HOUSING - BOX and PANEL

by

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B. Arch., University of Cincinnati
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Signature of Author.....
Department of Architecture
May 9, 1975

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Chairman, Departmental
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HOUSING: BOX AND PANEL

William H. Soupcoff

Submitted to the Department of Architecture on May 9, 1975, in partial fulfillment of the requirements for the degree of Master of Architecture.

The purpose of this thesis has been to do an in depth study of Housing using a system of prefabricated steel boxes and infill panels. The boxes are wholly fabricated in a factory containing all service components, stair, kitchen, bathrooms, etc. and then transported to site for erection. The infill panels, between boxes, are also partially fabricated in the factory and shipped to the site for erection. The assembly of the steel components in the factory has been designed to easily adapt to the existing Mobile Home production techniques. Using standard steel components has made it possible to address a nationwide market. The system is capable of going to at least 9 stories in height without any major changes to box and panel design.

The system does have specific limitations in planning due to the structural interdependency of box and panel. Another limiting factor is that all the mechanical elements have to be contained within the box. Even with these limitations, I feel that there is enough flexibility to design excellent living environments for people.

Thesis Supervisor: Eduardo Catalano
Title: Professor of Architecture

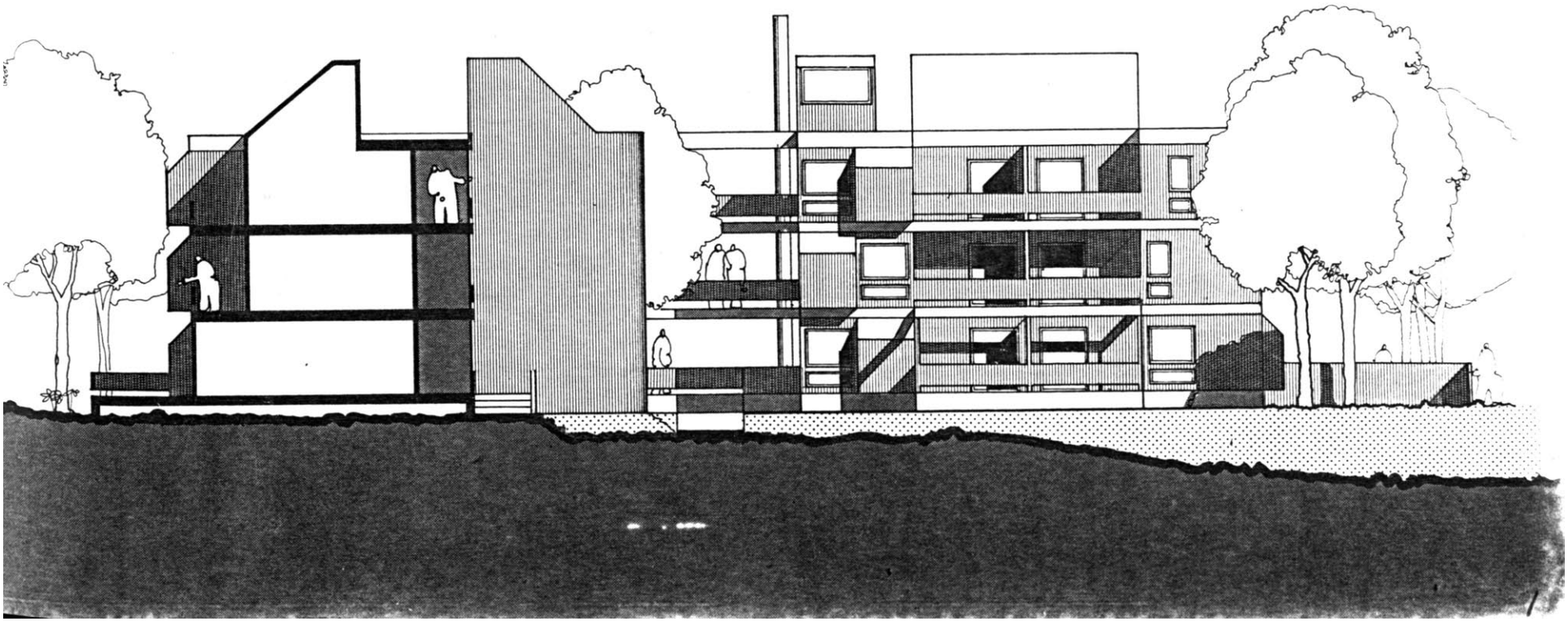
II

HOUSING

Box & Panel

GRADUATE THESIS
M.I.T.
ADVISOR:
Eduardo Catalano

William H. Soupcoff
75



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INTRODUCTION

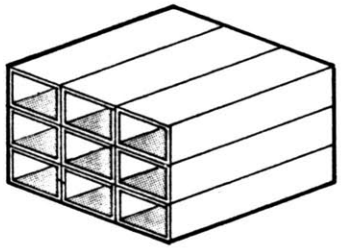
GOALS:

To develop a housing system capable of:

1) Using the existing production techniques of the Mobile Home Industry.
2) Combining on-site and factory production.
3) Appealing to a nationwide market.
4) Use for mobile homes, midrise, and highrise.
5) Use for houses and apartments up to 4 bedrooms in size.
6) Integrating with and respecting traditional American architectural character.

SYSTEM COMPARISON:

Boxes Stacked



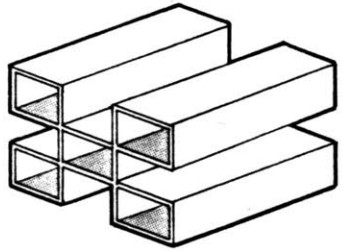
Major Advantages:

1) Complete factory production.
2) Minimum of site labor.

Major Disadvantages:

1) Redundance of walls, ceiling, and floor.
2) Transplanting large amounts of space.
3) No variation in dimensions of room width.

Boxes Staggered



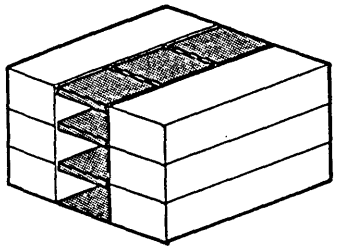
Major Advantages:

1) Minimizes redundancy of walls, floors, ceilings.
2) Transport one-half as many boxes.

Major Disadvantages:

1) Plumbing does not stack.
2) Planning difficulty due to total structural dependency of one box to another.

Box & Panel



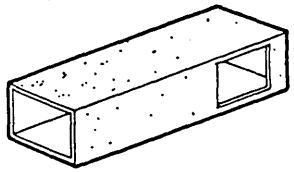
Major Advantages:

1) Plumbing stacks vertically.
2) Minimal shipment of air.
3) Capable of large spans between boxes.

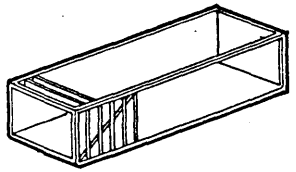
Major Disadvantages:

1) Planning is limited because of interdependency of panel upon box.
2) Field labor needed to finish interior of panel space.

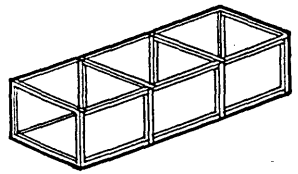
MATERIAL COMPARISON:



Concrete does not lend itself to the mass production technique of the Mobile Home Industry. Most Mobile Home factories are set to operate on a 20 min. (app.) rotation cycle time, because of concrete's long curing time. This would be prohibitive even with quick curing concrete. Also, concrete boxes address themselves to more specialized market, highrise construction, and therefore limit their application to a nationwide market.



Wood is the most common structural material in use today for fabrication of mobile home units, but it has obvious limitations in highrise construction both structurally and in meeting fire limitations.



Steel offers a nationwide market because of accessibility of standard steel sections. Steel also provides the structural capability of highrise construction. Although steel is restricted by fire limitations, it is possible to build to 9 stories in height with reasonably low fire rating requirements. (9 story steel construction = use group L-2 - 3/4 hr. fire rating of all structural members + 1 1/2 hr. fire rating on ground floor) Steel offers the designer a structural skeleton with max. planning flexibility.

FIRE CODE LIMITATIONS:

(Boca Code)

Use Group: L-2 (multi-family residential)
Construction Classification: (noncombustable construction) **Type 2**

FIRE RESISTANCE RATINGS FOR TYPE 2 CONSTRUCTION

Hours of Fire Protection

Structural Elements	2A	2B	2C
Fire Walls	2 hr.	2 hr.	2 hr.
Fire Divisions	1 1/2	1 1/2	1 1/2
Fire Enclosure of Exitways, Lifts, Exitway Hallways, and Stairways	2	2	2
Shafts other than Stairways	2	2	2
Exitway Access Hallways and Vertical Separation of Tenant Spaces	3/4	3/4	0
Columns, Girders, Trusses (other than roof trusses) and Framing	1 1/2	3/4	0
Structural Members supporting Walls	1 1/2	1 1/2	1 1/2
Floor Construction including beams	1 1/2	3/4	0

HEIGHT LIMITATIONS AND FLOOR AREA LIMITATIONS

L-2 (multi-family residential)	9st.-100'	4st.-50'	3st.-40'
*Max. Floor Area	22,800	15,000	9,600

*Note:
There is a sq. ft. area/floor reduction as building goes above first floor. The chart on the following page indicates these reductions.

AREA LIMITATION ADJUSTMENTS

No. of Stories	Reduct. Factor 2A	Sq. Ft. 2A	Reduct. Factor *2B	Sq. Ft. 2B
1	none	22,800	none	15,000
2	none	22,800	none	15,000
3	5%	21,660	20%	12,000
4	10%	20,520	20%	12,000
5	15%	19,400	30%	10,500
6	20%	18,240	40%	9,000
7	25%	17,100	50%	7,500
8	30%	15,960	60%	6,000
9	35%	14,820	70%	4,500

*PROTECTED NONCOMBUSTABLE CONSTRUCTION: (Boca Code 905.62)

When of 3/4 hr. protected noncombustable (type 2-B) construction, multi-family dwellings (use group L-2) may be increased to 9 stories or 100' in height when separated not less than 50' from any other building on the lot and from interior lot lines, the exitways are segregated in a fire area enclosed in a continuous fire wall of 2 hr. fire resistance and the first floor is not less than 1 1/2 hr. fire resistive construction.

Note:

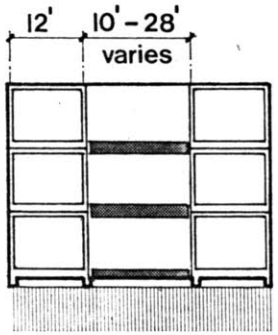
Two buildings, while being separated by 50', can be linked by a corridor or passage that is properly treated with 2 fire resistant construction.

Notes:

1. FIRE RETARDANT PLYWOOD is considered noncombustable and can be used in Type 2 construction.
2. Floor joists and/or ceiling joists need only be fire proofed from bottom and not from top.
3. FIRE WALLS must be continuous and extend from foundation to 2'-8" above roof line.

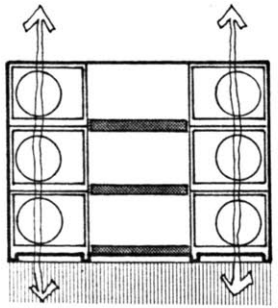
DECISION:

Upon completion of comperative analysis of preceeding building systems and structural materials, I have chosen to study a system of steel boxes and infill panels.



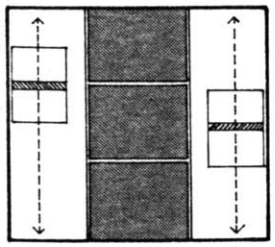
Box is a constant 12' width measured from center line of steel columns.

Panel is a variable which can change dimension from 10' - 28' in width.



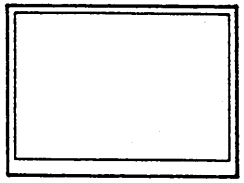
All wet core elements plumbing walls are prefabricated in factory and installed into box. Therefore, only the vertical connection from one plumbing wall to next is necessary in field. (assuming plumbing stacks)

It is possible to run plumbing horizontally in ceiling space but this is discouraged because of possible intervention with mechanical heat ducts or pipes.



Plumbing wet wall may be located freely in box according to design.

CONSTANT



The Box, which will be considered the CONSTANT element, is wholly fabricated in the factory. Because factory production is almost 1/2 the cost of field labor, it is desirable to do as much work as possible in the factory. For this reason all services (bathrooms, kitchens, etc.) will be factory installed in box in order to minimize field labor.

Components

bathrooms
kitchens
stair
mechanical room
    furnace
    washer
dryer
hot water heater

VARIABLE

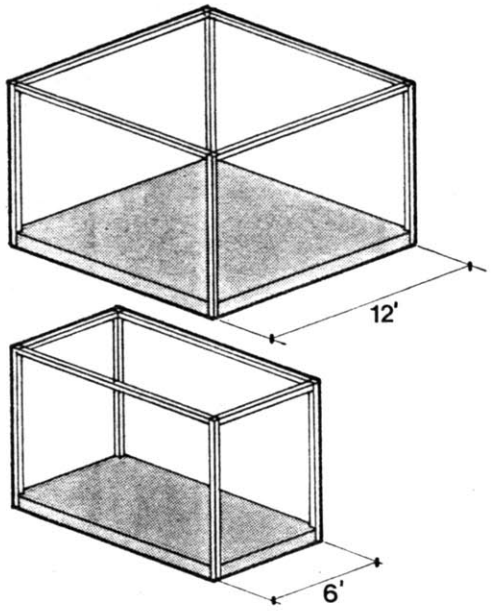
The INFILL PANEL, which will be considered the VARIABLE element, is partially fabricated in the factory. Because of the need to make structural and mechanical connections, the ceiling of the floor panel will be erected after it has been placed and bolted to adjoining boxes. All interior partitions will also be partially prefabricated in factory, shipped to site, erected, and finished by field labor.

Components

non-service areas
    living room
    family rooms
    bedrooms
storage
decks
2-story spaces
pitched roofs

STRUCTURE

BOX:

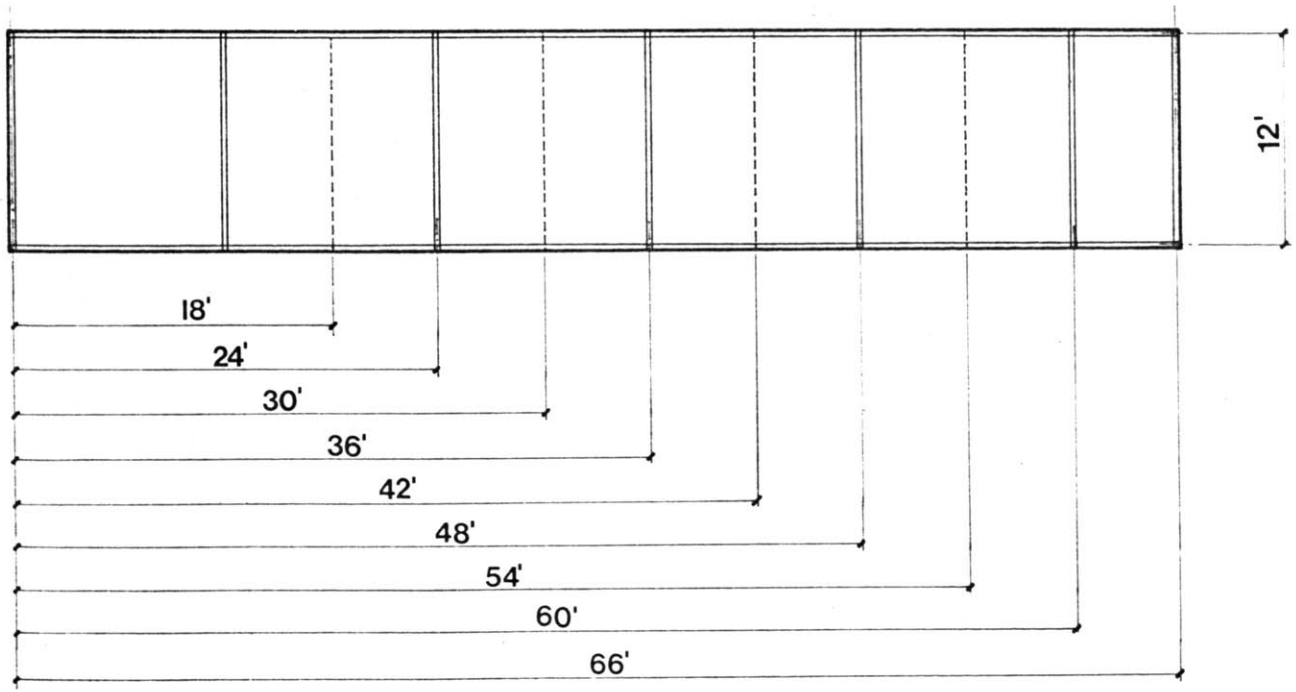


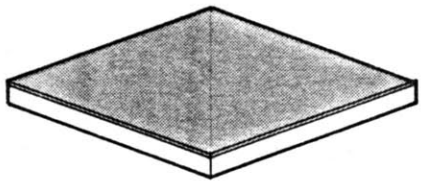
Box Structure is based on a 12' and 6' structural bay, measured to centerline of column. By combining these 2 bay sizes, various size boxes can be fabricated, ranging from 18' to 66' in length.

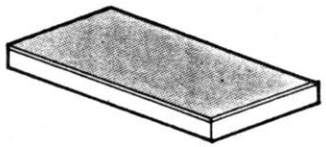
Boxes 67 feet in length are max. allowable by highway transportation limitations.

Most Common box lengths:

Townhouses 24' to 42'
Lowrise Apartments 24' to 42'
Highrise Apartments
single loaded 24' to 30'
double loaded 42' to 60'



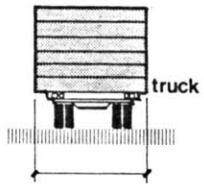


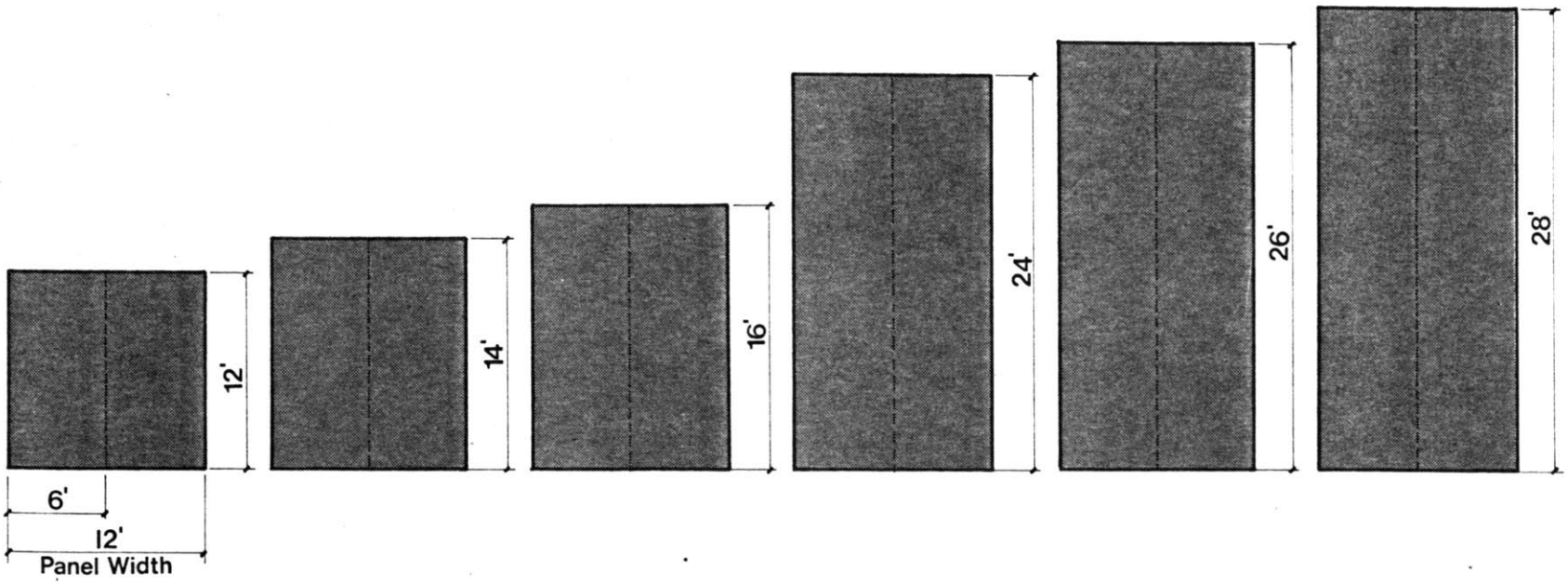


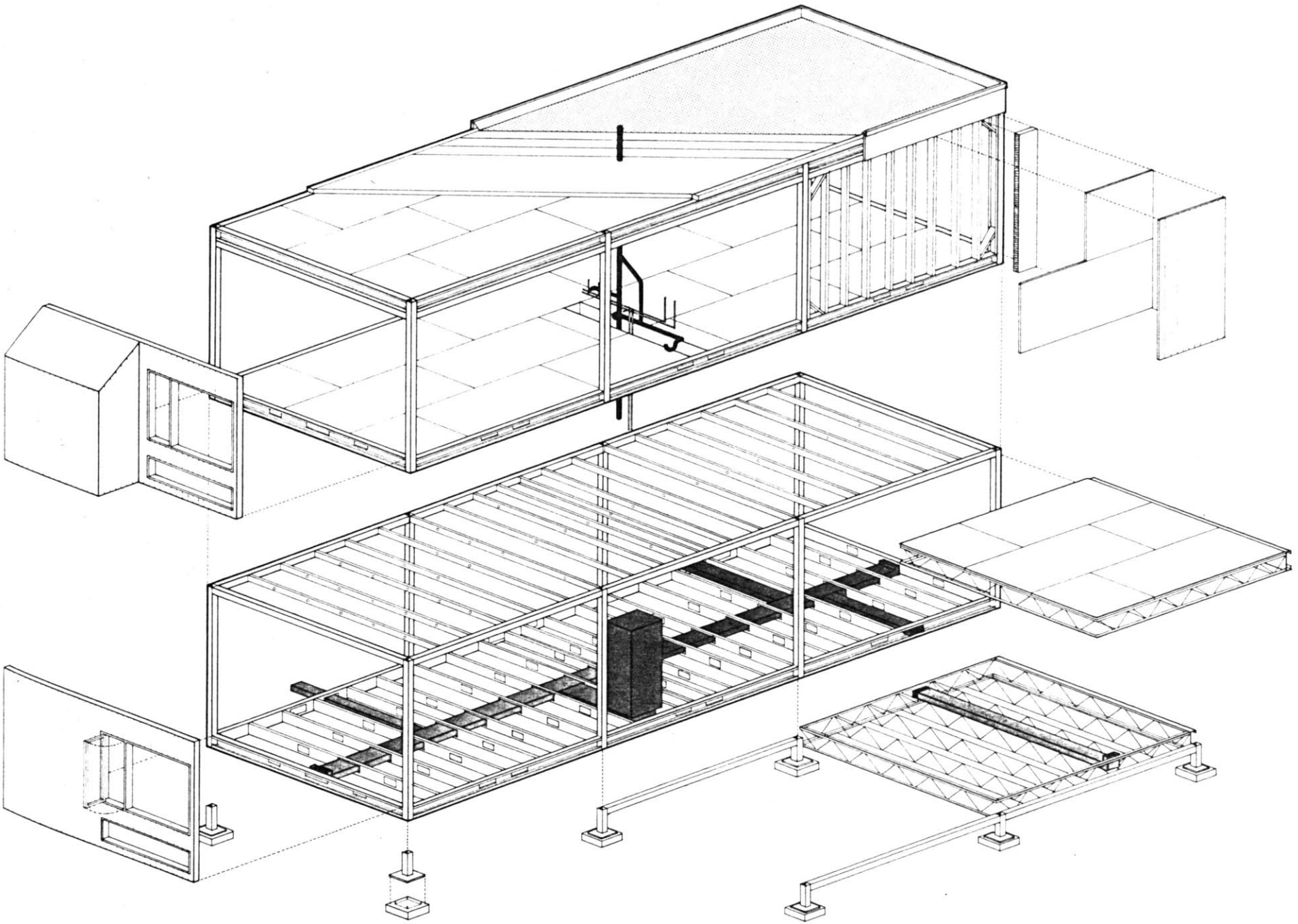
INFILL PANEL:

Panel Structure is based on a constant 12' and 6' width. Panel lengths variable and may be 12', 14', 16', 24', 26', and 28'.

