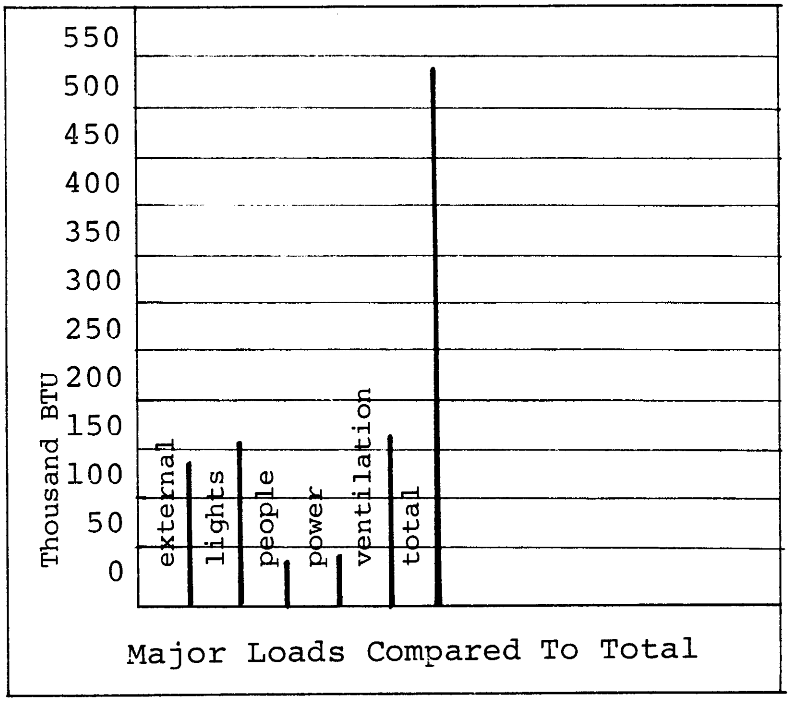


Figure 7.

Figures 6 and 7 clearly illustrate the significance of the lighting load which was calculated on a low assumed wattage of 2.5 watts per square foot of floor area. Lighting consumes nearly thirty percent of the energy budget, an asonishing fact when one considers that the cooling load calculation is based on data for three o'clock in the afternoon in August. A strategy for daylighting the tower would seem appropriate then, especially since most of the other loads are fixed.

In the following pages a method will be outlined for daylighting One Tampa City Center. The cooling load for this tower will then be calculated and compared with the Welton Becket tower.

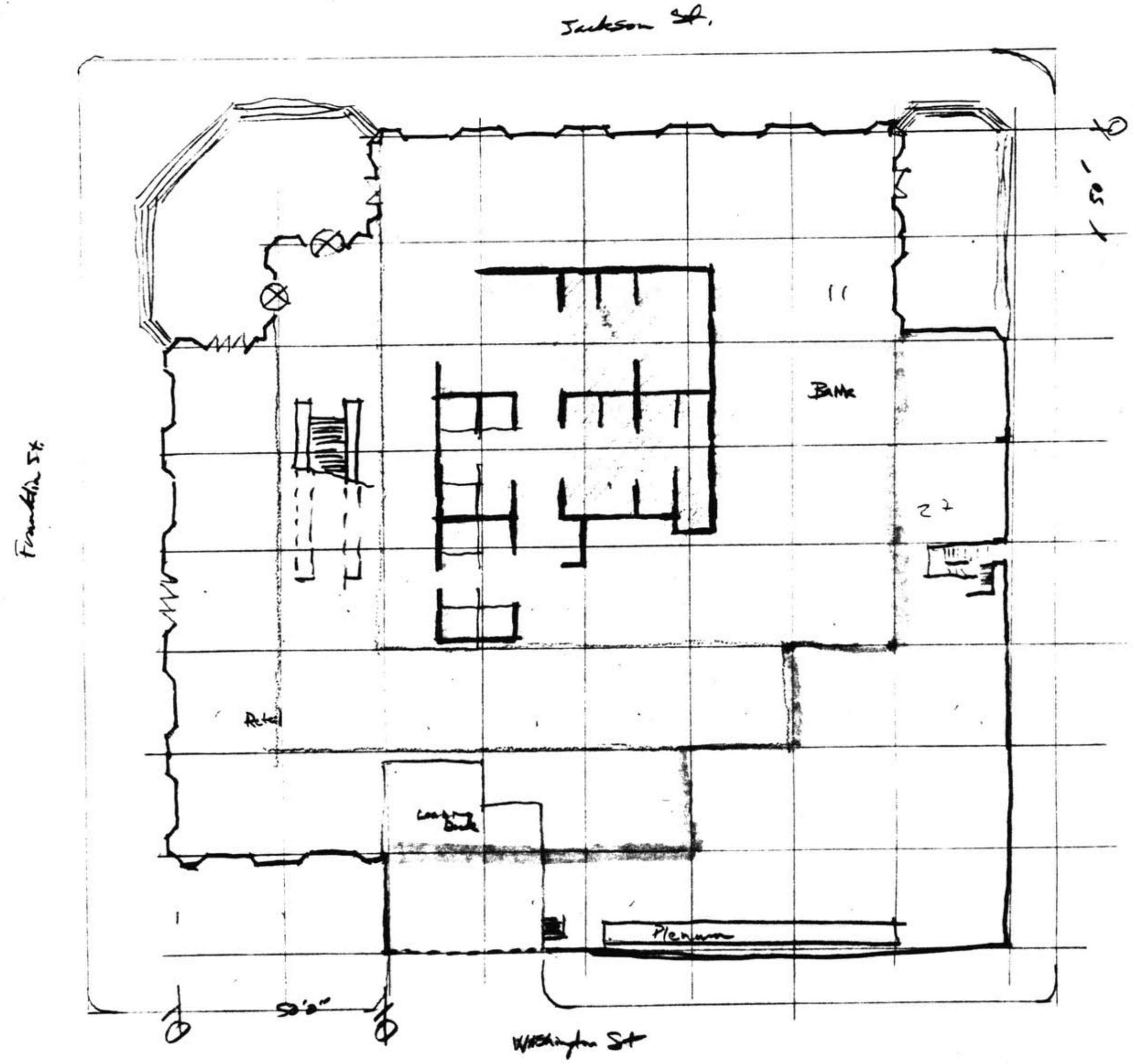


Figure 8.

Tracing of Welton Becket Ground Plan

SOLAR DATA

Chapter Four

A TI-59 program is used to generate solar altitude and azimuth data. The program provides more accurate information than the Mazria sun charts[4] which are given for four degree increments of latitude and do not compensate for longtitude.

To run the program record the listed program onto magnetic cards, partition calculator to five, and:

1. Enter longtitude, press A, longtitude will be printed
2. Enter latitude, press B, latitude will be printed
3. Enter time meridian, press C, time meridian printed
4. Press E to execute program (run time about 45 minutes)

Note:

To enter degrees and seconds use decimal format, e.g., 22^{0} 35', enter as 22.35.

The program will print the altitude and azimuth for your location for every hour the sun is above the horizon for the 21st day of every month. The data is then transferred to a revised ver-

---

[4] Edward Mazria, THE PASSIVE SOLAR ENERGY BOOK, Emmaus, Pa., 1979, pp 279-287.

sion of Mazria's sun chart.

The site plan tracing is given below for One Tampa Center. The street grid is approximately 22° west of true north.

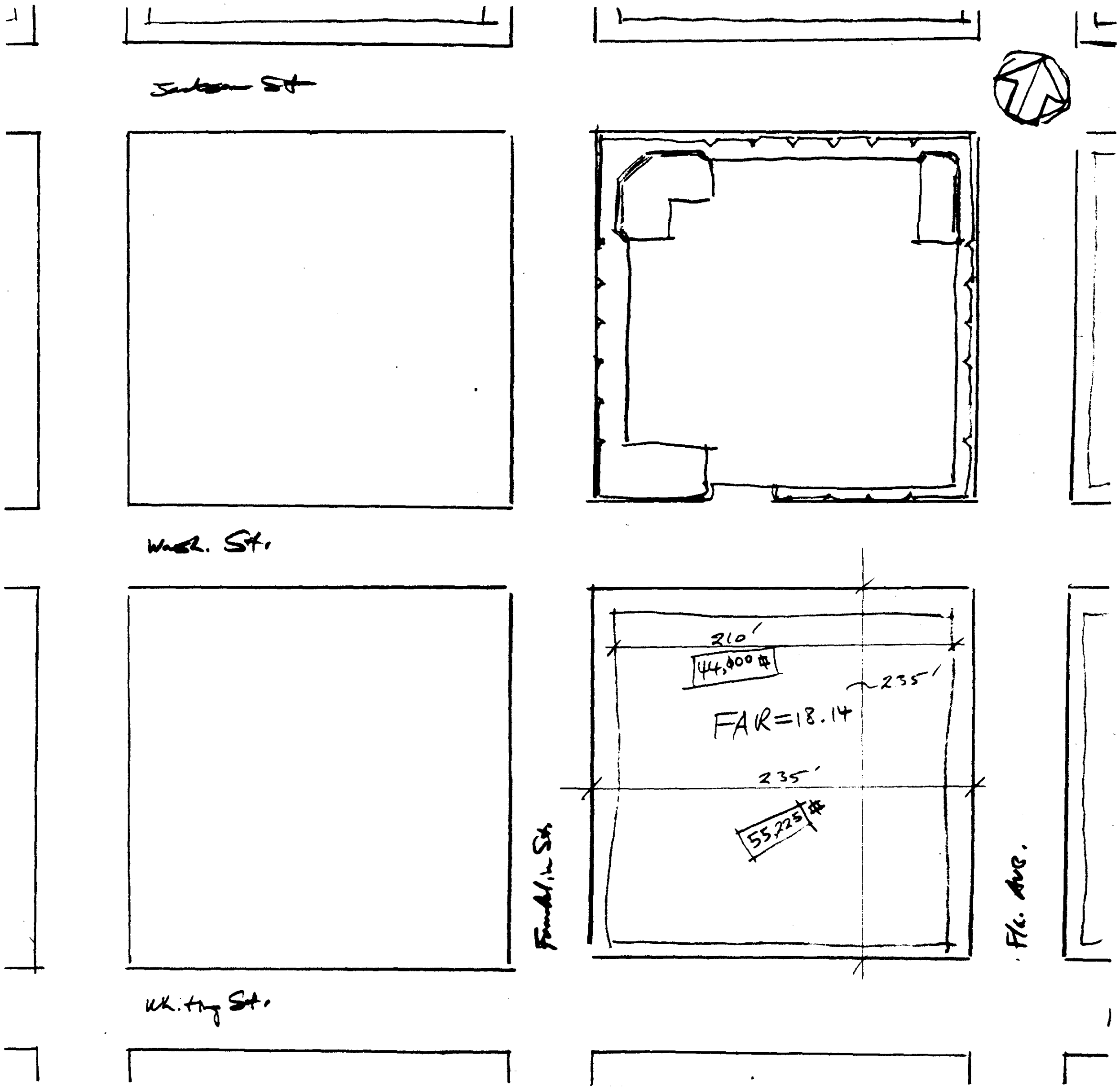


Figure 9.
Tracing of Site Plan

PROGRAM LISTING:

```
000  76 LBL
001  11  A
002  42 STO
003  06  06
004  02  2
005  07  7
006  03  3
007  02  2
008  03  3
009  01  1
010  02  2
011  02  2
012  03  3
013  07  7
014  42 STO
015  35  35
016  02  2
017  04  4
018  03  3
019  07  7
020  04  4
021  01  1
022  01  1
023  06  6
024  01  1
025  07  7
026  42 STO
027  36  36
028  43 RCL
029  35  35
030  69 OP
031  02  02
032  43 RCL
033  36  36
034  69 OP
035  03  03
036  69 OP
037  05  05
038  43 RCL
039  06  06
040  99 PRT
041  88 DMS
```

```
042  42 STO
043  06  06
044  91 R/S
045  76 LBL
046  12  B
047  42 STO
048  07  07
049  02  2
050  07  7
051  01  1
052  03  3
053  03  3
054  07  7
055  02  2
056  04  4
057  03  3
058  07  7
059  42 STO
060  35  35
061  04  4
062  01  1
063  01  1
064  06  6
065  01  1
066  07  7
067  00  0
068  00  0
069  00  0
070  00  0
071  42 STO
072  36  36
073  43 RCL
074  35  35
075  69 OP
076  02  02
077  43 RCL
078  36  36
079  69 OP
080  03  03
081  69 OP
082  05  05
083  43 RCL
```

```
084  07  07
085  99 PRT
086  88 DMS
087  42 STO
088  07  07
089  91 R/S
090  76 LBL
091  13  C
092  42 STO
093  08  08
094  03  3
095  00  0
096  01  1
097  07  7
098  03  3
099  05  5
100  02  2
101  04  4
102  01  1
103  06  6
104  42 STO
105  35  35
106  02  2
107  04  4
108  01  1
109  03  3
110  03  3
111  01  1
112  00  0
113  00  0
114  00  0
115  00  0
116  42 STO
117  36  36
118  43 RCL
119  35  35
120  69 OP
121  02  02
122  43 RCL
123  36  36
124  69 OP
125  03  03
126  69 OP
```

```
127  05  05
128  43 RCL
129  08  08
130  99 PRT
131  88 DMS
132  42 STO
133  08  08
134  98 ADV
135  98 ADV
136  91 R/S
137  76 LBL
138  15  E
139  01  1
140  03  3
141  42 STO
142  01  01
143  00  0
144  42 STO
145  05  05
146  09  9
147  42 STO
148  02  02
149  02  2
150  01  1
151  42 STO
152  03  03
153  76 LBL
154  45 YX
155  69 OP
156  25  25
157  69 OP
158  31  31
159  01  1
160  32 X:T
161  43 RCL
162  01  01
163  77  GE
164  23 LNX
165  91 R/S
166  76 LBL
167  23 LNX
168  01  1
169  05  5
```

PROGRAM LISTING continued:

```
170  42  STO
171  00   00
172  06   6
173  42  STO
174  04   04
175  76  LBL
176  34  √X
177  43  RCL
178  05   05
179  99  PRT
180  69  OP
181  00   00
182  43  RCL
183  47   47
184  69  OP
185  02   02
186  69  OP
187  05   05
188  98  ADV
189  76  LBL
190  43  RCL
191  69  OP
192  22   22
193  69  OP
194  23   23
195  73  RC*
196  02   02
197  42  STO
198  43   43
199  73  RC*
200  03   03
201  42  STO
202  44   44
203  76  LBL
204  44  SUM
205  43  RCL
206  06   06
207  75   -
208  43  RCL
209  08   08
210  95   =
211  94  +/-
212  65   ×
```

```
213  04    4
214  95    =
215  55    ÷
216  06    6
217  00    0
218  95    =
219  85    +
220  43  RCL
221  04   04
222  85    +
223  43  RCL
224  44   44
225  95    =
226  42  STO
227  09   09
228  01    1
229  02    2
230  88  DMS
231  22  INV
232  44  SUM
233  09   09
234  76  LBL
235  52  EE
236  00    0
237  32  X:T
238  43  RCL
239  09   09
240  77   GE
241  30  TAN
242  86  STF
243  03   03
244  76  LBL
245  30  TAN
246  68  NOP
247  43  RCL
248  09   09
249  65    ×
250  06    6
251  00    0
252  65    ×
253  93    .
254  02    2
255  05    5
```

```
256  95    =
257  50  I×I
258  42  STO
259  09   09
260  43  RCL
261  07   07
262  39  COS
263  65    ×
264  43  RCL
265  43   43
266  39  COS
267  65    ×
268  43  RCL
269  09   09
270  39  COS
271  85    +
272  43  RCL
273  07   07
274  38  SIN
275  65    ×
276  43  RCL
277  43   43
278  38  SIN
279  95    =
280  22  INV
281  38  SIN
282  95    =
283  42  STO
284  40   40
285  76  LBL
286  42  STO
287  00    0
288  32  X:T
289  43  RCL
290  40   40
291  77   GE
292  61  GTO
293  69  OP
294  30   30
295  69  OP
296  24   24
297  22  INV
298  86  STF
```

```
299  03   03
300  68  NOP
301  01    1
302  32  X:T
303  43  RCL
304  00   00
305  77   GE
306  44  SUM
307  45  Y×
308  76  LBL
309  61  GTO
310  43  RCL
311  43   43
312  39  COS
313  65    ×
314  43  RCL
315  09   09
316  38  SIN
317  55    ÷
318  43  RCL
319  40   40
320  39  COS
321  95    =
322  22  INV
323  38  SIN
324  95    =
325  42  STO
326  41   41
327  87  IFF
328  03   03
329  32  X:T
330  76  LBL
331  39  COS
332  69  OP
333  00   00
334  43  RCL
335  48   48
336  69  OP
337  04   04
338  43  RCL
339  04   04
340  69  OP
341  06   06
```

PROGRAM LISTING continued:

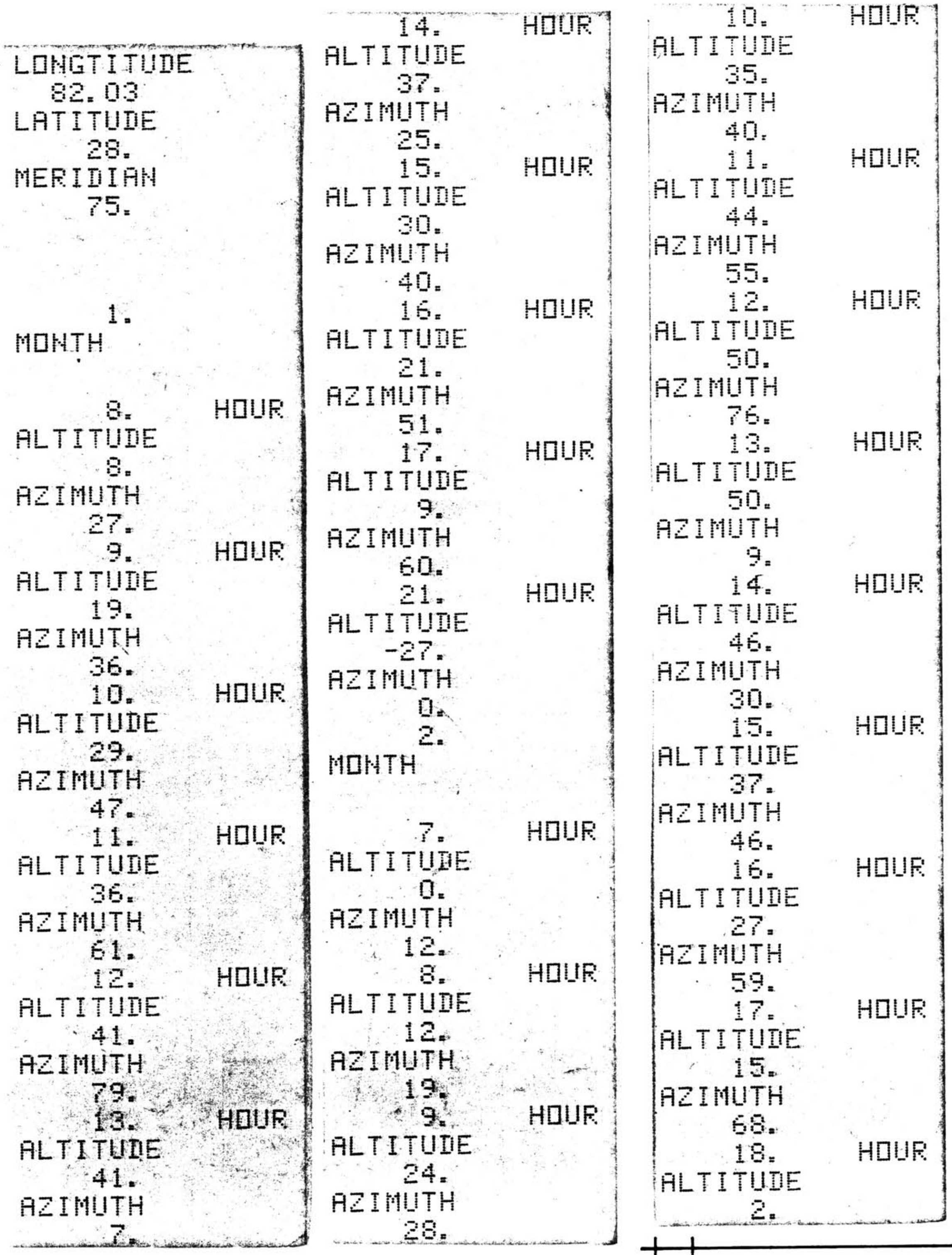
```
385  09    9
386  00    0
387  95    =
388  42  STO
389  41   41
390  22  INV
391  86  STF
392  03   03
393  61  GTO
394  39  COS
395  07    7
396  02    2
397  04    4
398  03    3
399  07    7
400  42  STO
401  37   37
402  04    4
403  01    1
404  01    1
405  06    6
406  01    1
407  07    7
408  00    0
409  00    0
410  00    0
411  00    0
412  42  STO
413  38   38
414  01    1
415  03    3
416  04    4
417  06    6
418  02    2
419  04    4
420  03    3
421  00    0
422  04    4
423  01    1
424  42  STO
425  39   39
426  03    3
427  07    7
```

```
428  02    2
429  03    3
430  00    0
431  00    0
432  00    0
433  00    0
434  00    0
435  00    0
436  42  STO
437  49   49
438  02    2
439  00    0
440  94  +/-
441  42  STO
442  10   10
443  01    1
444  00    0
445  93    .
446  08    8
447  94  +/-
448  42  STO
449  11   11
450  00    0
451  42  STO
452  12   12
453  01    1
454  01    1
455  93    .
456  06    6
457  42  STO
458  13   13
459  02    2
460  00    0
461  42  STO
462  14   14
463  02    2
464  03    3
465  93    .
466  01    1
467  05    5
468  42  STO
469  15   15
470  02    2
```

```
342  69  OP
343  00   00
344  43  RCL
345  37   37
346  69  OP
347  02   02
348  43  RCL
349  38   38
350  69  OP
351  03   03
352  43  RCL
353  40   40
354  69  OP
355  05   05
356  99  PRT
357  69  OP
358  00   00
359  43  RCL
360  39   39
361  69  OP
362  02   02
363  43  RCL
364  49   49
365  69  OP
366  03   03
367  43  RCL
368  41   41
369  69  OP
370  05   05
371  99  PRT
372  69  OP
373  24   24
374  97  DSZ
375  00   00
376  44  SUM
377  61  GTO
378  45  Yx
379  76  LBL
380  32  X:T
381  43  RCL
382  41   41
383  94  +/-
384  85    +
```

```
471  00    0
472  93    .
473  06    6
474  42  STO
475  16   16
476  01    1
477  02    2
478  93    .
479  03    3
```

