A Design for a Partially Solar Heated Residential and Commercial Development in Kendall Square, Cambridge, Massachusetts

by

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ABSTRACT

This thesis is a design of a commercial and residential development which incorporates in most of the residential units a proposed passive solar heating system. The principle constituants of this heating system are heat storing ceiling panels containing high heat of fusion salts, and "solar membrane". Solar membrane is basically transparent insulation, advantageous for admitting solar radiation into a space without allowing large conductive heat losses from it. This solar heating system seems suitable for high rise urban apartment situations and is so used in this thesis.

Numerous other ordinary architectural concerns have a substantial influence on the outcome of the design. The design includes 236 residential units (265,000 G.S.F.) along with 12,000 G.S.F. of space for community use and 253 residential parking spaces. 68,000 G.S.F. of commercial space are included as well as 95 additional commercial parking spaces. The site, in Kendall Square, Cambridge, has an area of nearly 300,000 sq. ft., so that the project as a whole has an F.A.R. of 1.6, or 1.1 not counting parking construction.

The thesis includes a brief schematic description of the passive solar heating system and its impact on the design. The design,and the rationale behind it,are described. Two illustrative performance projections for the solar heating system are given, based on the method detailed in my bachelor's thesis (mechanical engineering, May 1976, M.I.T.),the subject matter of which was the development of this method.

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INTRODUCTION

The two major intentions behind doing this thesis were; 1) that it be an interesting design exercise, and 2) that it be a continuation (though with a very different emphasis) of the work I did in my bachelor's thesis. The bachelor's thesis (mechanical engineering; May 1976; M.I.T.) was essentially an elaborate calculation projecting the performance of a passive solar heating system using two proposed building elements that, as yet, are under development. This thesis is a design of a residential and commercial development which attempts to use and accomodate these two building elements so as to provide the residence units with some solar heating.

THE PASSIVE SOLAR HEATING SYSTEM AND ITS IMPACT ON THE DESIGN

The first of these building elements is called "solar membrane". It is transparent, letting the sun's radiation in, but insulating, resisting the escape of heat. It consists of three sheets of a plastic film which has a high coefficient of light transmittance, sandwiched between protective sheets of glass inside and out. The four one inch air layers thus formed provide a good degree of insulation, with a U value of about 0.2 BTU/FT^2HR^oF. (Double glass enclosing one layer of air has a U value of about 0.58 BTU/FT^2HR^oF.) The overall coefficient of light transmission through this five layer assemblage is about 56%. (Double glass transmits about 70%, five layers of glass about 41%.) As in ordinary glass, this assemblage is opaque to infra-red radiation from bodies at room temperature. These properties of solar membrane make it attractive for use as the surface of a building which catches the sun's energy.

The second proposed building element performs another task essential to solar space heating: the storage of heat and the smoothing of the diurnal cycle of insolation. Thin layers of high heat of fusion salts (Glauber's salts), encased in polyester-sand concrete, could perform this task under some circumstances and when installed so as to actually intercept rays of sunlight entering the space. This building element, called a heat storing panel, when designed and arranged so as to provide adequate heat fluxes into and out of storage, could provide fairly simply the necessary temperature stabilization.

A complete solar heating system has two other tasks to accomplish: heat must be distributed from storage to where ever heat losses occur, and provision must be made for auxiliary heating. All four tasks (collecting, storing, distributing, and auxiliary heating), in a good system design, must be accomplished in a balanced and advantageous way. The concerns, and the responses to them, in such a design are very interactive with each other and with other architectural concerns, so that to converge on a good solution is not easily done and is well beyond the scope of this thesis. For instance, the auxiliary heating system, if it includes air ducts may also accomplish the task of heat distribution. If the auxiliary heating system does double duty in that manner and requires a significant investment anyway, there may be less incentive to maximize the area of solar membrane (therefore using auxiliary heating more often) and benefits from a reduced solar membrane area would aquire greater attractiveness. These benefits include a reduced need for temperature stabilization due to a smaller impact of the diurnal cycle and could include also a better architectural/spatial quality, lower heat loss and lower construction cost. An optimum solar heating system design could depend on the lifestyle of the residents; if they are regularly out (at work) during the afternoon there could be less demand for the heat storage panels to surpress the space temperature at that time (and during weekends some solar radiation would be excluded to maintain a comfortable temperature). Nevertheless, for the purpose of proceeding with a particular, though schematic design, a choice was made of the building type which most lends itself to the application of this proposed heating system, and from there, some basic decisions were taken as to how the solar membrane and the heat storage panels would generally be used in the design.

The following three reasons suggest that a multi-storey appartment building lends itself well to this method of solar heating. The basic intention behind the development of solar membrane is to integrate the solar energy collecting surface with the building skin, saving the need for special additional investment in solar collectors. In an urban situation there is usually no room on or around an apartment building for the deployment of an area of solar collectors commensurate with the building's floor area so that such an integration represents a special opportunity for urban situations.

Calculations in my bachelor's thesis showed that solar membrane is best used on only one wall of a house, the south wall. Through east and west walls, or the roof, the possible heat gains are not worth the additional heat losses (since opaque walls can be much more insulating than solar membrane). Apartment units commonly have only one window wall, and, having only one, they are perhaps ammenable to it being nearly all window.

Solar energy, with the climate and at the latitude of Cambridge, is not especially abundant, and an essential part of a solar heating system is a building with minimal heat losses. An apartment unit surrounded by others left and right, above and below has automatically restricted heat losses.

The design of the residential portion of this development then, arranges apartment units so that most of them face south, or nearly south; they are combined into blocks that avoid shading each other or being shaded by other buildings (see site plan), and they have south facing facades made primarily of solar membrane.

The heat storing panels are installed on the ceilings just inside the solar membrane. As suggested by Timothy Johnson, venetian blind like louvres are envisioned which, when covering the solar membrane, reflect the sun's rays entering the space up onto the ceiling (see duplex section showing energy flows). The louvres would be adjustable so that sun light could be made to hit the ceiling independently of the sun's altitude in the sky. Additionally, these louvres would act like ordinary venetian blinds to control glare, and could be raised at night or on cloudy days. In deflecting the light onto the ceiling they reduce, on winter days when the sun is low in the sky, the volume of the south facing room that is crossed by the sun's radiation (this volume would generally be uncomfortably hot during insolation).

These basic design decisions lead consequently to others. The appartment blocks have single loaded corridors running along their north sides; taking advantage of this single loaded arrangement, many of the appartment units are duplexes which then have access to small windows on the building's north facade, ammelioratᵢₙ₉ the inefficiency of single loaded corridors. In fact flats can also be designed, two layers of which can ~~also~~ be served by one corridor (see unit plans). Single loaded corridors permit natural cross ventilation and the borrowing of light for spaces such as kitchens, which bound the corridor and are the farthest from the window wall.

The solar membrane, in going from floor to ceiling, provides little sense of closure or privacy. Planter boxes 2½' by 2½', and 4' from the solar membrane, for the living-dining spaces at least, are often used to provide the sense of closure without blocking near horizontal sun rays in winter (see sections). For the duplex bedrooms on the south side of the high rise building the lack of a sense of closure remains a problem somewhat unresolved; perhaps wide window sills and louvres that stay in place below 30" above floor level would be sufficient.

For the winter sun to get past and <u>over</u> the planter boxes the solar membrane needs to be set back 6½' from their outer edges; for the winter sun to get passed and <u>under</u> the planter boxes the solar membrane should be set back much less from the outer edge, 2' perhaps, providing some protection from the summer sun. These two set backs of differing dimensions result in a building which in section has a south facade that steps back 4½' every two storeys.

In plan however, the tendency for solar membrane is to make long south walls that do not jog in and out. For them to do so increases the heat loss through them without increasing the heat gain, and in order to maintain the privacy of one unit from another the jogs would have to be primarily opaque resulting in one unit shading another.

THE DESIGN: DESCRIPTION AND EXPLANATION

The Site and Context

The site chosen was the triangular parcel of land at Kendall Square in Cambridge, Massachusetts. It is bounded by Main Street, Broadway, and Ames Street, and has on it a few old one storey commercial and light industrial buildings, plus a subway power station right at the Kendall Square corner. None of these buildings need be preserved. The site is flat and has hardly any trees. It has an area of nearly 300,000 sq. ft. or about 6.7 acres.

The context for this site is in some ways very strong and in others, very weak. It includes the Kendall Square subway station and a five bus bus station. It is on Main Street, which has the beginnings of a commercial strip. The Kendall Square location is where the Longfellow Bridge from Boston arrives in Cambridge. The site has to its west and east more of the same barren land which would also eventually be developed with commercial, residential, office, light industrial buildings, and a hotel. There is currently no neighborhood character or pleasant urban fabric that suggests how the site should be developed.

The site has an east-west orientation and a large fifteen storey monolithic office building to the north that would suffer little should any long shadows enter its property.

The Program

The design process began with a very rudimentary program:

Housing -	240,000 G.S.F. or about 200 units at 1,200 G.S.F. per unit
Commercial space -	50,000 G.S.F. of which some good portion should be a department store.
Parking -	one space per unit and one per 1,000 G.S.F. of commercial space, as required by the state building code.
Subway station -	entries and exits
Bus stop -	five busses.

The square footage figures were suggested by Matthew Gottsegen, whose M. Arch. A.S. thesis (June 1976) included, along with development proposals, substantial research on how the vacant land near Kendall Square might be developed. The figures are from the low end of the possible development densities.

The design as drawn has square footages roughly as follows:

Housing -	265,000 G.S.F. for 236 residential units, and 12,000 G.S.F. of community/public space. The amount of community space could easily be increased by making parts of it two storeys, as shown in section BB. The number of residential units could be increased by altering the ratio of duplexes to flats.

Commercial space - 68,000 G.S.F. of which 45,000 G.S.F. are the department store (39,400 G.S.F. at grade, and at the second level, 5,600 G.S.F. are basement storage spaces).

Parking - 95 commercial parking spaces (38 on Main Street, 57 underground).

253 residential parking spaces (53 at grade, 200 underground).

216 enclosed bicycle parking spaces and 13 motorcycle parking spaces (both figures could easily be increased).

126,000 G.S.F. is the total of the entire parking level (including mechanical spaces, excluding department store storage) plus the covered residential parking area at +2' on Broadway.

The total square footage as drawn is then roughly 471,000 G.S.F. which constitutes an F.A.R. of almost 1.6. The same figures, not counting the parking and mechanical areas as above, are: 333,000 G.S.F. which corresponds to an F.A.R. of about 1.1.