Panels stacked horizonatally during transportation.







EXPLODED AXONOMETERIC

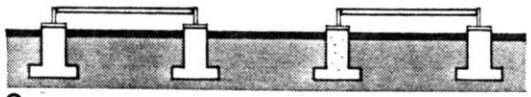
1

SITE:

2

SITE PREPARTION:

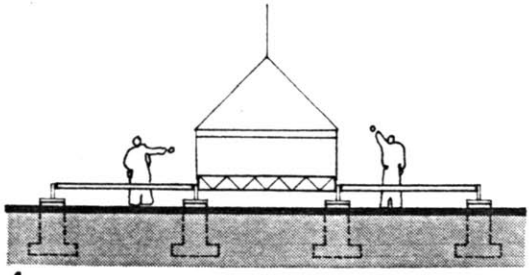
1. Install all ground services (ele., plumbing, sewage, etc.)
2. Build forms and pour foundation levers.
3. Set and bolt foundation column cap.



3

PREPARE FOUNDATIONS:

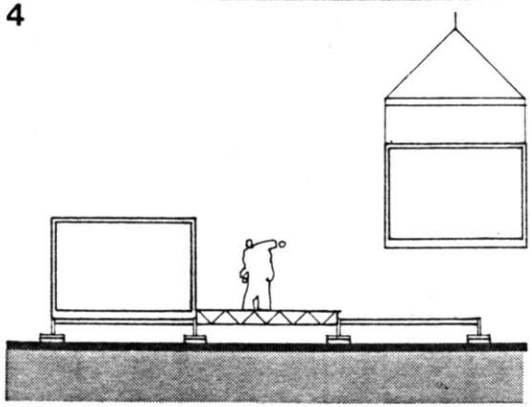
1. Set and bolt closure beams.
2. Erect masonry block wall between piers.
3. Place and bolt infill bearing beams.



4

PANEL ERECTION:

1. Place floor infill panel.
2. Bolt floor panel to beam.

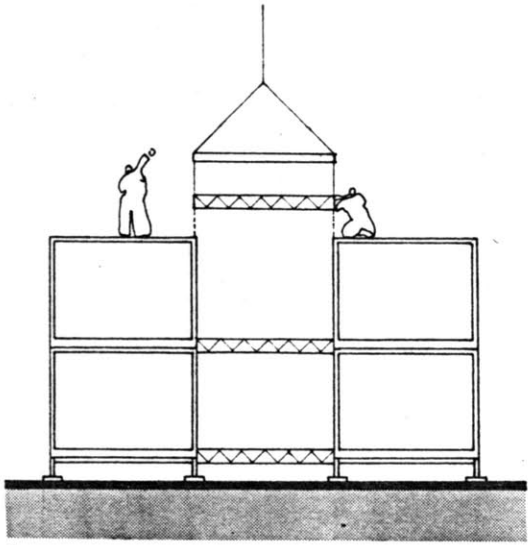


5

BOX ERECTION:

1. Connect box to foundation cap.
2. Bolt box to floor panel.
3. Connect air ducts between box and floor panel.
4. Connect electrical lines.
5. Connect plumbing to ground services.

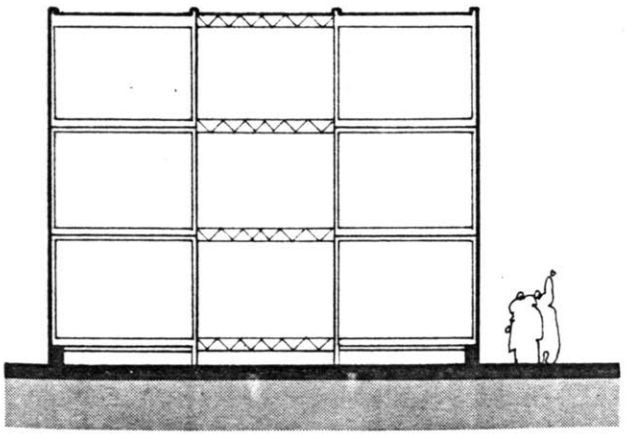
SITE ERECTION



6

SECOND FLOOR ERECTION:

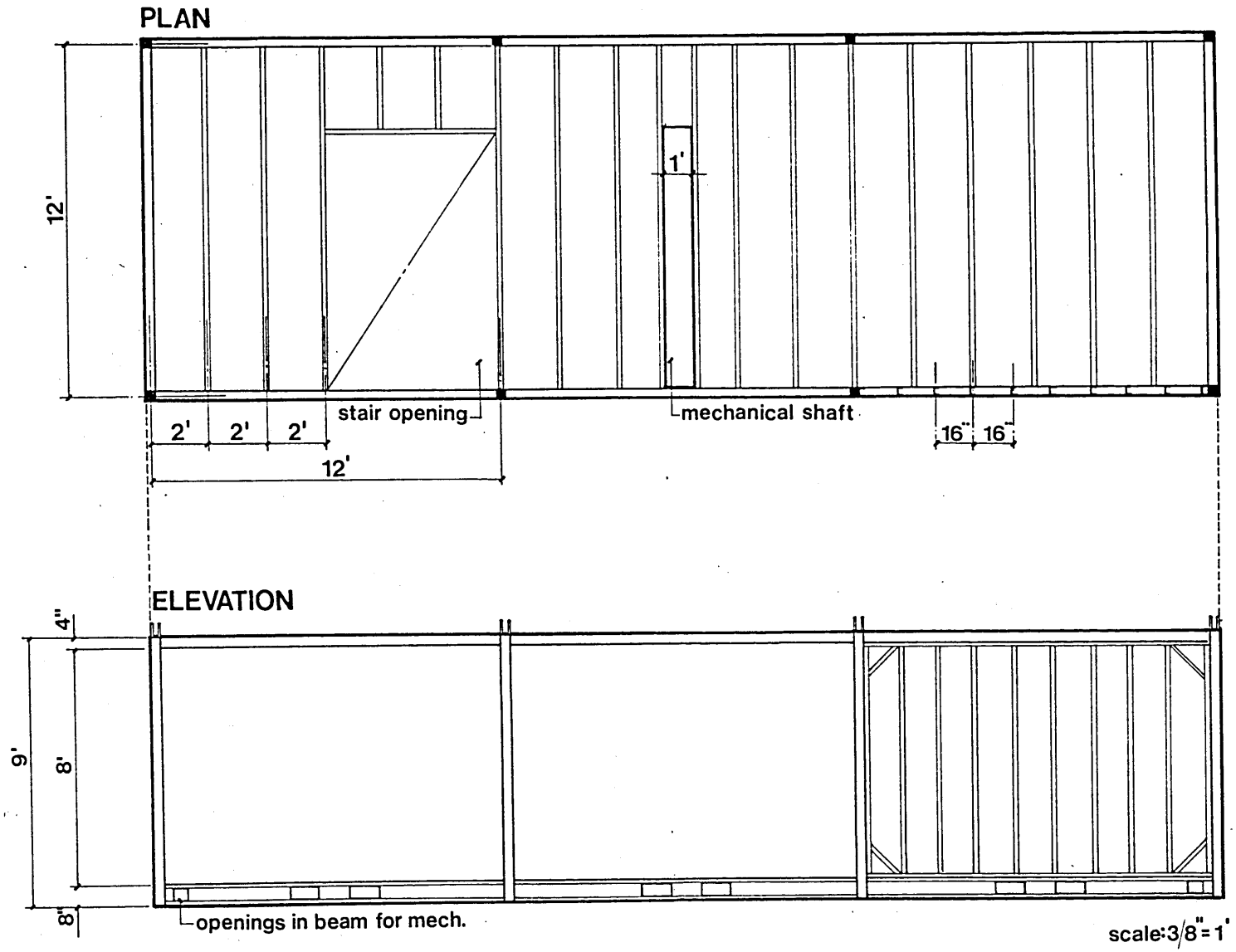
1. Place and connect floor panel to boxes.
2. Connect mechanical ducts.
3. Connect plumbing wet wall between first floor box and second floor box.
4. Install interior wall partitions in infill area between boxes. (first floor)
5. Install exterior wall infill on first floor.



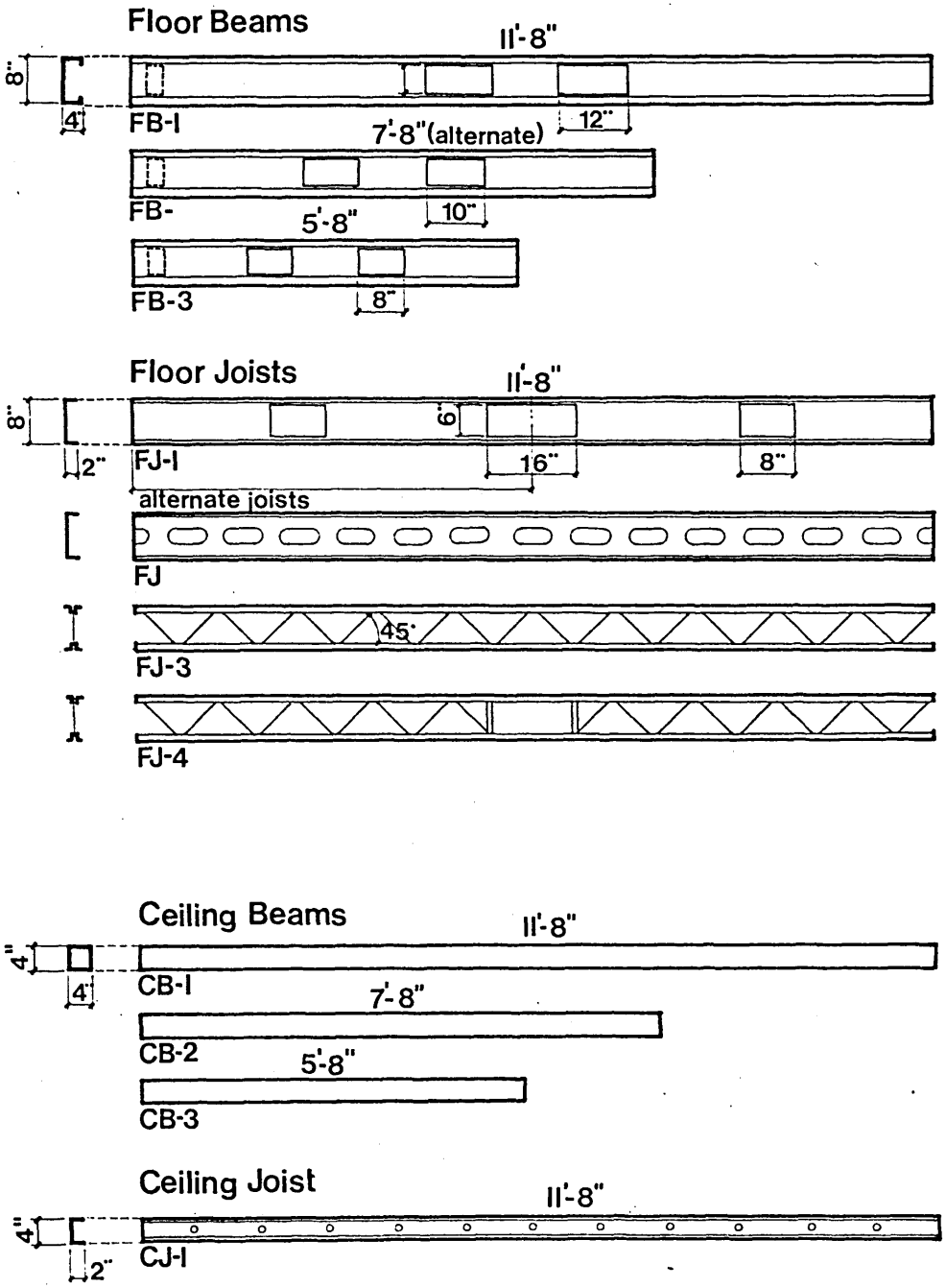
7

FINSH WORK:

1. All interior finishes in the infill zone to be completed.
2. Exterior facia strip placed at floor joints.
3. Roof flashing connections.
4. Site work.
   a. landscaping
   b. parking
   c. lighting
   d. etc.

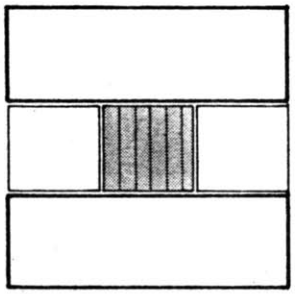


BOX STRUCTURE

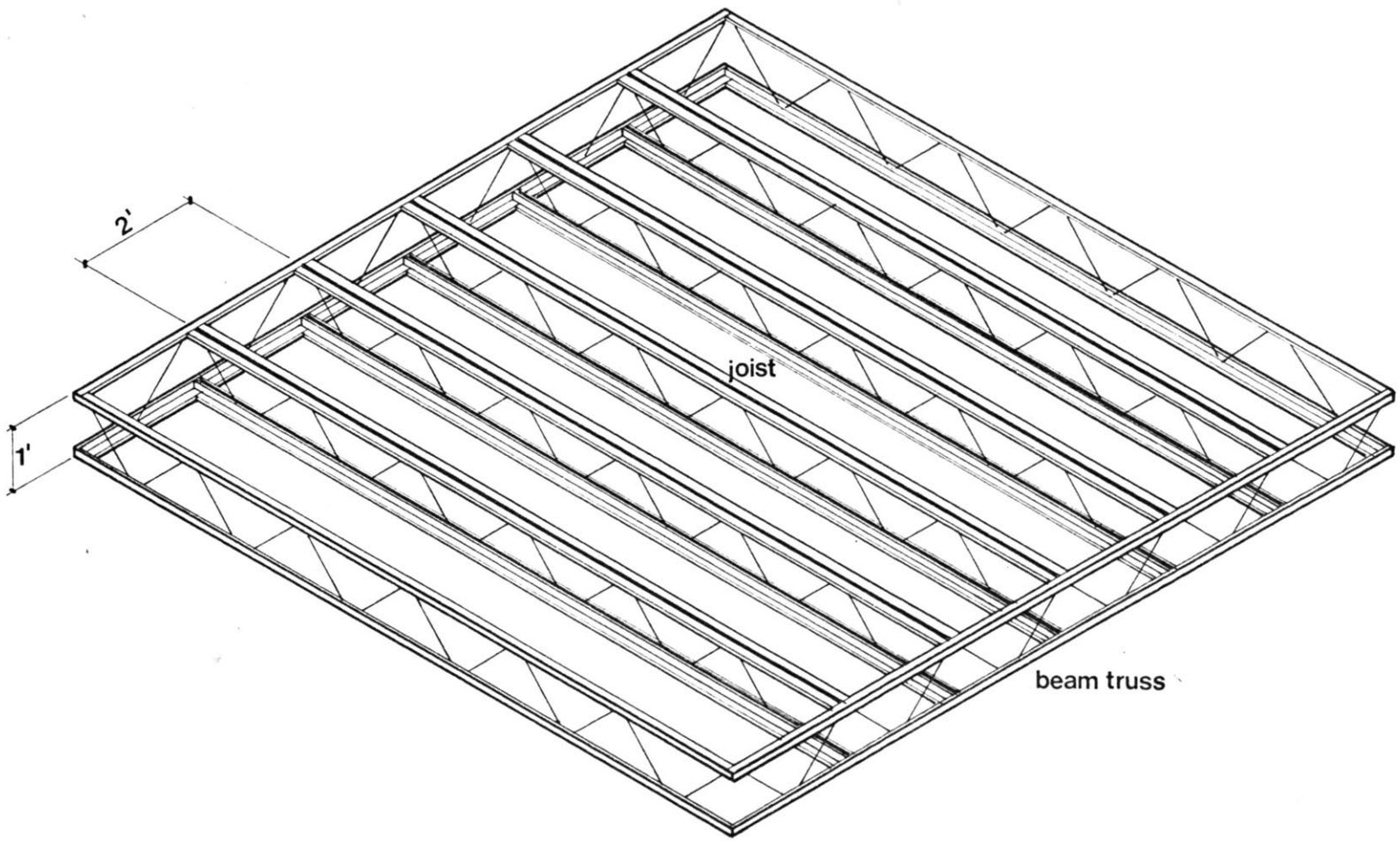


scale 3/8 = 1'

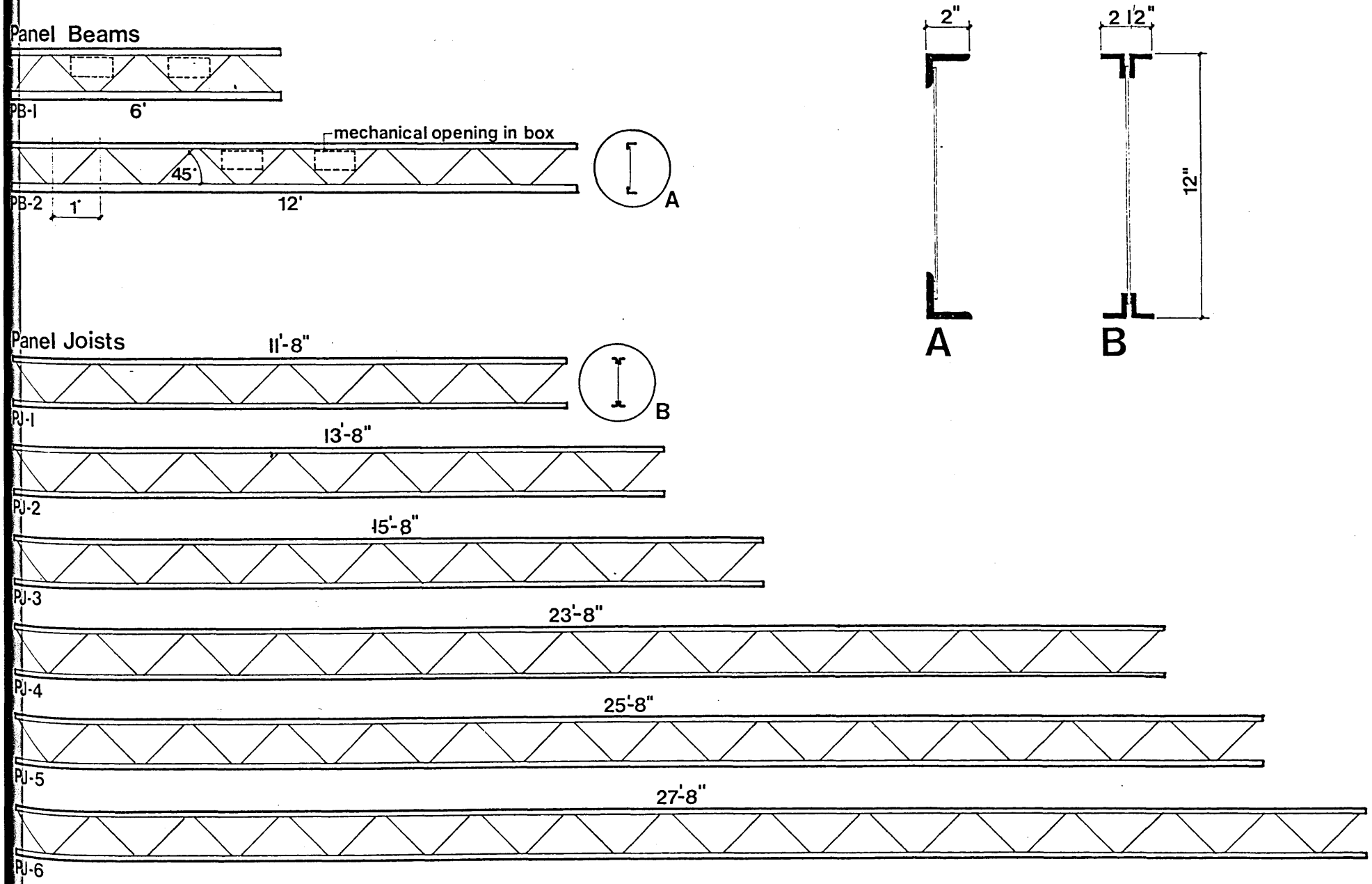
BEAMS & JOISTS (BOX)