SAMPLE OUTPUT:



```
LONGTITUDE
  82.03
LATITUDE
    28.
MERIDIAN
    75.



     1.
MONTH


     8.     HOUR
ALTITUDE
     8.
AZIMUTH
    27.
     9.     HOUR
ALTITUDE
    19.
AZIMUTH
    36.
    10.     HOUR
ALTITUDE
    29.
AZIMUTH
    47.
    11.     HOUR
ALTITUDE
    36.
AZIMUTH
    61.
    12.     HOUR
ALTITUDE
    41.
AZIMUTH
    79.
    13.     HOUR
ALTITUDE
    41.
AZIMUTH
     7.
```

```
    14.     HOUR
ALTITUDE
    37.
AZIMUTH
    25.
    15.     HOUR
ALTITUDE
    30.
AZIMUTH
    40.
    16.     HOUR
ALTITUDE
    21.
AZIMUTH
    51.
    17.     HOUR
ALTITUDE
     9.
AZIMUTH
    60.
    21.     HOUR
ALTITUDE
   -27.
AZIMUTH
     0.
     2.
MONTH

     7.     HOUR
ALTITUDE
     0.
AZIMUTH
    12.
     8.     HOUR
ALTITUDE
    12.
AZIMUTH
    19.
     9.     HOUR
ALTITUDE
    24.
AZIMUTH
    28.
```

```
    10.     HOUR
ALTITUDE
    35.
AZIMUTH
    40.
    11.     HOUR
ALTITUDE
    44.
AZIMUTH
    55.
    12.     HOUR
ALTITUDE
    50.
AZIMUTH
    76.
    13.     HOUR
ALTITUDE
    50.
AZIMUTH
     9.
    14.     HOUR
ALTITUDE
    46.
AZIMUTH
    30.
    15.     HOUR
ALTITUDE
    37.
AZIMUTH
    46.
    16.     HOUR
ALTITUDE
    27.
AZIMUTH
    59.
    17.     HOUR
ALTITUDE
    15.
AZIMUTH
    68.
    18.     HOUR
ALTITUDE
     2.
```

SUN PATH CHART:

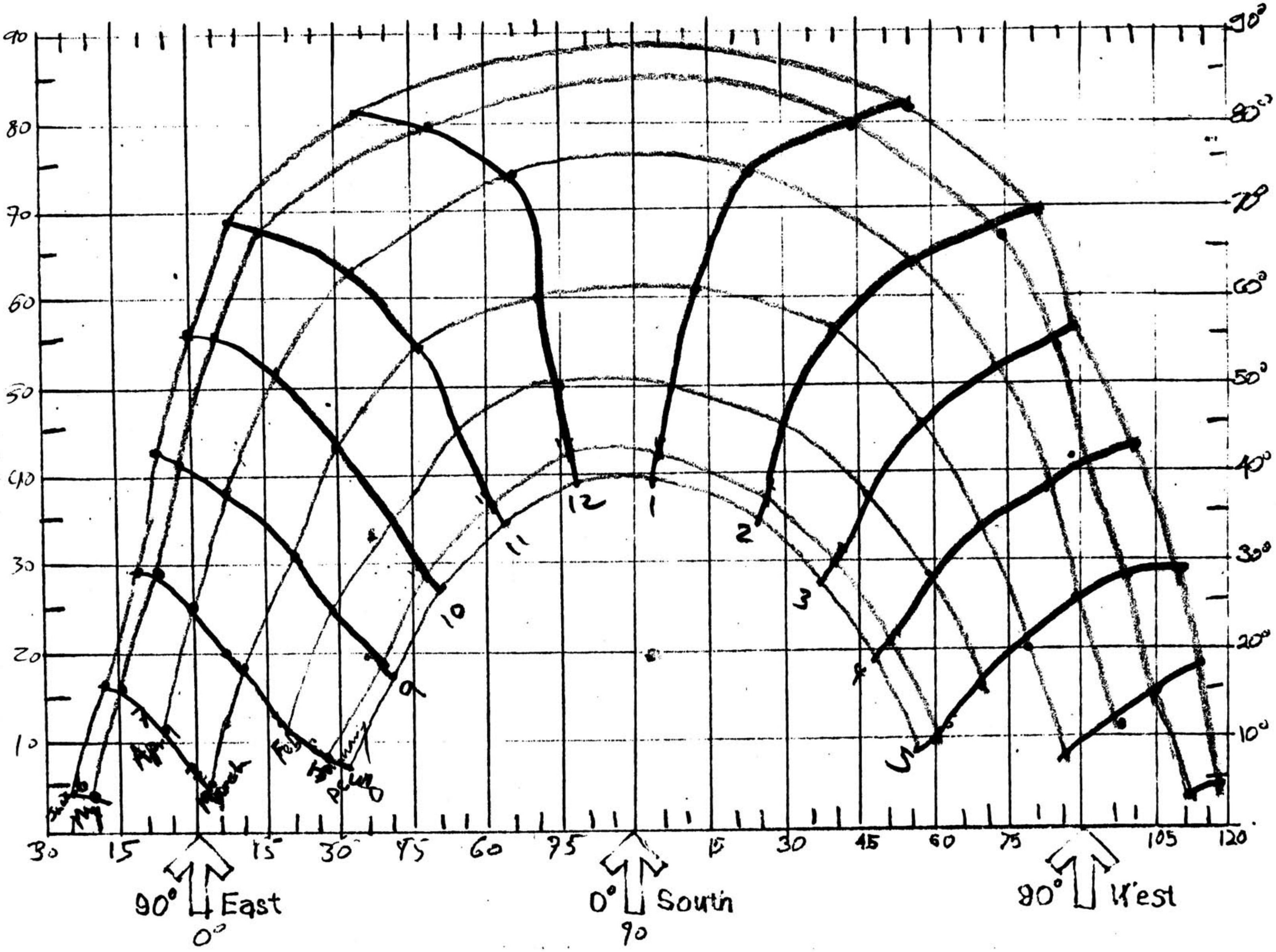


Figure 10.

SHADING BY BUILDING MASS

Chapter Five

One of the simplest methods of maximizing daylight penetration into a building is to let the building self-shade itself. By so doing one lets in diffuse light but rejects direct sun light. The latter is not at all allowed in a large commercial building in a hot-humid climate because of the huge thermal gain resulting.

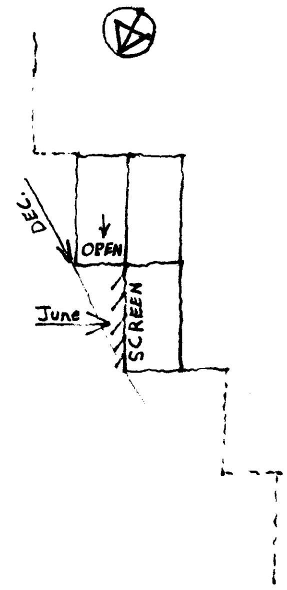
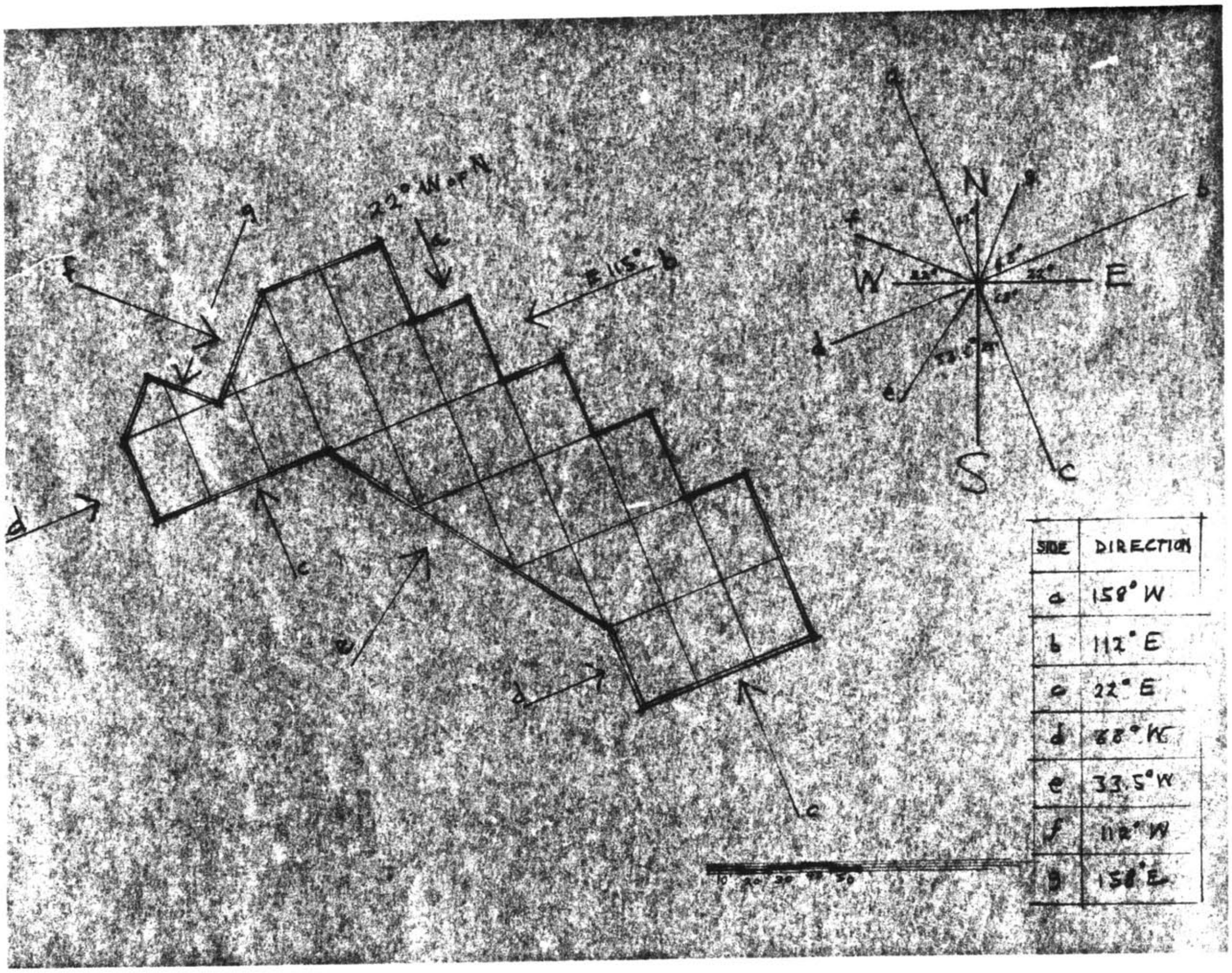


Figure 11.

Initially a thirty foot bay was chosen and the width derived trigonometrically from the lowest morning sun azimuth in winter (December 22) and the greatest (June 22). The result was a twenty-one by thirty foot bay. Because of the orientation of the street grid, the June sun strikes the building perpendicularly at dawn. The direct sun light is screened out of the thirty foot side while the twenty foot dimension never receives direct sun light all year.

This arrangement created a crenelated plan on the north-east and north-west sides. A correspondence also resulted between the street grid and the bay arrangement because the street orientation coincided with the June azimuth. The depth was kept beneath sixty feet since daylight will not be effective much more than two and one-half times the window height. Figure 12 shows the initial wall orientations.



SIDE	DIRECTION
a	158° W
b	112° E
c	22° E
d	68° W
e	33.5° W
f	112° W
g	158° E

Figure 12.

Although the plan is rather irregular it is not without precedent. Figures 13 and 14 are 60 State Street designed by SOM and the Winthrop Building in Boston.

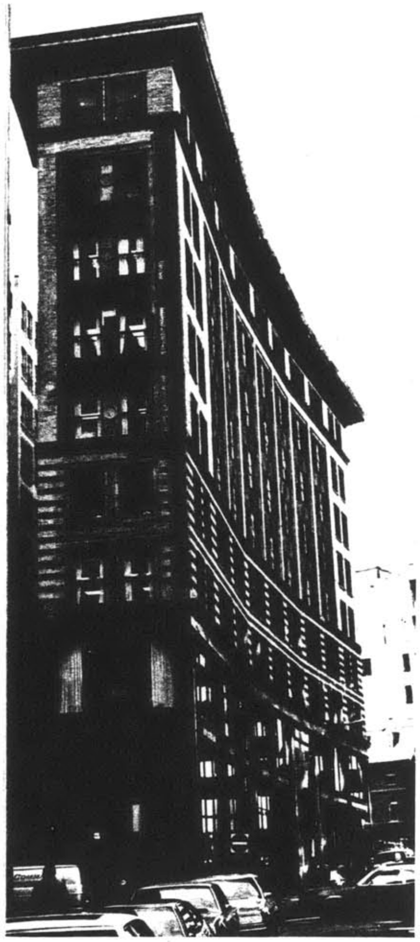


Figure 14.

Figure 13.

Letting the building follow the sun and respond to it produces understandable architecture and avoids the senseless "left-over" spaces illustrated in figures 15-17.

Figure 15.

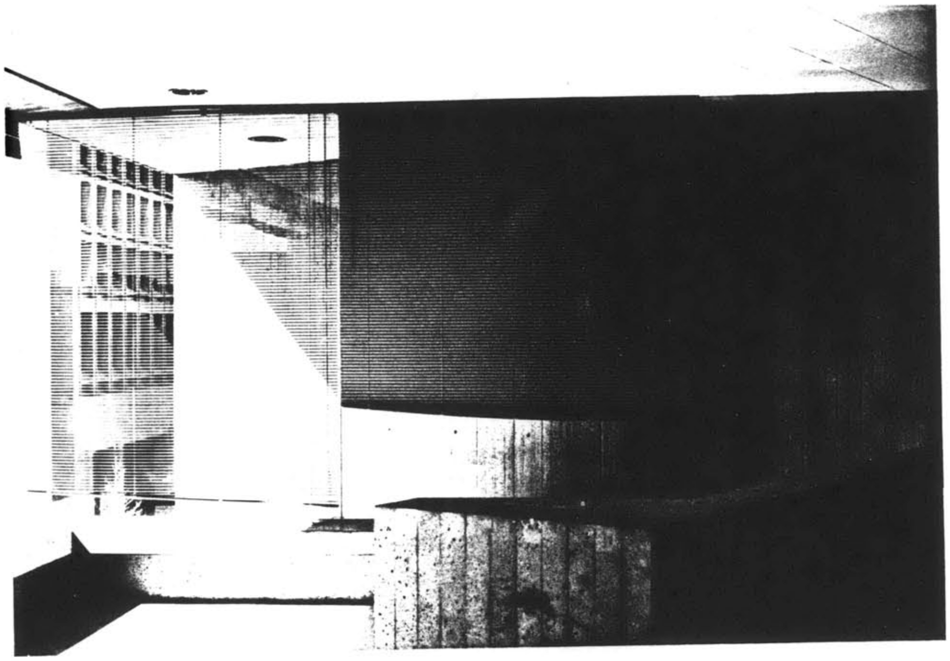


Figure 16.

Figure 17.

An interesting play between sunlight and the night lights can also result as seen with the John Hancock tower.

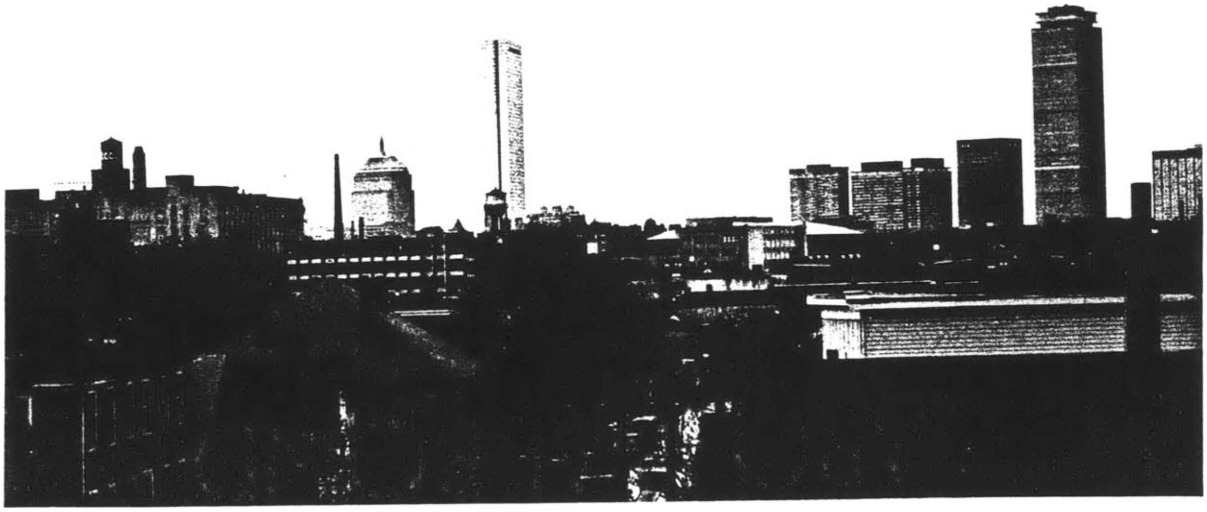


Figure 18.

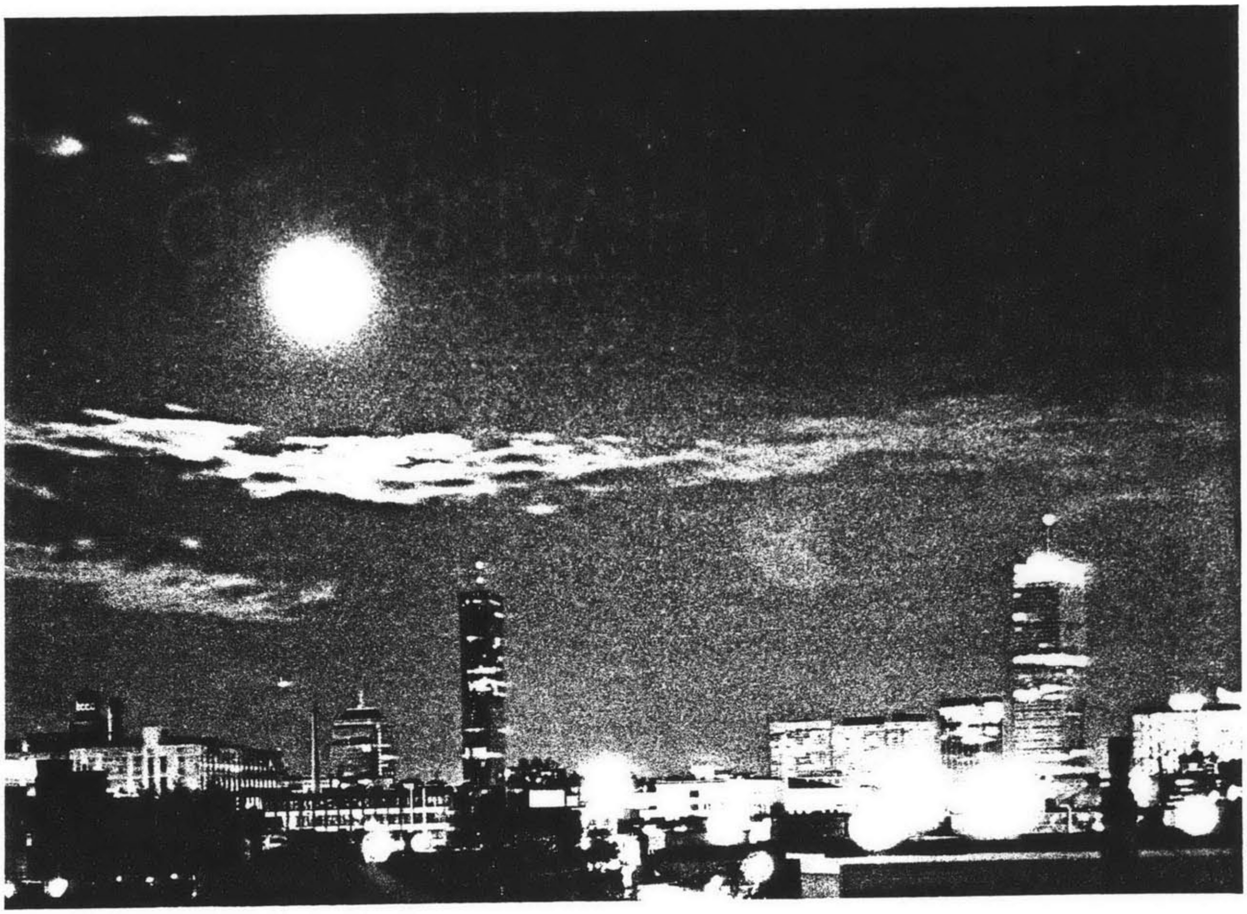


Figure 19.