Design Objectives

In order to expand upon the rudimentary program a more specific set of design objectives was stated as follows during the semester. Not all of the issues here raised were substantially addressed.

1) objectives for the housing:

- There should be a variety of the dwelling units; from efficiency units to five bedroom units; penthouse like units to units with small gardens on the ground; units with a gradual pedestrian relationship to Cambridge streets, and units that have easy access to a parking garage; there should be duplex units and units with differing spatial organizations and bedrooms accomodating to children.

– The units are intended to be independent of each other in the usual American manner; there is no special intention to create architecturally a close knit community.

– Nearly every unit should have a privately owned balcony, garden, or access to the outside.

2) objectives for the commercial space:

– The commercial space should be practical, adequately servicable, and located so as to be easily accessible by shoppers.

– The individual commercial spaces should reinforce each other in making an attractive, busy, commercial zone (a strip) on the site, distinct from other residential zones.

3) objectives for the public open spaces:

– There should be a variety of these spaces, providing places for children to play in, places for specific summer and winter activities, such as basketball or skating; places for fairly large scale group outdoor events such as the assembling of holiday parades.

– The outdoor spaces should be pleasantly landscaped, and some small portions of the site will operate simply as little city parks.

– The present impoverished topography needs to be improved upon. The large, windowless masses of the commercial buildings and earth moving operations will be useful in this regard.

4) objectives for the project's impact on the site and surrounding Cambridge:

— The indecisive commercial quality of Main Street should be made more decisive by the location of the new commercial space along Main Street.

— The surrounding open land has very little to offer the site; the new development will concentrate on making its own site hospitable, rather than contributing much to the land north and west of the site.

— Since future development of this land to the north and west is expected, the potential for strong links to that future development must be provided.

5) objectives for the parking facilities:

— The parking facilities should be compact and convenient to use and control, but should not necessarily allow parking near every unit; some units will have access to their parking spaces only after a fairly long walk, partially outside.

6) objectives for the bus and subway stations:

— These stations should be functionally convenient, not reduced to the utilitarian minimum, but instead, pleasant, and to the extent possible, easily supervised by police or other citizens.

Site Planning Rationale and Design Features

Apartment units are collected into two ten storey blocks along the northern, Broadway edge of the site where the long shadows they cast go onto the street rather than onto another portion of the site. One block is rotated away from Broadway to face more directly south, and to relieve what would otherwise be a 700' north wall of building. The space then freed at ground level on Broadway is allocated to unspecified community uses, such as a small health care clinic, a woodworking shop, or photographic darkrooms. The other ten storey block remains parallel to Broadway, leaving room for a large public space in the middle of the site. The height of this block is limited by the set back (from the center line of Broadway) requirement. The building tapers down into Kendall Square because this seemed to me a preferable massing, and one which would probably make a smaller contribution to the windiness of Kendall Square. The north-south corridor joining the two blocks contains elevators and a fire stair, and consists of double height spaces since there are corridors only every second floor. These spaces could easily accomodate laundry facilities and more with the installation of mezzanines. The exterior walls of this corridor should be largely opaque to prevent overheating in the morning and the afternoon, and to prevent high heat losses at other times. The east elevation of this corridor, visible when driving west on Broadway, could be designed to include three or four of the huge advertising bill boards currently on the site. The building has a motor entrance on Broadway, but its major pedestrian entrance is from the public space south of the building, closely related to a subway exit on, and a pass through to Main Street. Fire stairs occur along the continuous Broadway elevation at about the required 150' intervals. (Actually, some of the intervals are too long and another stair tower needs to be added.)

The commercial space is laid out along Main Street. It starts in Kendall Square with a restaurant associated with a trellis covered, outdoor eating space usable in summer by office workers taking lunch breaks, and possibly as an outside cafe. It continues along Main Street with a zig zagging facade, as shown in the perspective sketch with the drawings. This zig zag form accomplishes four things: It provides spaces distinct from the thoroughfare of the sidewalk from which to enter shops or look in windows. Outdoor sales to a small extent could be accomodated in them. Extending the sidewalk into the shops in this way permits the street trees to stand away from the street edge where in this case they would not be plantable due to the subway station (see section BB). The zig zag differentiates the facade into portions that directly face motorists going east on Main Street (that for this block will be a one way street), which could be a sometimes advantageous alternative to the usual, flat, continuous, commercial facade. The zig zag also allows a few of the apartments built above the commercial space to have terraces as well as clear sight lines to the street and its activity. Service access to these stores is not especially convenient: a truck dock on Main Street connects to a service corridor running behind the stores. The corridor leads at one end to a trash chute, and at the other, to a dumpster enclosure.

The department store is located between the bus stop and the subway station. It should act as a virtual ground form barrier between the bus stop and the residential public space which, along with the Main Street commercial building, it helps to define. It acts as a ground form because a three storey walk up block of apartments are built on top of it, trees are planted on top of it, and an earth berm is piled against it. It improves the topography of the site, providing a place for community use that has a view of the central public space, providing a staging point for the bridge which would be a connection to future development across Ames Street, and providing a north slope for the children's play area which includes a small sled run.

At the north west corner of the site a small amount of four layered housing is arranged in rows running north south. On Ames Street, this was done to reestablish the linear, enclosed form of a street so severely undermined by the bus stop and other vehicular uses consolidated in that corner of the site. The other, shorter, north south row completes the enclosure of the children's play area and contributes to the definition of the north entrance to the site. This entrance would become the site's connection to future developments to the north west. The day care center is located on the ground floor of this short, north south row of housing, at the entrance to the play area. The play area is surrounded by private gardens at 2' above grade and with two storey outdoor fire escape stairs. Hopefully, families with young children would occupy the associated units and their children would benefit from easy access to the play area (and from there to places ever further afield). The north south row on Ames Street has a zig zag facade which orients windows of solar membrane south west, instead of due west, the former being a preferable orientation.
A group of four duplex units share each little yard partially enclosed by the stairs which access the 3^rd^ and 4^th^ floor duplexes. Under these stairs could be enclosures for trash cans and bicycles.

Other features included in the design are small gardens at the bases of the ten storey housing blocks. In section BB it is attempted to fit in gardens accessible to the first floor as well as gardens accessible to the second floor. Hopefully, deciduous plants providing privacy between gardens in summer, would allow sufficient sunlight to pentrate the first floor apartment during winter. Privacy in the first floor garden from the second floor apartment might be provided with a trellis or awning. Twelve small gardens are provided that do not have direct access to any unit;

these would operate as do the Victory Gardens, for people, groups, or clubs that are sufficiently enthusiastic about gardening.

The two other major features of the central space are simply a flat 50' by 120' lawn, and a region of densely planted trees. The paved area at the street level adjacent to the department store is intended as a place that could be used for outdoor sales. On the roof of the second layer of the department store is room for a basketball court . A portion of the Main Street commercial space that is shaded in winter by a building across the street, has room for a tennis court. Both of these courts would unfortunately have an east west orientation.

No space usable by the community was included in this design on top of the ten storey blocks, though one glance at the south elevation shows that there would be more than one reason for including some roof top spaces.

Parking for the sixteen duplex units on Ames Street is provided nearby at grade, while parking for the other apartment buildings enclosing the play area (including the units built at the top of the earth berm) is provided at the first floor of the nearest ten storey block. All other residential parking is underground and serves the housing along Main Street and along Broadway, elevators connecting the residential levels to the parking level. Motorcycle parking is provided where columns obstruct what would otherwise be a car parking place. Bicycle parking for housing along Broadway is at the parking level, accessed by special ramps. All other bicycle parking is at grade, fairly near where one starts to go up to one's apartment.

Refuse collection is accomplished with trash chutes, usually associated with fire stairs, that empty into trash rooms at the parking level. From there carts can be rolled to elevators that lift them to street level at one of the three dumpster locations.

Mechanical rooms for the apartment units are at the basement level; horizontal distribution of the services is shown diagrammatically in sections AA and BB, and vertically in the schematic structural system drawing. The department store has its own mechanical room at grade. The commercial space along Main Street is served by mechanical rooms at the parking level, which could be supplemented by roof top machines beyond the tennis court.

In deploying the residential units so as, in most cases, to catch winter sunlight, and in responding to some site planning intentions, a variety of dwelling situations has naturally arrisen, although the constraints of accomodationg solar membrane and the heat storing panels do severely limit how the exterior edge of an apartment unit is treated.

ILLUSTRATIVE PERFORMANCE PROJECTIONS

The following calculations are based on the methods used in my bachelor's thesis. They give estimates for two useful parameters of performance of the passive solar heating system. One is a percentage of a year's heating that is provided by the sun, and the other is the range of temperature fluctuation that the heat storage panels permit.

The calculations are for an apartment unit like the 1,615 G.S.F. duplex shown in plan and in the energy flow section, but proceed considering only one 10' high floor as though it were insolated from the other. The unit is assumed to face directly south. The heat loss rate for the 10' by28' by 32' portion of building is taken as 150 BTUH/^{o}F. The insolation that it receives is taken from the Carrier Handbook of Air

Conditioning System Design, using the table for insolation through glass with a transmission coefficient of 88% and for a latitude of 40^{o} N. The entries in this table are multiplied by 56/88 to include the effect of solar membrane having a transmission coefficient of 56%. The effect of Cambridge being at about $42\frac{1}{2}^{o}$ N is ignored. The table already includes reductions in insolation caused by mullions. The transparent area available to insolation is taken as 9' x 27'.

In the following table the percentage of useful heating provided by the sun is calculated. Insolation which would raise the average sustainable temperature inside the space above $65^{o}F$ is not counted as useful (the calculation uses $65^{o}F$ degree-months, similar to $65^{o}F$ degree-days).