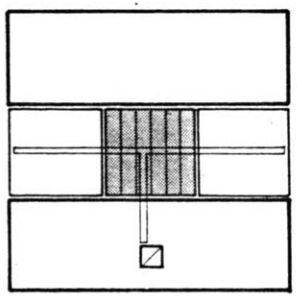
Plan



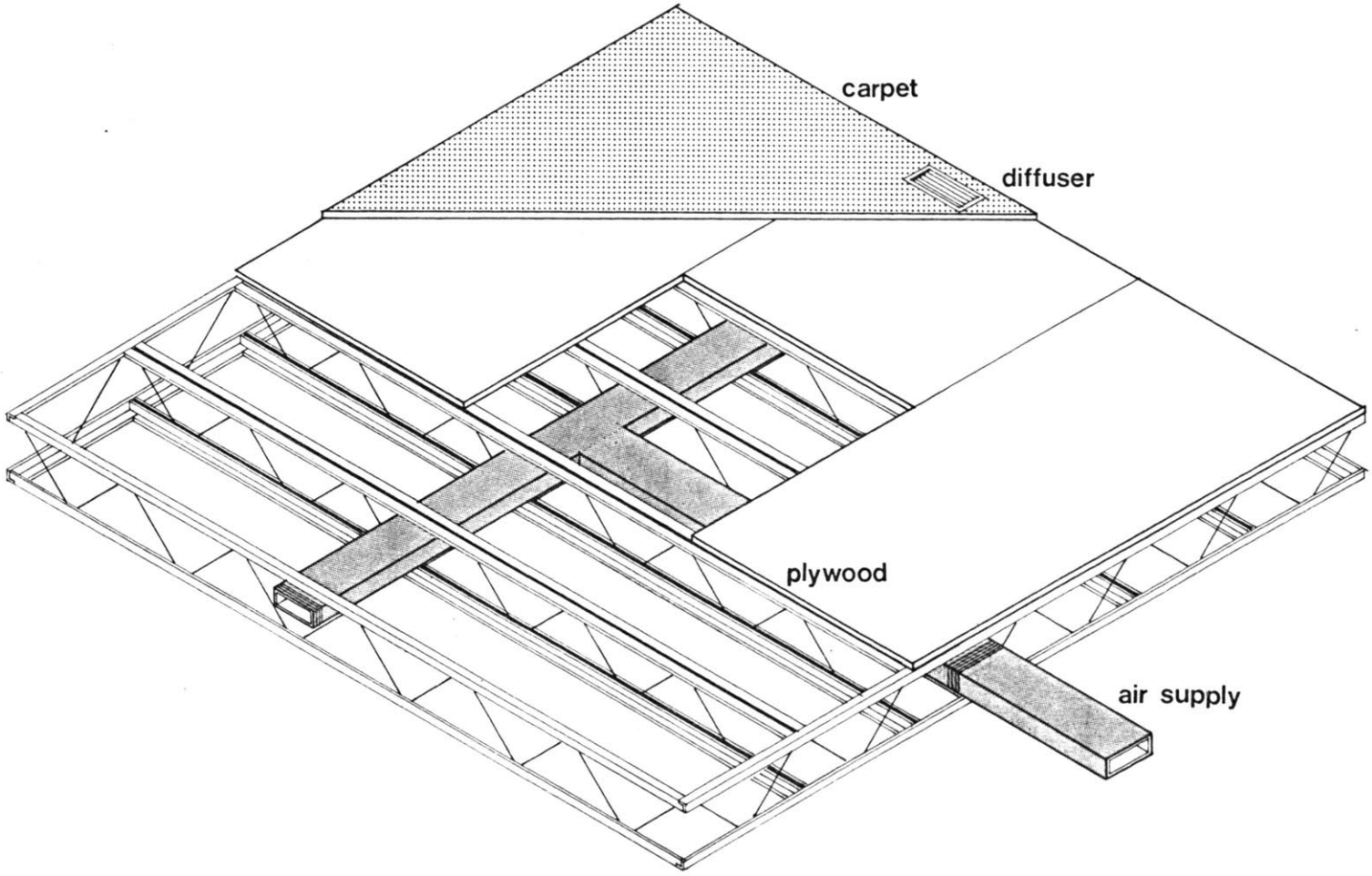
INFILL PANEL



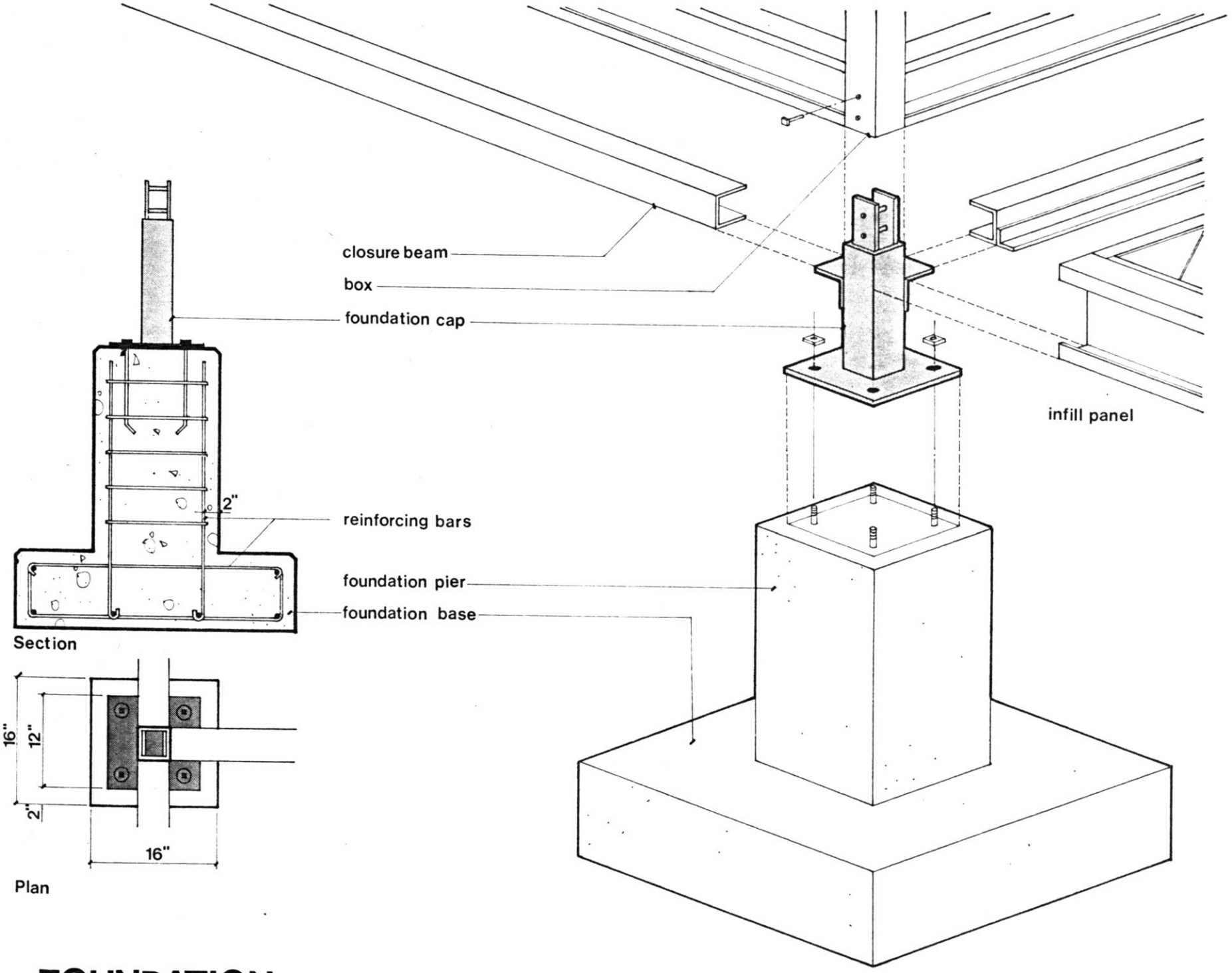
INFILL PANEL COMPONENTS



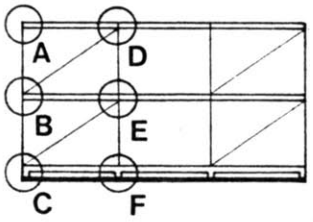
Plan

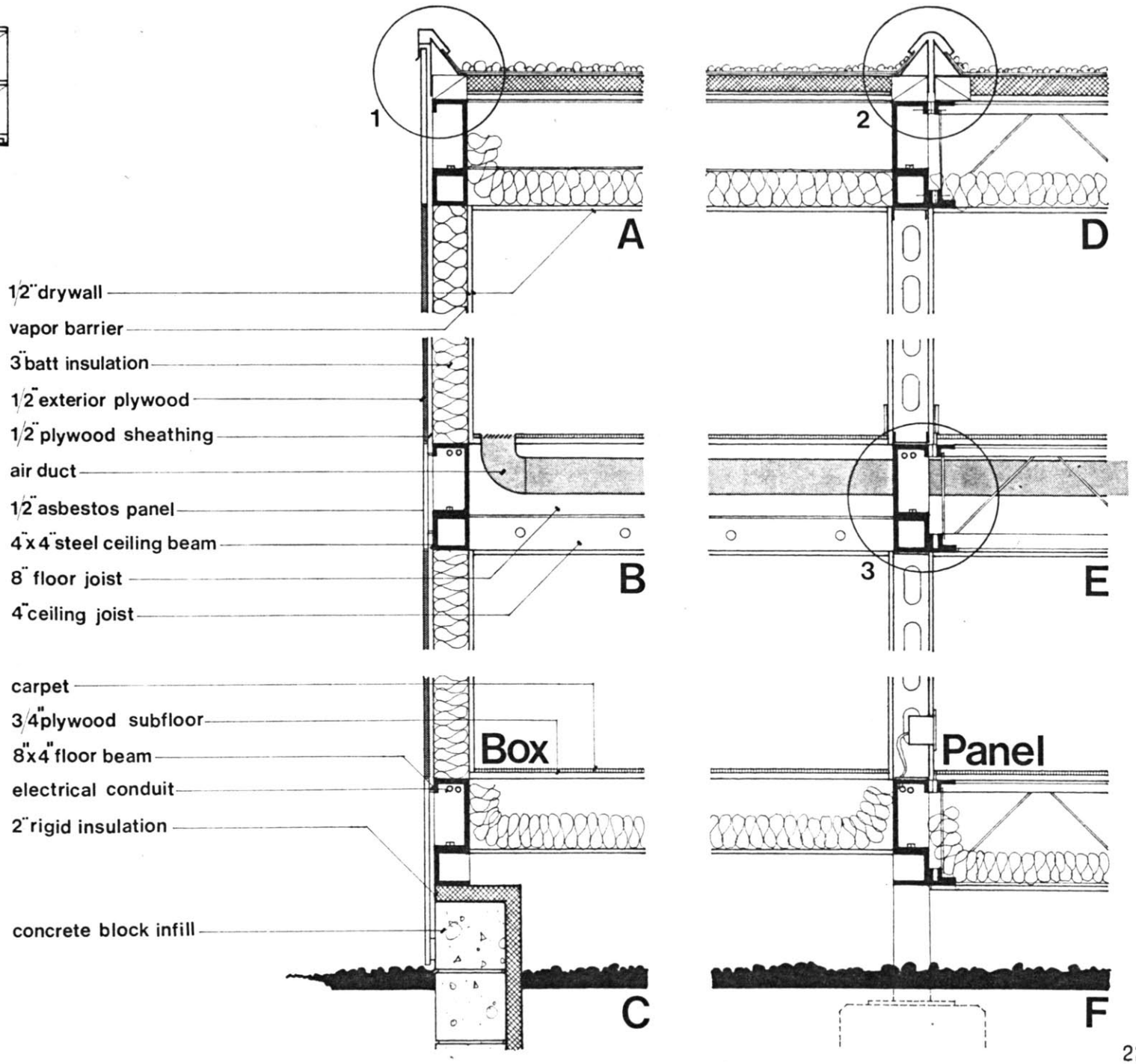


INFILL PANEL

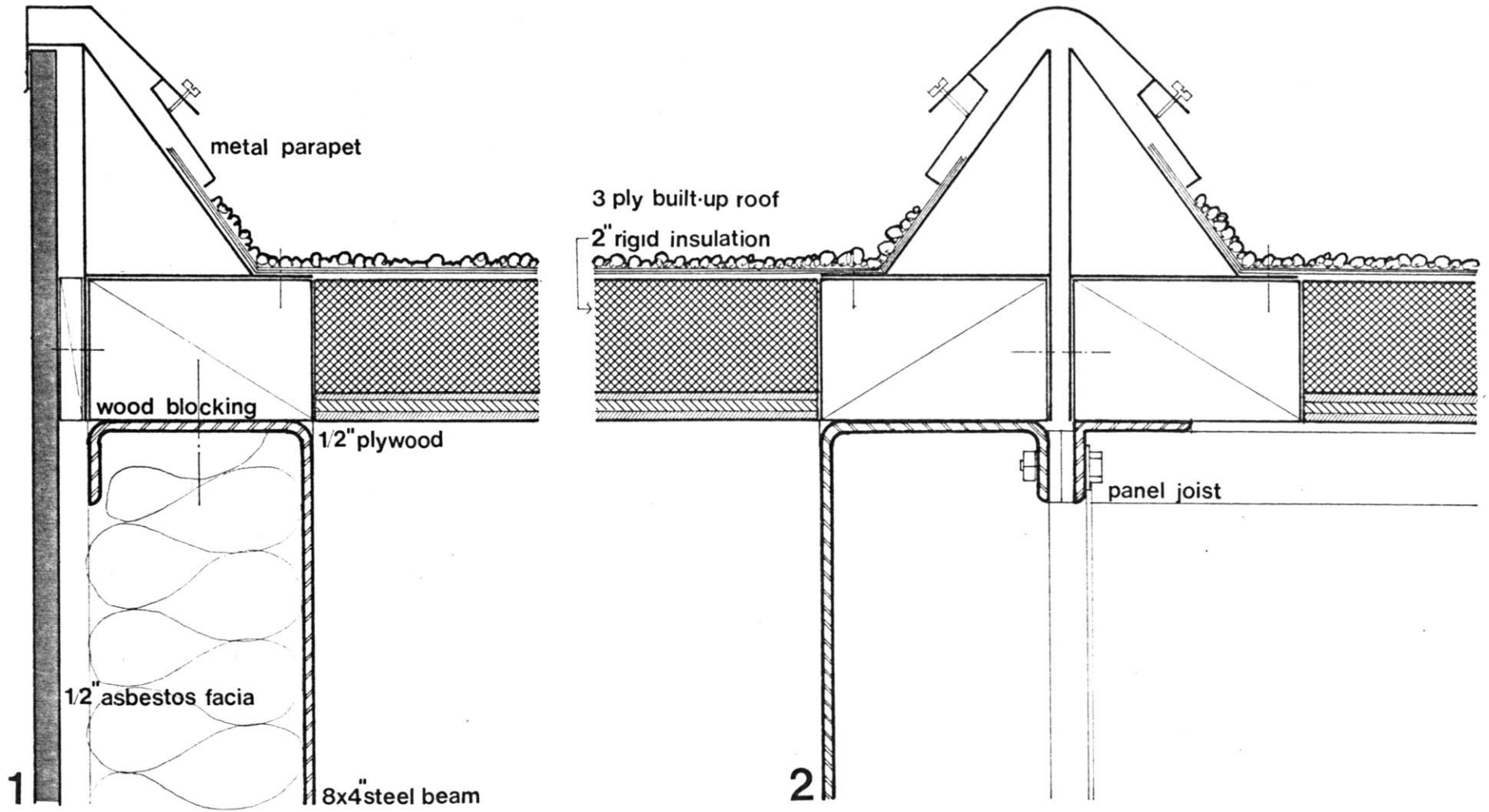

closure beam
box
foundation cap
infill panel
2"
reinforcing bars
foundation pier
foundation base
Section
16"
12"
2"
16"
Plan

FOUNDATION

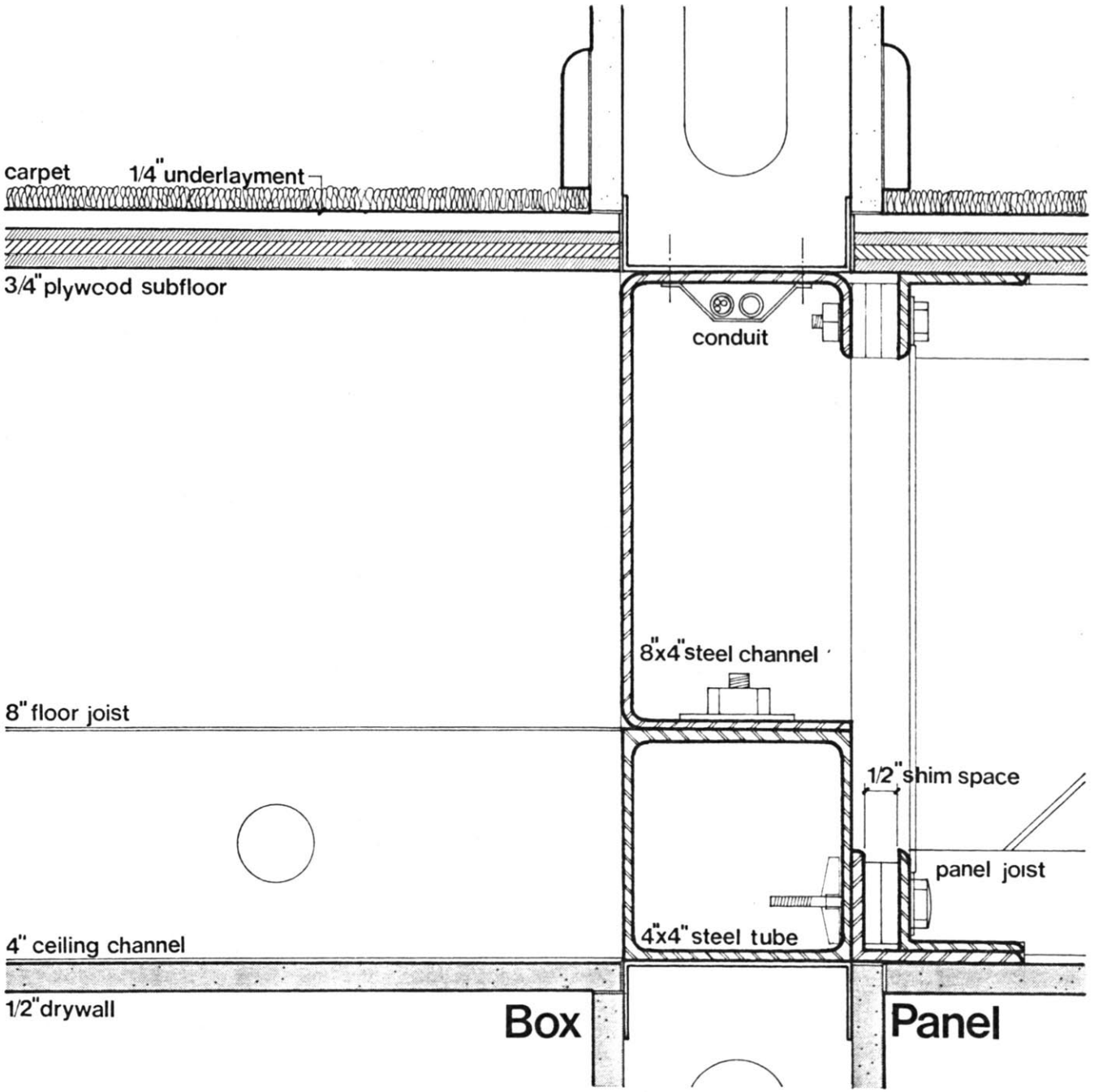




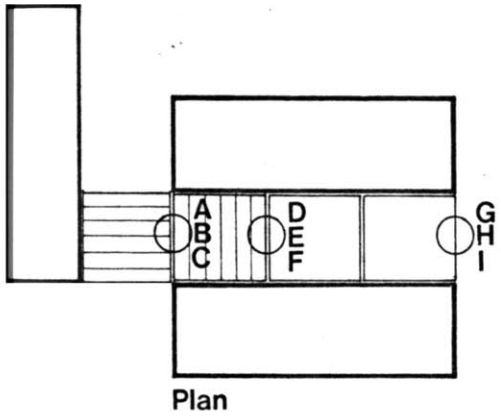
SECTION
scale: 3/4" = 1'


metal parapet
wood blocking
1/2" plywood
1/2" asbestos facia
8x4" steel beam
1
3 ply built-up roof
2" rigid insulation
panel joist
2

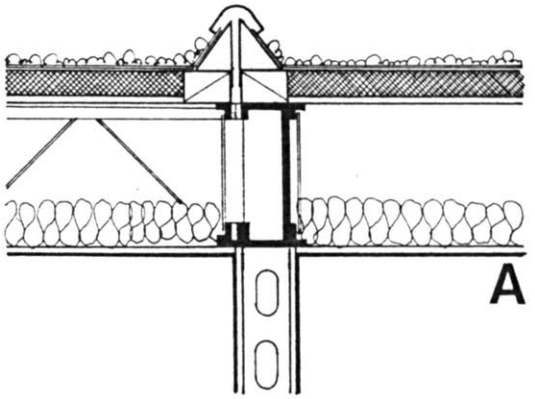
DETAILS 1&2

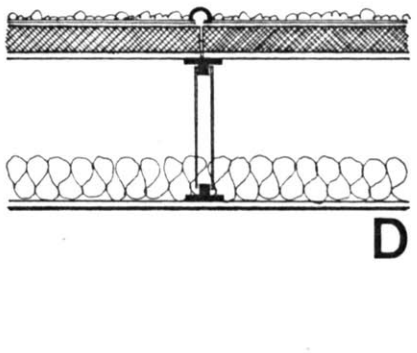

carpet
1/4" underlayment
3/4" plywood subfloor
conduit
8"x4" steel channel
8" floor joist
1/2" shim space
panel joist
4"x4" steel tube
4" ceiling channel
1/2" drywall
Box
Panel