SHADING WITH EXTERIOR SCREENS

Chapter VI

Walls which cannot be shaded by adjacent walls require the use of exterior screens. One can use Mazria's shading mask[5] and the previously generated sun chart to determine the proper angles for one-hundred percent shading. I found it often easier to do it graphically once the range was determined. Figures 20-24 illustrate some examples of possible screens.

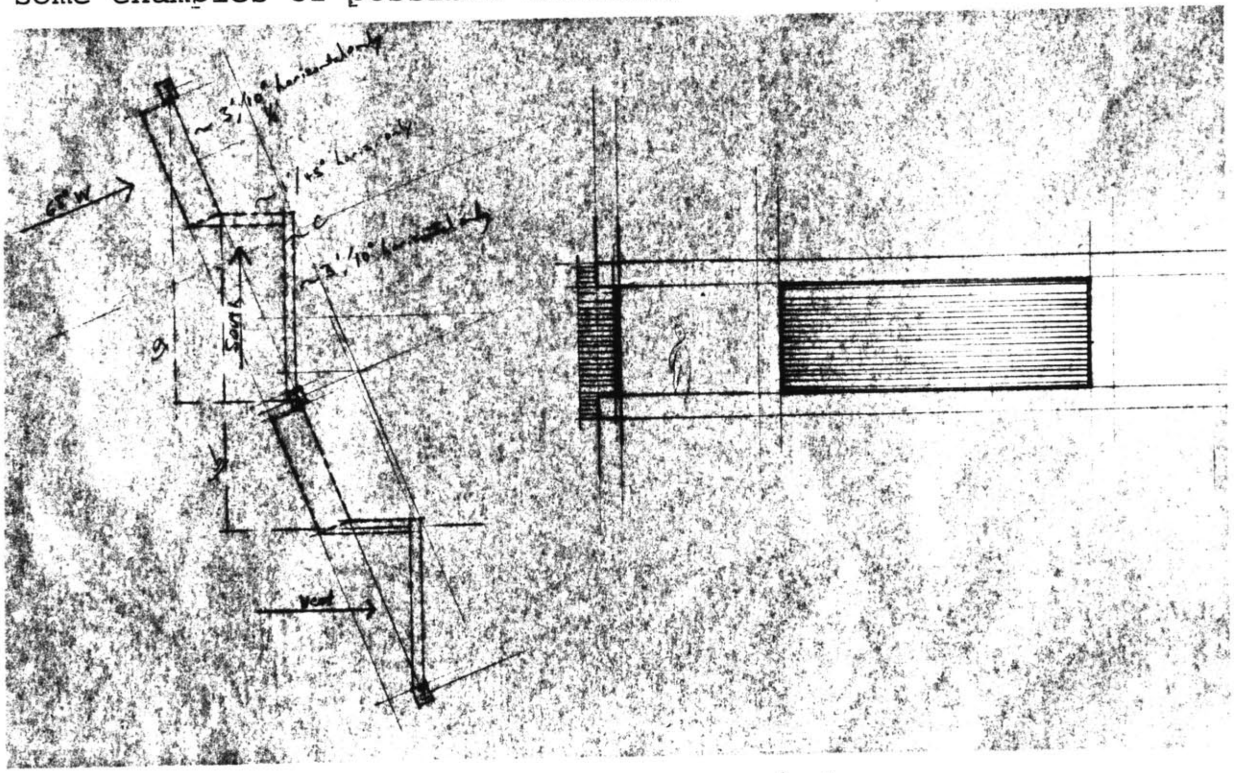
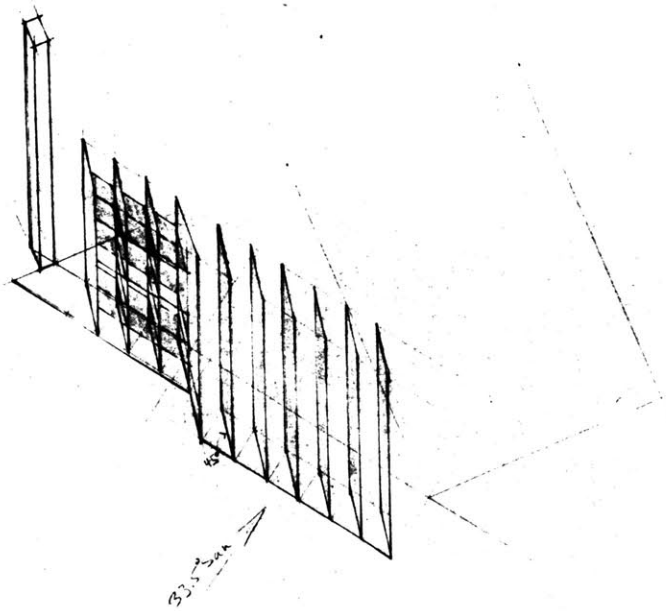
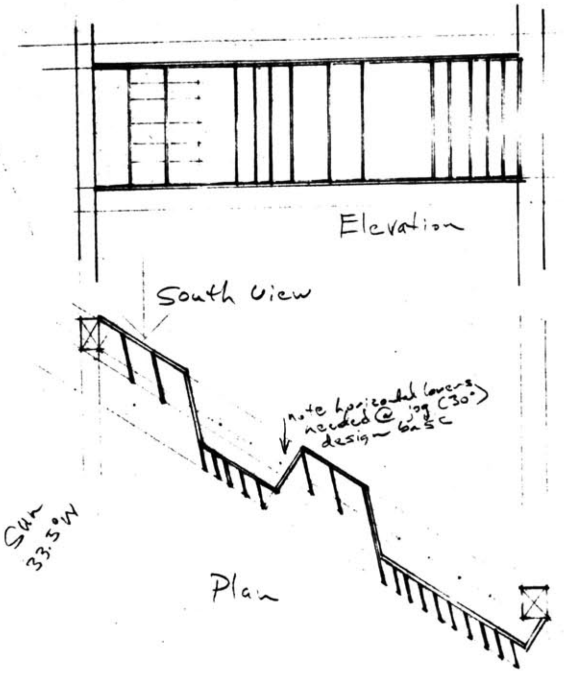


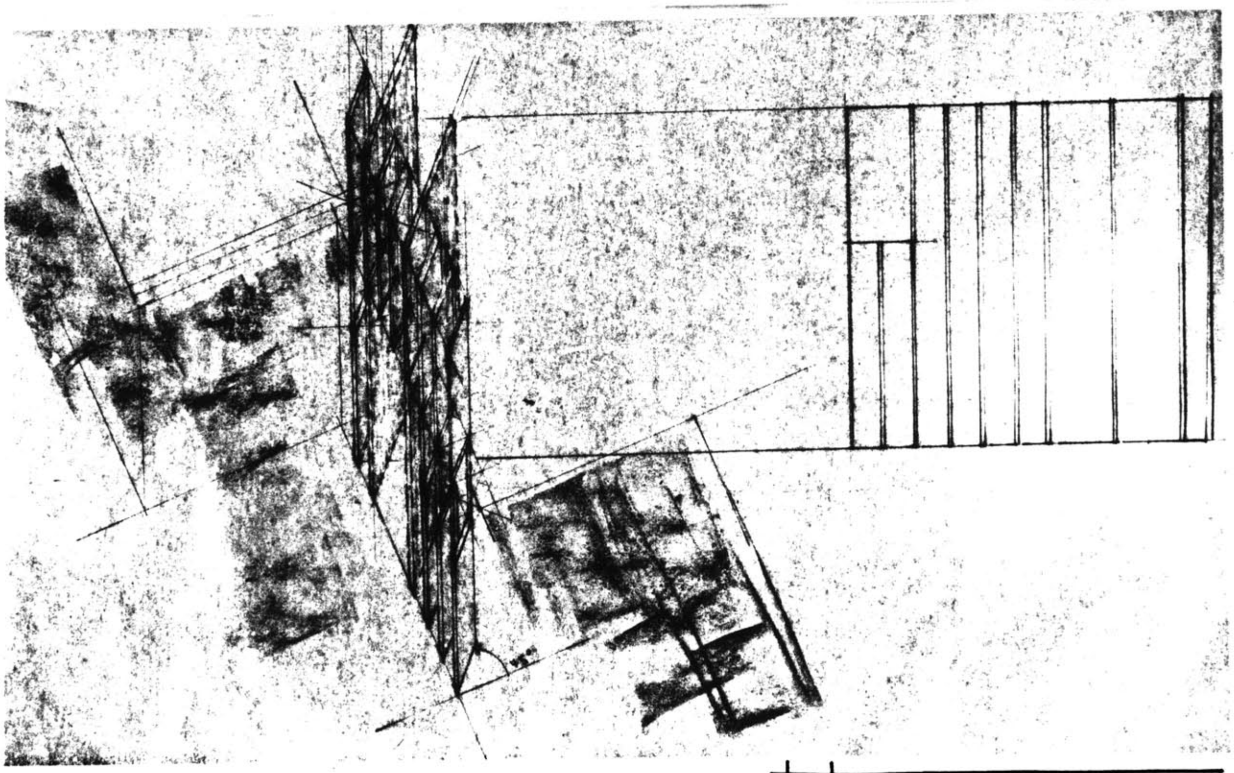
Figure 20.

---

[5] op. cit., p. 307.







Figures 21 and 22.

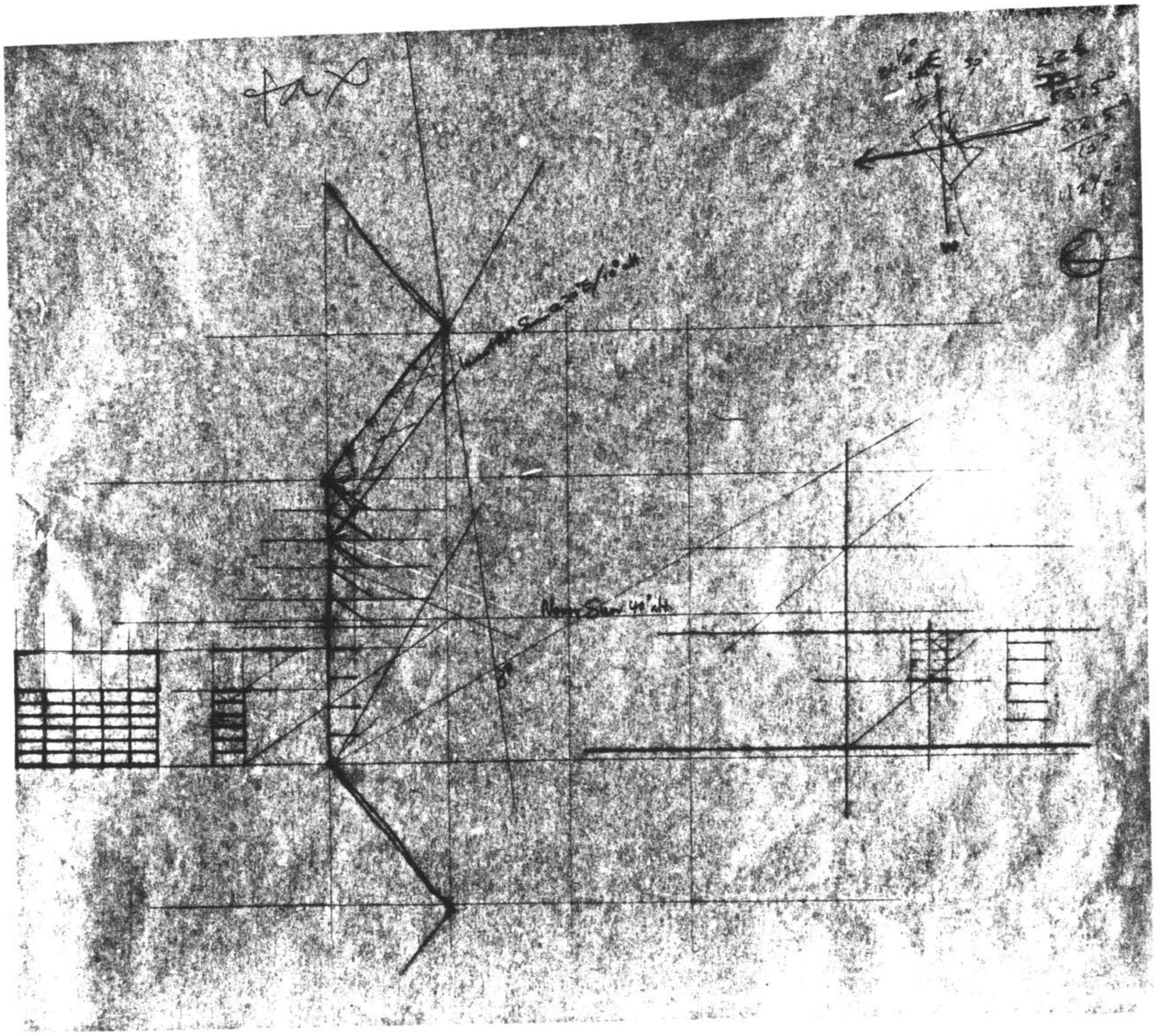


Figure 23.

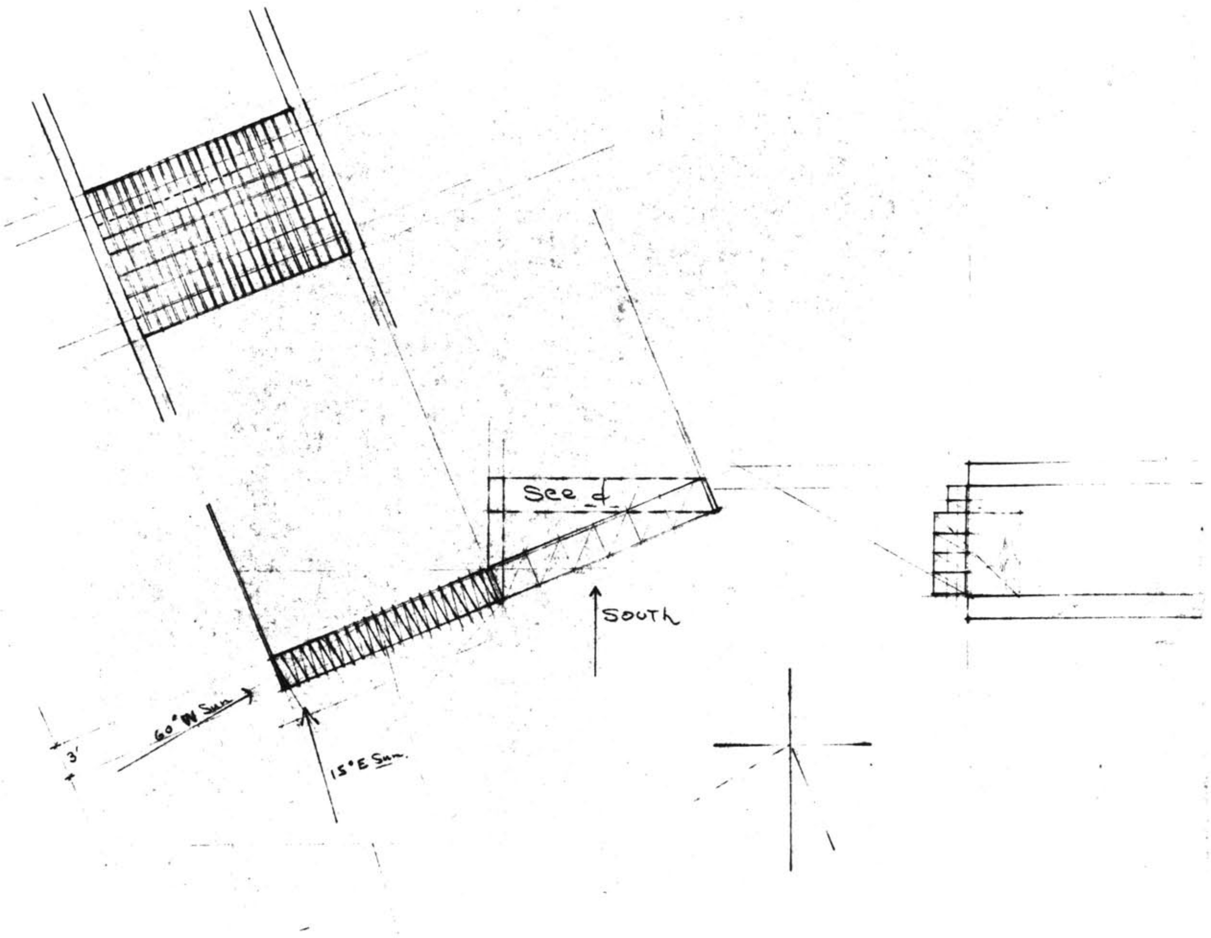


Figure 24.

Figures 25 through 27 show examples of solar screening devices employed in the work of José Luis Sert, one of the masters of these devices. It is interesting to note that the screens used on Peabody Terrace actually become habitable porches while the ones used on the Harvard Science Center and Holy oke Center scale down very massive buildings.

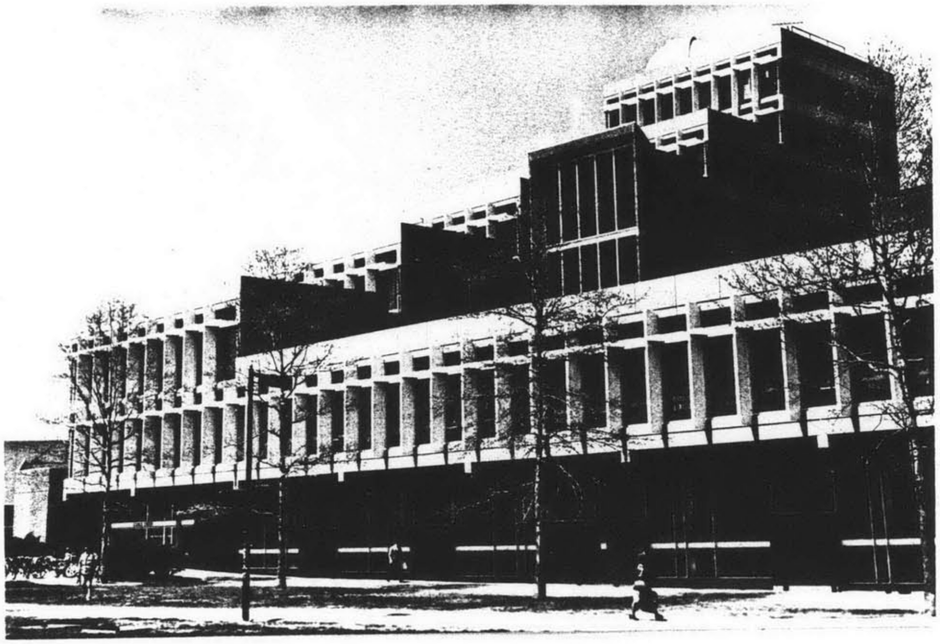


Figure 25.

Figure 26.

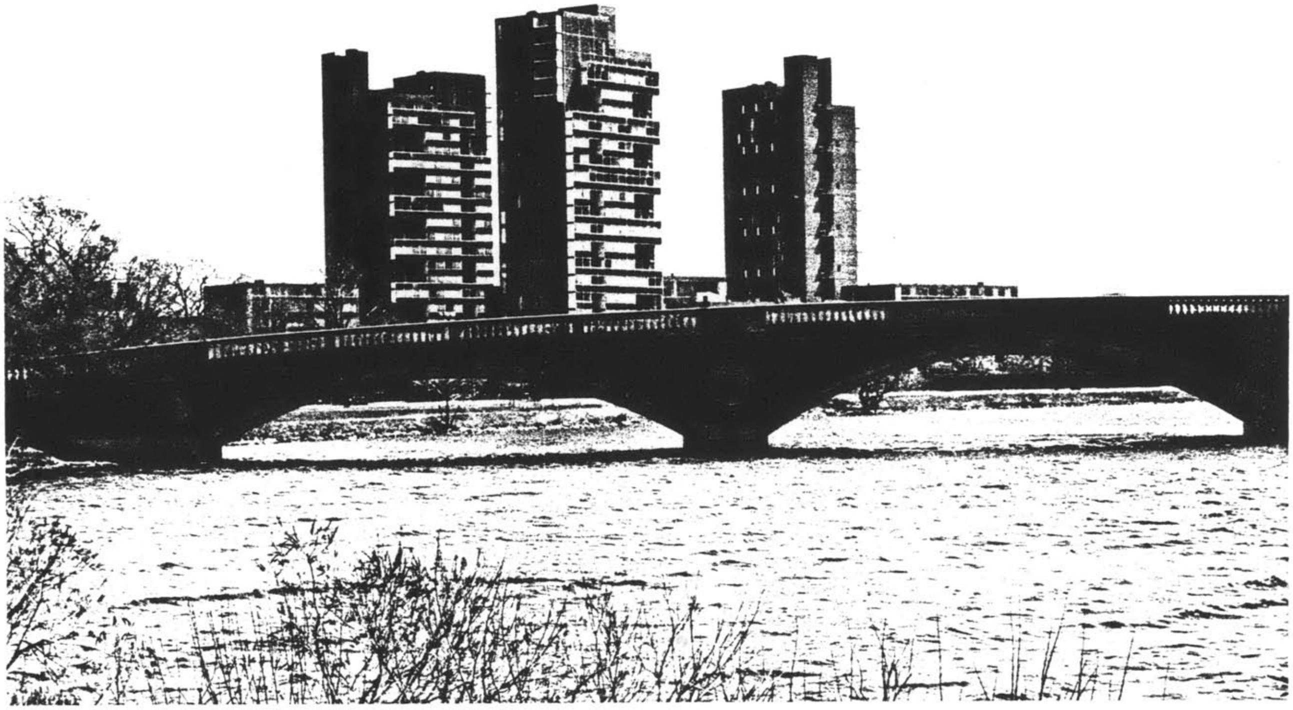


Figure 27.