TABLE 1 (continues on next page)

	JAN 21	FEB 20	MAR 22	APR 20	MAY 21	JUN 21
INSOLATION BTU/FT^2 DAY	691	712	559	411	249	194
X CLOUDINESS REDUCTION FACTOR	0.47	0.56	0.57	0.56	0.59	0.62
X 27'x9' = AVERAGE = BTU/DAY	78,948	96,957	77,392	55,963	35,663	29,190
÷ 50 BTUH/$^\circ$F ÷ 24 HRS/DAY = AVERAGE SUSTAINABLE ΔT $^\circ$F=	22	27	21	16	10	8
AVERAGE AMBIENT TEMP. $^\circ$F	28	29	37	46	58	67
SUSTAINABLE INSIDE TEMP. T=	50	56	58	62	68	75
DEGREE MONTHS NEEDING AUXILIARY HEATING 65°-T =	15	9	7	3	···> SUM = 45 <····	
BOSTON DEGREE MONTHS 65°- AMBIENT TEMP.	37	36	28	19	7 ···> SUM = 194 <····	

TABLE 1 (continued)

	JUL 23	AUG 24	SEP 22	OCT 23	NOV 21	DEC 22
INSOLATION BTU/FT^2 DAY	249	411	559	712	691	667
X CLOUDINESS REDUCTION FACTOR	0.64	0.63	0.61	0.58	0.48	0.48
X 27'x9' = AVERAGE = BTU/DAY	38,686	62,958	82,824	100,420	80,627	77,857
÷ 50 BTUH/°F ÷ 24 HRS/DAY = AVERAGE SUSTAINABLE ΔT °F=	11	17	23	28	22	22
AVERAGE AMBIENT TEMP. °F	72	69	64	54	43	32
SUSTAINABLE INSIDE TEMP. T=	83	85	87	82	65	54
DEGREE MONTHS NEEDING AUXILIARY HEATING 65°- T =	→ SUM = 45 ←				0	11
BOSTON DEGREE MONTHS 65°- AMBIENT TEMP.	→ SUM = 45 ←		1	11	22	33

The table shows that heating for 194 degree-months was necessary and that the sun provided heating for all but 45 of them. The percentage of heating provided by the sun over the year, assuming perfect storage and an inside temperature of 65°F (before counting the heating effects of electric appliances and people) is (194 - 45)/194, or 77%. The same calculation, assuming that 20% of the insolation is obstructed by overhangs, plants, or balcony furniture, produces the figure of 64% solar heating during a year.

The projection for the variation of the temperature inside the space during a day is a much more complicated calculation. It involves determining how much heat is being stored during insolation, which depends very much on the sun's position in the sky since this effects what fraction of the insolation actually hits the ceiling heat storage panels. The dynamic effect of the space's sensible thermal storage capacity must be accomodated by making the calculation an iterative one. An outdoor temperature variation must be assumed. Simplifying assumptions are made: that the diffuse component of insolation is distributed in the same portions as the direct solar radiation, that the high heat of fusion salts have a phase change temperature from which they never vary. The following table assembles this and other information into a temperature variation over 48 hours for the particular circumstance defined by all the assumptions and specifics in the calculation. The result, a high temperature of 76.24°F and a low of 61.33°F (without the use of auxiliary heating) is not bad, and suggests that using latent heat storage panels on the ceiling and reflecting louvres on the south walls of solar membrane is a plausible means of heat storage and temperature stabilization.

TOTAL BTU'S PENETRATING MEMBRANE
× SHADING FACTOR
× 0.7 ← 70% { 85% OF INCIDENT LIGHT × REFLECTED TO CEILINGS; 85% OF FACADE WITH LOUVRES } ASSUMED EFFECTIVENESS OF LOUVRES
× 0.9 ← 90% ABSORBTION ON DARK CEILING PANELS
× 0.87 ← FRACTION OF HEAT ABSORBED AT SURFACE WHICH FLOWS INTO STORAGE
GIVES

SENSIBLE HEAT STORAGE CAPACITY 5,000 BTU/°F,

LATENT STORAGE → SPACE 300 BTU/FT² HR °F,

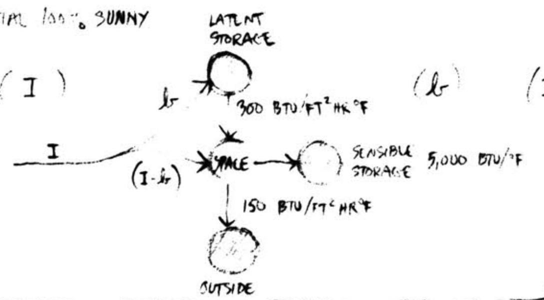
SPACE → OUTSIDE 150 BTU/FT² HR °F,

PHASE CHANGE TEMP. = 80°F,

$$T = \frac{1}{5,225}\left[4,775\,T_p + 2,400 + 150\,T_{outside} + (I-b)_M\right]$$

BTU/HR.

TIME	DEC 22ND 40°N CARRIER INSOLATION TABLE ENTRY BTU/FT² HR	TOTAL PENETRATING SOLAR MEMBRANE 27' × 9' REDUCED BY 0.8 FOR WHATEVER PARTIAL OBSTRUCTION OF THE SOLAR MEMBRANE AND BY 56/88 FOR THE HIGHER REFLECTIVITY OF SOLAR MEMBRANE	FRACTION OF INSOLATION WHICH COULD HIT CEILING DETERMINED TRIGONOMETRICALLY USING PROFILE ANGLES: SHADING FACTOR	AMOUNT ABSORBED BY CEILING BTU	REMAINDER CAUSING INSTANTANEOUS HEATING ON THE HOUR BTU	DURING THE HOUR BTU	OUTSIDE TEMP DURING THE HOUR °F	SPACE TEMPERATURE °F ON THE HOUR	SPACE TEMPERATURE °F ON THE HOUR		TIME
7							24	61.33	65.53	MIN TEMPS.	7
8	51	6,197	0.16	543	5,654	2,827	25	61.90	65.74		8
9	99	12,029	0.55	3,626	8,402	7,028	30	63.37	66.88		9
10	134	16,281	0.69	6,157	10,124	9,263	34	65.26	68.46		10
11	158	19,197	0.91	9,575	9,622	9,873	37	67.18	70.11		11
12	165	20,048	1.00	10,988	9,059	9,341	40	68.92	71.66		12
1	158		0.91			9,341	42	70.57	73.07		1
2	134		0.69			9,873	43	72.21	74.50		2
3	99		0.55			9,263	42	73.57	75.65	MAX TEMPS.	3
4	51		0.16			7,028	40½	74.33	76.24		4
5						2,827	39	74.18	75.93		5
6		127,456 BTU					37	73.45	75.04		6
7							34½	72.71	74.16		7
8		TOTAL 100% SUNNY					32	71.96	73.29		8
9							30	71.22	72.43		9
10							29	70.51	71.62		10
11		(I)		(b)	(I-b)	$(I-b)_M$	28	69.83	70.85		11
12							27	69.17	70.11		12
1							26	68.57	69.41		1
2							25	67.96	68.75		2
3							24½	67.40	68.12		3
4							24	66.88	67.54		4
5							23½	66.39	66.99		5
6							23	65.92	66.47		6
7							24	65.53	66.03		7
						AVERAGE TEMPS. →	31.67°F	69.04°F	70.78°F		