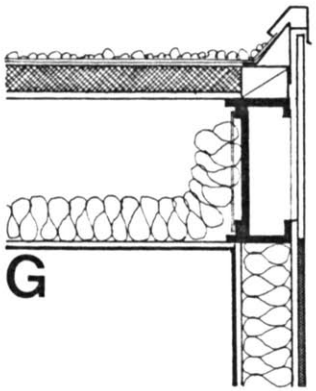
DETAIL 3

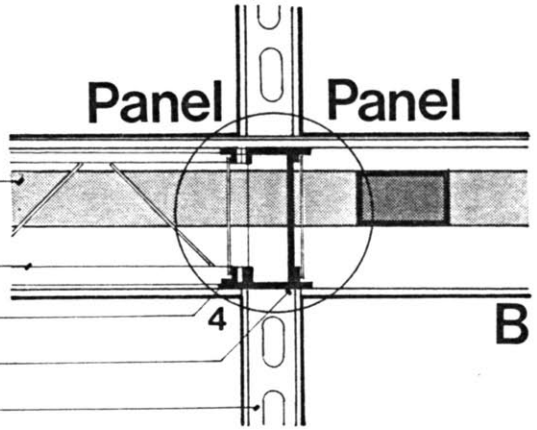


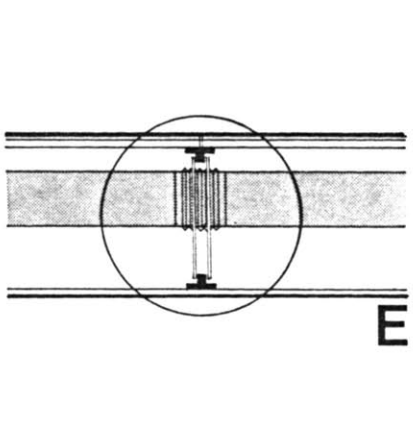
Plan

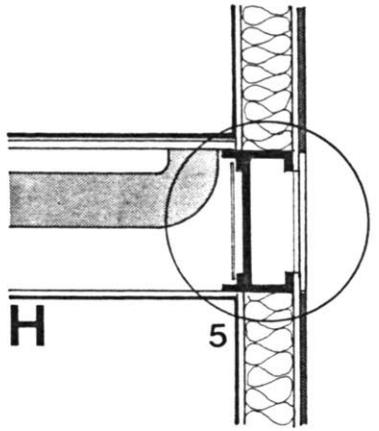












air supply

12" panel joist

panel beam

12" x 4" panel closure beam

4" metal stud

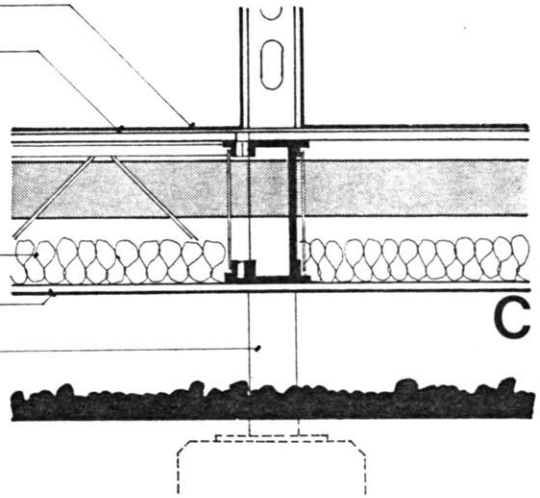
carpet

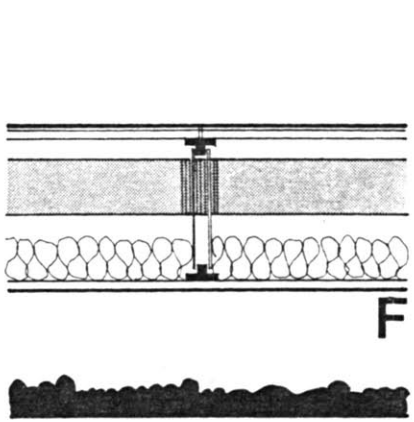
3/4" plywood subfloor

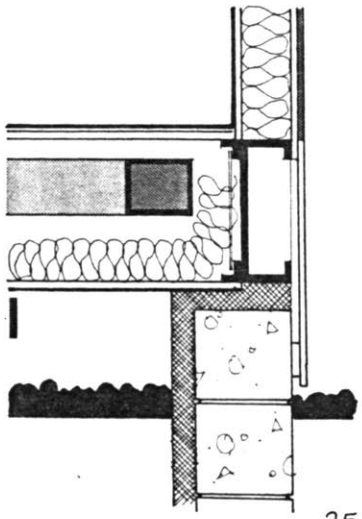
3" batt insulation

1/2" plywood

column cap beyond

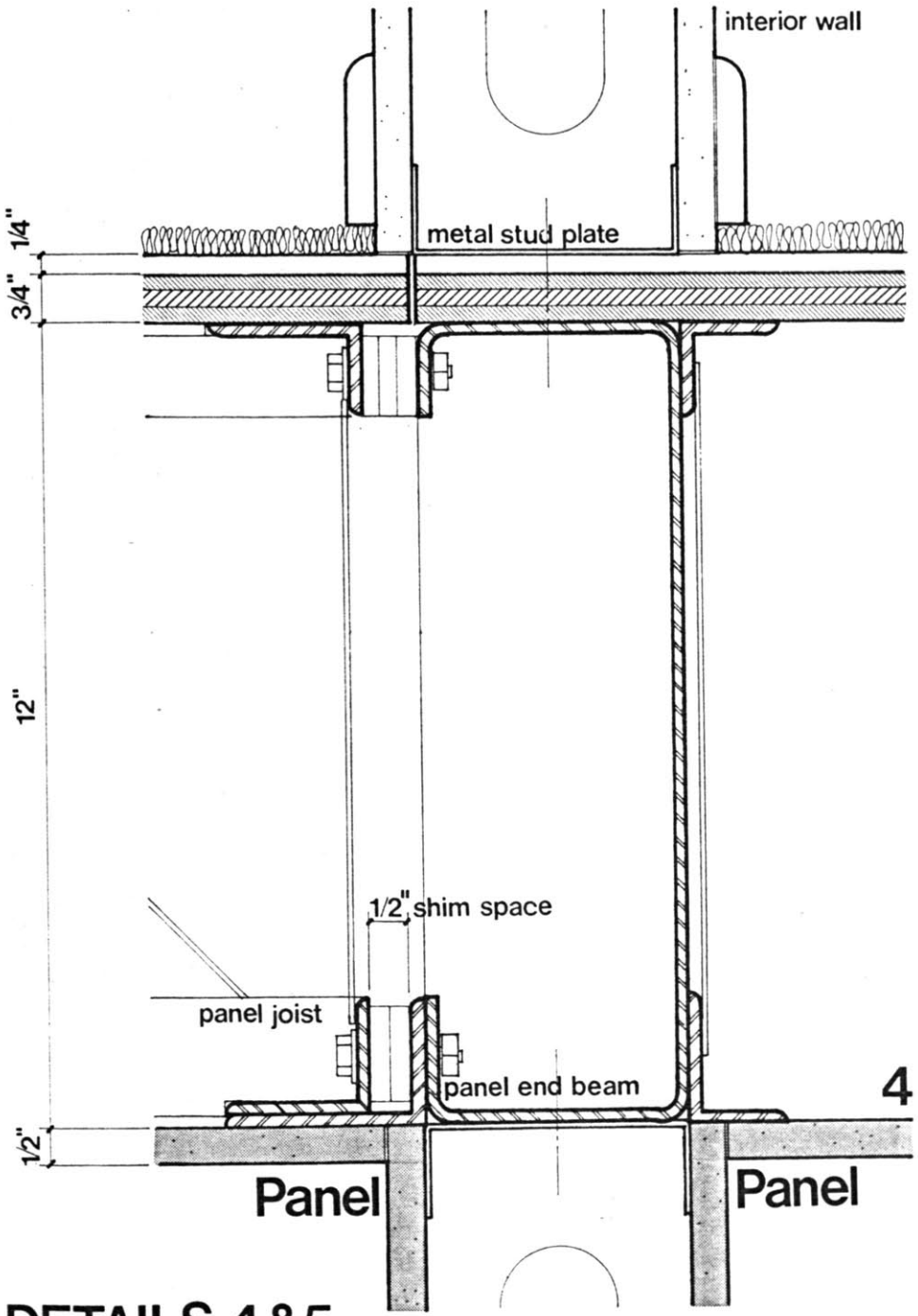


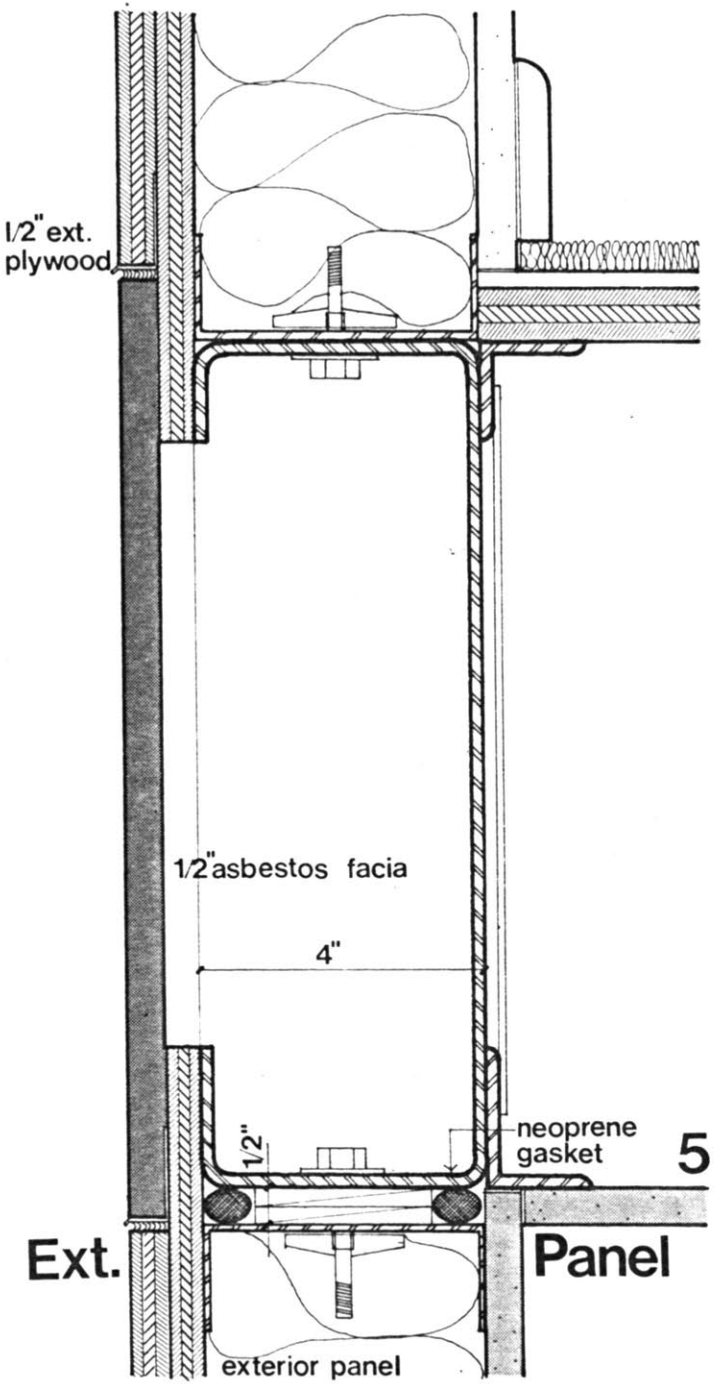




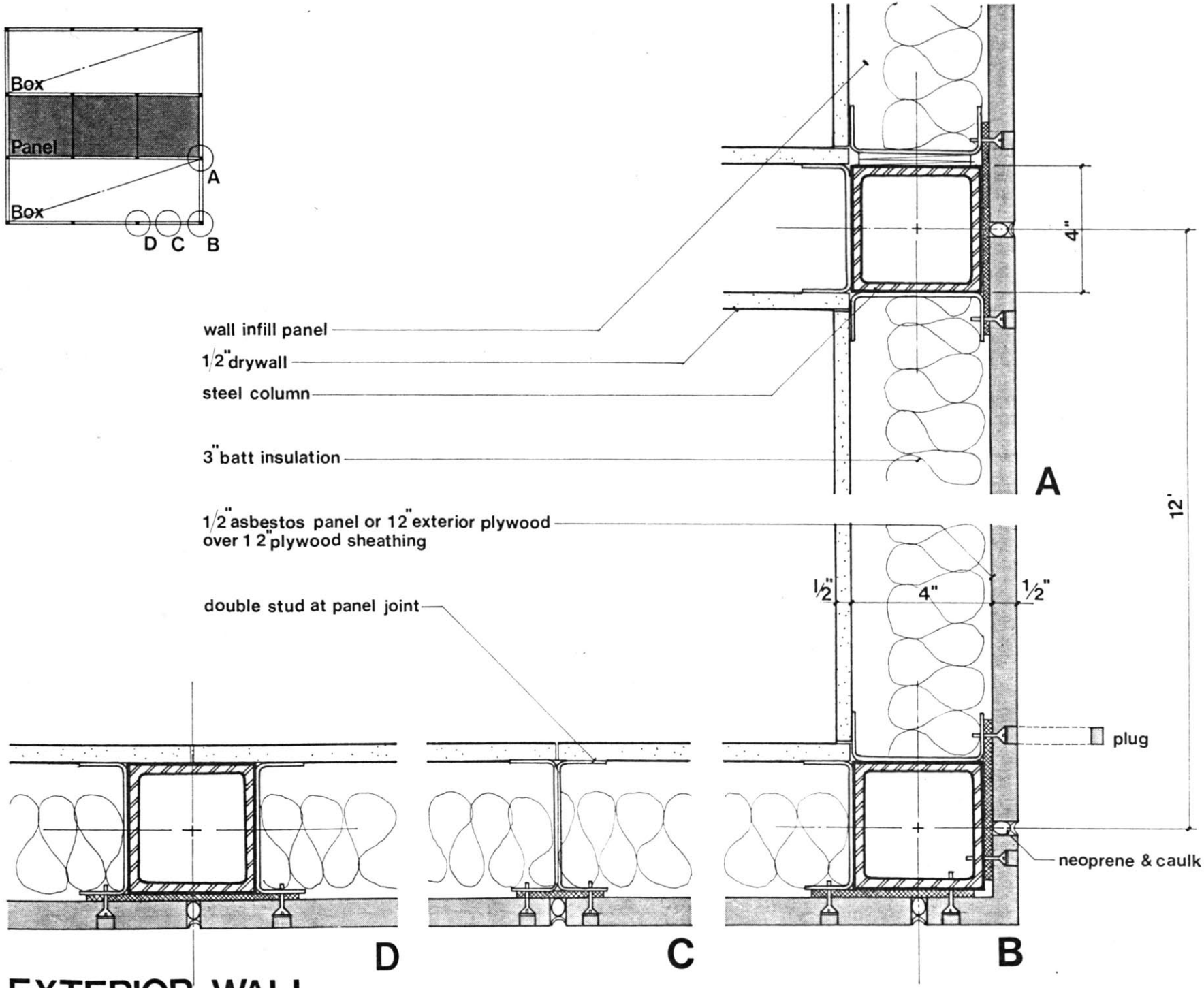
SECTION

scale 3/4" = 1'


interior wall
1/4"
3/4"
metal stud plate
12"
1/2" shim space
panel joist
panel end beam
4
1/2"
Panel
Panel


1/2" ext. plywood
1/2" asbestos facia
4"
1/2"
neoprene gasket
5
Ext.
Panel
exterior panel

DETAILS 4&5

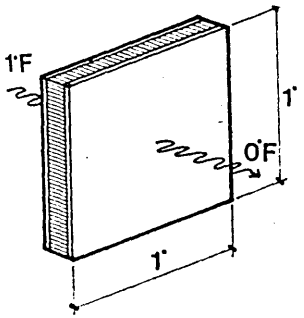


EXTERIOR WALL

MECHANICAL

MECHANICAL STUDY

The following study is primarily made for individual or combined lowrise housing units, but the principles are valid for analyzing the heating needs for most small building structures. This study is directed at quickly analyzing and calculating where and how heat is lost from a house. Upon determining where and how heat is being lost, "Rule of Thumb" estimates can be used for determining amount of BTU/Hr. heat loss. This information can be used in comparing different types of fuel, to size and pick individual furnace and boiler types, or to be combined with other house loads to determine loads for a central heating system.



DEFINITIONS:

BTU (British Thermal Unit) is the heat or energy needed to raise one pound of water 1° Fah.

U-Coefficient is the number of BTU/Hr. that pass through one square foot of wall, floor, roof, etc., when temperature difference between inside and outside is 1° Fah.

COSTS:

If costs were not an important factor in determining which fuel to use for heating, most builders and users would pick Electricity, Gas, Oil, and Coal, in that order. Electricity has the advantages of instantaneous response, individual thermostatic control, and metering, no combustable parts, being clean, and being quiet. The other fuel sources need combustable parts; also Oil and Coal are not only dirty but need large storage areas.

Because cost is many times the decision maker in determining the type of fuel to be used, it is important to know the relative efficiencies of the four major fuels and their costs/unit.

FUEL	HEAT/UNIT	EFFICIENCY
Electricity	3.41 BTU/watt	95 - 100%
Gas	1,052 BTU/cub. ft.	70 - 80%
Oil	141,000 BTU/gal.	70 - 80%
Coal	14,600 BTU/lb.	65 - 75%

COSTS: (Continued)

In order to make a rough cost comparison of the various fuel types, one only needs to know the amount of energy (BTU/Hr.) to heat a building and the cost of each fuel source in a given locale.

Formula:

$$\frac{\text{BTU/Hr. (needed heat house)}}{\text{BTU's (per unit) x efficiency}} = \text{UNITS/Hr. x COST/UNIT} = \$/\text{Hr.}$$

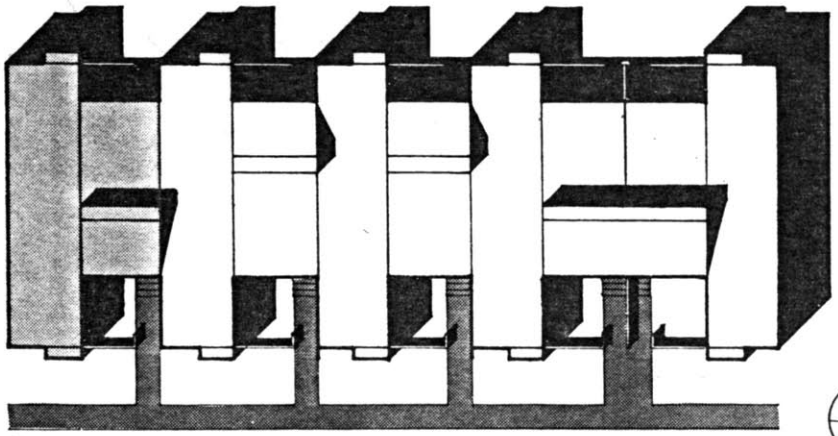
Example:

given: 1 gallon of Oil = 141,000 BTU
given: efficiency of fuel = 75%
assume: 40¢ per gallon
assume: 100,000 BTU/Hr. needed to heat house

$$\frac{100{,}000 \text{ BTU/Hr.}}{141{,}000 \text{ BTU/gal x } 75\% \text{ efficiency}} = .95 \text{ gal/Hr. x } 40¢ \text{ gal.} = 38¢/\text{Hr.}$$

Note:

By computing for each fuel, one can quickly compare fuel costs.



Site Plan

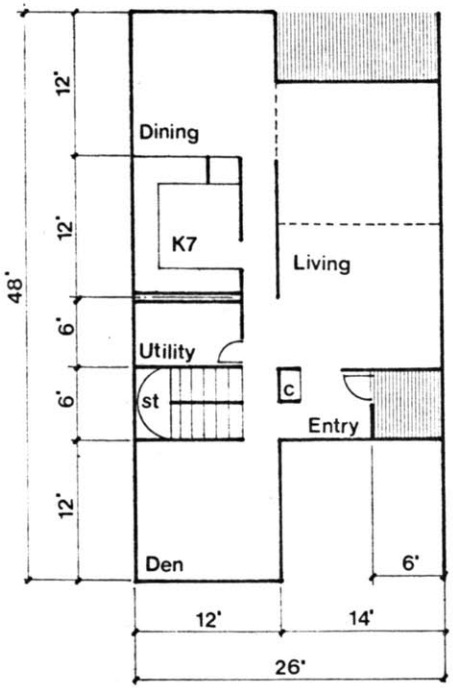
DESIGN CRITERIA:

HEAT LOSS EXAMPLE

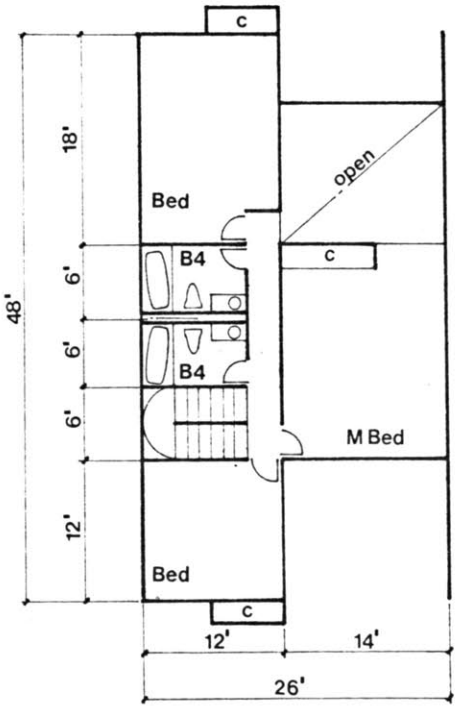
Objective: Determine BFUH Loss thru Building

Assumptions:

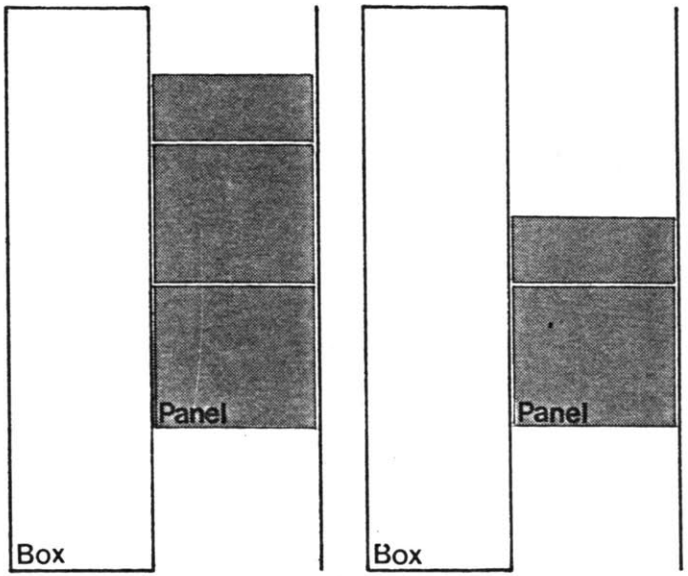
1. Area - New England
2. Calculate for worst condition - nighttime
3. Design temperatures: 70° activity areas
   66° sleeping areas
   64° storage areas
4. Insulating glass (1/4" air space)
5. Wood door (1 1/2" solid)



1st Floor

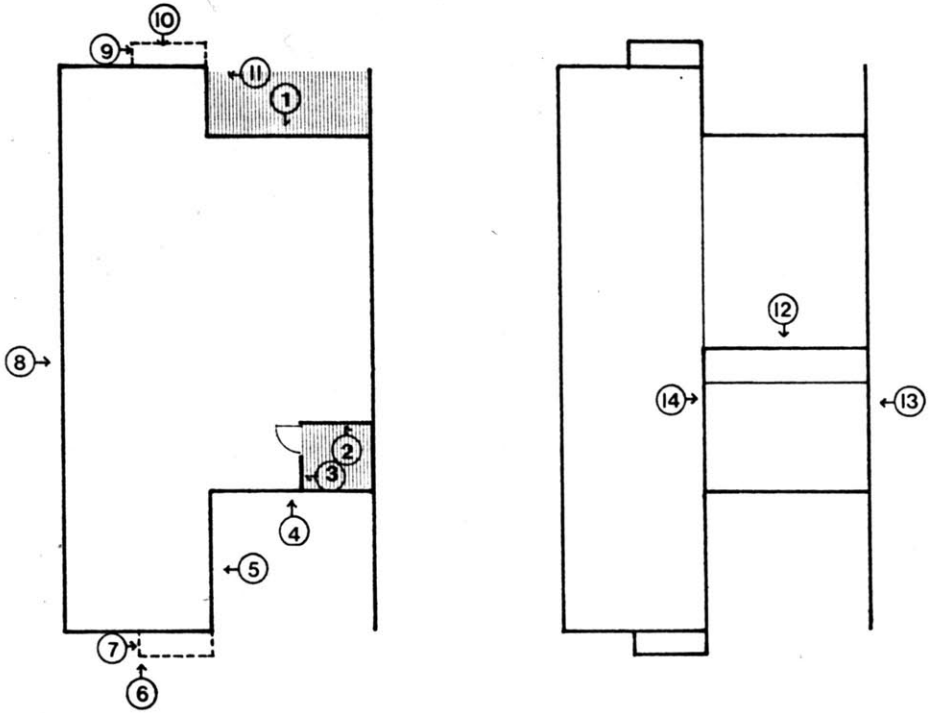


2nd Floor

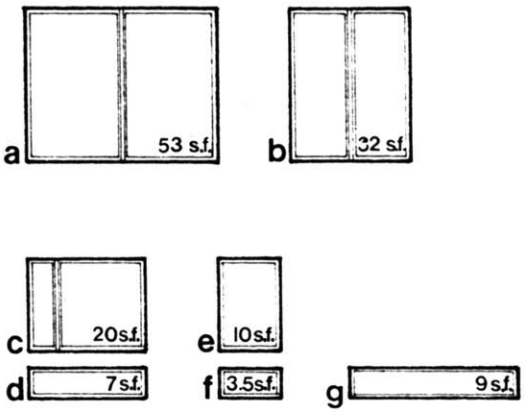


MECHANICAL ANALYSIS

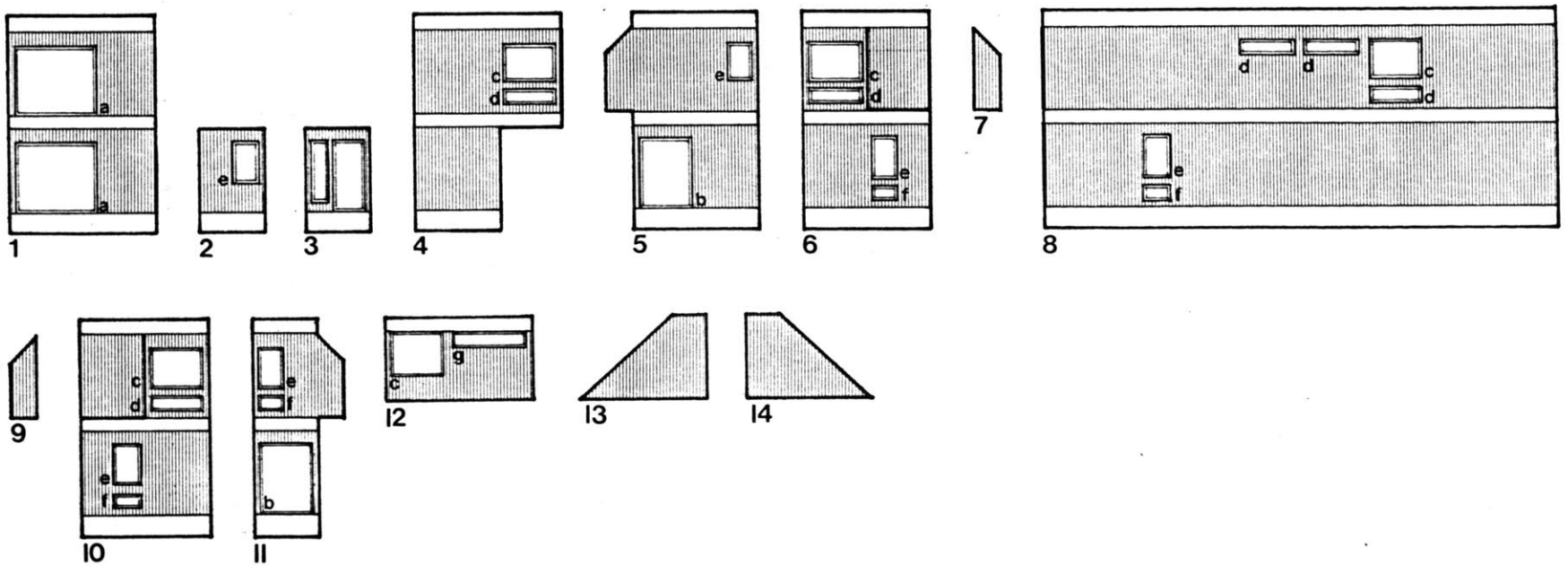
WALL & GLASS LOCATIONS



WINDOWS



ELEVATIONS



1ST FLOOR HEAT LOSS

SPACE	ITEM	AREA	U-COEFF.	ΔT	HEAT LOSS
LIVING	WALL	135 sq. ft.	x .091	x 70	860
	GLASS	106	x .65	x 70	4,800
	ROOF	168	x .10	x 70	1,000
	INFILTRATION	4,200 cub. ft.	x 0.018	x 70	5,300
	SLAB EDGE	20 lin. ft.	x 24BTU/FT		480
sub total					11,340 BTU/H
KITCHEN - DINING	WALL	318 sq. ft.	x .091	x 70	2,000
	GLASS	60	x .65	x 70	2,750
	INFILTRATION	2,700 (2) cub.ft.	x 0.018	x 70	1,000
	SLAB EDGE	42 lin. ft.	x 24 BTU/FT		6,800
sub total					12,550 BTU/H
DEN	WALL	278 sq. ft.	x .091	x 70	1,800
	SLABS	46	x .65	x 70	2,100
	INFILTRATION	1,150 (1.5)cub.ft.	x 0.018	x 70	870
	SLAB EDGE	36 lin. ft.	x 24BTU/FT	x	2,220
sub total					6,990 BTU/H
UTILITY	WALL	54	x .091	x 64	320
	GLASS	-	-	-	-
	INFILTRATION	43 (.5)	x 0.018	x 64	240
	SLAB EDGE	6	x 24 BTU/FT		144
sub total					704BTU/H
STAIR	WALL	100	.091	x 70	640
	GLASS	27	.65	x 70	1,200
	INFILTRATION	1,200 (1)	0.018	x 70	1,500
	ROOF	72	.10	x 70	510
sub total					3,850 BTU/H

1st FLOOR HEAT LOSS (cont.)