One finds them much more appealing than the rifle slots used to screen the MIT Student Center Library. A rather perverse solution...

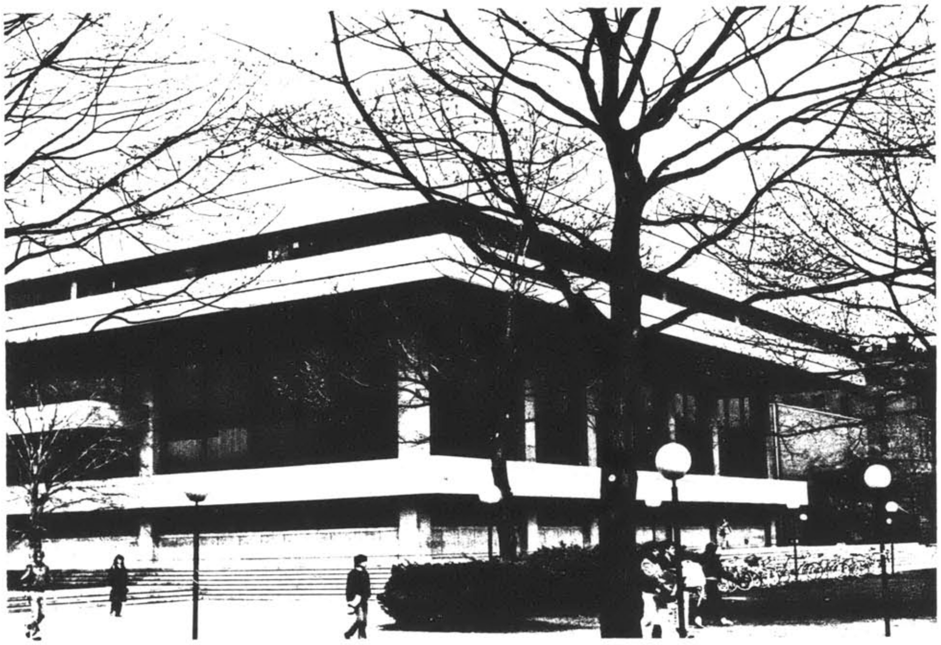


Figure 28.

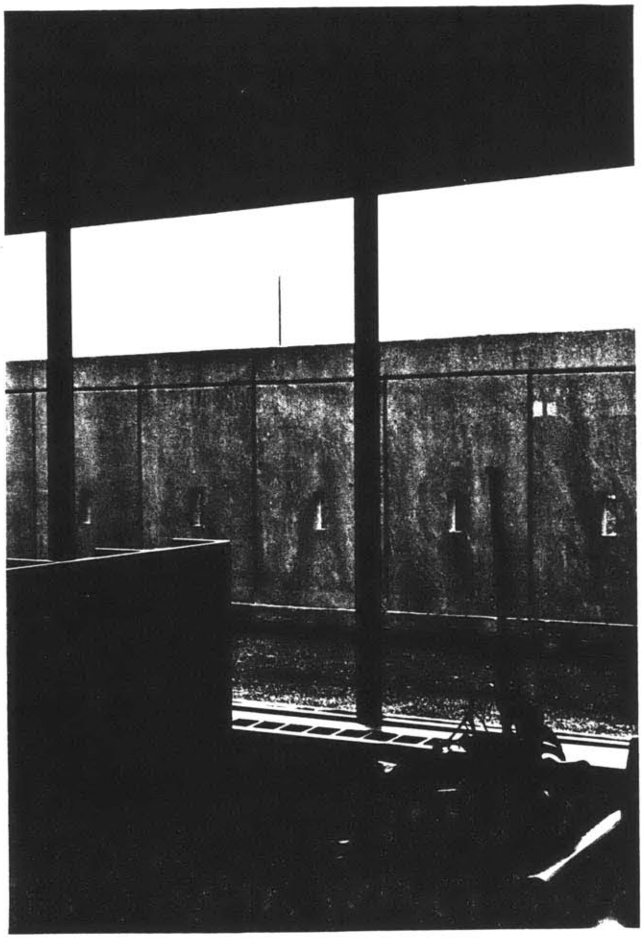


Figure 29

Finally, one might wonder why all the vertical fins on Boston City Hall are the same even though of different orientation to the sun. Even the tower in the background acknowledges the difference by reducing the glazing where high solar gains are anticipated.

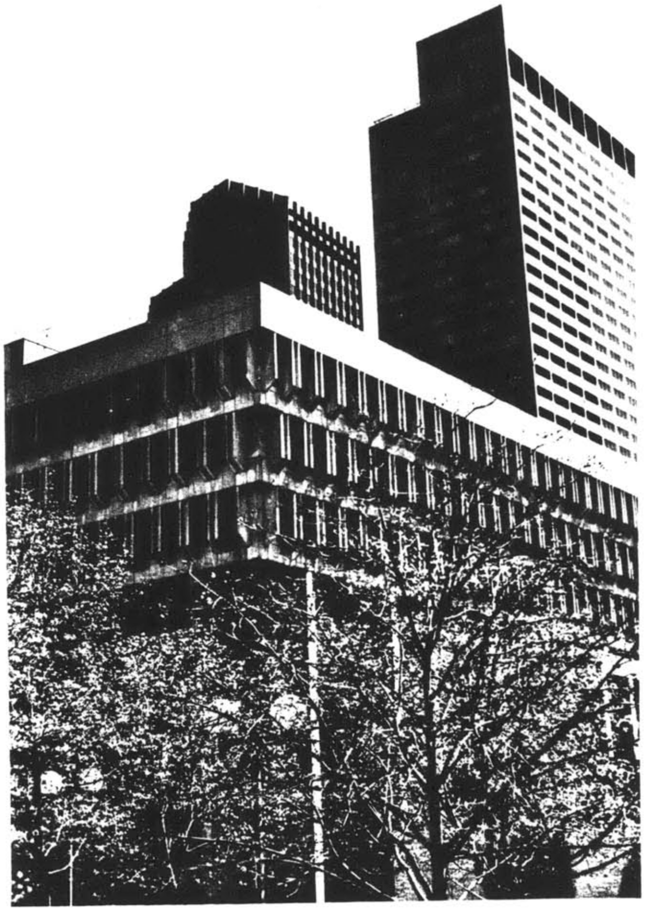


Figure 30.

Coherence can be maintained in the devices by utilizing the same depth dimensions or same fin width, etc. Definition can also be given to particular areas by changing the sizes in even multiples. For cost reasons this size range should be limited.

Most of the fins envisioned in the tower are actually not opaque but open to light from the non-sun side. They are assembled from cut tubes stacked on each other at an angle. They therefore block the direct sunlight but let diffuse light through the tubes.

INTERRELATED STRUCTURAL AND TRANSPORT DECISIONS

Chapter Seven

Approximations of structural requirements were made with reference to the recently published PLANNING AND DESIGN OF TALL BUILDINGS, MONOGRAPH ON, compiled by the American Society of Civil Engineers. Steel construction was chosen because of the building height and need to keep the floor to ceiling height as high as possible. A modified belt-truss/frame - shear truss system would probably produce a strong enough frame without having to use moment connections. The latter increase the beam depth or necessitate more columns. Figures 31 through 34 illustrate some of the types of systems presently being used. The structure for the Welton Becket tower is shown in Figure 35. Supposedly, the concrete shear core reinforced steel tower is the most economical structurally up to forty stories. However, the core uses a lot of space thereby decreasing the net floor area.

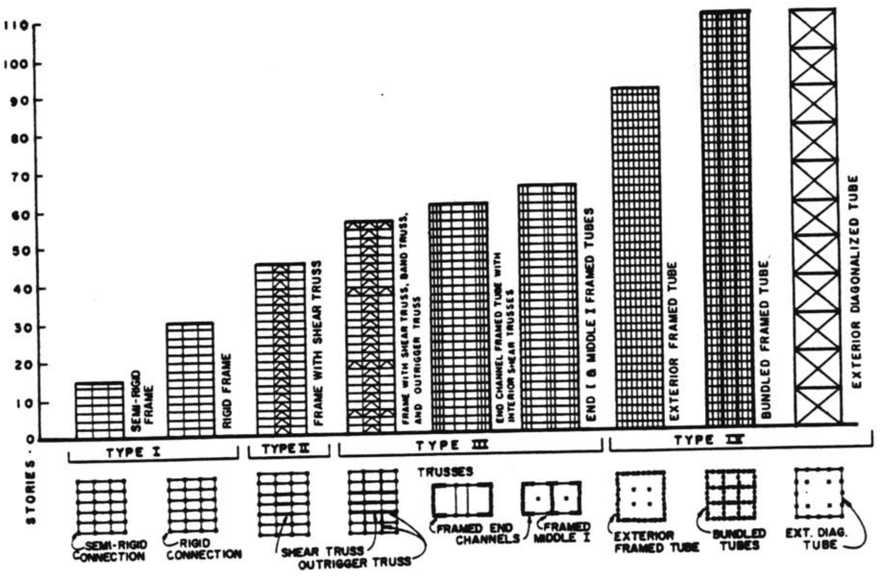


Fig. 2.3 Comparison of structural systems

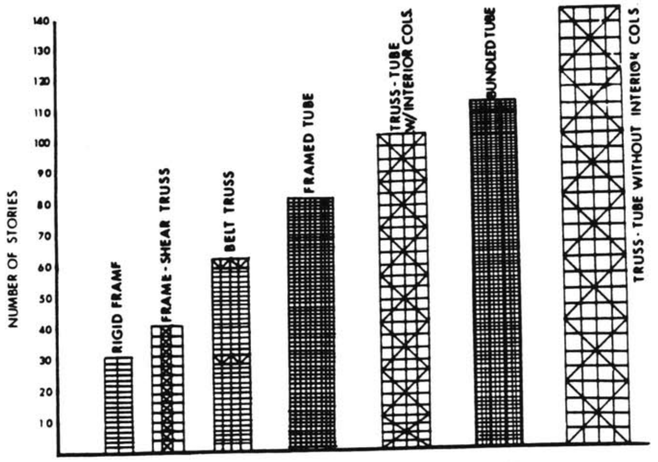


Fig. 1.1 Types of steel structure *(Khan, 1974)*

Figure 31.[6]

6. Higgins et al, STRUCTURAL DESIGN OF TALL STEEL BUILDINGS, Vol. SB, Mono. on P&D of TB, ASCE, New York, 1979, p. 38.

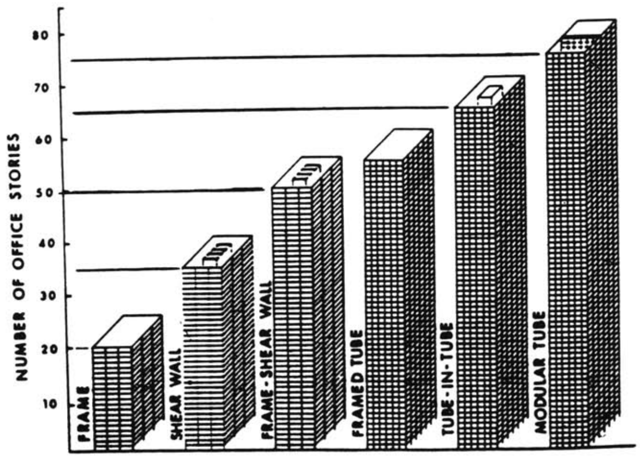


Fig. 1.2 Concrete structural systems for office buildings *(Khan, 1974)*

Figure 32,33[8]

7. op. cit., p. 359.

Figure 33.[7]

8. Khan et al, TALL BUILDING SYSTEMS AND CONCEPTS, Vol. SC, Mono. on P&D of TB, ASCE, New York, 1980, p. 5.

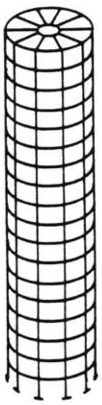


Fig. 5.7 Circular tubular framework

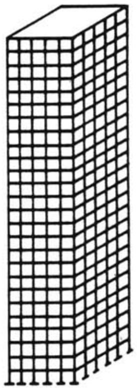


Fig. 5.8 Rectangular tubular framework

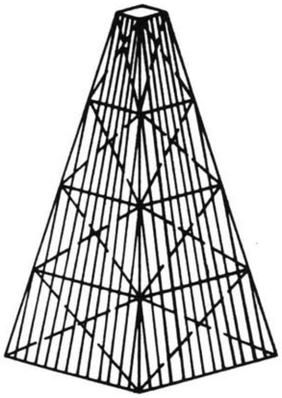


Fig. 5.9 Trussed tubular frame with sloping exterior columns

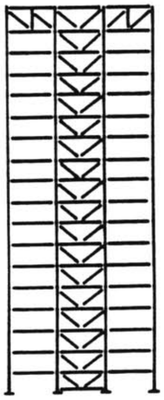
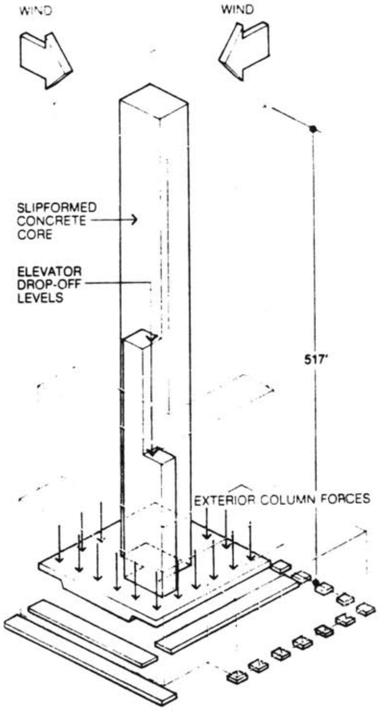


Fig. 5.10 Center braced core capped with truss attached to exterior tie-down columns

The number of elevators were approximated using the methods described in MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS by Mc Guinness and Stein.[9] Twenty high-speed elevators would service the tower which would have four ten story zones. From the top zone down, they would each need respectively six, five, five, and four 3500 pound cars. The majority of these would have to be high speed to compensate for the elevators being spaced at the extreme ends of each floor. (see plan in next section) These figures seem to agree closely with what is in the Welton Becket design.



ONE TAMPA CITY CENTER, ENGR. LEV ZETLIN ASSOC.

.Figure 35.

PROGRESSIVE ARCH., p. 53.

---

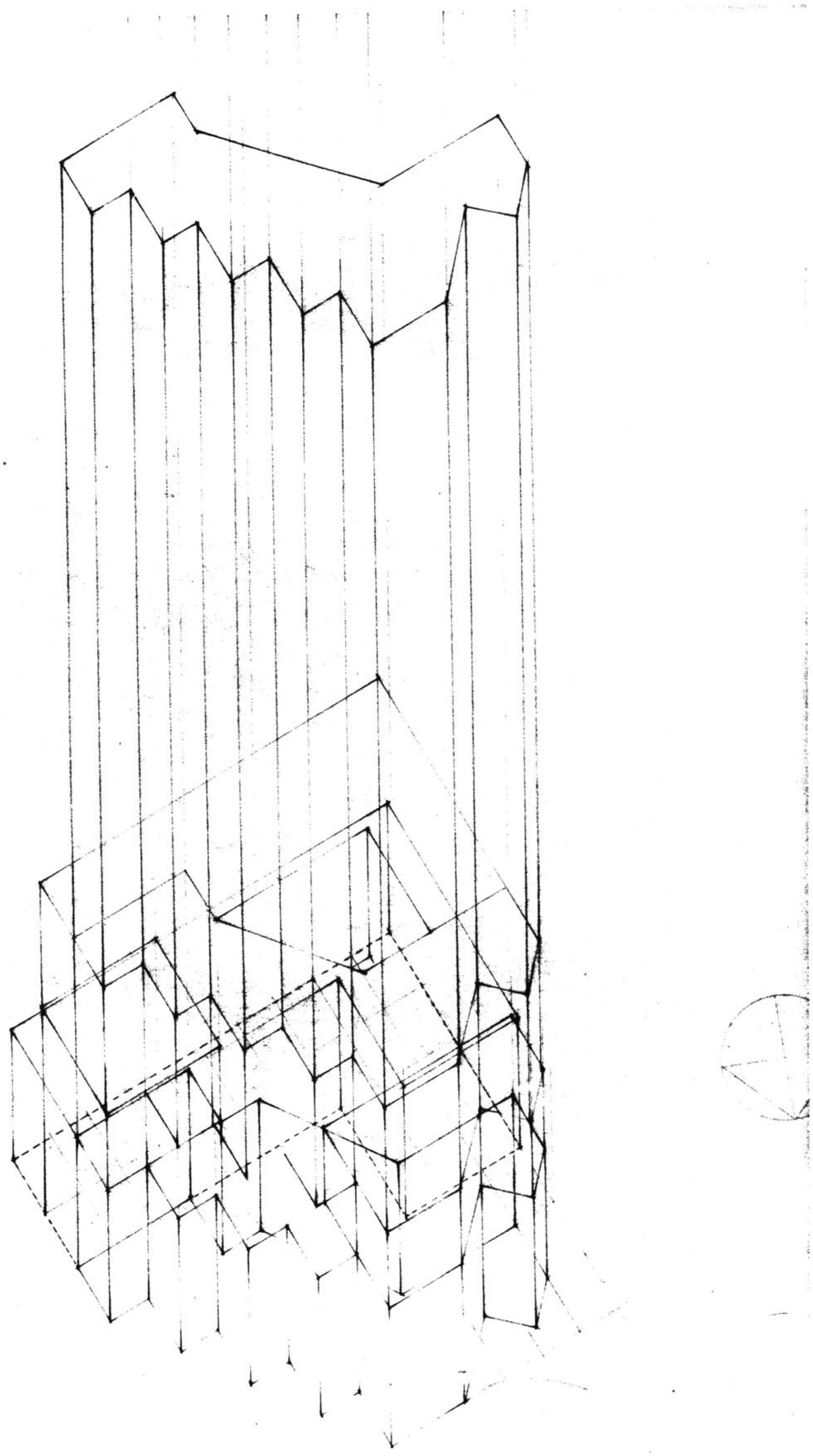
[9] William McGuinness and Benjamin Stein, MECHANICAL AND ELECTRICAL EQUIPMENT FOR BUILDINGS, New York, 1964, pp. 867-934.

1/32nd SCALE MODEL AND SCHEMATIC PLANS

Chapter VIII

The following pages contain early massing study drawings and schematics for the entire center. Each floor of the tower contains approximately 14,400 square feet. The main tower has forty such floors plus equipment floors. Seventy-two percent of the square footage required by the program is contain-in the tower. The remainder is in the lower building and two sub floors. A waterfall commencing on the ground level flows down into the lower,central atrium space where it is used to scatter the light and mask noise created in the space. Light enters this space through the atrium and also the portal frame opening. Although the portal frame opening results from more structural considerations; it has a side effect of lowering the wind level on the street.

Figure 36.



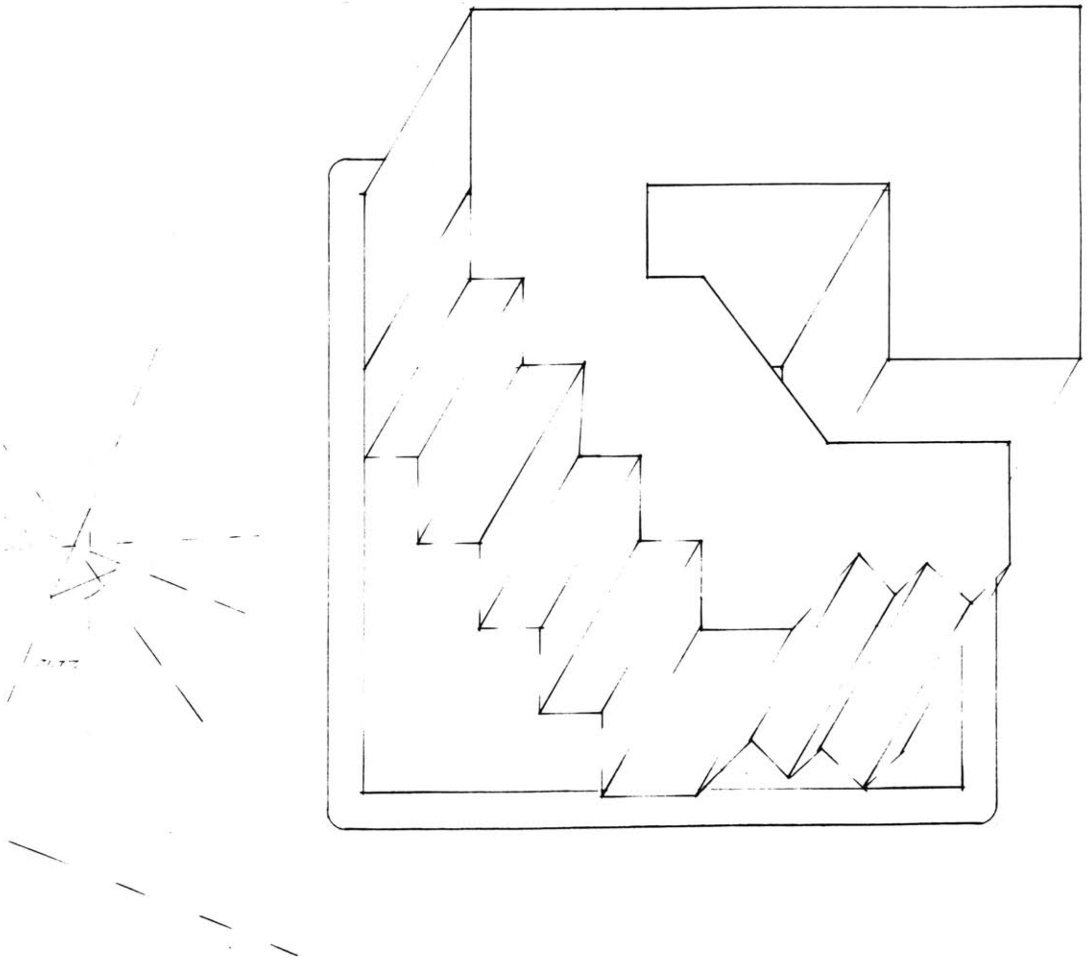


Figure 37.