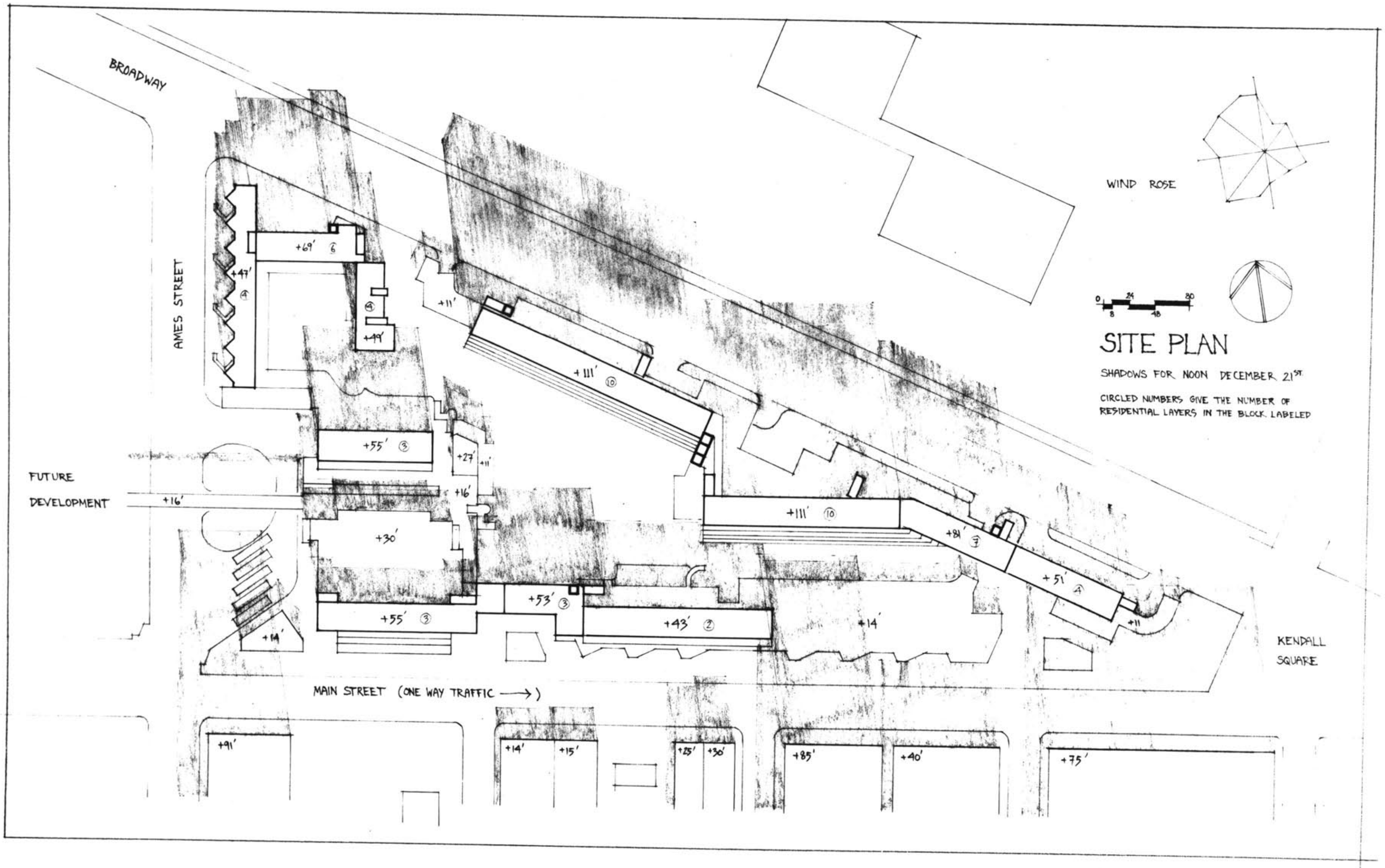


∴ DAY'S HEAT LOSS = 134,532
DAY'S TOTAL INSOLATION · 127,456
∴ SUN PROVIDE 95% OF HEAT

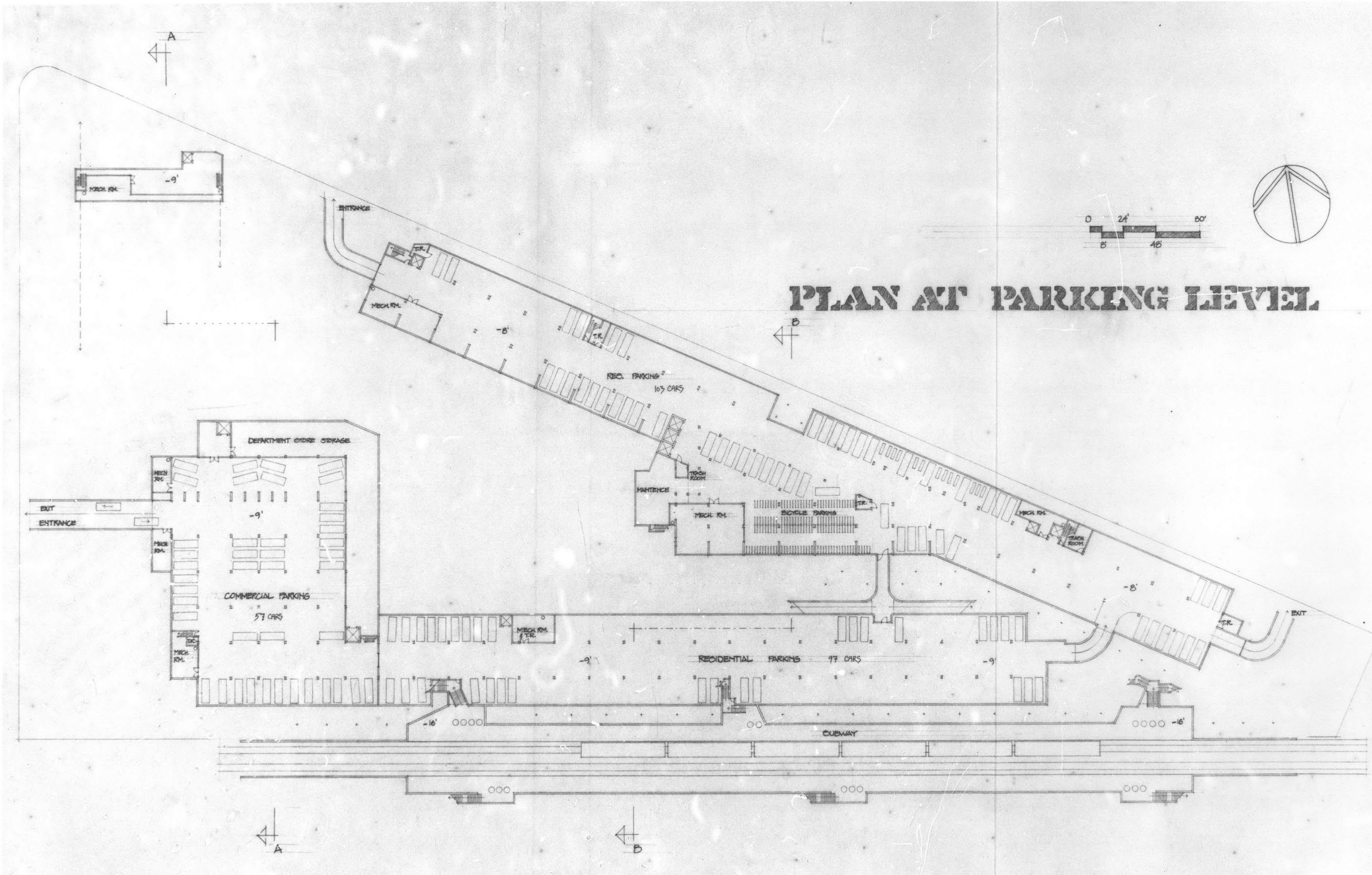
∴ DAY'S HEAT LOSS = 140,796 BTU
DAYS TOTAL INSOLATION = 127,456 BTU
∴ SUN PROVIDED 91% OF HEAT