FOYER	WALL	74 sq. ft.	x .091	x 70	480
	GLASS	12	x .65	x 70	550
	DOOR	26	x .49	x 70	900
	INFILTRATION	400 (1) cub. ft.	x 0.018	x 70	510
	SLAB EDGE	8 lin. ft.	x 24 BTU/FT		194
sub total					2,634 BTU/HR

1st floor total Heat Loss/Hr.	37,868 BTU/H

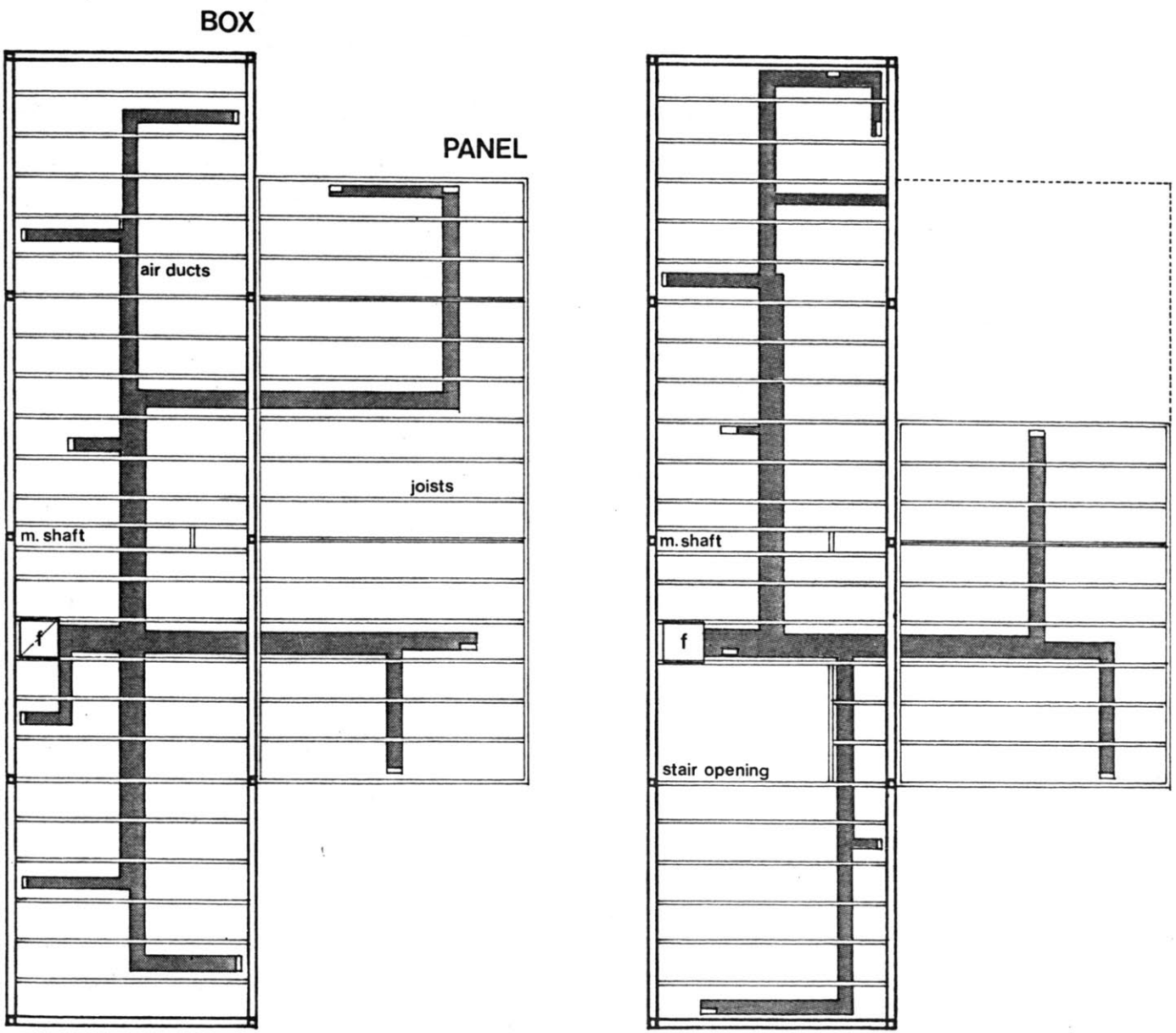
2ND FLOOR HEAT LOSS

SPACE	ITEM	AREA	U-COEFF	ΔT	HEAT LOSS
BED 1	WALL	255 sq. ft.	x .091	x 68	1,550
	GLASS	41	x .65	x 68	1,300
	ROOF	250	x .10	x 68	1,700
	INFILTRATION	1,900 (1.5)cub.ft.	x 0.018	x 68	3,500
sub total					8,050 BTU/H
BED 2	WALL	210 sq. ft.	x .091	x 68	1,300
	GLASS	37	x .65	x 68	1,600
	ROOF	170	x .10	x 68	1,150
	INFILTRATION	1,250 (1.5)cub.ft.	x 0.018	x 68	2,250
sub total					6,300 BTU/H
MASTER BED	WALL	270 sq. ft.	x .091	x 68	1,700
	GLASS	54	x .65	x 68	2,400
	ROOF	300	x .10	x 68	2,050
	INFILTRATION	2,850 (1.5)cub.ft.	x 0.018	x 68	5,300
sub total					9,450 BTU/H
BATHS	WALL	78 sq. ft.	x .091	x 70	550
	GLASS	18	x .65	x 70	850
	ROOF	72	x .10	x 70	540
	INFILTRATION	580 (1) cub.ft.	x 0.018	x 70	750
					2,690 BTU/H

*Rule of Thumb:
Net Heat Loss x 1.6 = Furnace Capacity

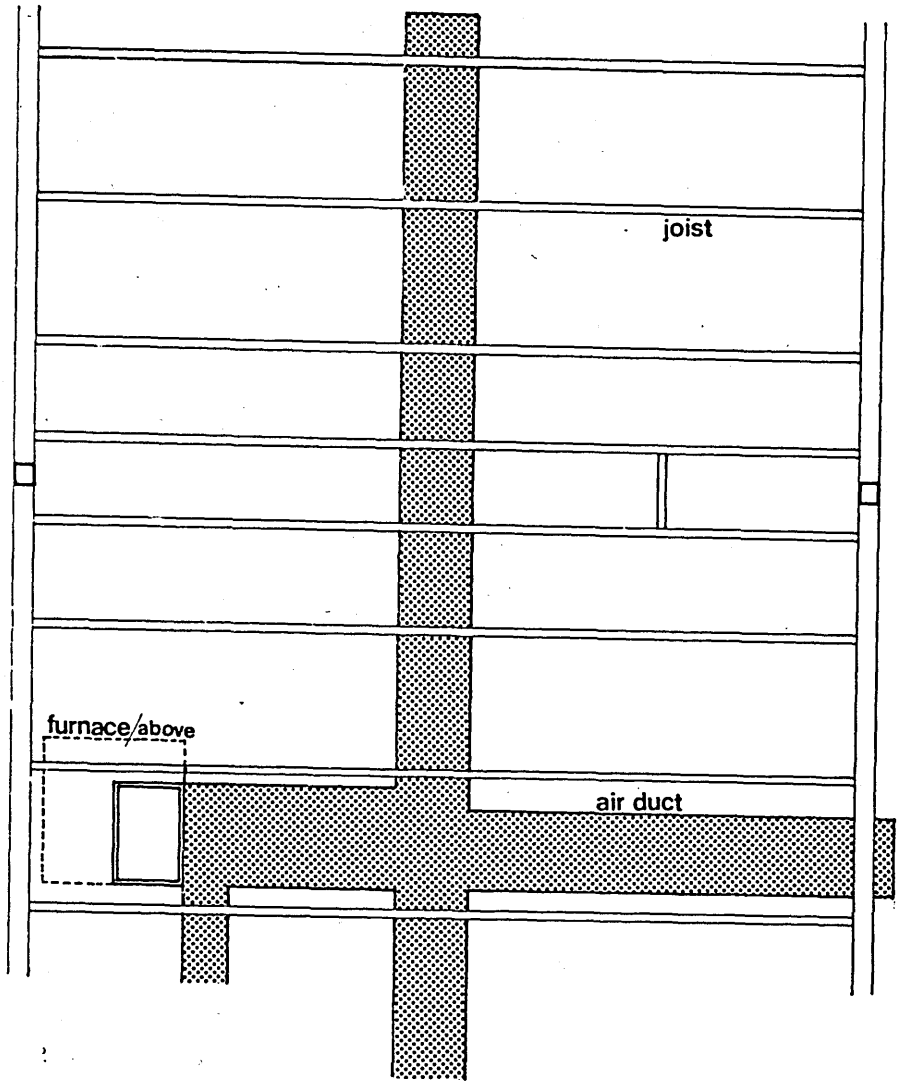
2nd Floor Total Heat Loss/Hr.	26,490 BTU/H
TOTAL NET HEAT LOSS	64,358 BTU/H
*1.6 x NET	102,000 BTU/Hr

FURNACE CAPACITY

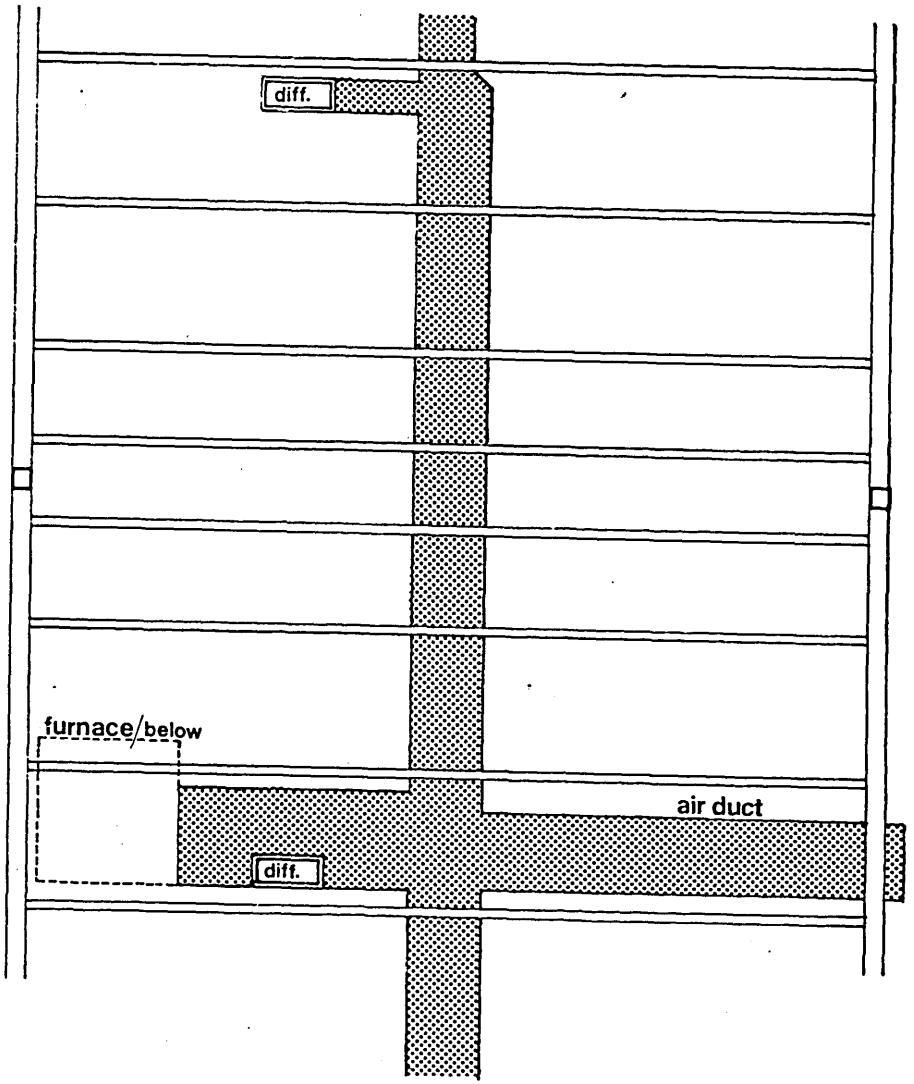


HEATING DUCT DISTRIBUTION

scale 1/8" 1'

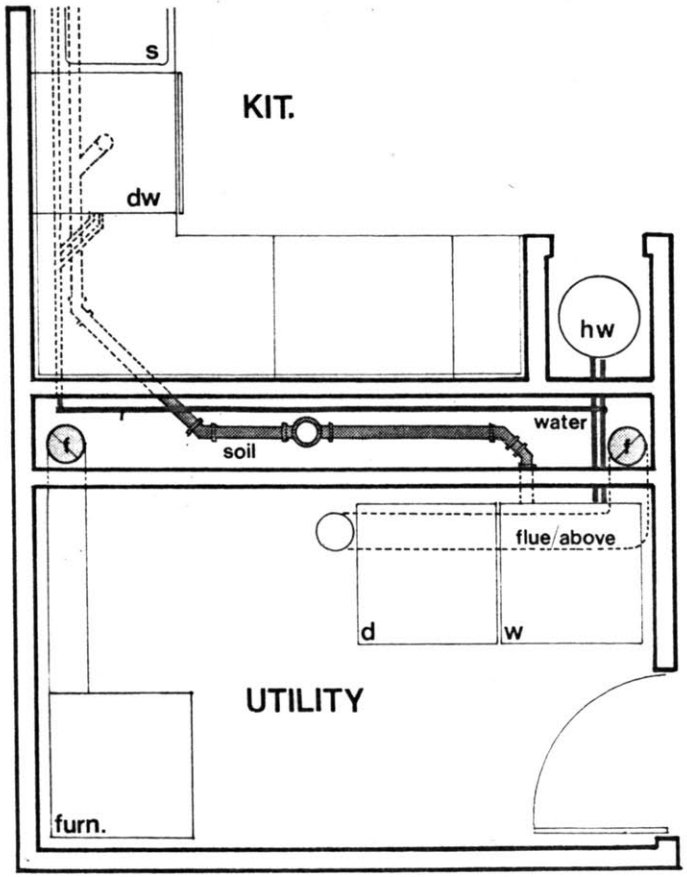


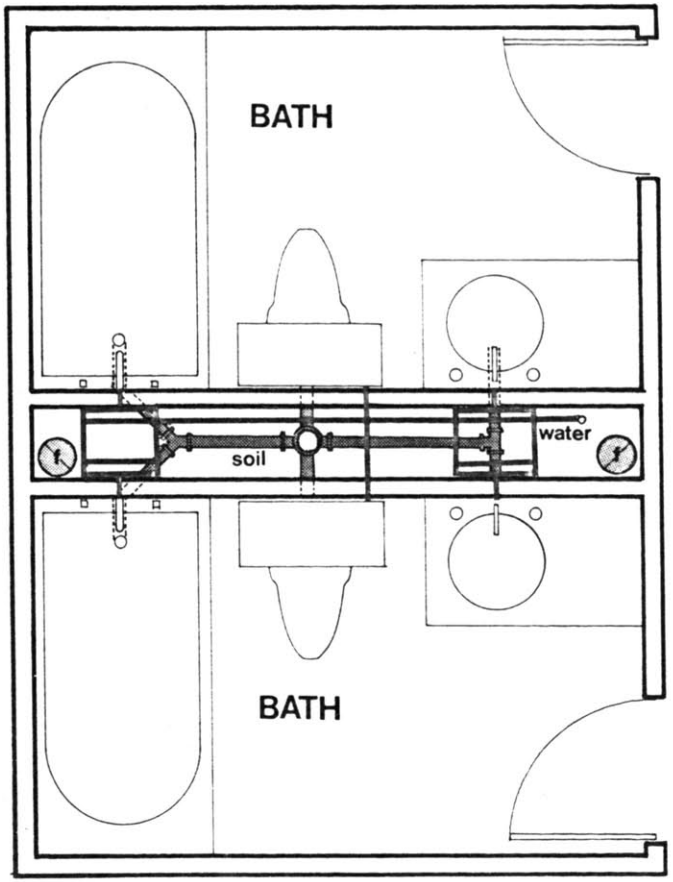
1st FLOOR



2nd FLOOR

MECHANICAL INTEGRATION Structure, Heating, Plumbing


s
KIT.
dw
hw
water
soil
flue/above
d
w
UTILITY
furn.


BATH
soil
water
BATH

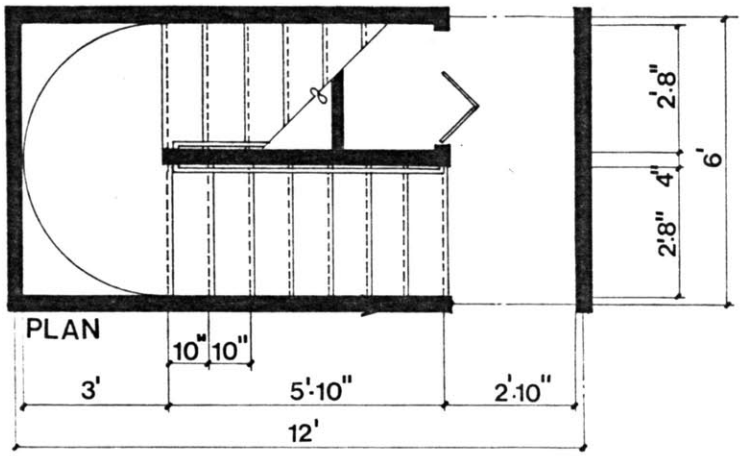
PLANNING:

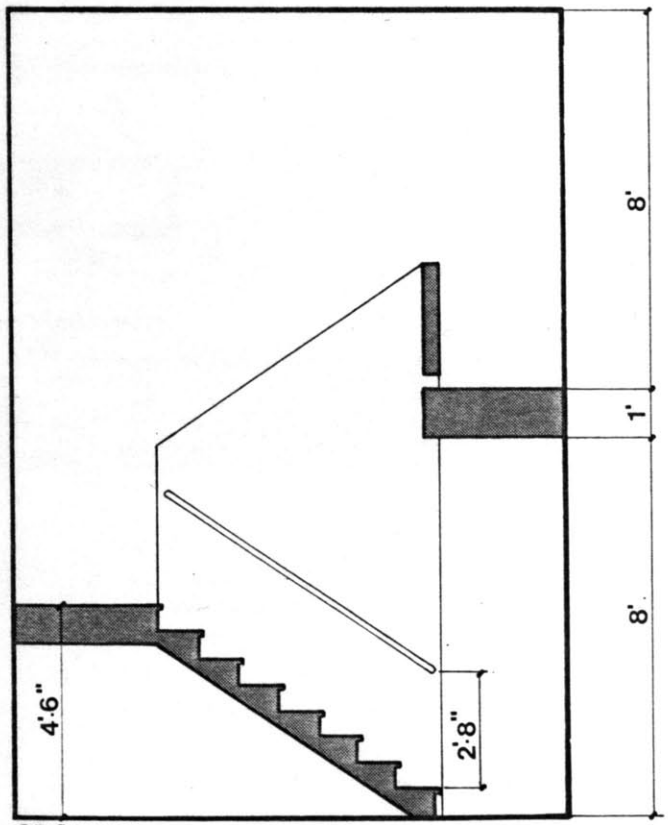
components
apartments
townhouses

MINIMUM ROOM AREAS (F.H.A. standards)

SEPARATE ROOM AREAS	0 BEDROOM	1 BEDROOM	2 BEDROOM	3 BEDROOM	4 BEDROOM
Living		160 sq. ft.	160 sq. ft.	170 sq. ft.	180 sq. ft.
Dining		100	100	110	120
Kitchen		60	60	70	80
Bedroom (primary)		120	120	120	120
Bedroom (secondary)			80	80	80
Others (den, family, etc.)		80	80	80	80
Foyer		25	25	25	25
COMBINED ROOM AREAS					
Living and Dining Area		200 sq. ft.	200 sq. ft.	220 sq.ft.	230 sq. ft.
Living and Dining Room		240	240	260	270
Living and Dining and Bedroom	240				
Living and Bedroom	190				
Kitchen and Dining Room		150	150	160	180
Living and Dining and Kitchen		260	270	290	310
OTHER ROOM AREAS					
Storage (interior)	100 cub.ft.	100 cub.ft.	140 cub.ft.	180cub.ft.	200 cub.ft.
Storage (at least 1/3 interior)	150 cub.ft.	150 cub.ft.	200 cub.ft.	250cub.ft.	300 cub. ft.
Closet (primary bedroom)		5 lin. ft.	5 lin. ft.	5 lin.ft.	5 lin. ft.
Closet (secondary bedroom)		3	3	3	3
Linen	1'-6" lin.ft.	1'-6"	1'-6"	1'-6"	1'-6"
NUMBER OF BATHROOMS					
Middle Income	1	1	1 1/2-2	2	2 1/2