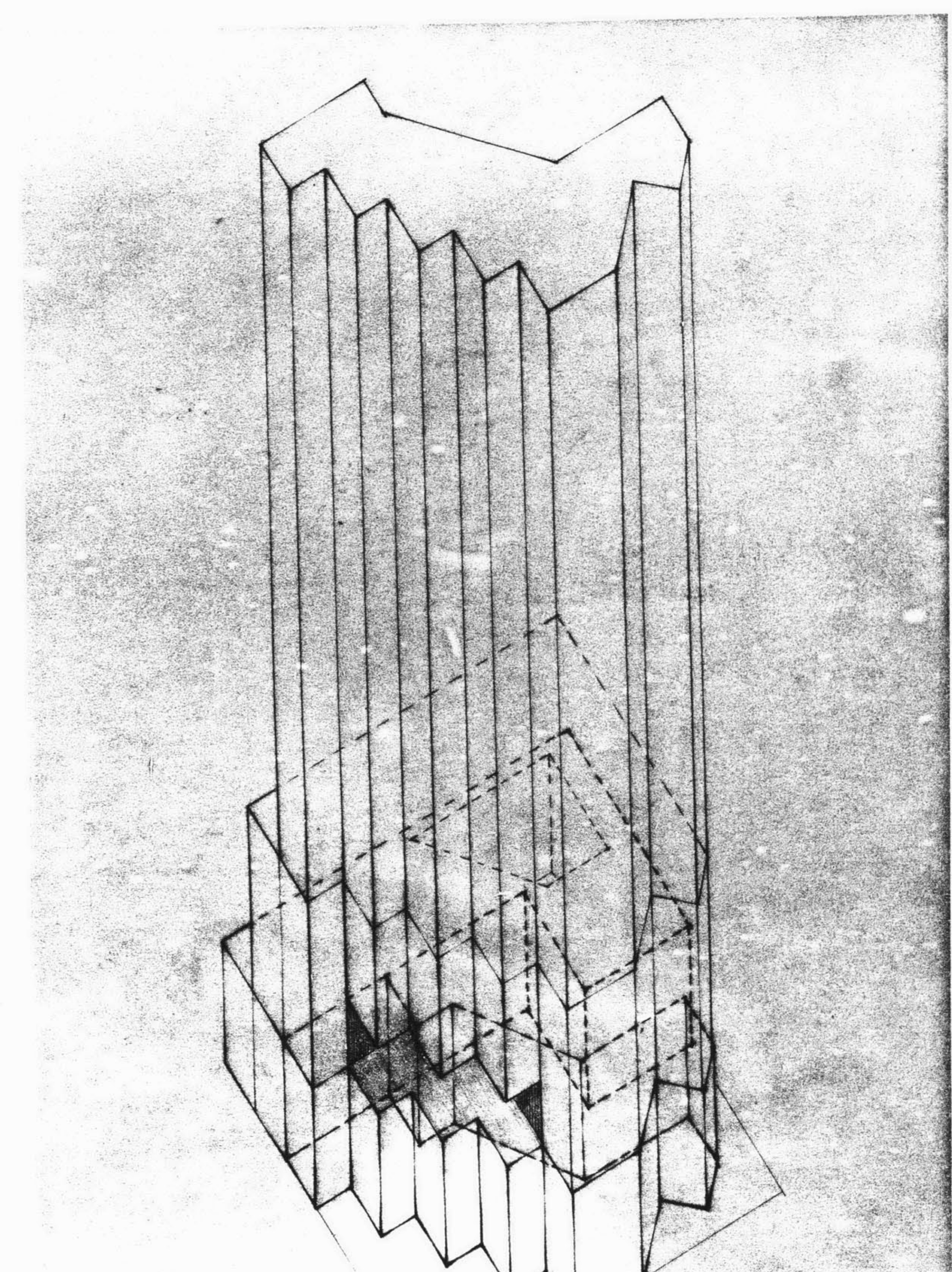


Figure 38.

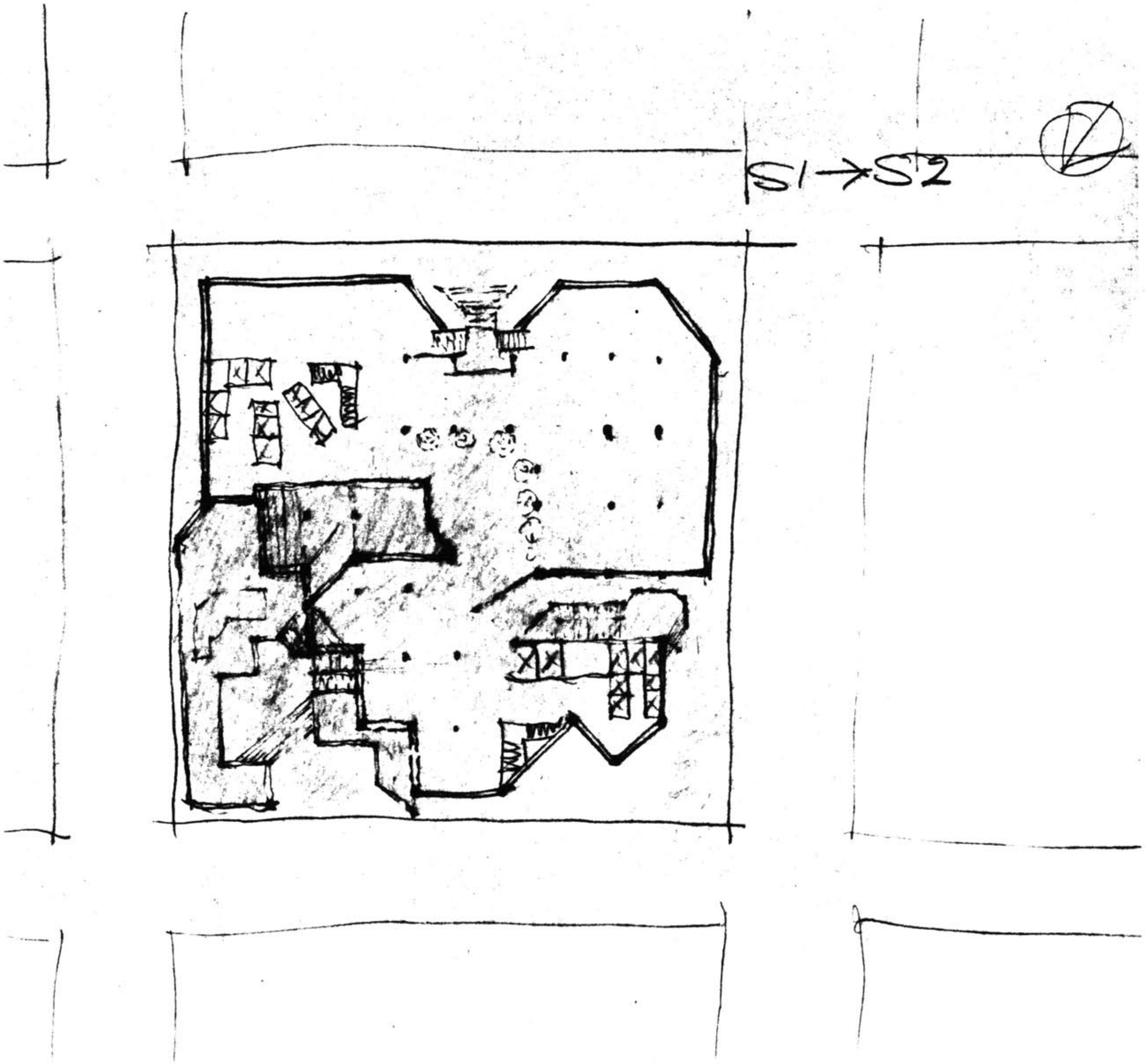


Figure 39.

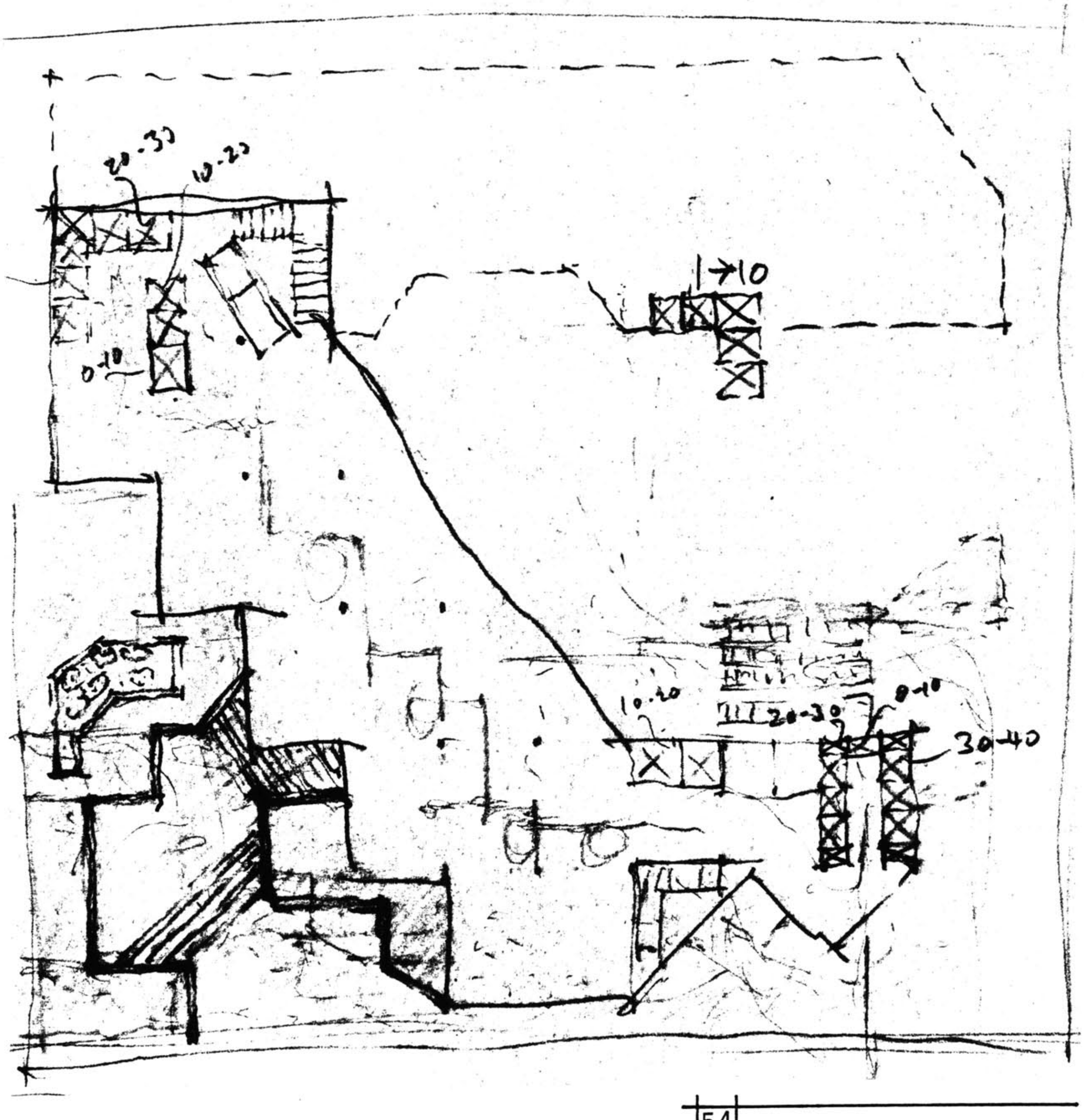


Figure 40.

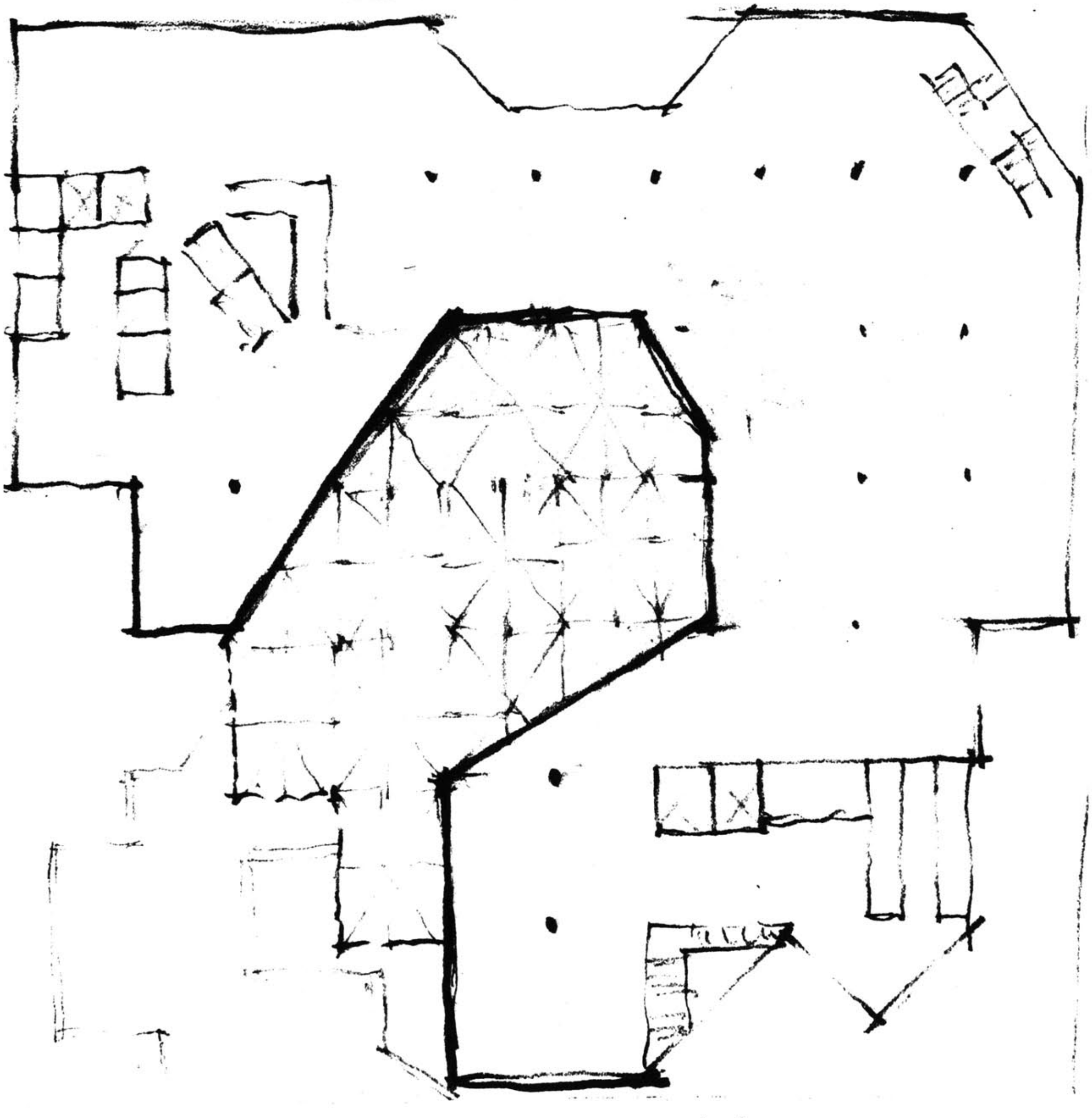


Figure 41.

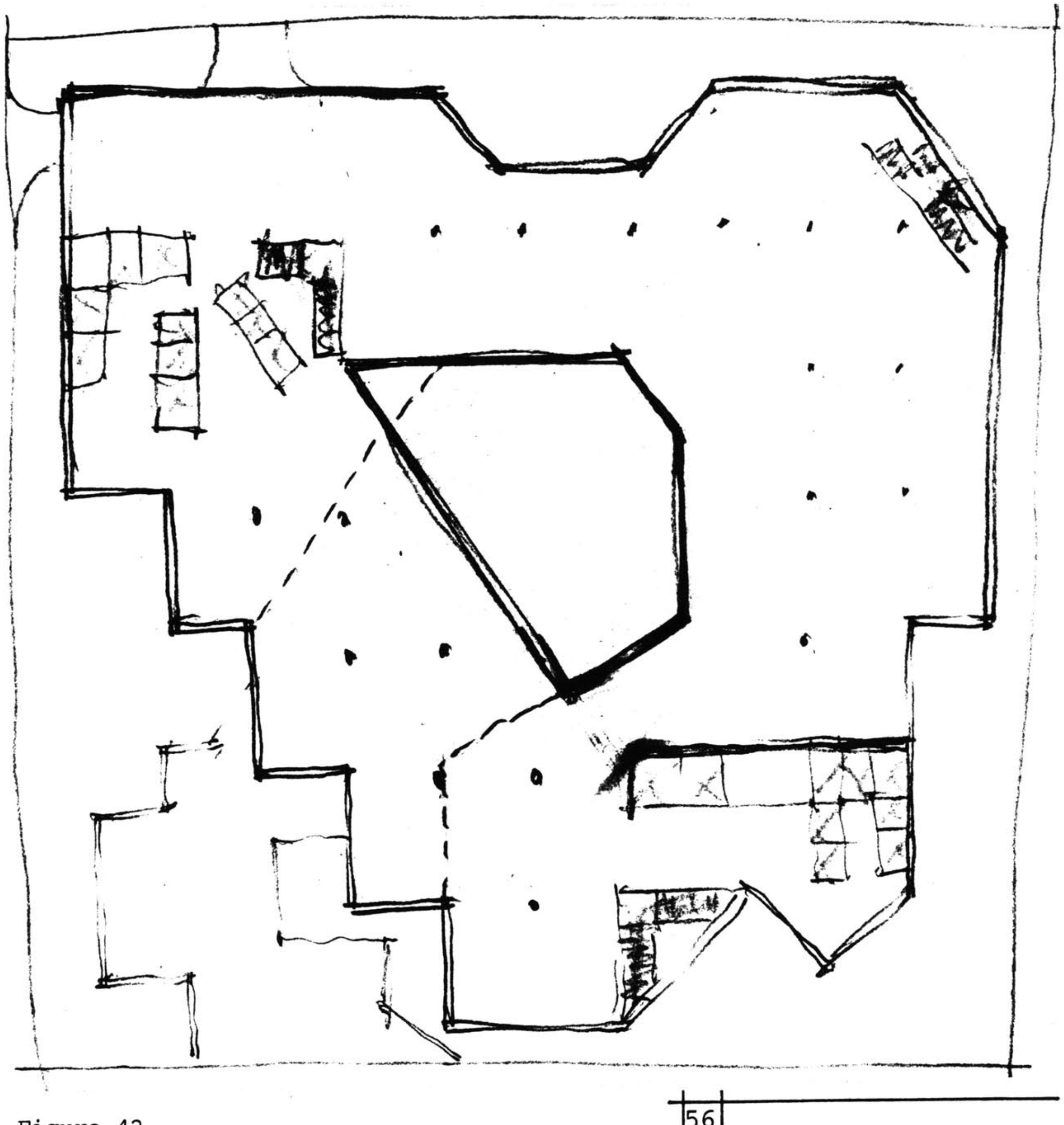


Figure 42.

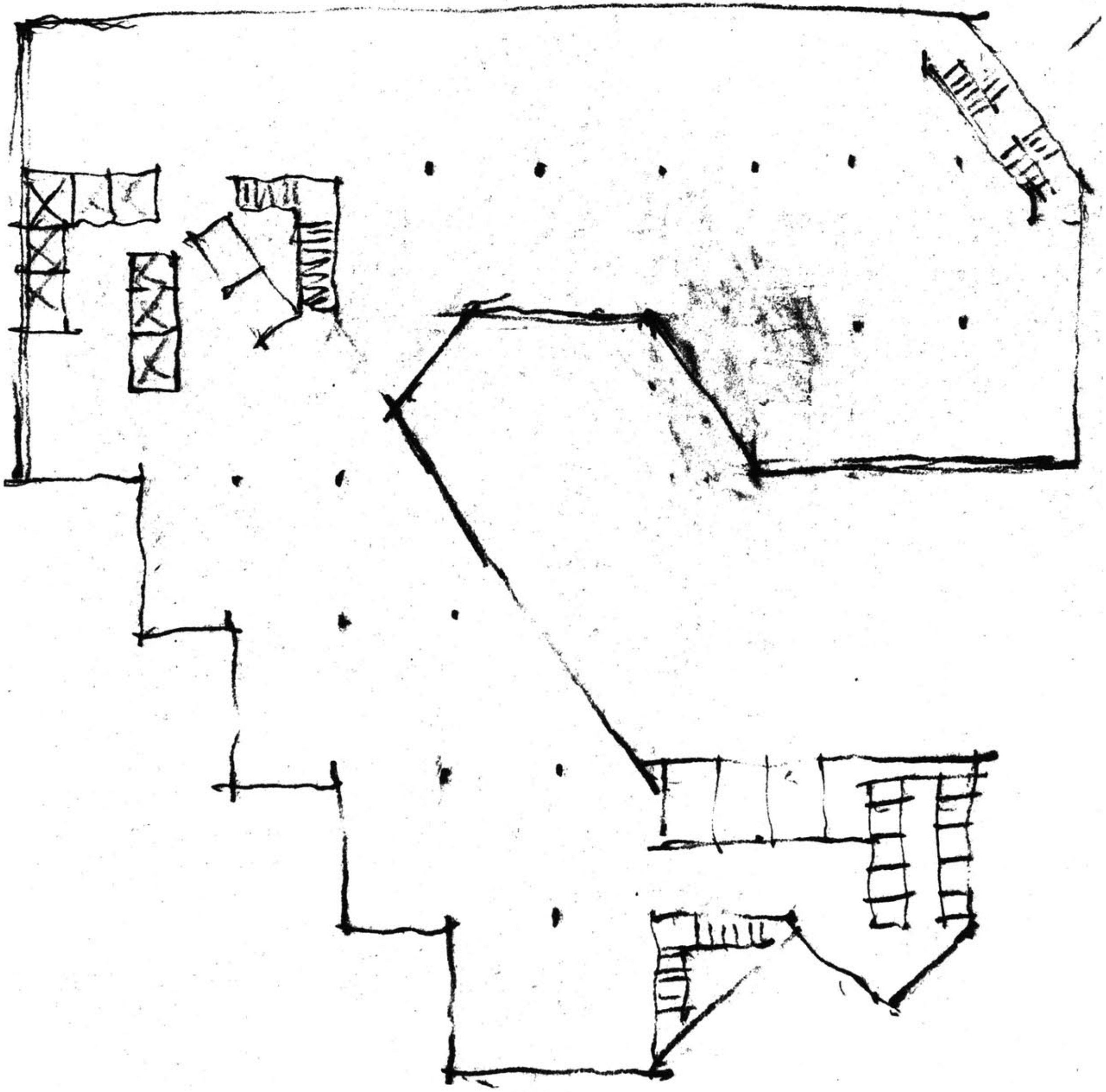


Figure 43.