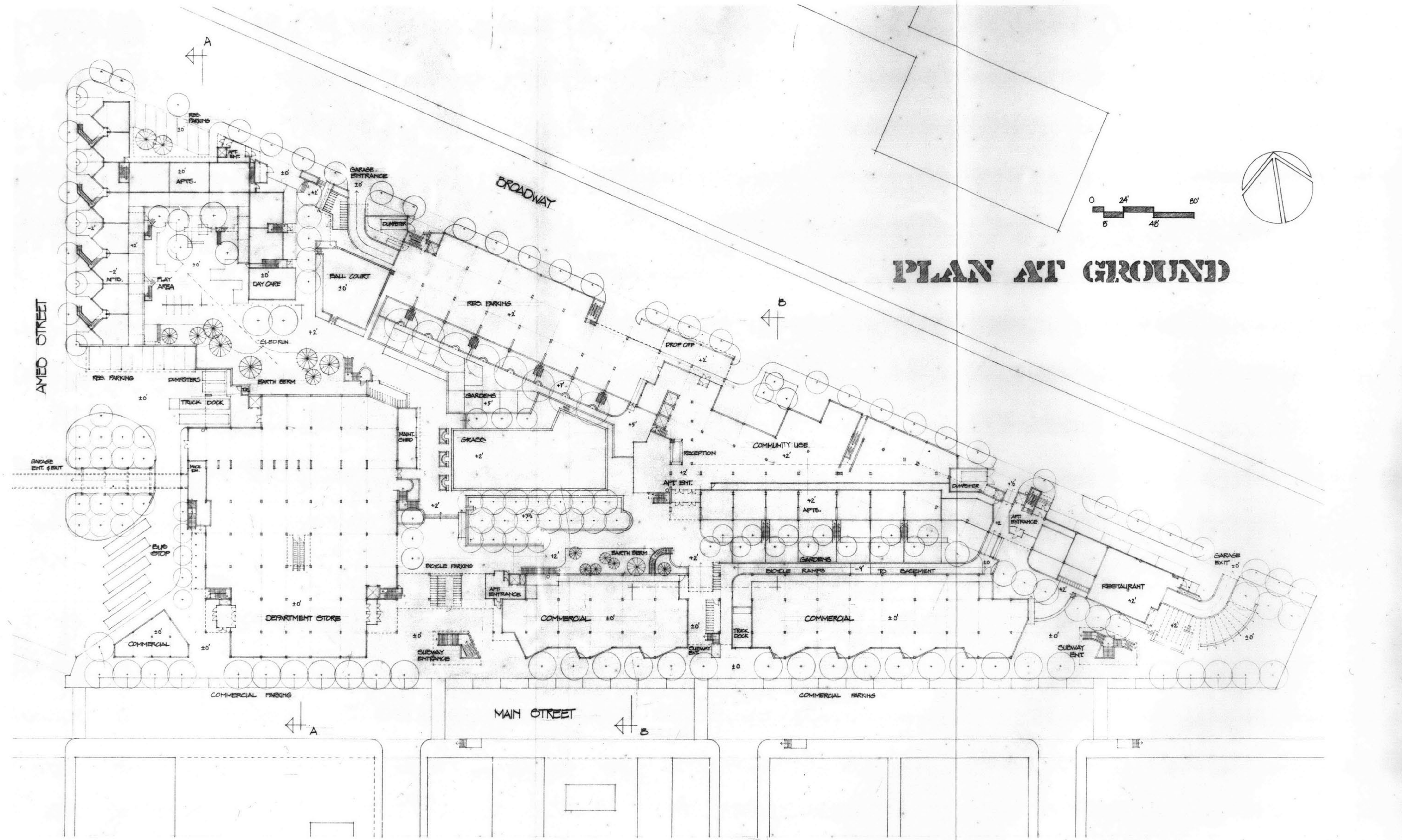
PROJECTION OF SPACE TEMPERATURE VARIATION WITH TIME

TABLE 2.
61.33°F ↔ 76.24°F

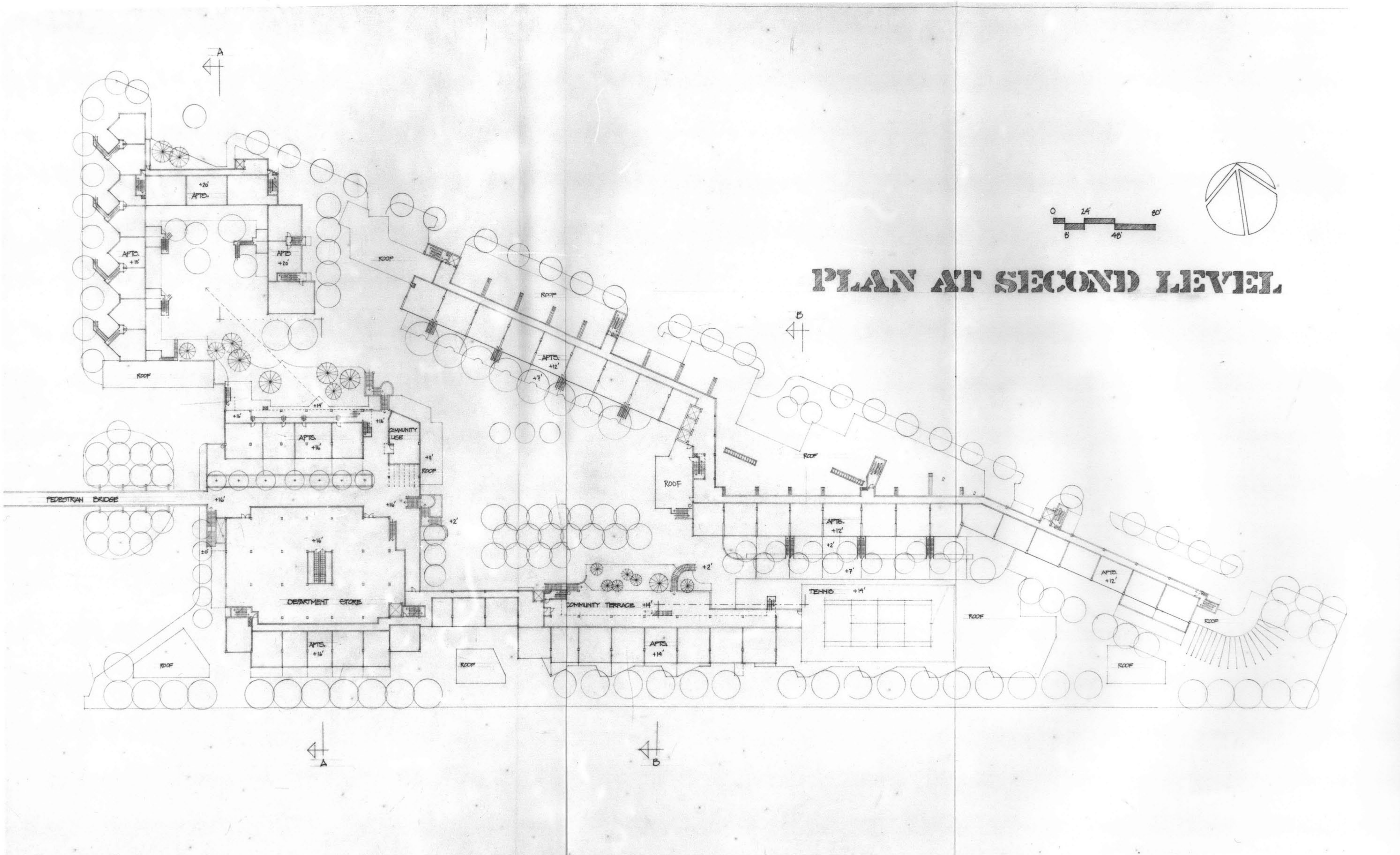

BROADWAY
AMES STREET
FUTURE DEVELOPMENT
MAIN STREET (ONE WAY TRAFFIC ⟶)
KENDALL SQUARE
WIND ROSE
SITE PLAN
SHADOWS FOR NOON DECEMBER 21ST
CIRCLED NUMBERS GIVE THE NUMBER OF RESIDENTIAL LAYERS IN THE BLOCK LABELED
+69' 6
+47' 4
+49' 4
+11'
+111' 10
+55' 3
+27'
+16'
+30'
+53' 3
+43' 2
+111' 10
+84' 7
+51' 4
+14'
+91'
+15'
+25'
+30'
+85'
+40'
+75'

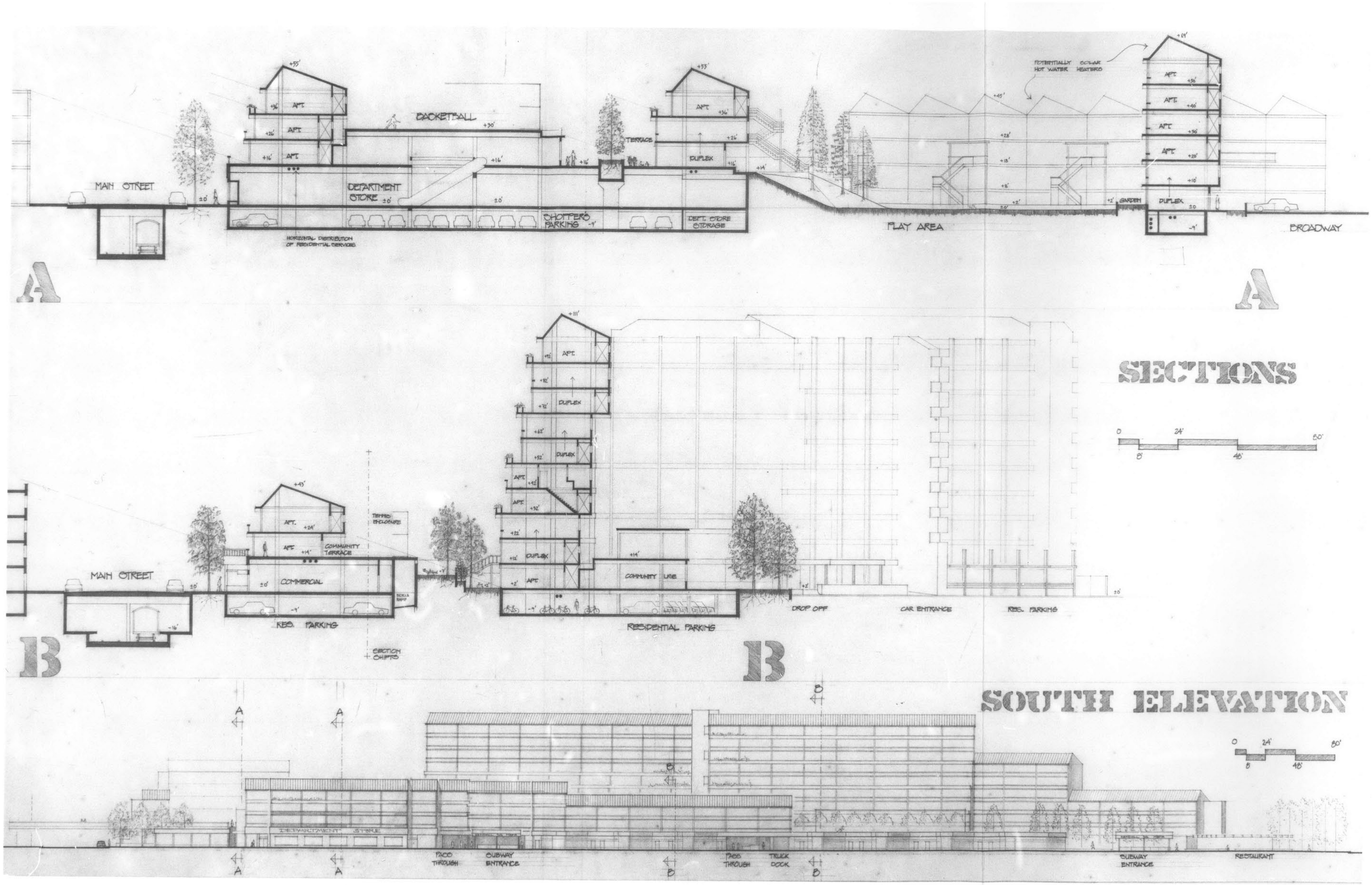
PLAN AT PARKING LEVEL

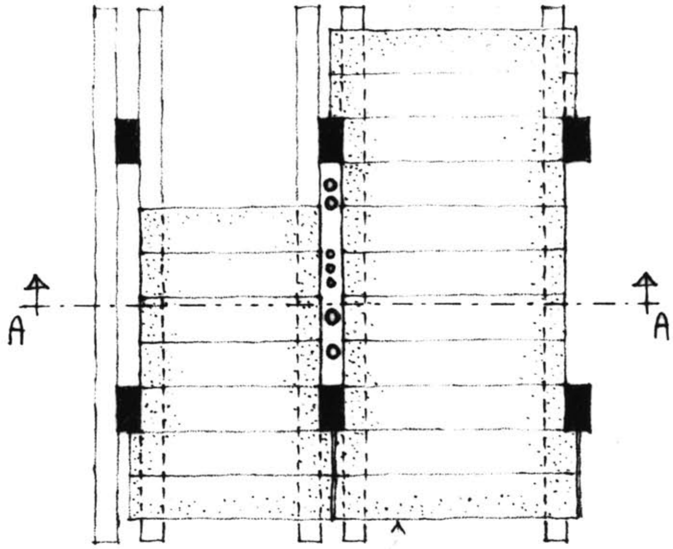


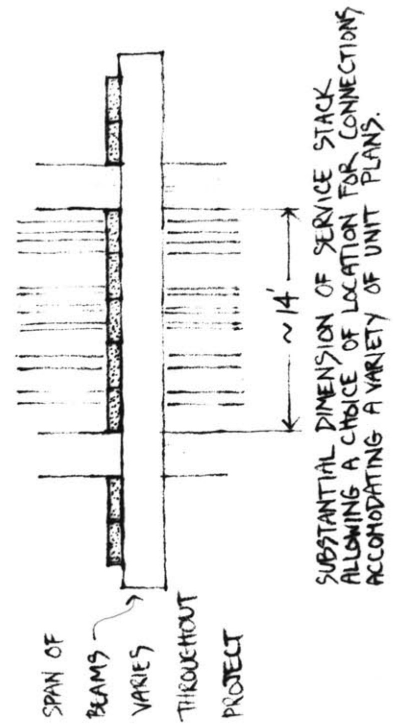


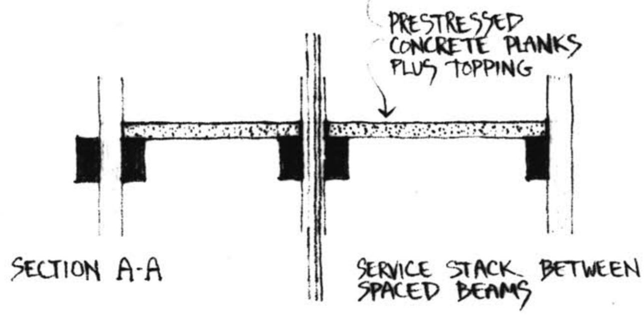
PLAN AT GROUND


PLAN AT SECOND LEVEL
0
8'
24'
48'
80'
A
B
APTS.
+20'
APTS.
+15'
APTS
+20
ROOF
ROOF
APTS.
+12'
+7'
+14'
+16'
APTS.
+16'
COMMUNITY USE
+11'
ROOF
PEDESTRIAN BRIDGE
+16'
+16'
+2'
±0'
+16'
DEPARTMENT STORE
APTS.
+16'
ROOF
ROOF
COMMUNITY TERRACE +14'
APTS.
+14'
+2'
ROOF
ROOF
APTS.
+12'
+2'
+7'
TENNIS +14'
ROOF
ROOF
APTS.
+12'
ROOF