INTERIOR STAIR





SECTION

STAIR DESIGN

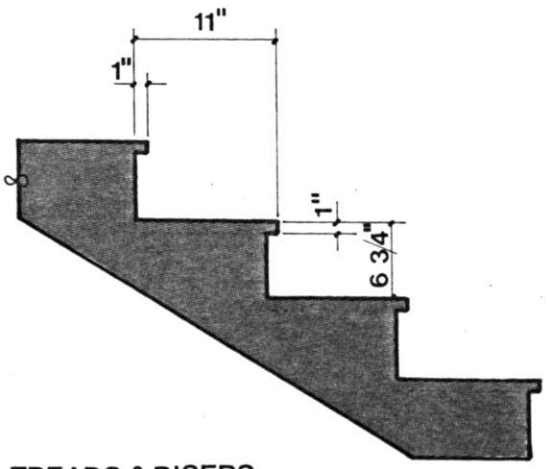
F/F = 9'-0"
= 108"

assume: riser @ 6 3/4"
108/6.75 = 16 risers

Rule of Thumb: 2r + t = 24" to 25"
2(6 3/4") + t = 24" to 25"
t = 10 1/2" to 11 1/2"

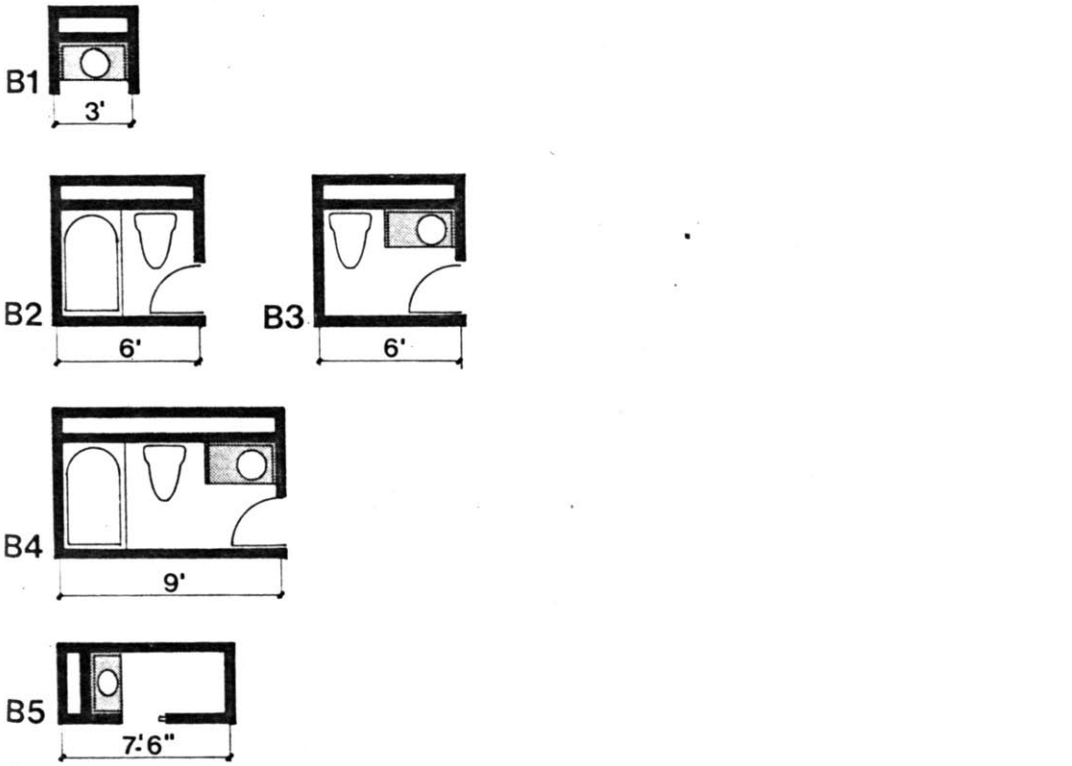
16 risers @ 6 3/4"
14 treads @ 11"

Railing Height @ 2'-8"

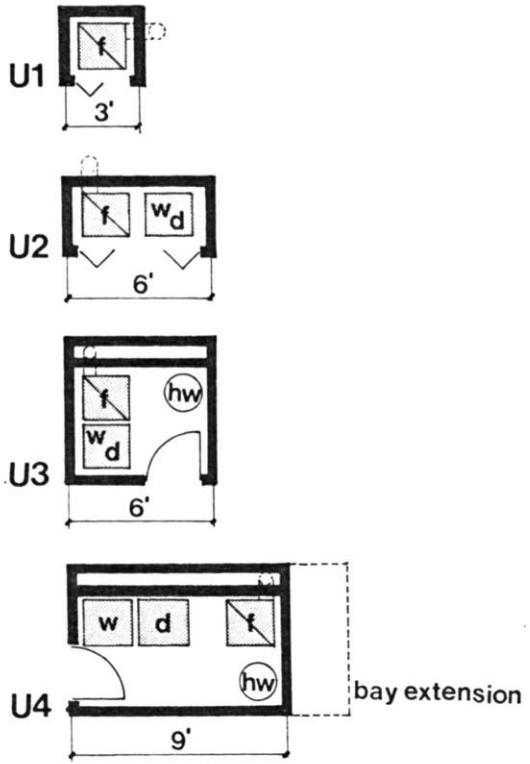


TREADS & RISERS

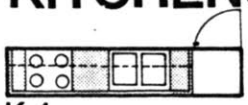
BATHROOMS



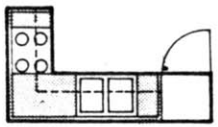
UTILITY ROOMS



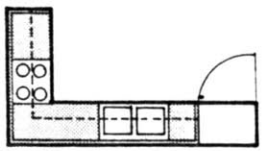
KITCHENS



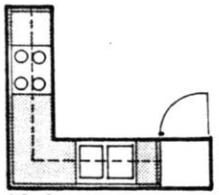
K-1



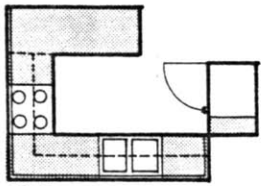
K-2



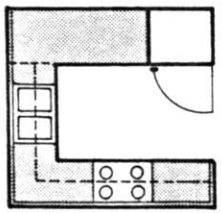
K-3



K-4



K-5



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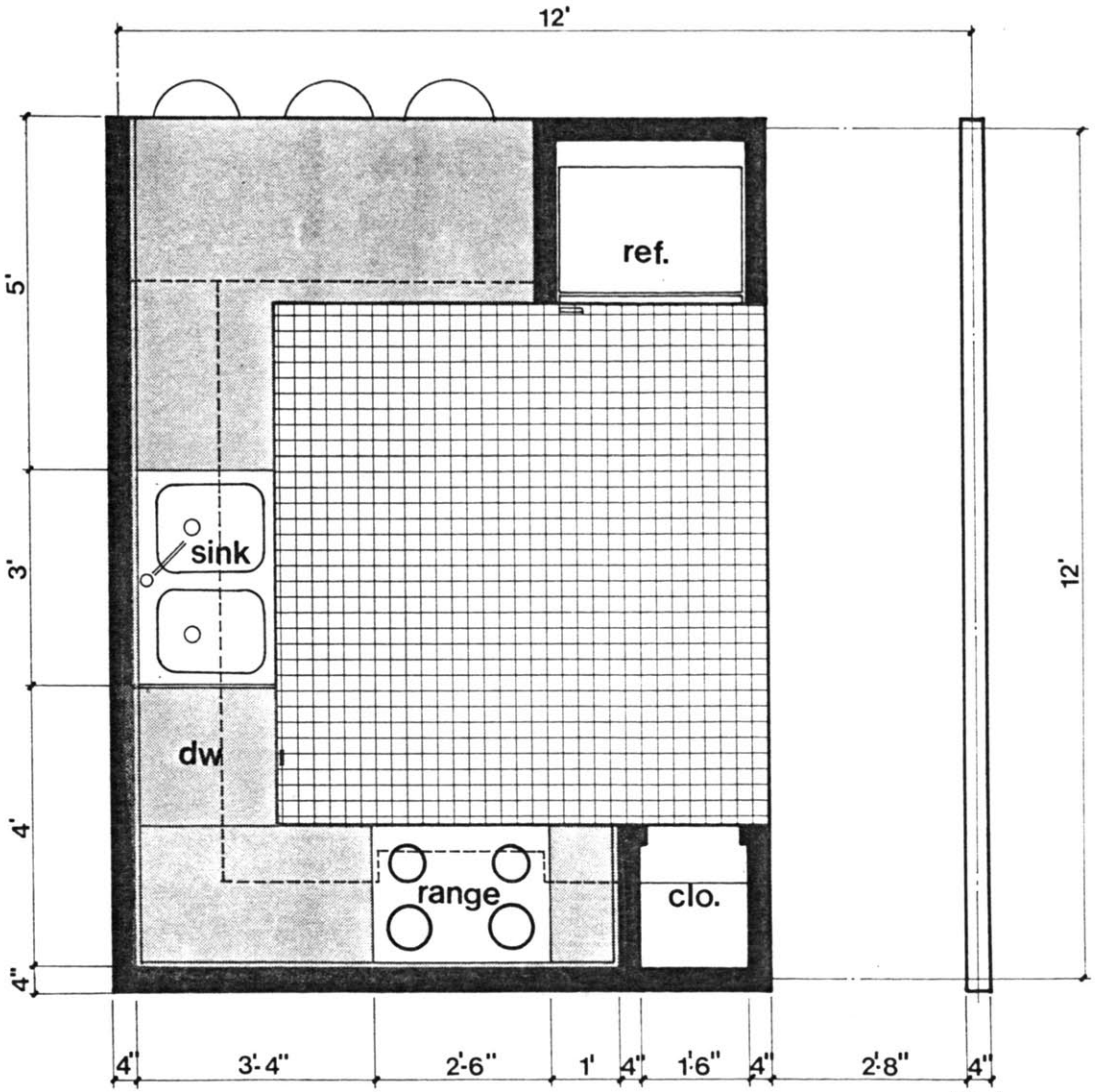


K-7

scale: 3/8" = 1'

EXTERIOR SIDING

Exterior finish for all lowrise construction to be 1/2" exterior grade plywood over 1/2" plywood sheathing.

Finish: natural

WINDOWS

Anodized Aluminum
Color - dark brown
Operable windows: casement
awning

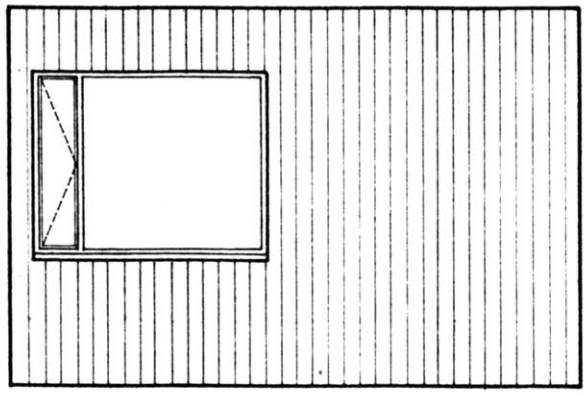
Glass:

Insulating glass - Double (1/4" air space)
U-coefficient = 0.65

Note:

Bottom window of type 2 and 3 may be replaced by ventilating grill for fancoil or through the wall airconditioning unit.

WINDOWS



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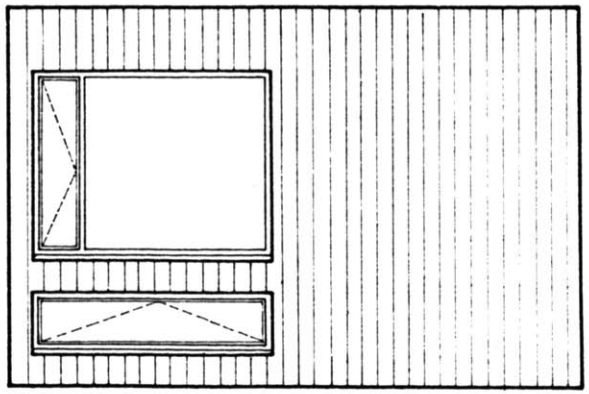

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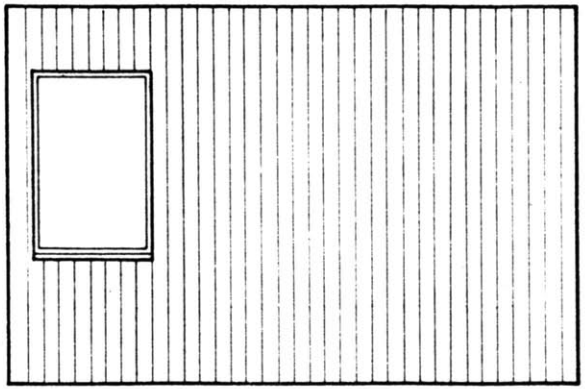

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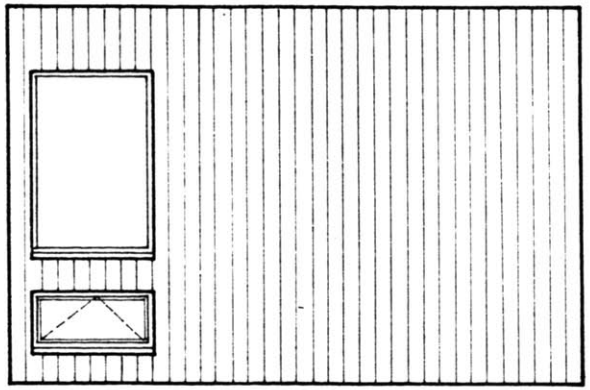

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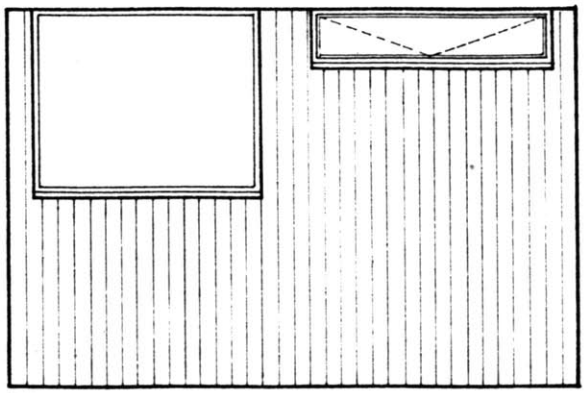

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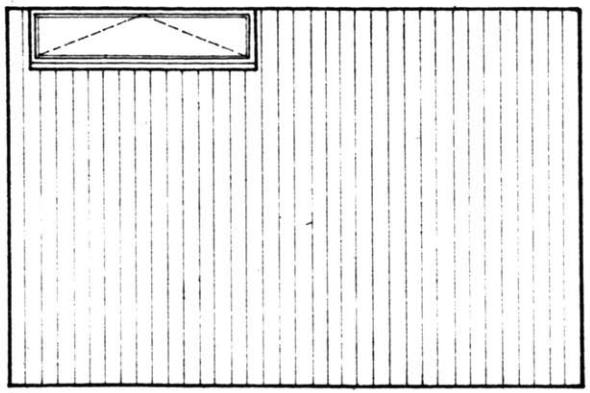

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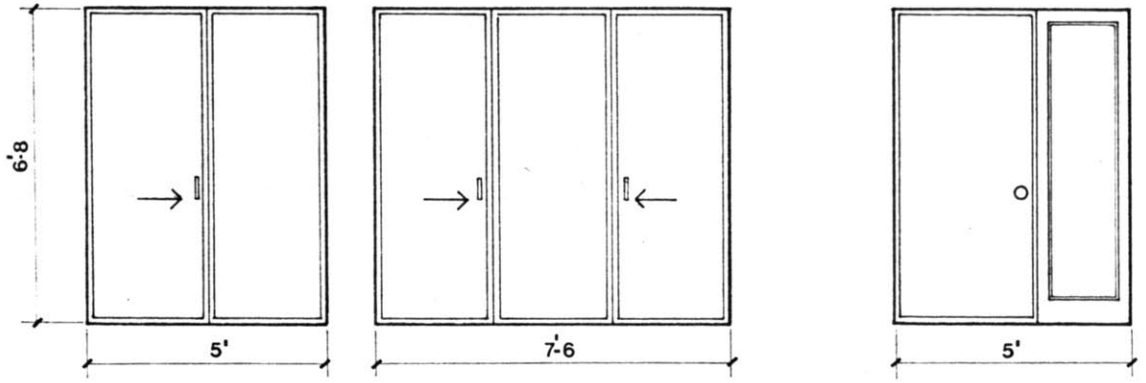
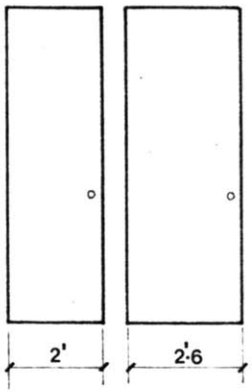
WINDOWS (Lowrise)

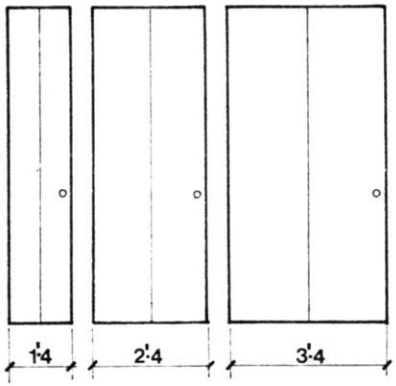
EXTERIOR DOORS:

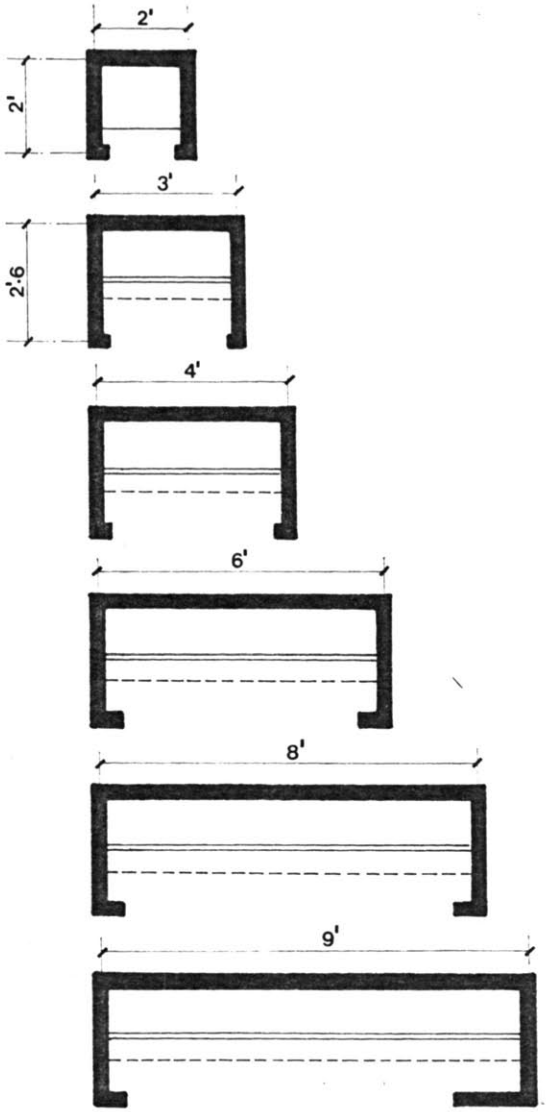


INTERIOR DOORS:



CLOSET DOORS:





CLOSETS

DOORS & CLOSETS

WINDOWS

EXTERIOR SIDING:

1/2" or 3/4" Corspan asbestos panels bolted to heavy gauge metal studs (sheet).

Finish: stone gray
Properties:
Density: 100 lbs/cub.ft.
Tensile Strength: 1200 psi
Squareness of cut: 1/8" in 24"
Length variance: + 1/8"
Width variance: ± 1/8"
Weight: 1/2" = 4.7 lbs/sq. ft.
3/4" = 7.0 lbs/sq. ft.
Max. length = 15 feet
Safe span: 1/2" = 4 feet
3/4" = 5 feet

WINDOWS:

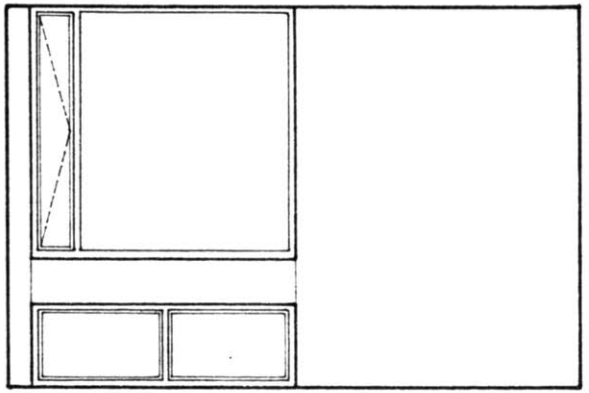
Anodized Aluminum
Color: black
Operable windows: casement

GLASS:

Insulating glass = Double (1/4" air space)
U-coefficient = 0.65

*Note:

Bottom window of type 2 used for ventilating grill for through the wall unit or fan coil.