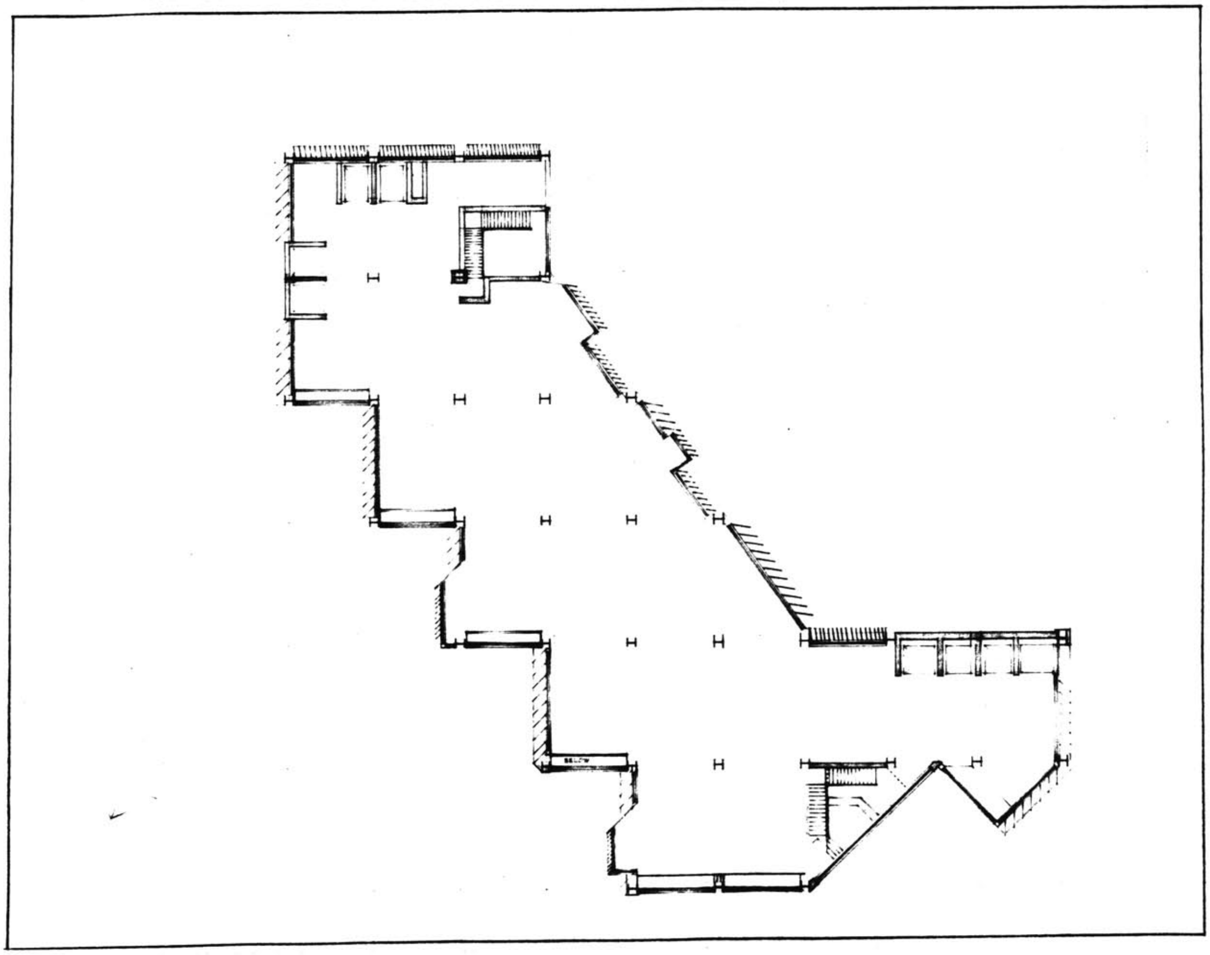


Figure 44.

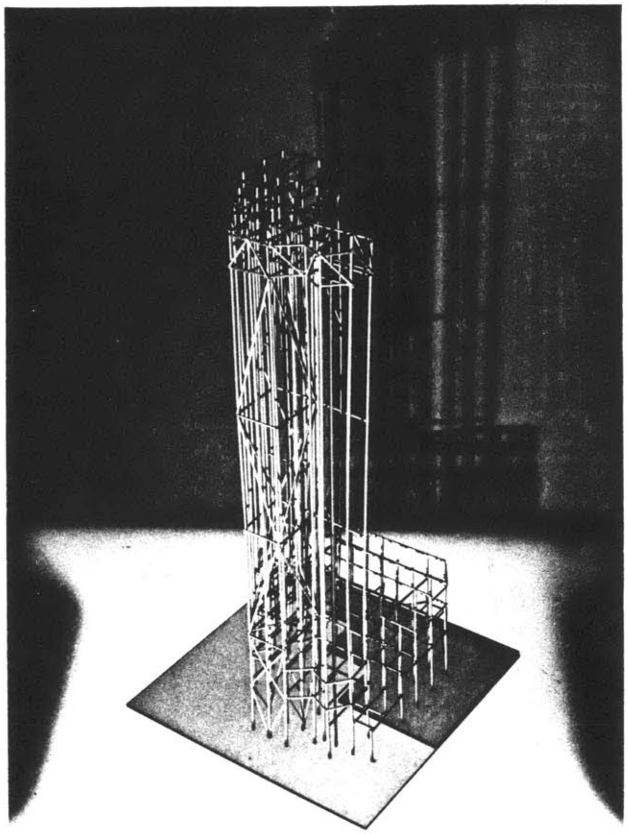


Figure 45.

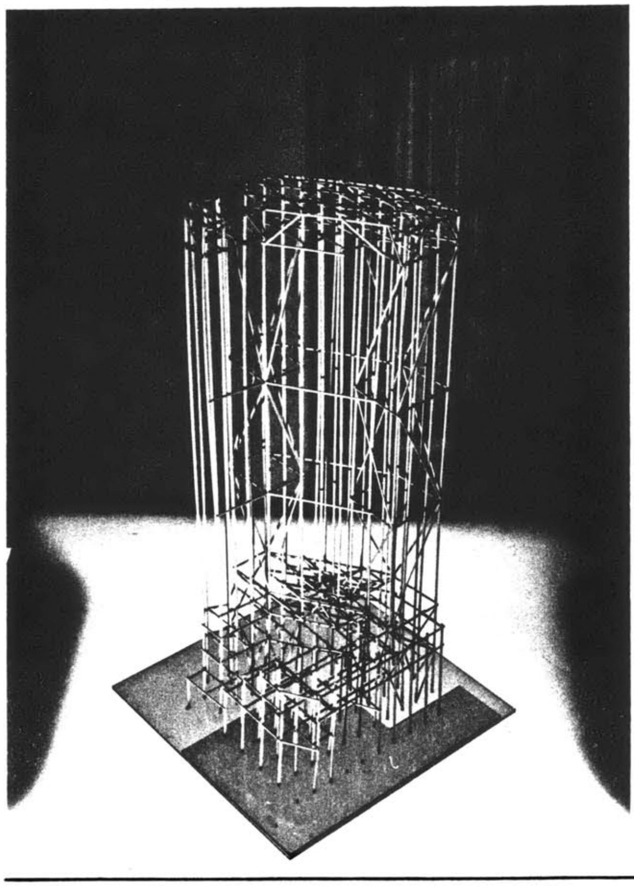


Figure 46.

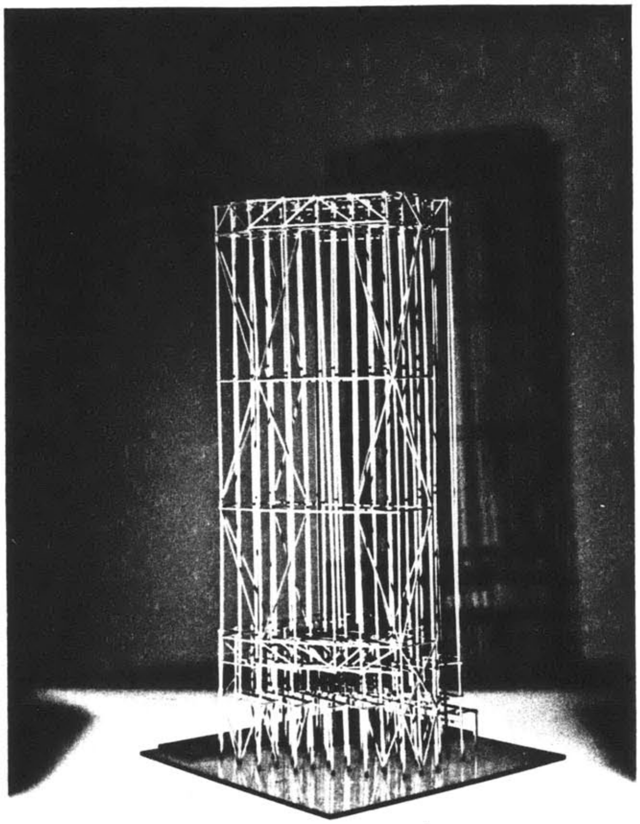


Figure 46.

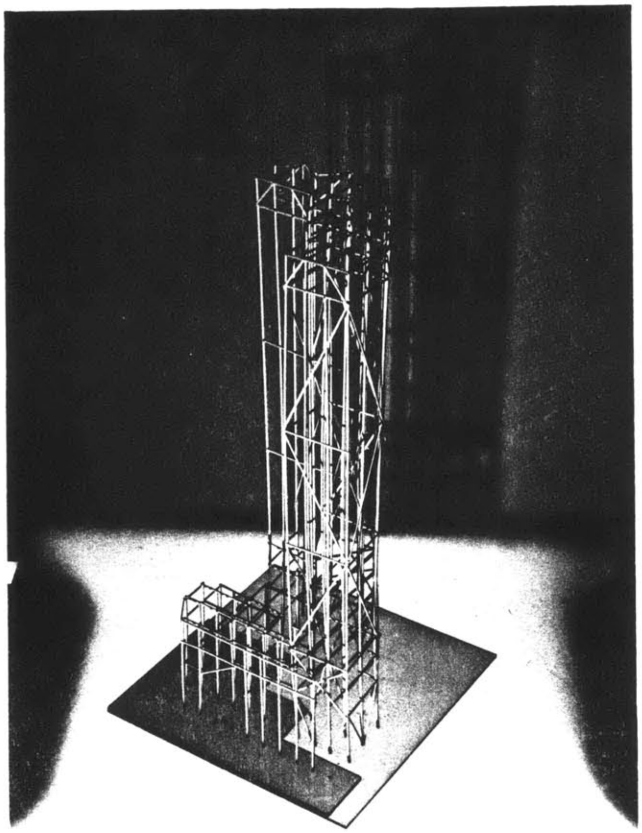


Figure 47.

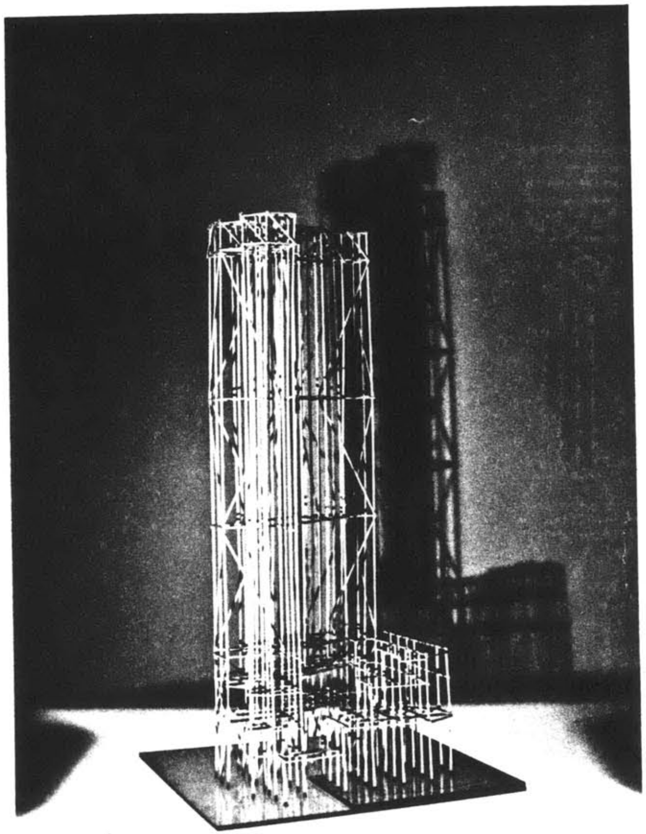


Figure 48.

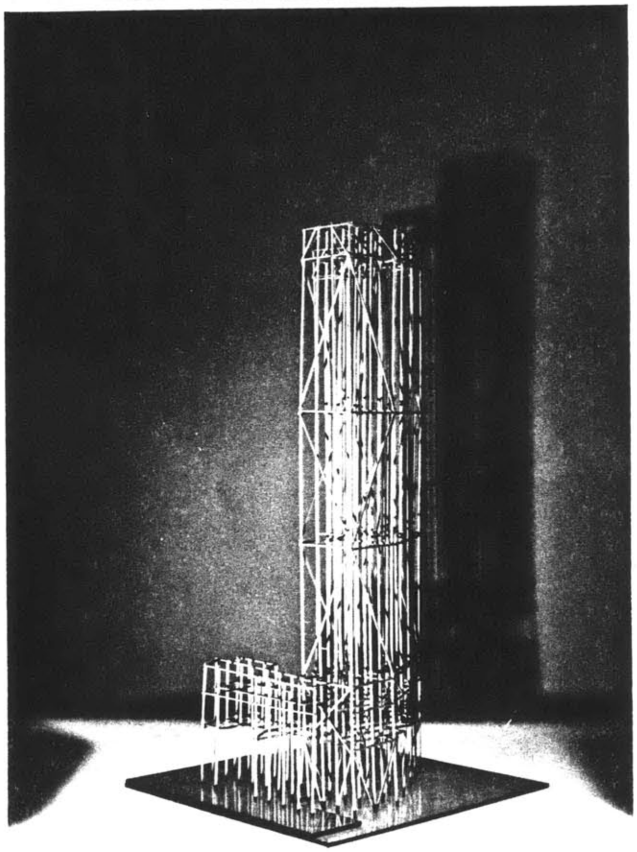


Figure 49.

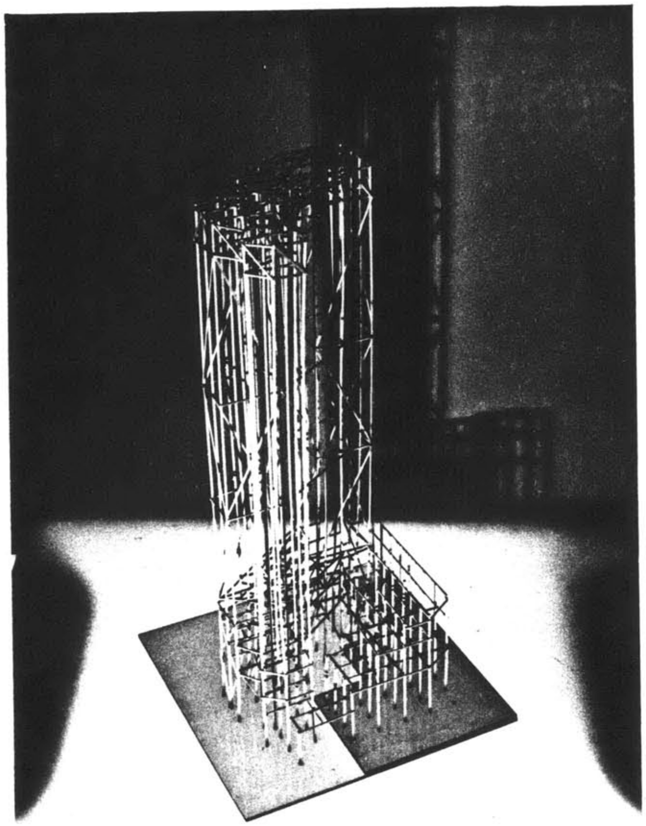


Figure 50.

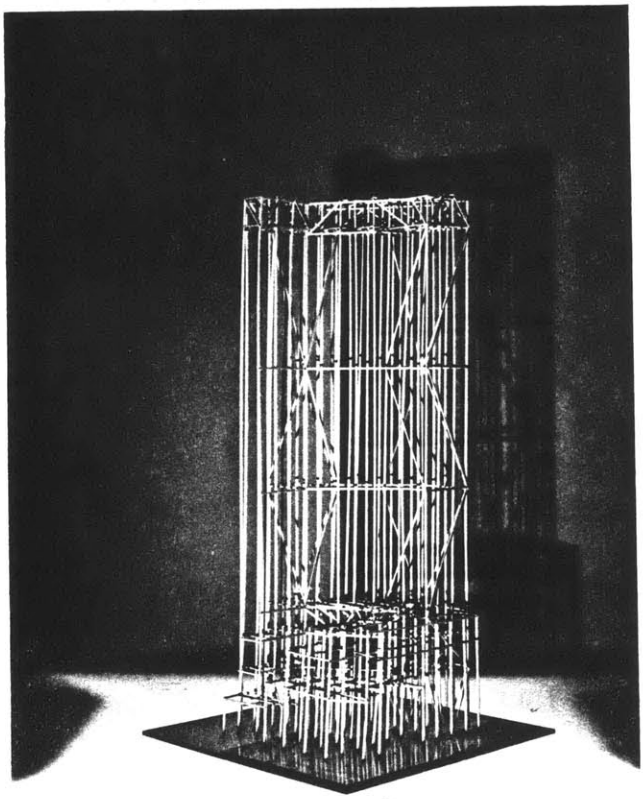


Figure 51.

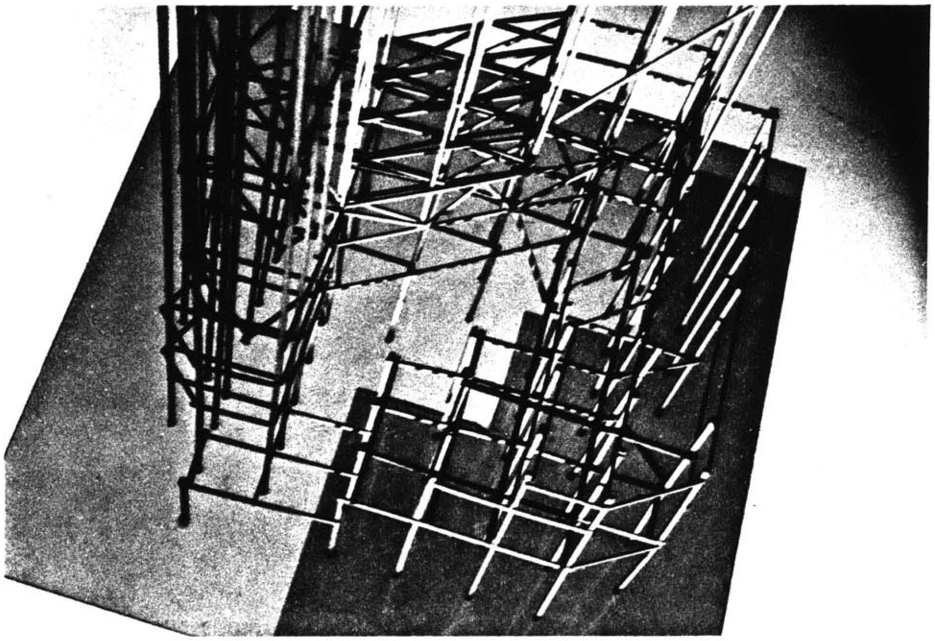


Figure 52.

1/2 INCH SCALE LIGHTING MODEL

Chapter Nine

A 1/2 inch scale lighting model of a two bay, two floor section of the tower was built and tested. The screens used on the model do not accurately model the actual screens; however a sense of the quality of light and space was obtained. The actual screening devices would have to be modeled at at least twice the scale and then tested in a black box.