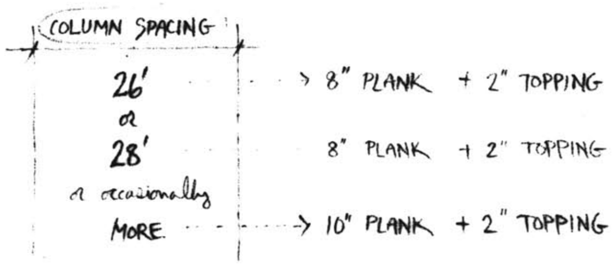

MAIN STREET
BASKETBALL
APT.
TERRACE
DUPLEX
DEPARTMENT STORE
SHOPPERS PARKING
DEPT. STORE STORAGE
HORIZONTAL DISTRIBUTION OF RESIDENTIAL SERVICES
POTENTIALLY SOLAR HOT WATER HEATERS
GARDEN
PLAY AREA
BROADWAY
A
A
SECTIONS
0
24'
8'
48'
80'
MAIN STREET
COMMUNITY TERRACE
COMMERCIAL
RES. PARKING
SECTION SHIFTS
COMMUNITY USE
RESIDENTIAL PARKING
DROP OFF
CAR ENTRANCE
RES. PARKING
B
B
SOUTH ELEVATION
0
24'
8'
48'
80'
DEPARTMENT STORE
PASS THROUGH
SUBWAY ENTRANCE
PASS THROUGH
TRUCK DOCK
SUBWAY ENTRANCE
RESTAURANT

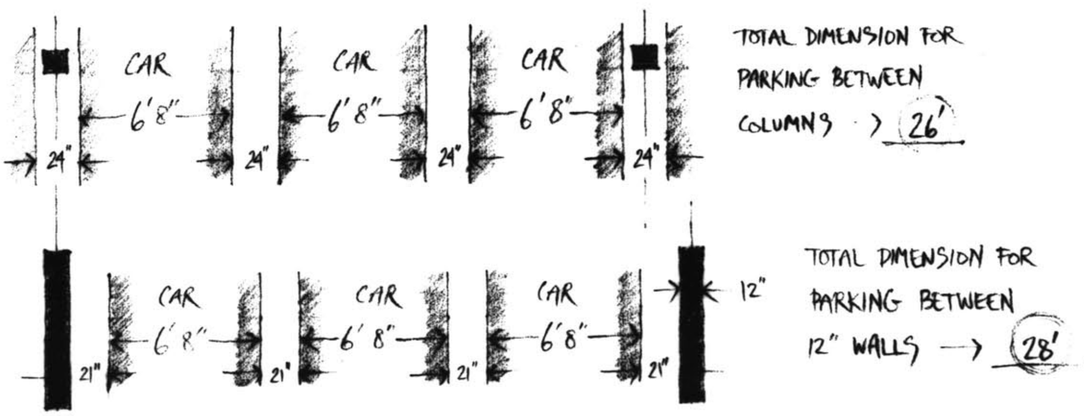






SCHEMATIC STRUCTURAL SYSTEM

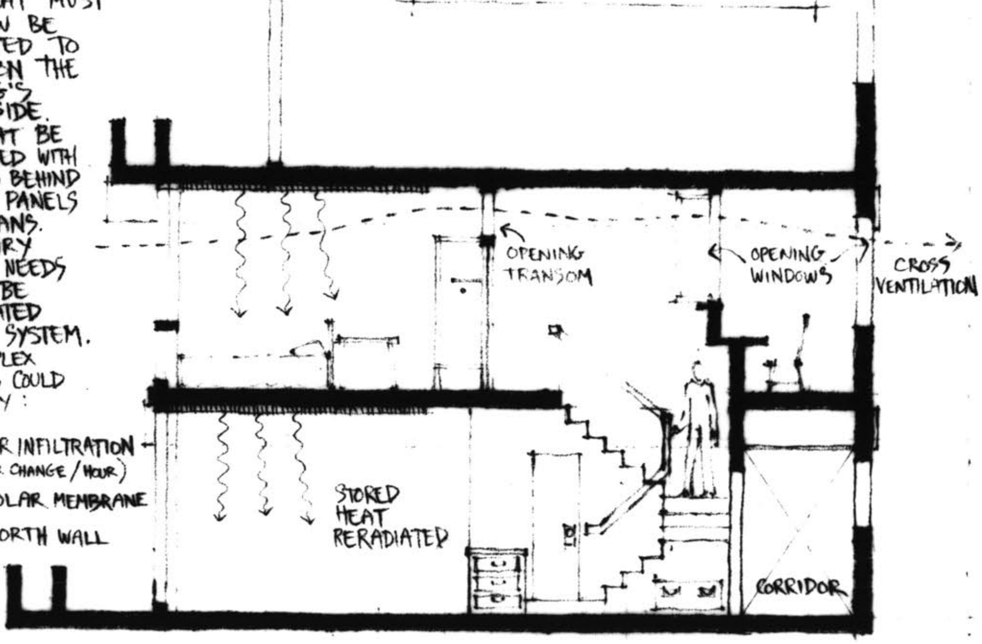




DUPLEX SECTION SHOWING ENERGY FLOWS
+ VENTILATION + NATURAL LIGHTING

- STORED HEAT MUST SOME HOW BE DISTRIBUTED TO SPACES ON THE BUILDING'S NORTH SIDE.
- THIS MIGHT BE ACCOMPLISHED WITH AIR DUCTS BEHIND THE SALT PANELS OR WITH FANS.
- AUXILLIARY HEATING NEEDS ALSO TO BE INCORPERATED INTO THE SYSTEM.
- TOTAL DUPLEX HEAT LOSS COULD BE ROUGHLY:

140 BTUH/°F AIR INFILTRATION (½ AIR CHANGE / HOUR)
112 BTUH/°F SOLAR MEMBRANE
45 BTUH/°F NORTH WALL
~ 300 BTUH/°F



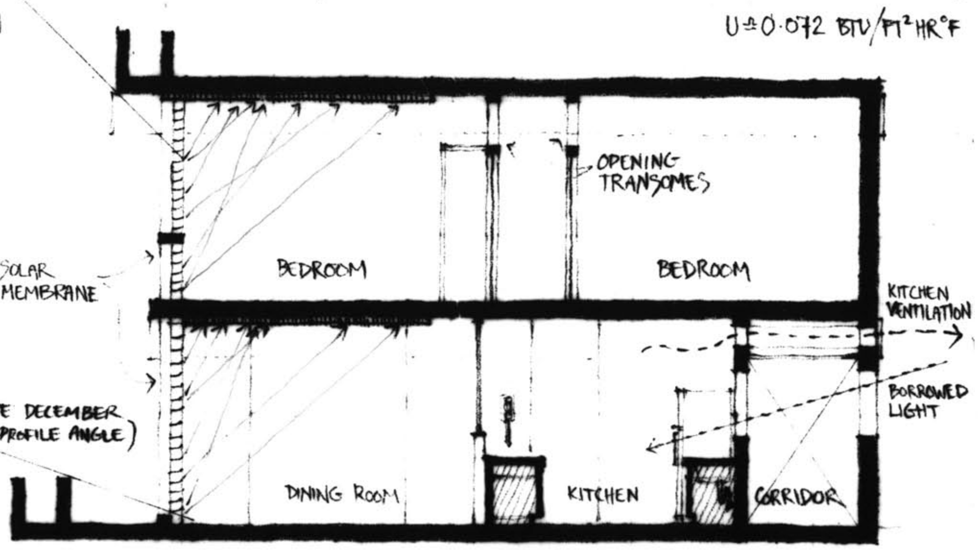
SOUTH WALL: ~ 100% SOLAR MEMBRANE
U ≏ 0.2 BTU/FT² HR °F

NORTH WALL: 20% QUINTUPLE GLAZING
80% 6" FIBERGLASS
U ≏ 0.072 BTU/FT² HR °F

45° SUN RAY (EARLY MARCH PROFILE ANGLE)

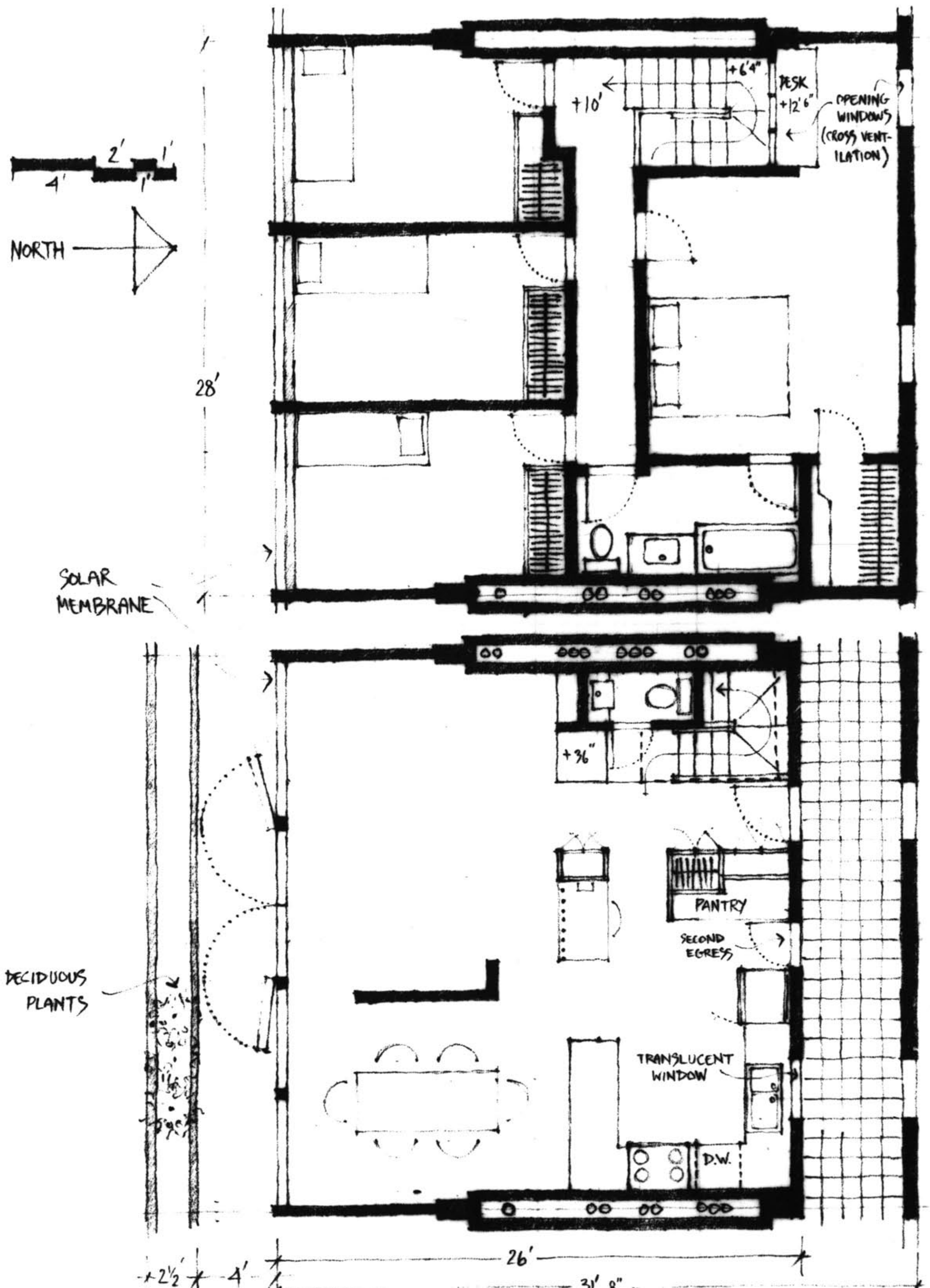
SOLAR MEMBRANE

19° SUN RAY (LATE DECEMBER PROFILE ANGLE)