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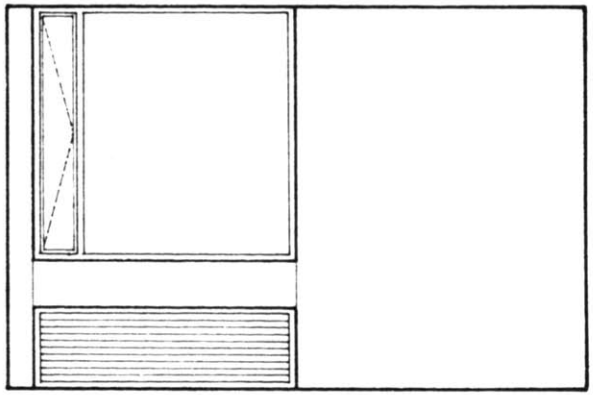
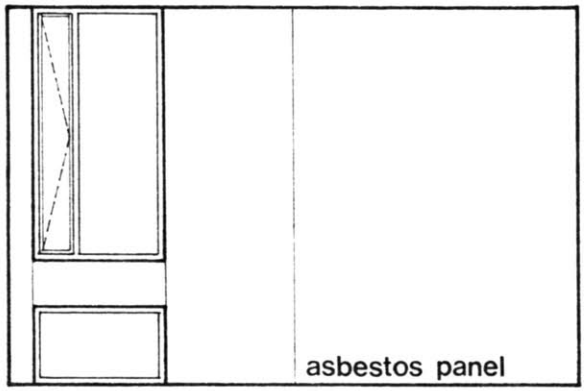


2 mechanical vent



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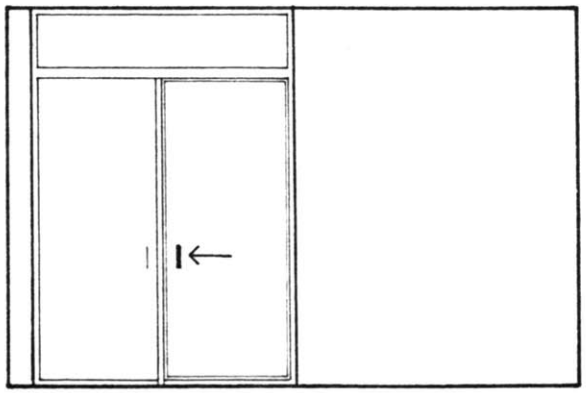

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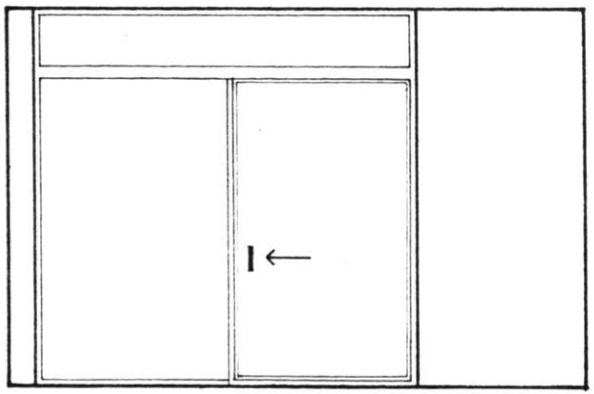
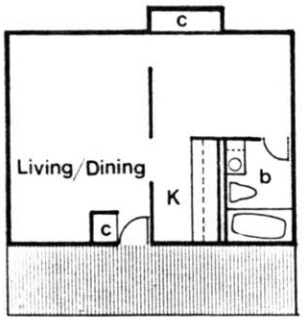


5

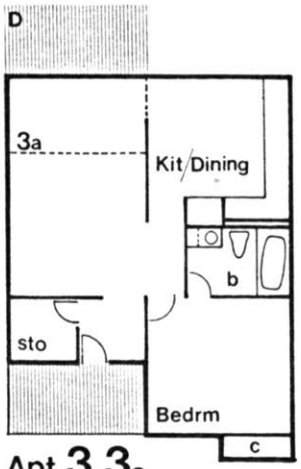
APARTMENTS

TYPES:

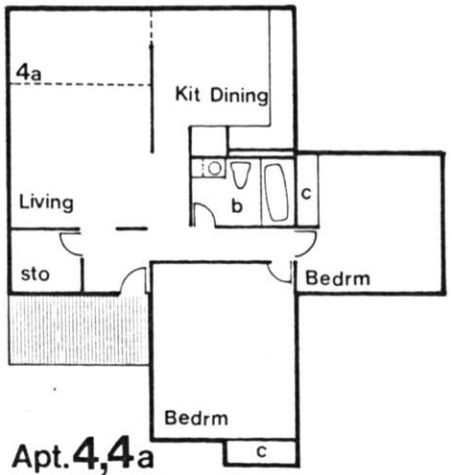


Apt. 1
430 sq ft

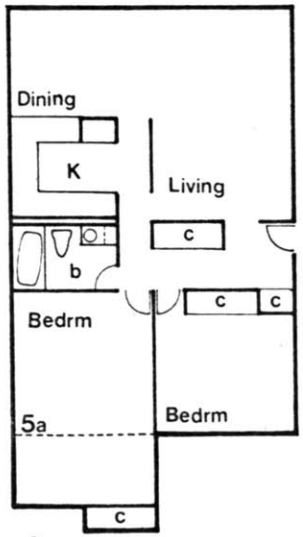
Apt. 2, 2a
2 – 590 sq ft
2a – 520 sq ft



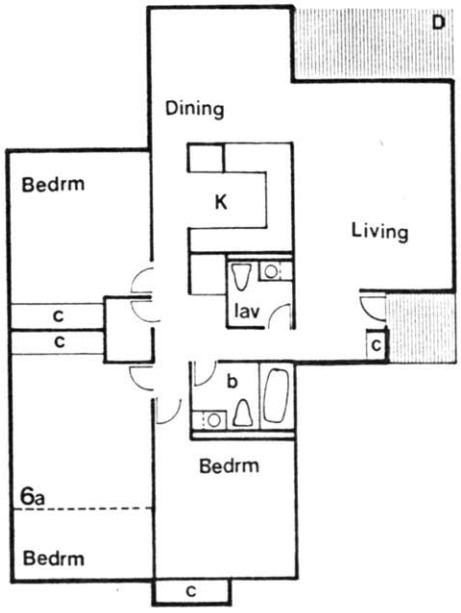
Apt. 3, 3a
3 – 660 sq ft
3a – 580 sq ft



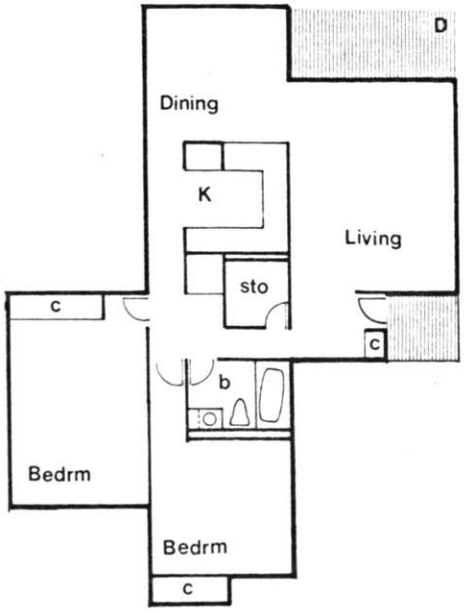
Apt. 4, 4a
4 – 860 sq ft
4a – 790 sq ft



Apt. 5, 5a
5 – 930 sq ft
5a – 860 sq ft

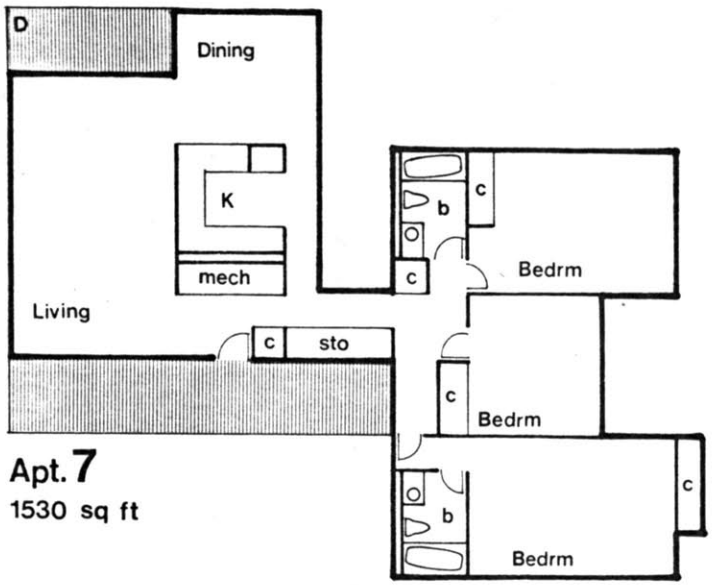


Apt. 6, 6a
6 – 1440 sq ft
6a – 1370 sq ft

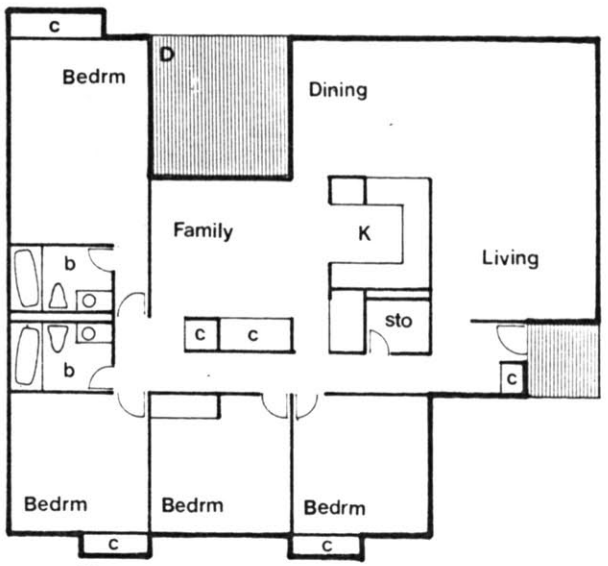


Apt. 6b
1230 sq ft

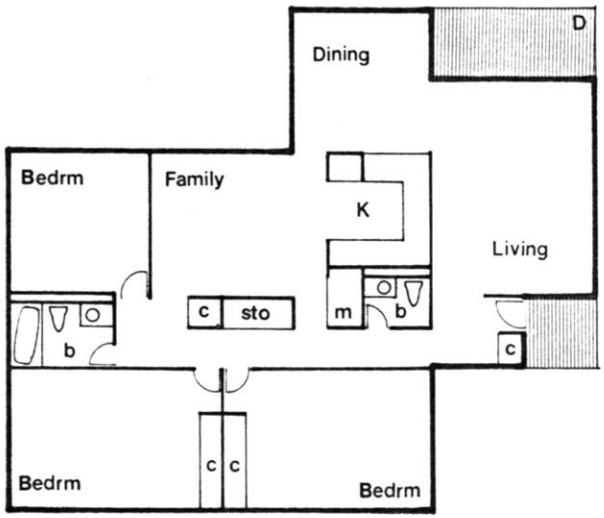
APARTMENTS



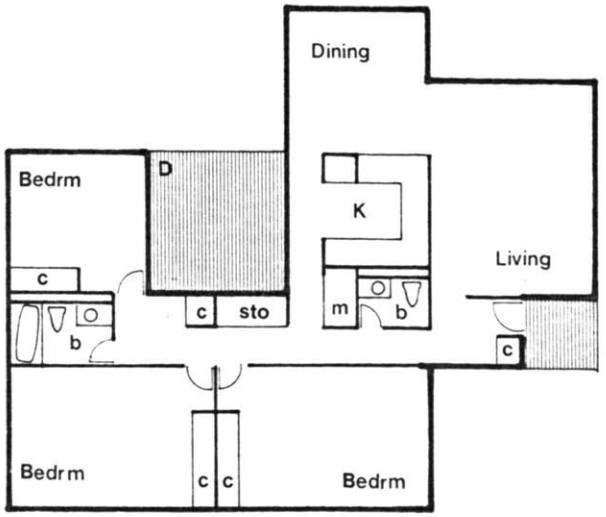
Apt. 7
1530 sq ft



Apt. 8
1590 sq ft

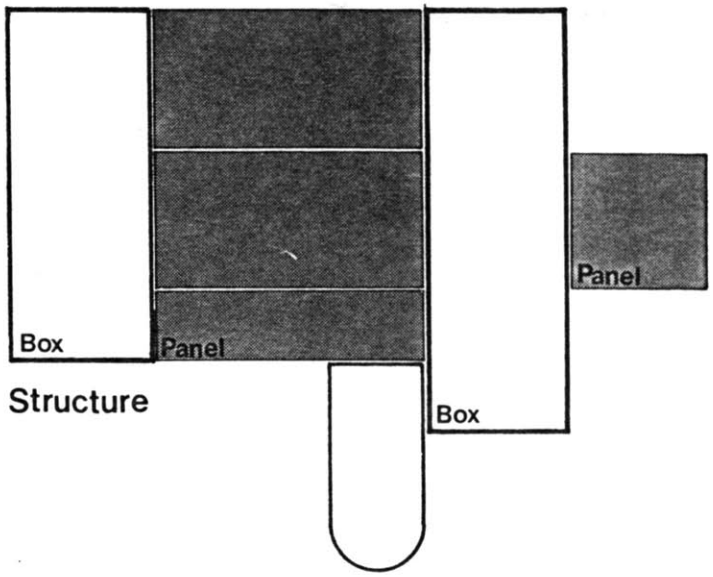


Apt. 8a
1350 sq ft

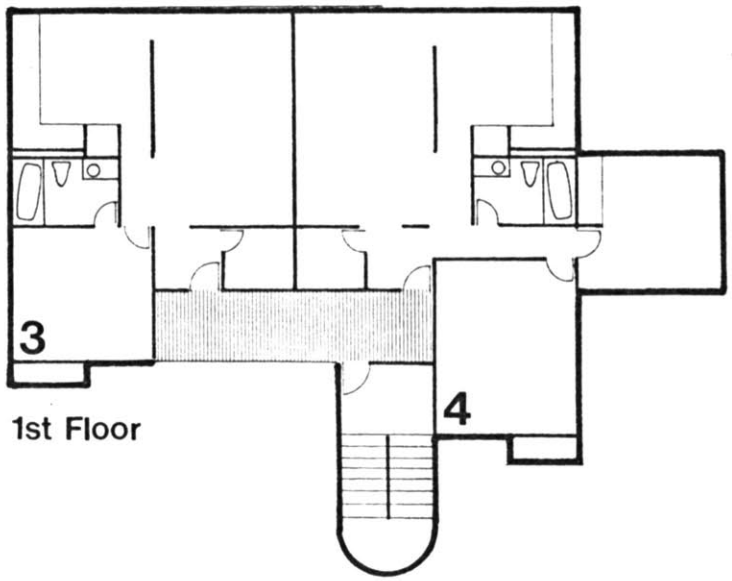


Apt. 8b
1200 sq ft

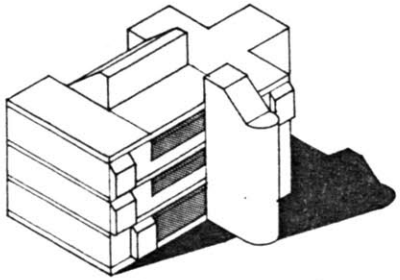
APARTMENTS (cont.)