On a moderately overcast day with an illumination level of approximately six to seven thousand foot candles, a lighting level of 125-200+ fc was obtained in the model. Even with one side completely covered, the light level did not go below 60 fc. One could reasonably expect then to have 50-100 fc in the actual tower. Except for task lighting, one would not need to use overhead lighting.

The model and some of the apparatus used to test it are shown on the following pages.

Figure 52.

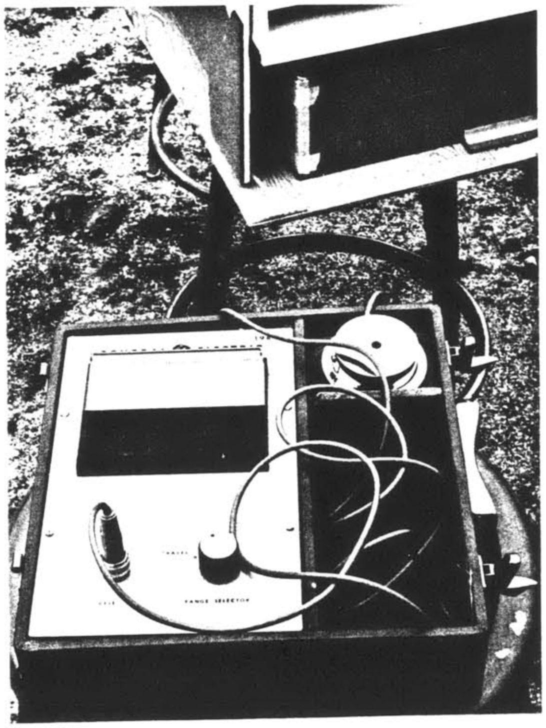


Figure 53.

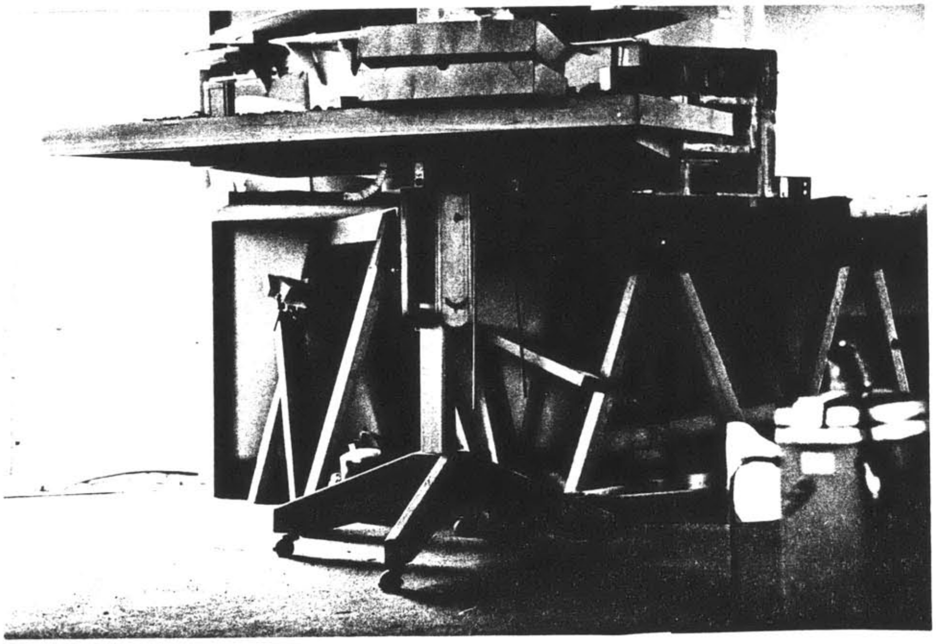


Figure 54.

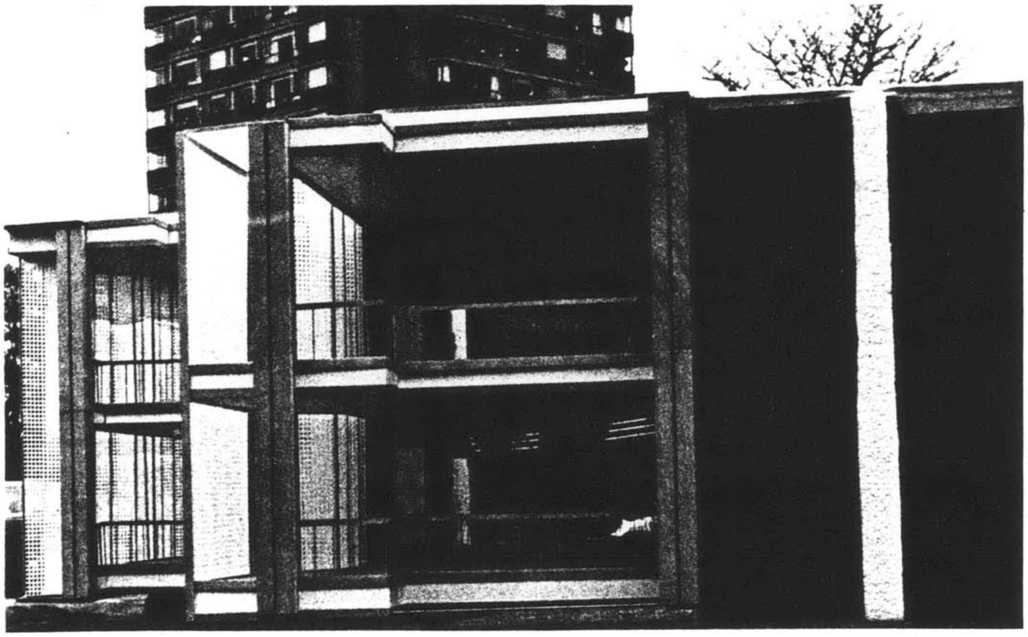


Figure 55.

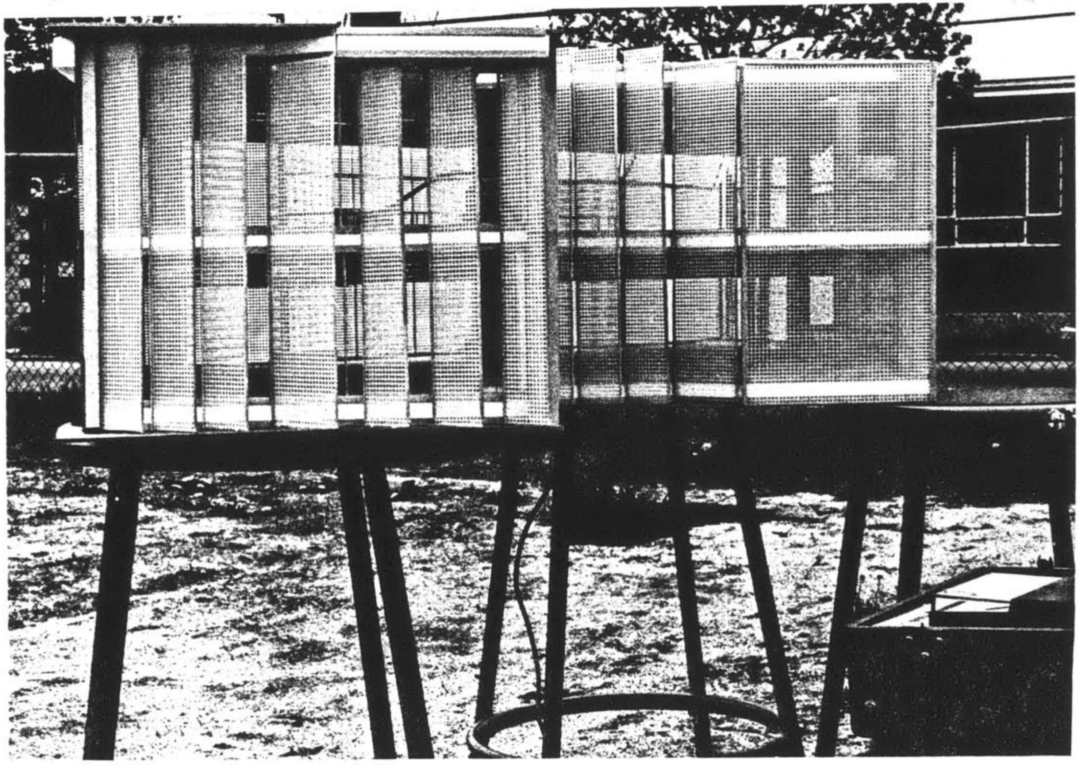


Figure 56.

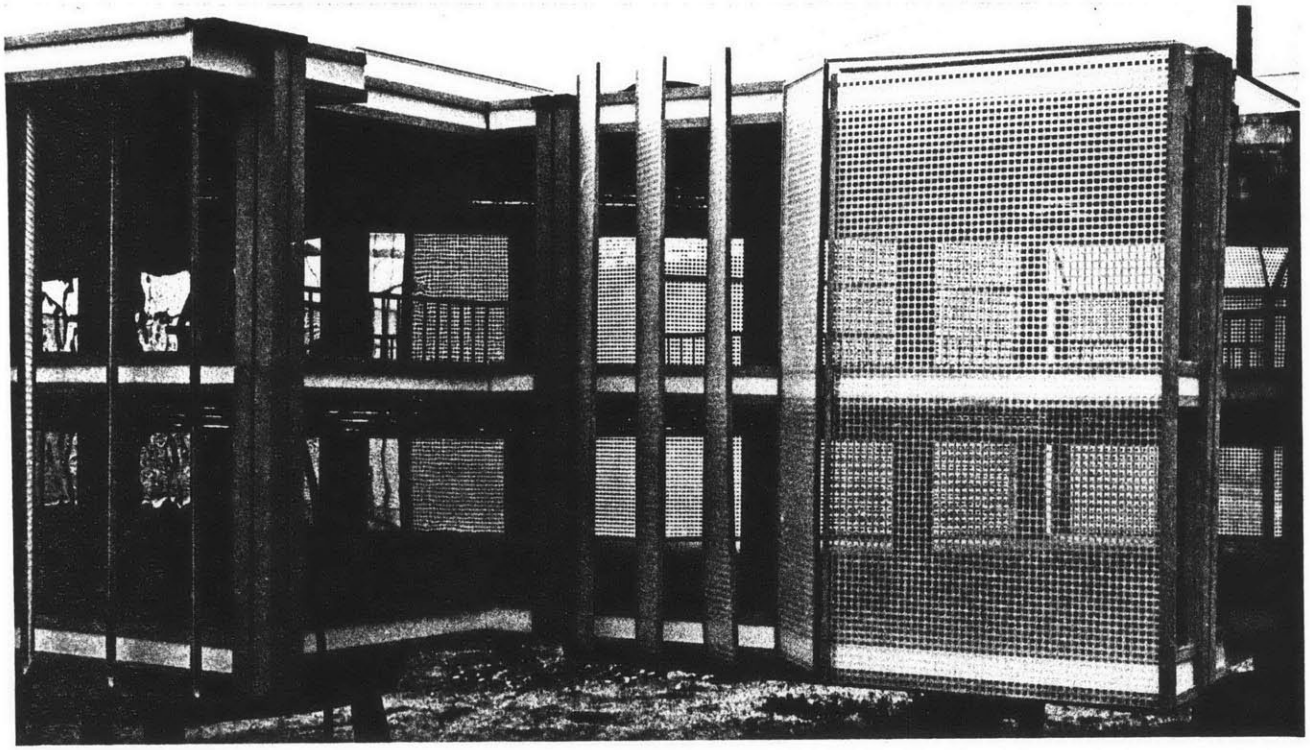


Figure 57.

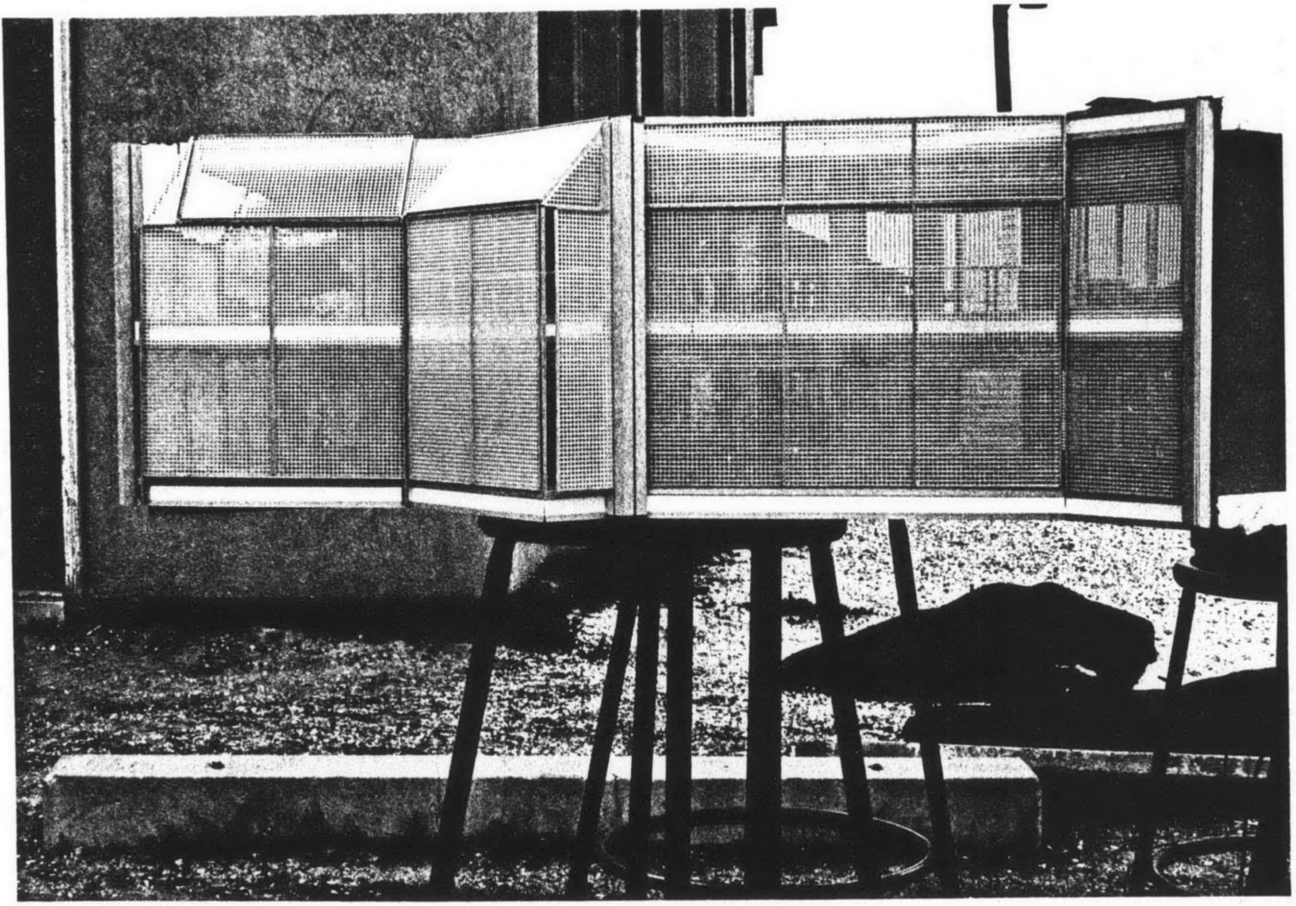


Figure 58.

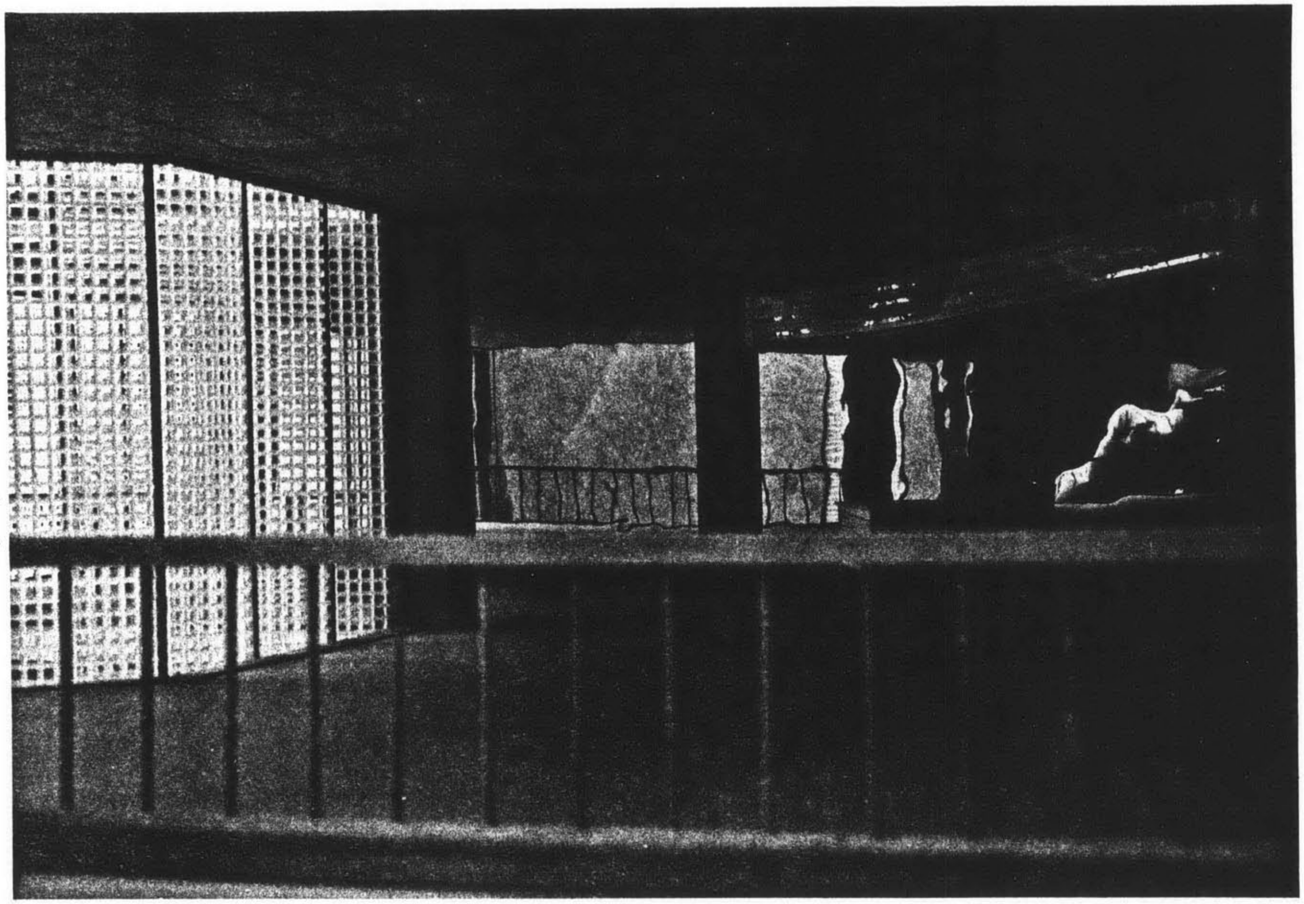


Figure 59.

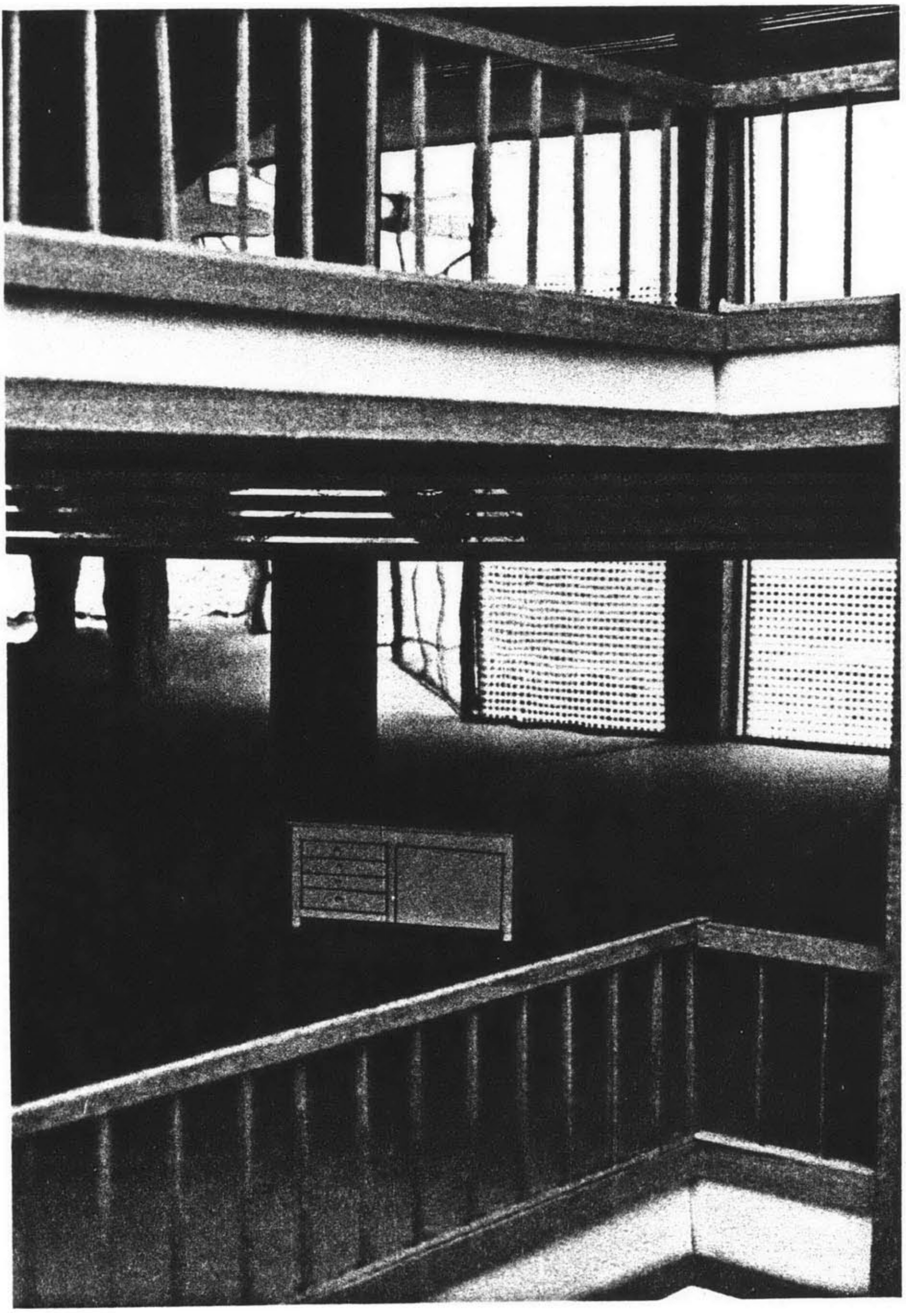


Figure 60.