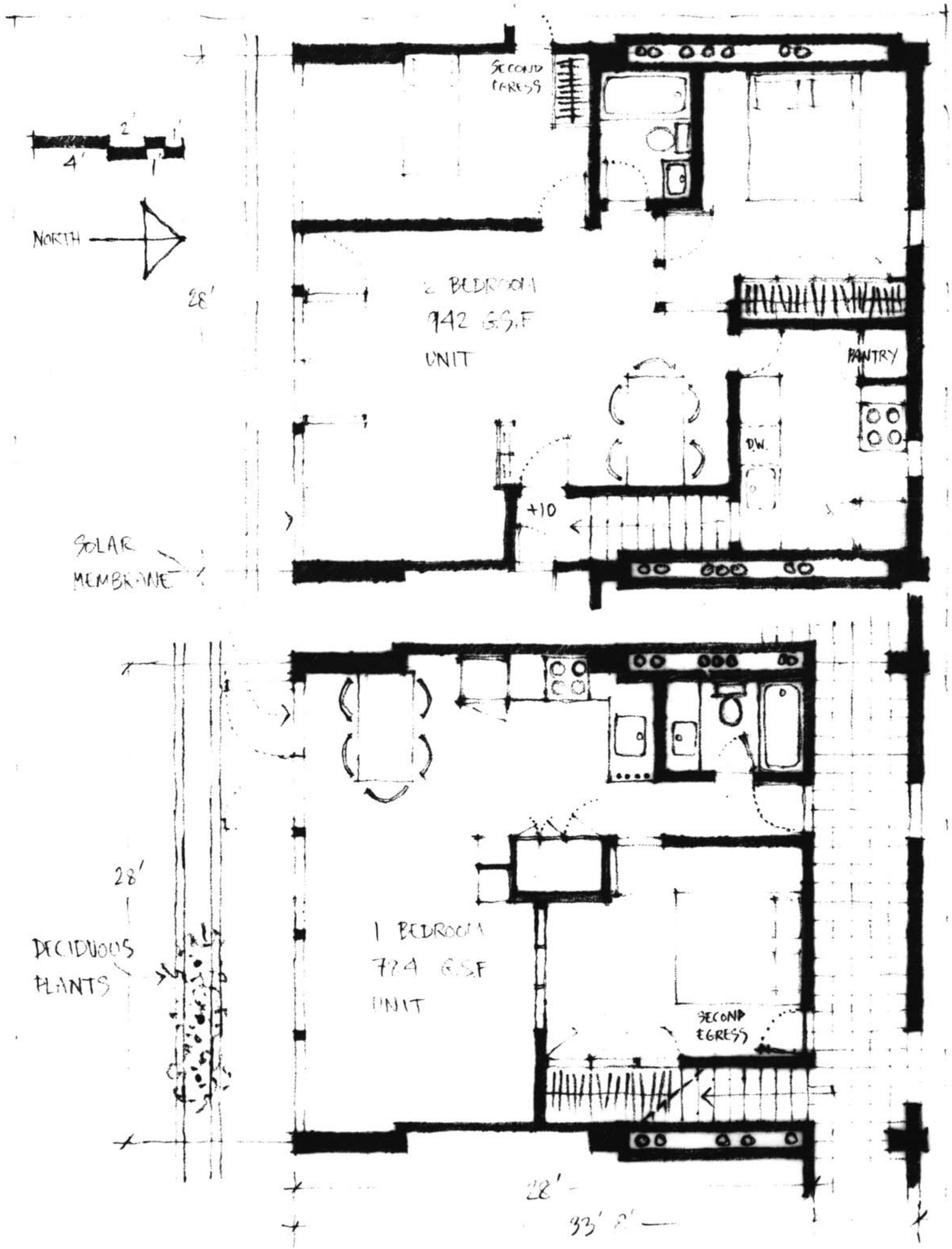


LOUVRES, LIKE VENETIAN BLINDS, REFLECT SUN'S RAYS ONTO HEAT STORING CEILING PANEL CONTAINING GLAUBER'S SALTS.

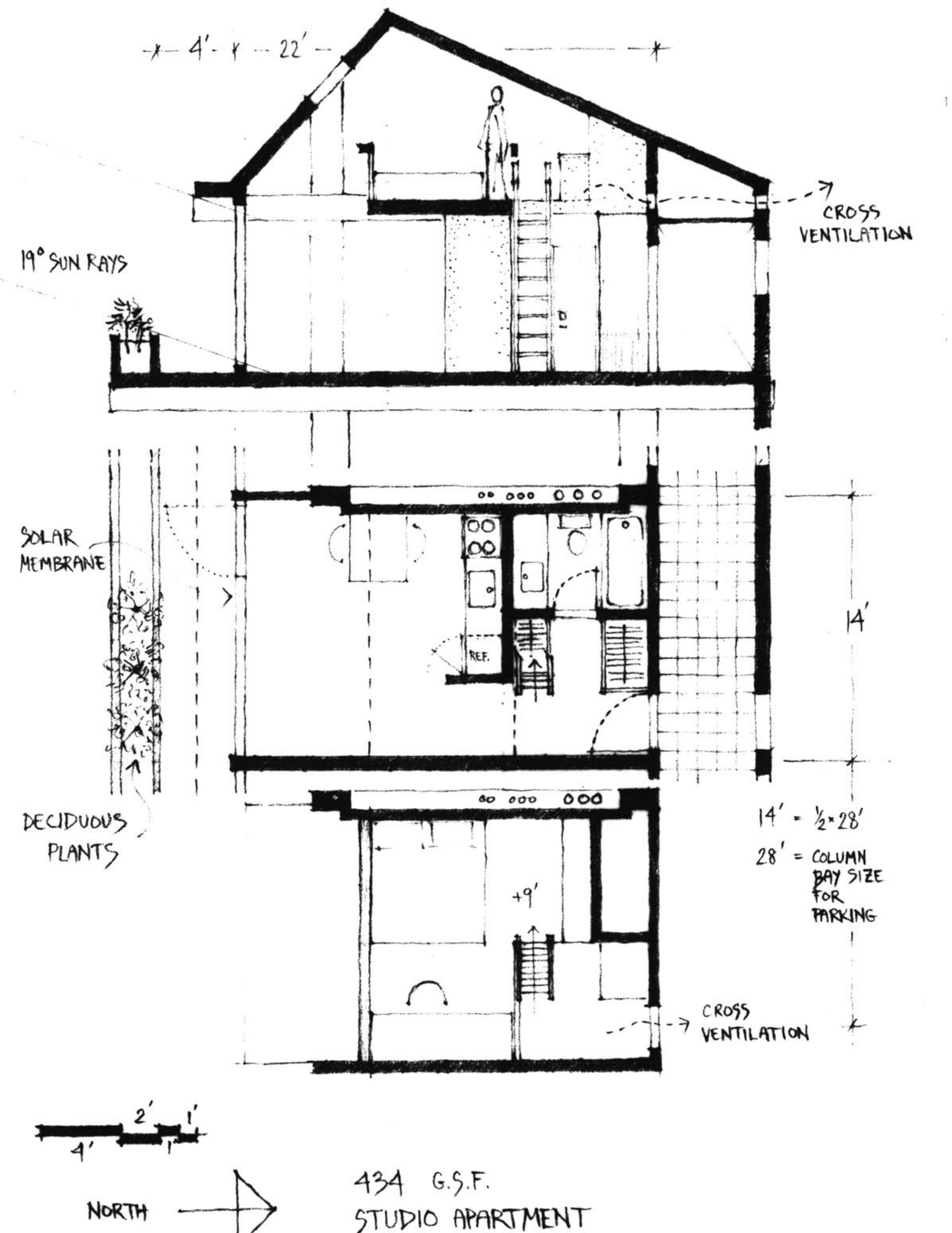
LOUVRES CONTROL GLARE AND CAN BE DRAWN UP AT NIGHT OR ON CLOUDY DAYS.



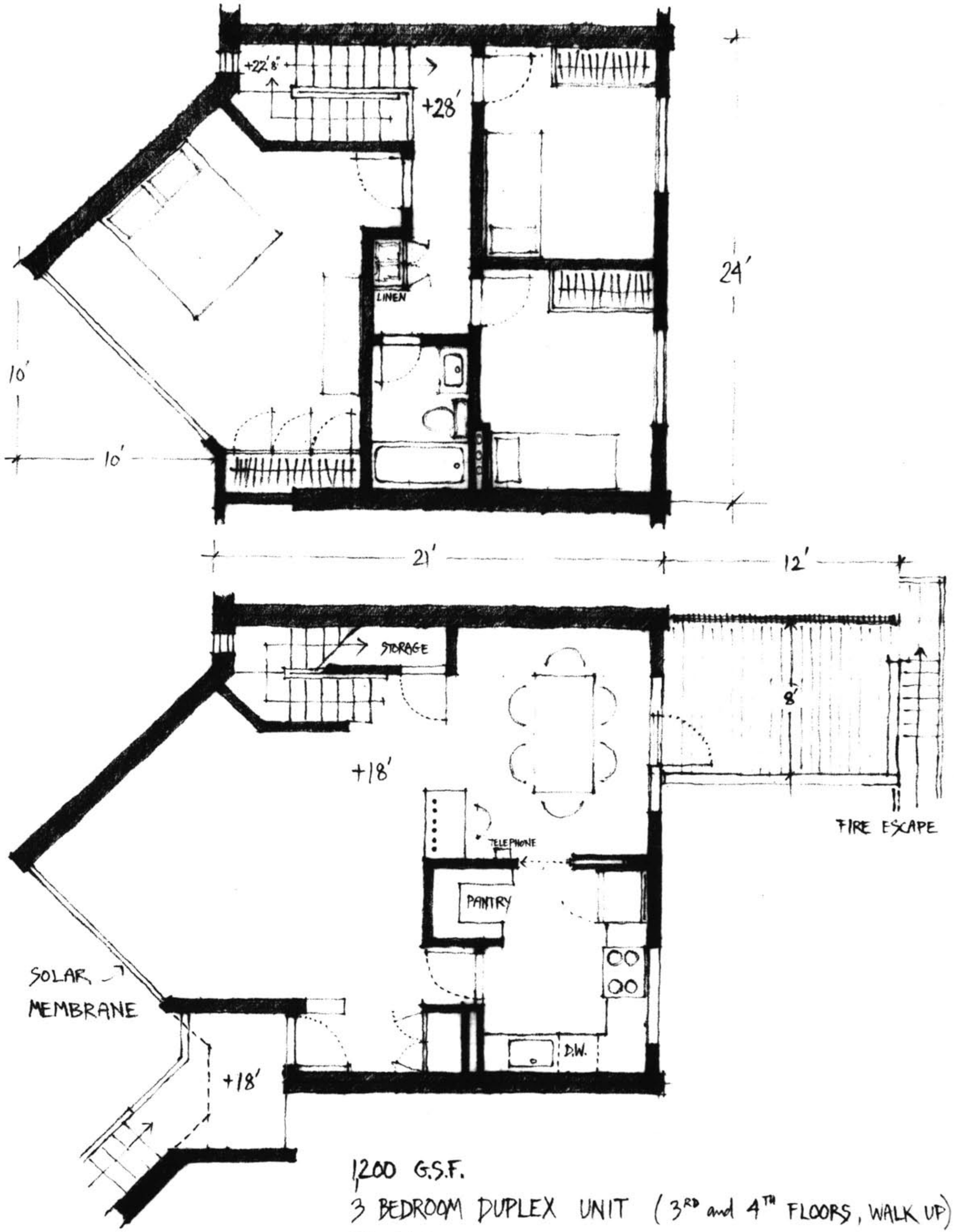
1,615 G.S.F. 4 BEDROOM DUPLEX UNIT
IN HIGH RISE BLOCKS AND ELSEWHERE.



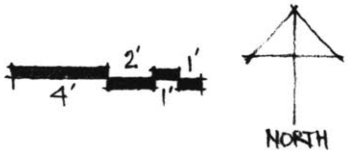
PAIR OF FLATS AT ELEVATIONS +32 AND +42 IN SECTION BB
A PAIR OF THIS TYPE IS INTERCHANGEABLE WITH DUPLEXES



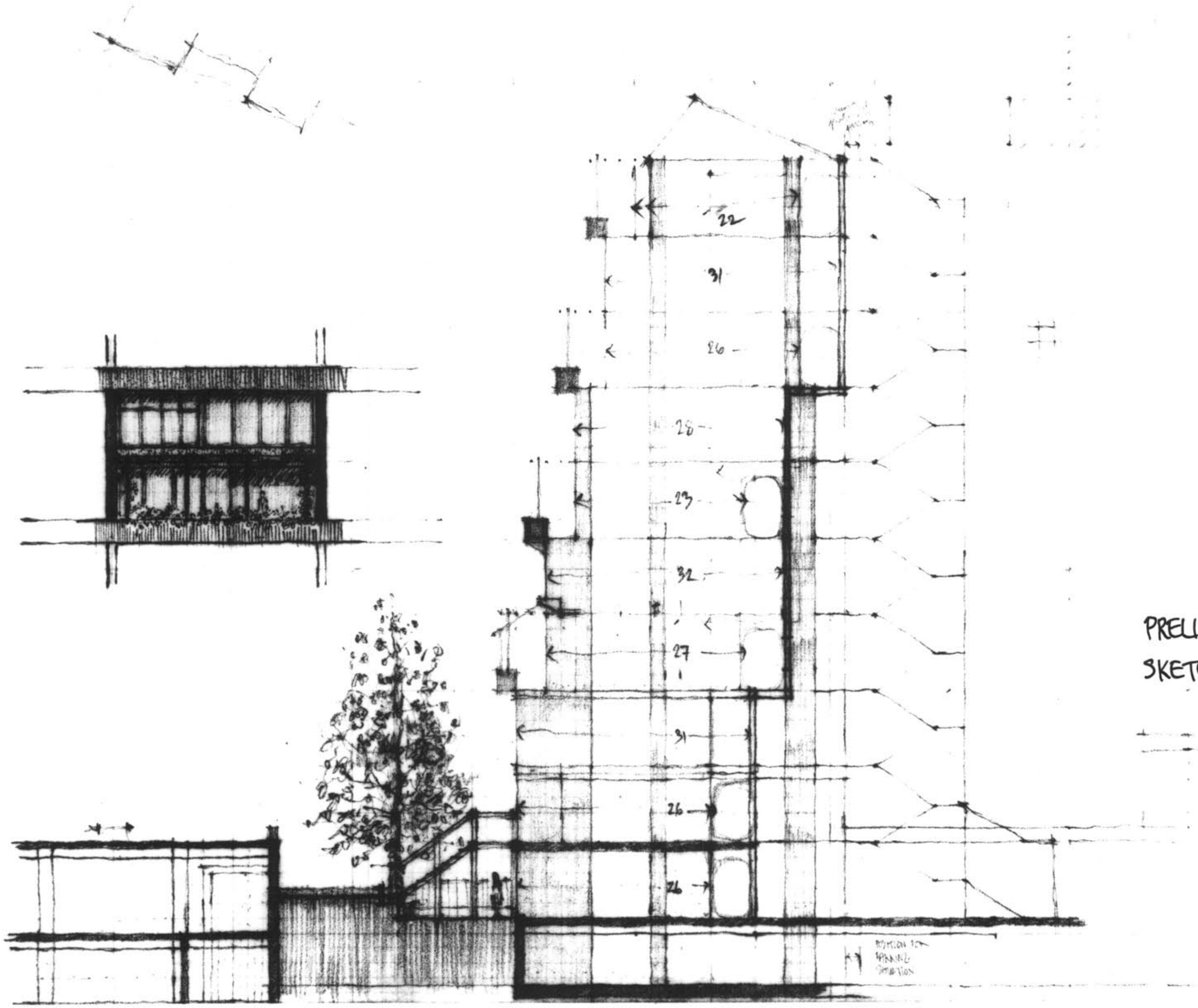
434 G.S.F.
STUDIO APARTMENT
FOR TOP FLOORS OF HIGH RISE BLOCKS



1,200 G.S.F.
3 BEDROOM DUPLEX UNIT (3RD and 4TH FLOORS, WALK UP)
ON EAST SIDE OF AMES ST.
SOLAR MEMBRANE FACES SOUTH WEST
RATHER THAN DIRECTLY WEST.

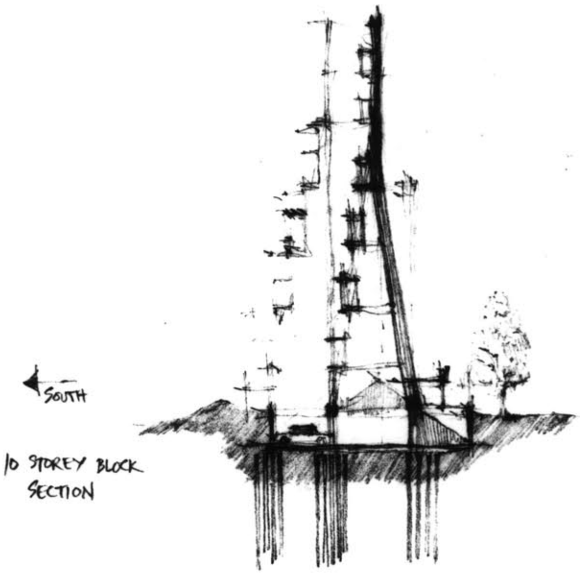


PERSPECTIVE SKETCH

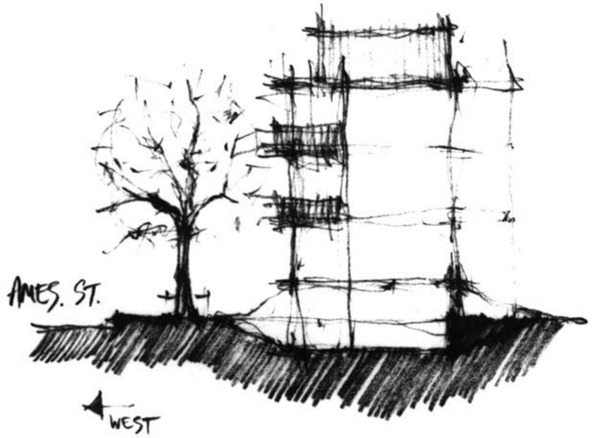


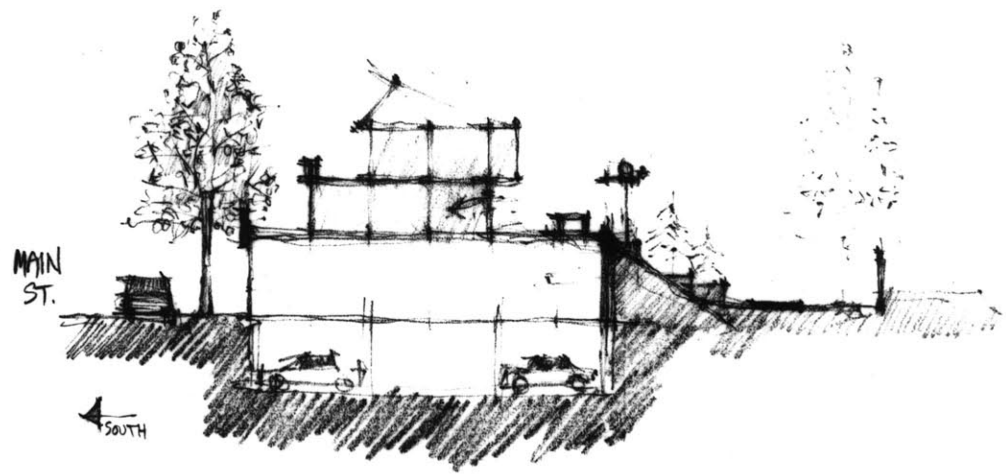
PRELIMINARY
SKETCH

SOUTH ELEVATION



10 STOREY BLOCK SECTION





PRELIMINARY SKETCHES

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