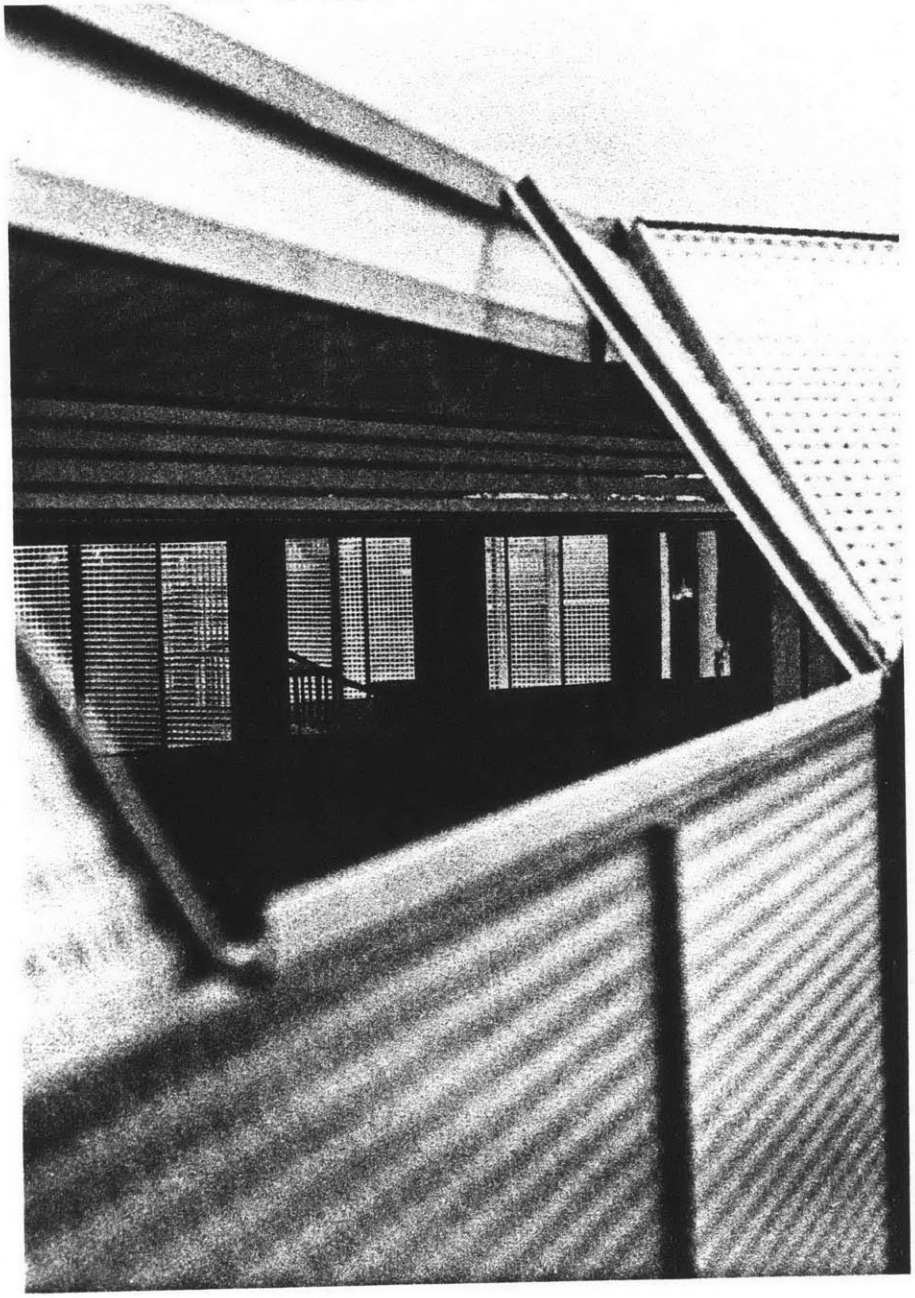


Figure 61.

FEASIBILITY AND CONCLUSIONS

Chapter X

Cooling load reduction and cost:

Initial:

34.2 BTU/Hr/SF x 800,ooo SF= 27,360,000 BTU/Hr

27,360,000/ 12,000 Btu/Hr/ton= 2,280 tons

2,280x $1500/ton= $3,420,000

New:

wall	38,022	
glass	35,952	conduction
	24,010	solar
	97,984	

as percent of former,

97,984/ 134,709= 72%

Savings:

lighting	138,179
wall and glass	36,725
	174,904

174,904/534,723=32%

.32x34.2x800,000/12,000= 729.6 tons

729.6x$1500/ton= $1,094,400

Savings in energy:

cooling,

(40x52)7 kwh/ton(729 tons)($.08/kwh)

=$849,139.20

lighting, (assume 70% savings or reduction)

2.5watts/Sf x 800,000(.70)($.08)

= $112,000

total/first year= $961,139.20

Revenue generated by increased perimeter office space at $2 SF increase:

(625-500 LF)(15ft)(40floors)($2 SF)

= $150,000/yr.

Total:

961,139.20

150,000.00

$1,111,139.20

Assuming similar structure and envelope cost as percentage of total[10] as shown in Figure 62 for 60 State Street in Boston and $70 versus $80 SF construction cost:

Initially:

800,000($70)(.165+.287)= cost structure & envelope in Welton Becket tower

= $25,312,000

Redesign:

800,000($80)(.165+.287)= $28,928,000

Increase:

= $ 3,616,000

This amortized for twenty years at 13% interest which is probably what would have been available at the time of financing yields the following interest and principal schedule after deducting $1,094,000 lowering of cooling plant cost and taking 10% of this figure for initial capital outlay:

Amount financed:

$2,269,440.00

```
  3616000.      -
  1094400.      =
  2521600.


                CLR

      240.
   1.0833




   2521600.     x
        0.1     =
    252160.
   -252160.     +
   2521600.     =
   2269440.

   2269440.     PRT
                CLR
```

amt. Financed

```
       240.
     1.0833
 2269440.00
   26588.21

  319058.49
      14.06
```

```
           1.
  2243923.85
    25516.15 P
   293542.35 I
    25516.15
   293542.35

           2.
  2214885.65
    29038.20
   290020.29
    54554.35
   583562.64

           3.
  2181839.23
    33046.42
   286012.07
    87600.77
   869574.71

           4.
  2144231.33
    37607.90
   281450.59
   125208.67
  1151025.31

           5.
  2101432.32
    42799.01
   276259.48
   168007.68
  1427284.79

           6.
  2052725.66
    48706.66
   270351.83
   216714.34
  1697636.62
```

```
        7.
1997295.89
  55429.77
 263628.73
 272144.11
1961265.35

        8.
1934215.02
  63080.87
 255977.62
 335224.98
2217242.97

        9.
1862426.93
  71788.08
 247270.41
 407013.07
2464513.38

       10.
1780729.76
  81697.17
 237361.32
 488710.24
2701874.70

       11.
1687755.73
  92974.03
 226084.46
 581684.27
2927959.16

       12.
1581948.25
 105807.47
 213251.02
 687491.75
3141210.18
```

```
       13.
1461535.92
 120412.34
 198646.16
 807904.08
3339856.34

       14.
1324502.76
 137033.15
 182025.34
 944937.24
3521881.68

       15.
1168554.58
 155948.18
 163110.31
1100885.42
3684991.99

       16.
 991080.49
 177474.09
 141584.40
1278359.51
3826576.39

       17.
 789109.21
 201971.28
 117087.21
1480330.79
3943663.60

       18.
 559259.33
 229849.88
  89208.61
1710180.67
4032872.22
```

```
       19.
 297682.70
 261576.63
  57481.86
1971757.30
4090354.08

       20.
      0.00
 297682.70
  21375.79
2269440.00
4111729.88
```

Depreciation amounts to $45,388.80 taken on a straight line basis over forty-five years with a salvage value of ten percent.

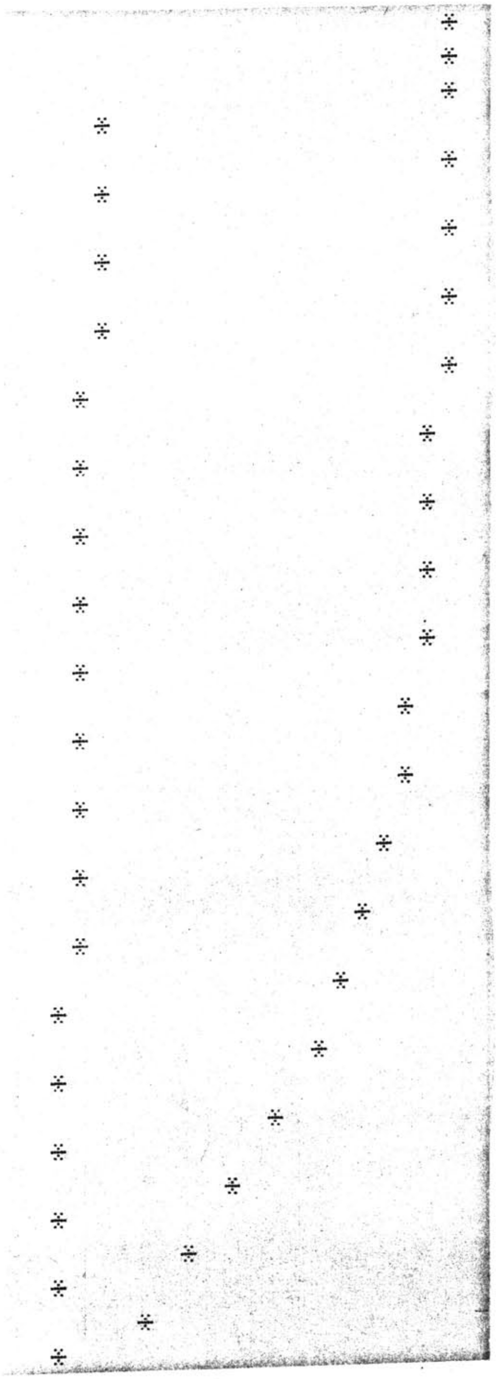
Adding together interest and depreciation and deducting the annual debt service of $319,058.49 and then taking 50% of this figure for each of the years yields the cash resulting from the tax benefits a corporation would have. Adding then to this figure for each year the energy savings and increased rental income generates the following yearly net cash flow. Also given are the discounted cash flows based on a discount rate of 20% which a corporation would probably have to receive. Year twenty also includes proceeds from refinancing the loan.

YEAR	NET CASH	DISCOUNTED (NET PRESENT VALUE)
1	$961,546.28	$788,236.08
2	959,785.25	644,980.09
3	957,781.19	527,624.14
4	955,500.40	431,494.58
5	952,904.85	352,760.64
6	949,951.02	288,282.26
7	946,589.47	235,485.67
8	942,763.92	192,261.31
9	938,410.31	156,880.09
10	933,455.77	127,924.85
11	927,817.34	104,234.09

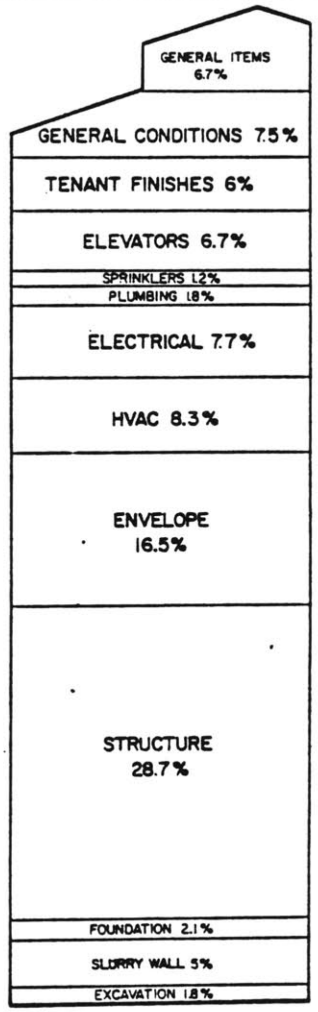
YEAR	NET CASH	DISCOUNTED (NET PRESENT VALUE)
12	921,400.62	84,855.87
13	914,098.19	69,010.06
14	905,787.78	56,057.29
15	896,330.26	45,473.65
16	885,567.31	36,829.81
17	873,318.71	29,773.97
18	859,379.41	24,017.90
19	843,516.04	19,325.45
20	3,094,903.00	58,125.86
	TOTAL	$ 4,273,633.66

The internal rate of return generated from these same cash flows based on the initial investment of $252,160.00 is 381%. It would obviously be a good investment. Although other factors like inflation, tax credits, energy escalation, etc. are not considered in this analysis they would probably increase the figure. With such a high return it would take a major factor to bring it down substantially. None of these would to such a degree.

The following plot of these values also shows the early payback when income is plotted against its discounted return.



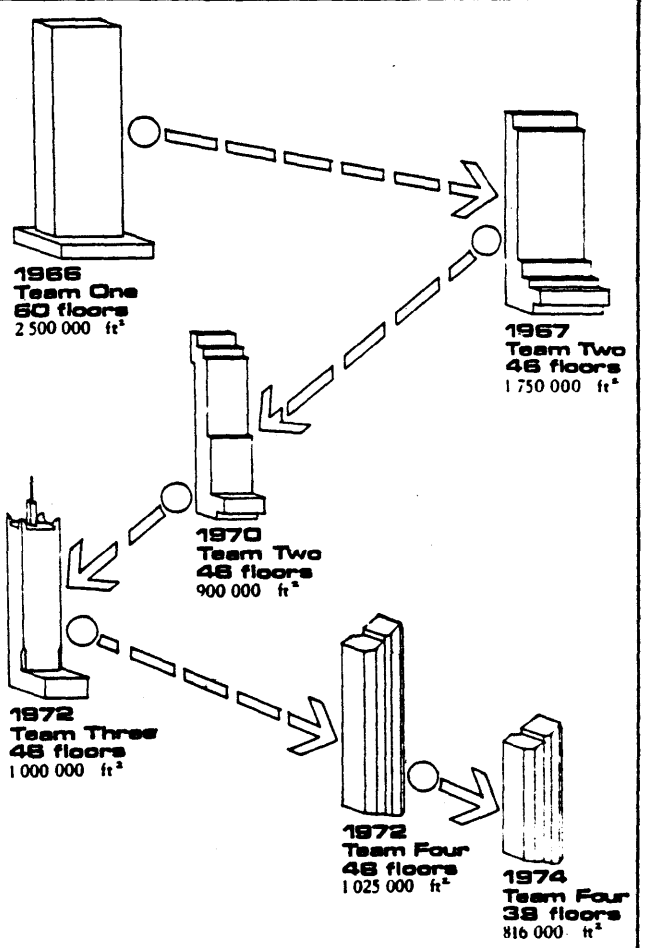
0 to $1,000,000



3.5 RELATIVE COST BREAKDOWN [58]

Figure 62.[11]

Figure 63.



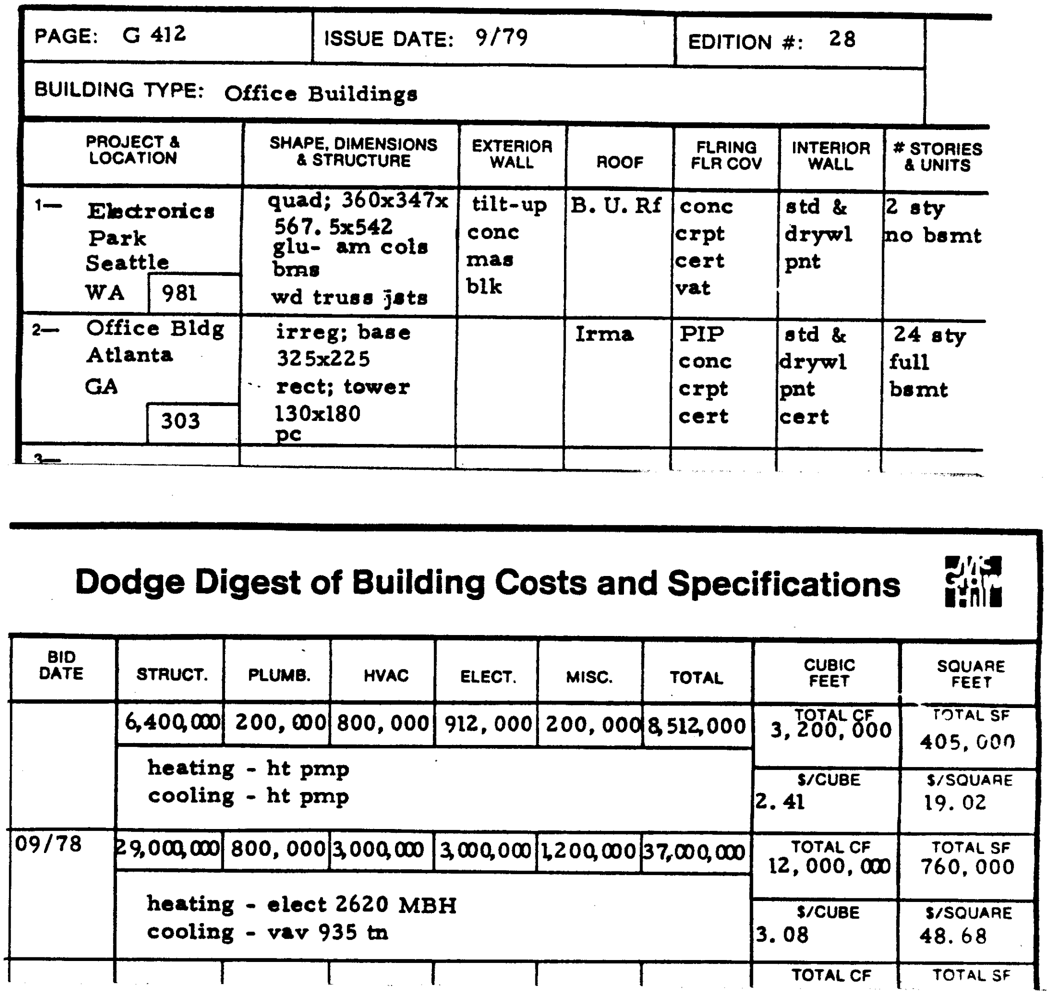
1.17 SUMMARY OF DESIGN PROPOSALS

Figure 64.[12]
60 State Street Final Size

10. unpublished paper, Jim Becker et al, SIXTY STATE STREET, A CASE STUDY, MIT, Cambridge, p. 44.

11. Ibid.

12. Becker, p. 19.



PAGE: G 412	ISSUE DATE: 9/79	EDITION #: 28
BUILDING TYPE: Office Buildings		

	PROJECT & LOCATION	SHAPE, DIMENSIONS & STRUCTURE	EXTERIOR WALL	ROOF	FLRING FLR COV	INTERIOR WALL	# STORIES & UNITS
1—	Electronics Park Seattle WA 981	quad; 360x347x 567.5x542 glu- am cols bms wd truss jsts	tilt-up conc mas blk	B. U. Rf	conc crpt cert vat	std & drywl pnt	2 sty no bsmt
2—	Office Bldg Atlanta GA 303	irreg; base 325x225 rect; tower 130x180 pc		Irma	PIP conc crpt cert	std & drywl pnt cert	24 sty full bsmt
3—							

Dodge Digest of Building Costs and Specifications

BID DATE	STRUCT.	PLUMB.	HVAC	ELECT.	MISC.	TOTAL	CUBIC FEET	SQUARE FEET
	6,400,000	200,000	800,000	912,000	200,000	8,512,000	TOTAL CF 3,200,000	TOTAL SF 405,000
	heating - ht pmp cooling - ht pmp						$/CUBE 2.41	$/SQUARE 19.02
09/78	29,000,000	800,000	3,000,000	3,000,000	1,200,000	37,000,000	TOTAL CF 12,000,000	TOTAL SF 760,000
	heating - elect 2620 MBH cooling - vav 935 tn						$/CUBE 3.08	$/SQUARE 48.68
							TOTAL CF	TOTAL SF

Figure 65.[13]

---

[13] DODGE DIGEST OF BUILDING COSTS AND SPECIFICATIONS, Oct. 1980-March 1981, edition no. 30, New York, p. G 412.

Conclusion:

Daylighting can create interesting and pleasant environments even in high-rise office towers and do so economically. Perhaps too, it can help re-create or entice our fascination with the tower as seen in Figure 66 from the children's tower in Boston's Waterfront park to the Customs Tower and Boston's newer office towers. It might even go as far as the fantasy of the Victorian tower:

Figure 66.

Figure 67.