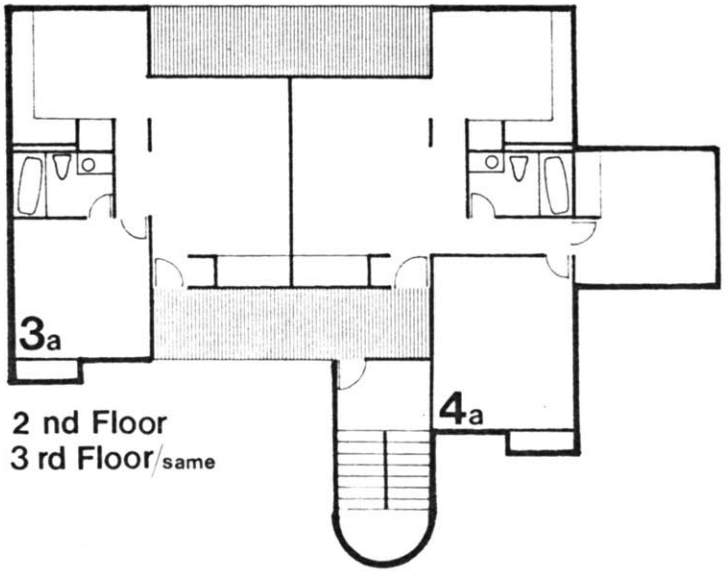


Structure



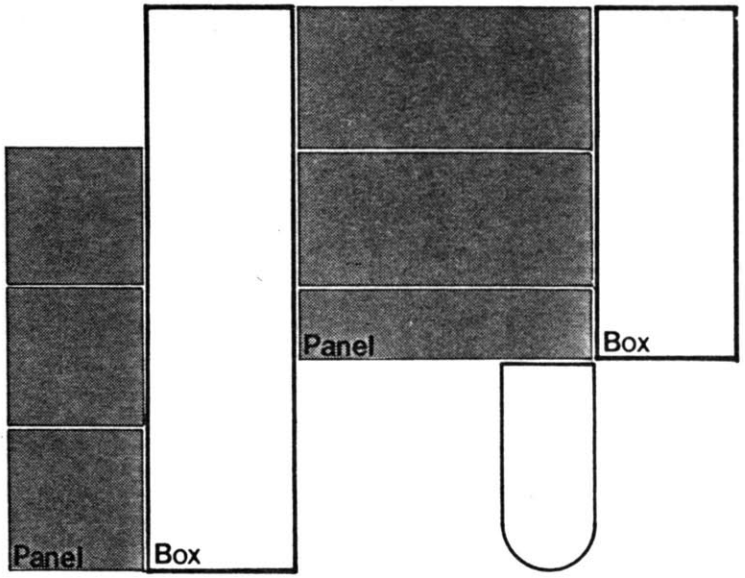
1st Floor



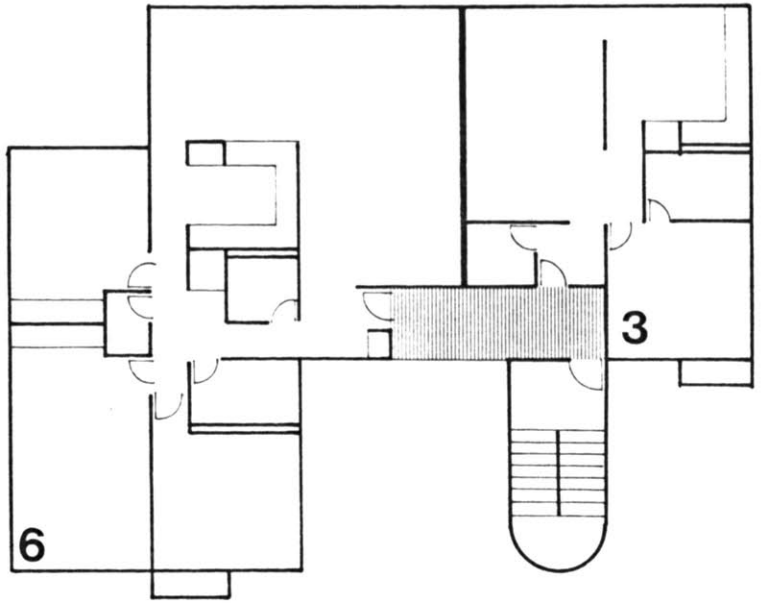


2 nd Floor
3 rd Floor/same

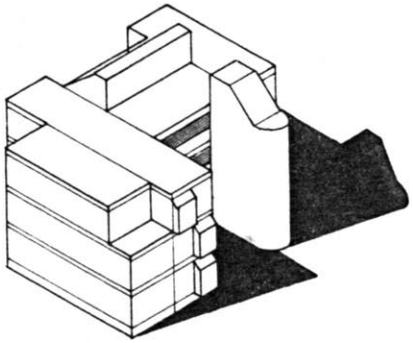
APT. COMBINATIONS

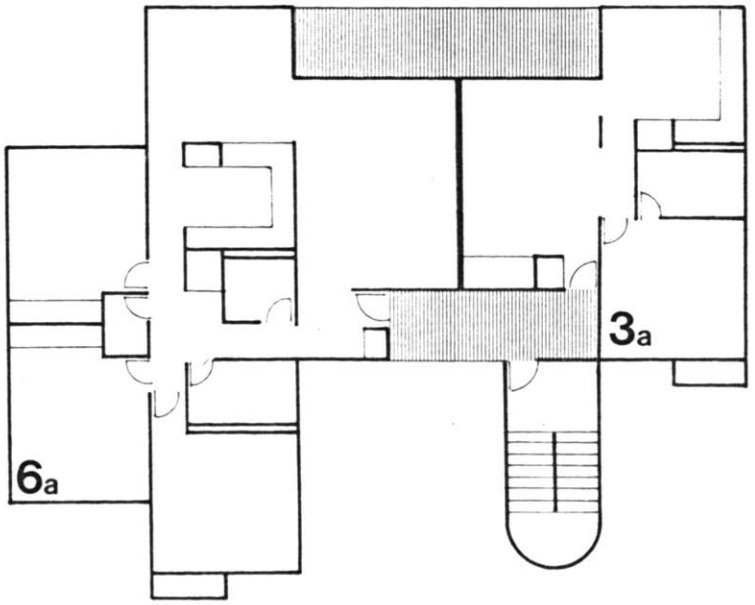


Structure



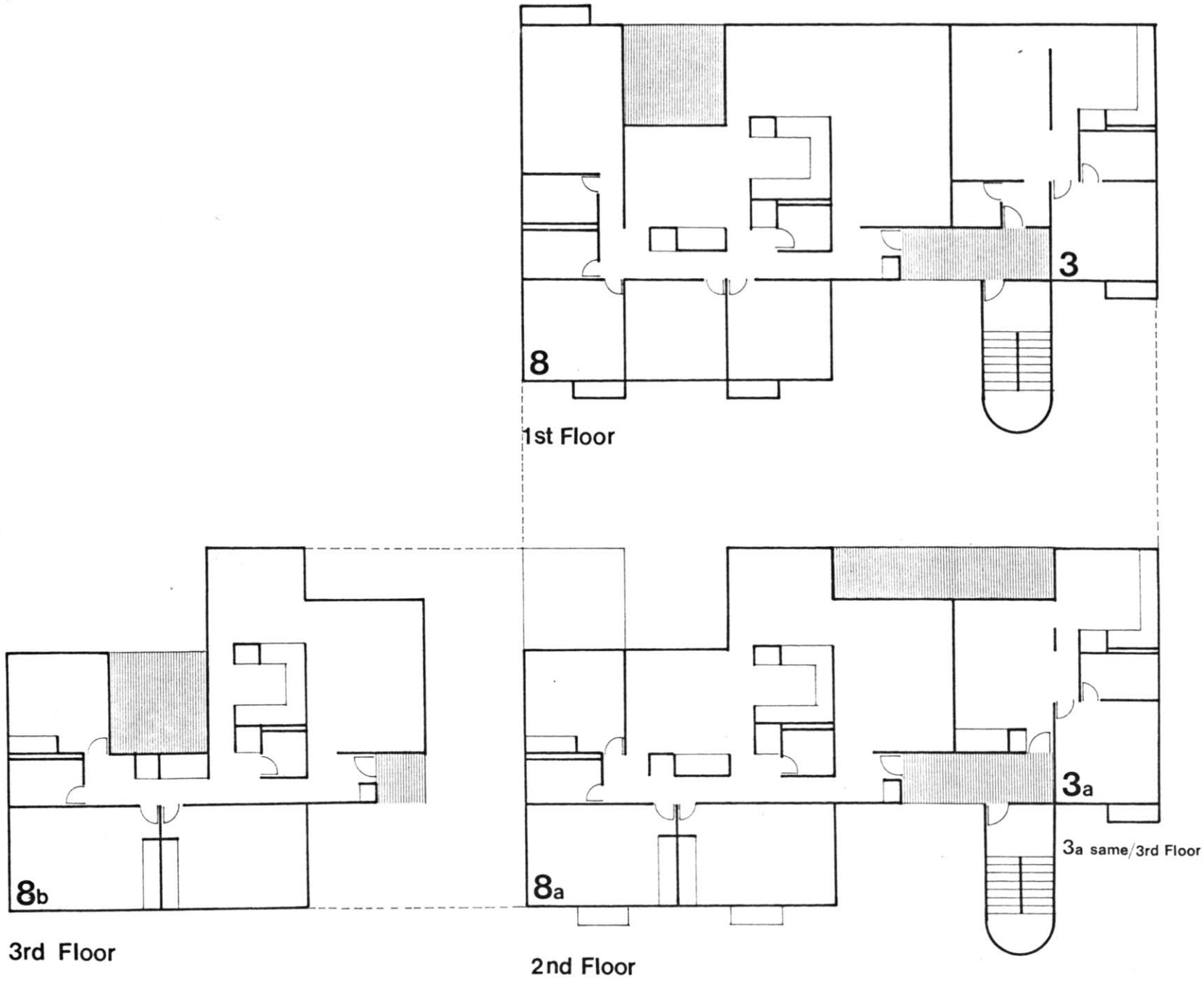
1st Floor



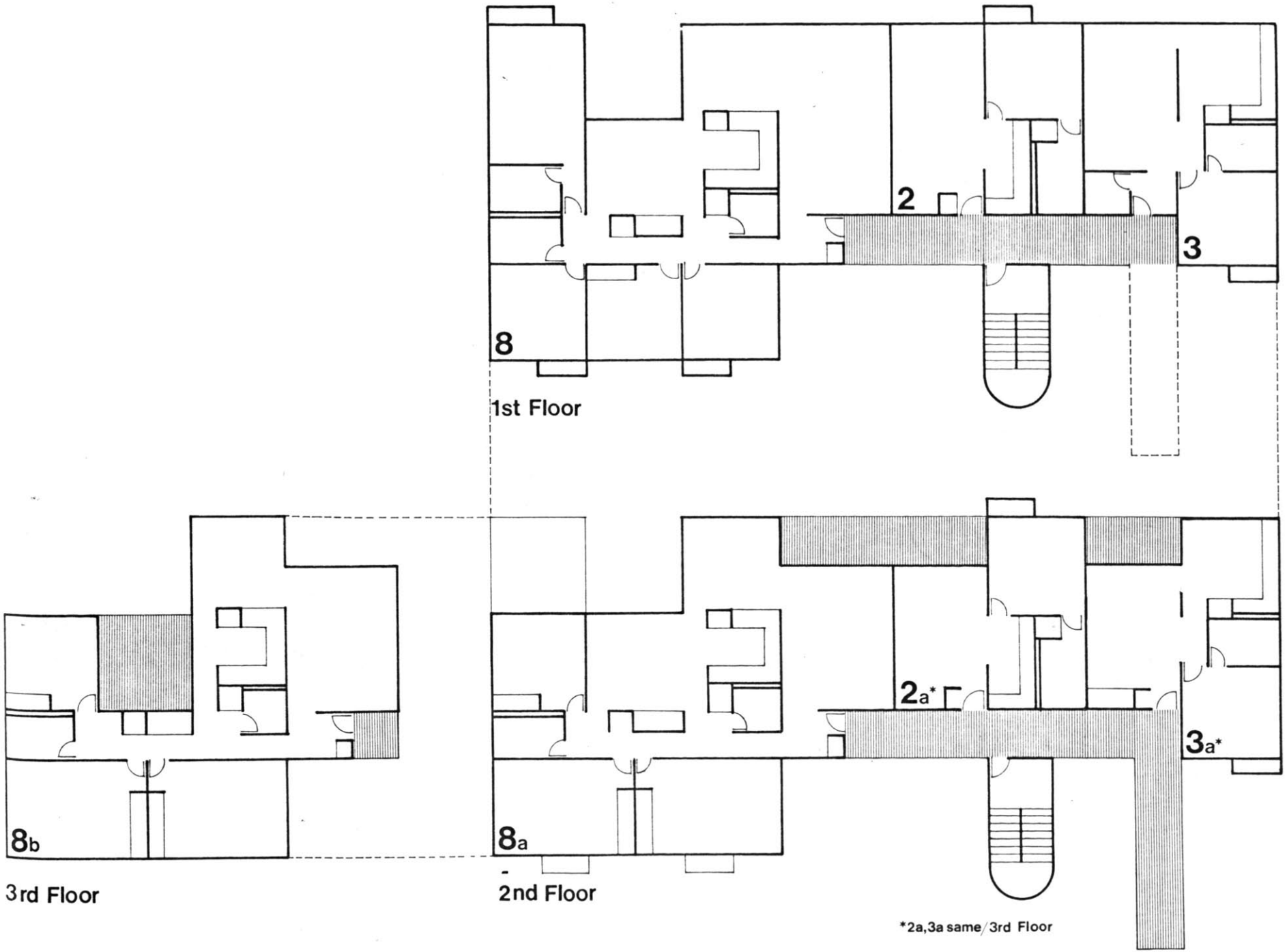


2 nd Floor
3 rd Floor/same

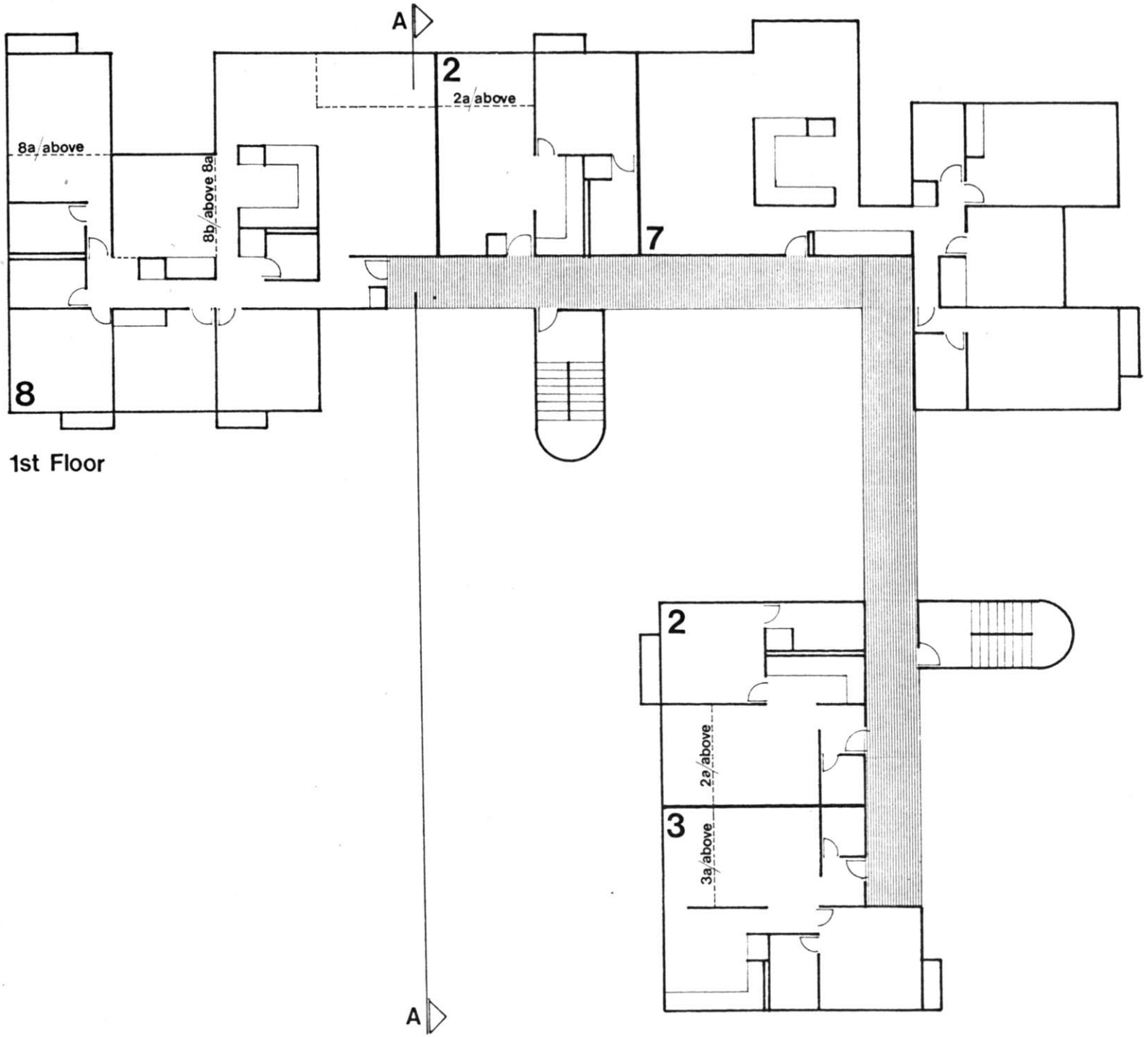
APT. COMBINATIONS



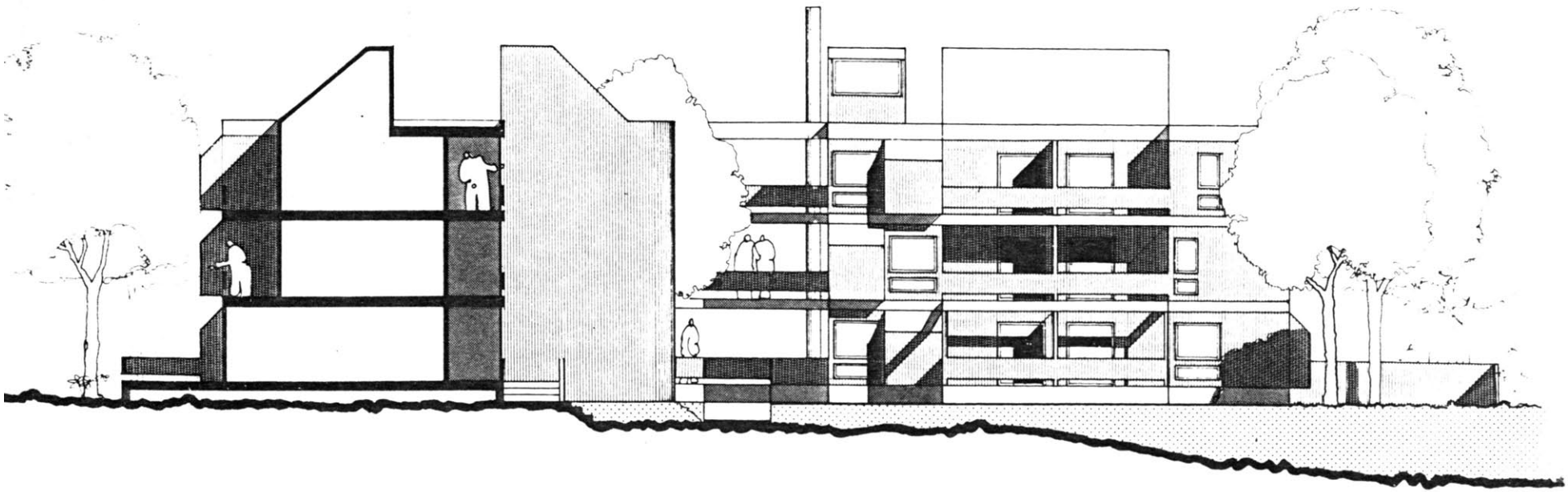
APT. COMBINATIONS



APT. COMBINATIONS



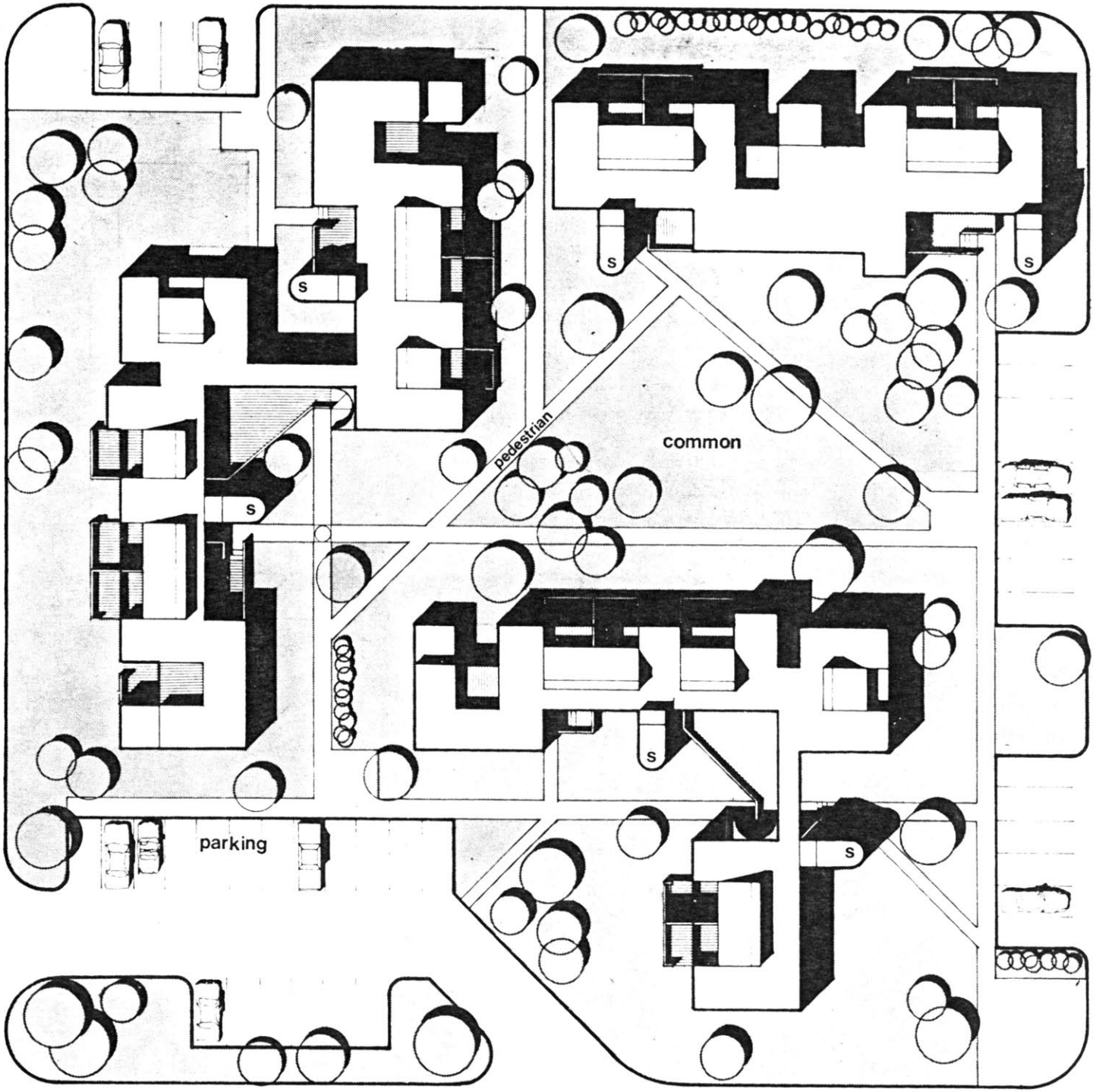
APARTMENT BUILDING (15 Apartments)
(5 Apt. Floor – 3 Floors)



AA

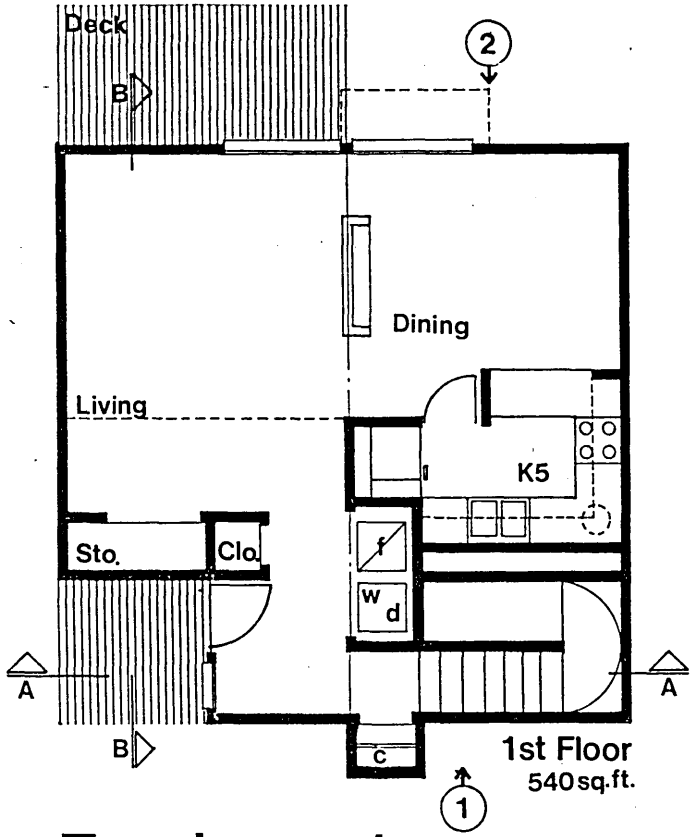
FACTS:

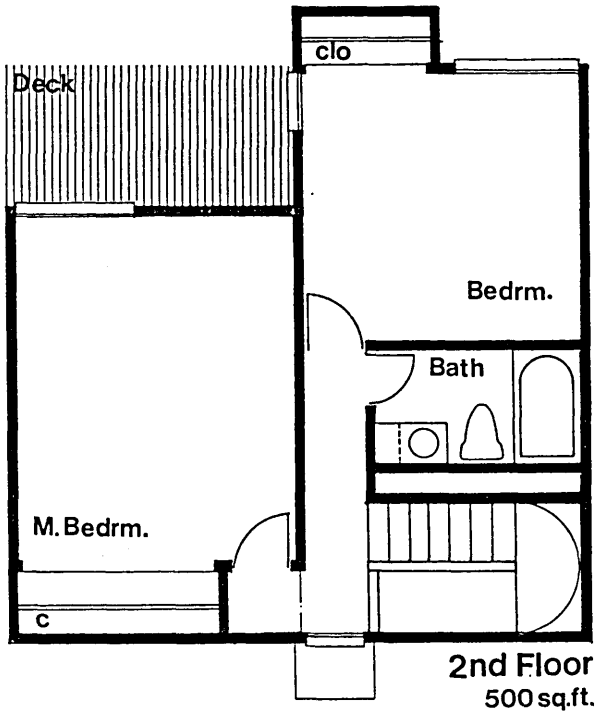
2 acres
44 units
40 parking



SITE PLAN
scale 1" = 40'

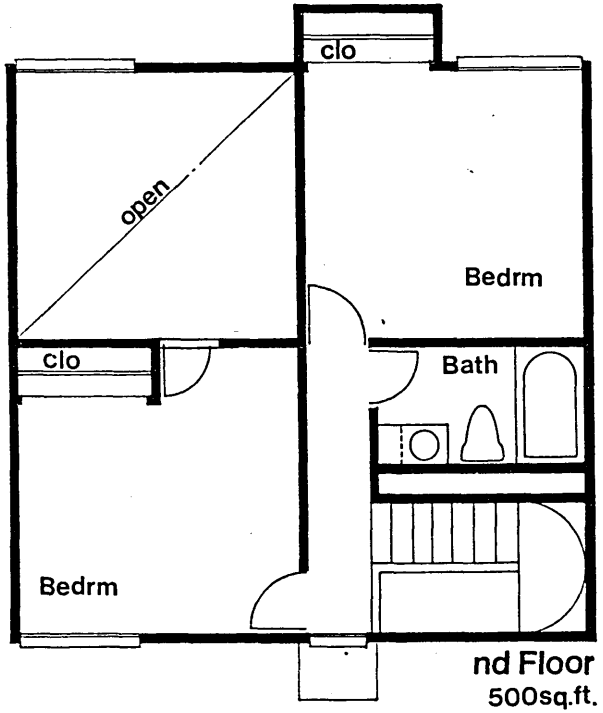
TOWNHOUSES

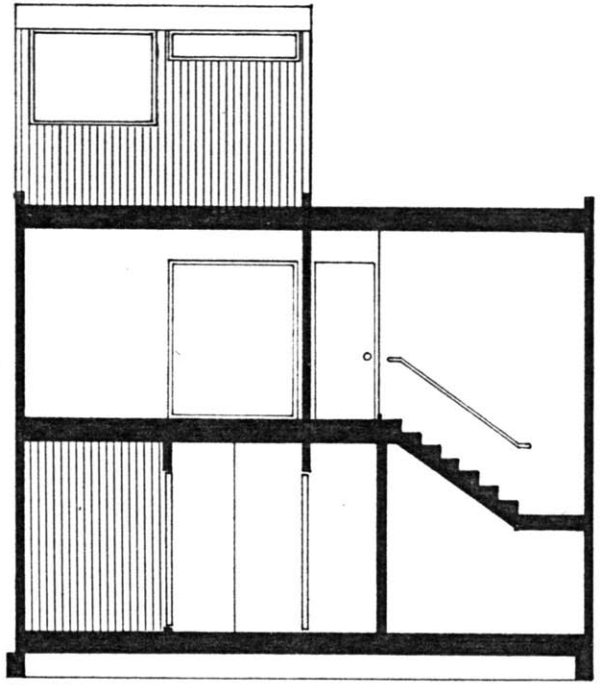




Townhouse 1

Total – 1040 sq ft





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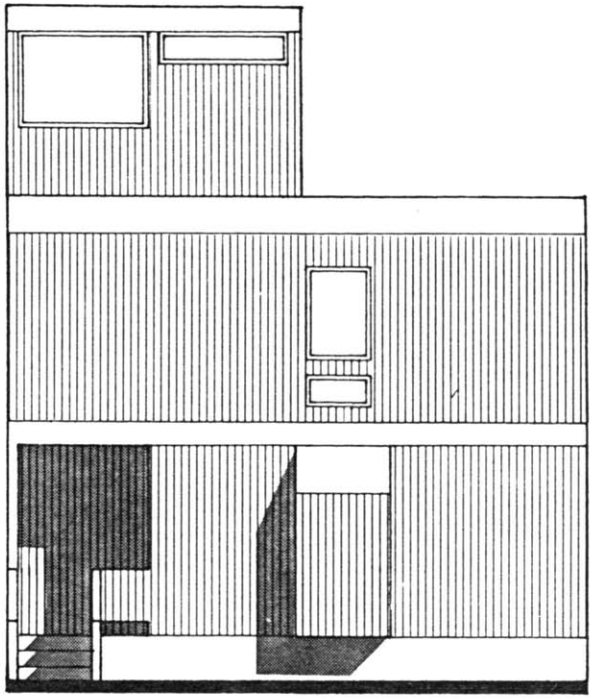

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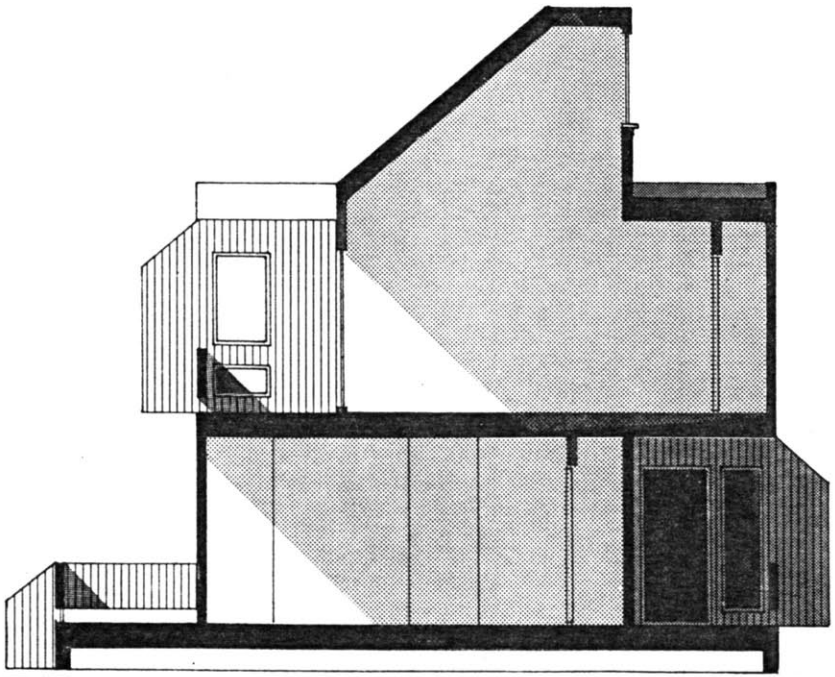

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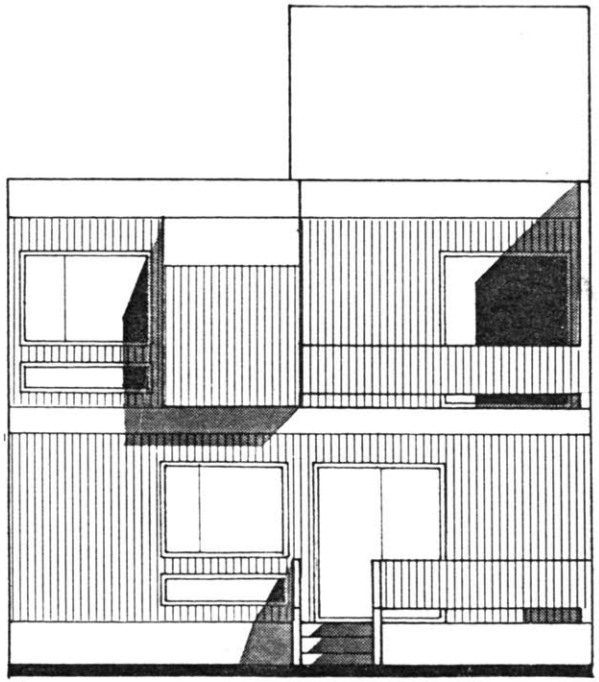

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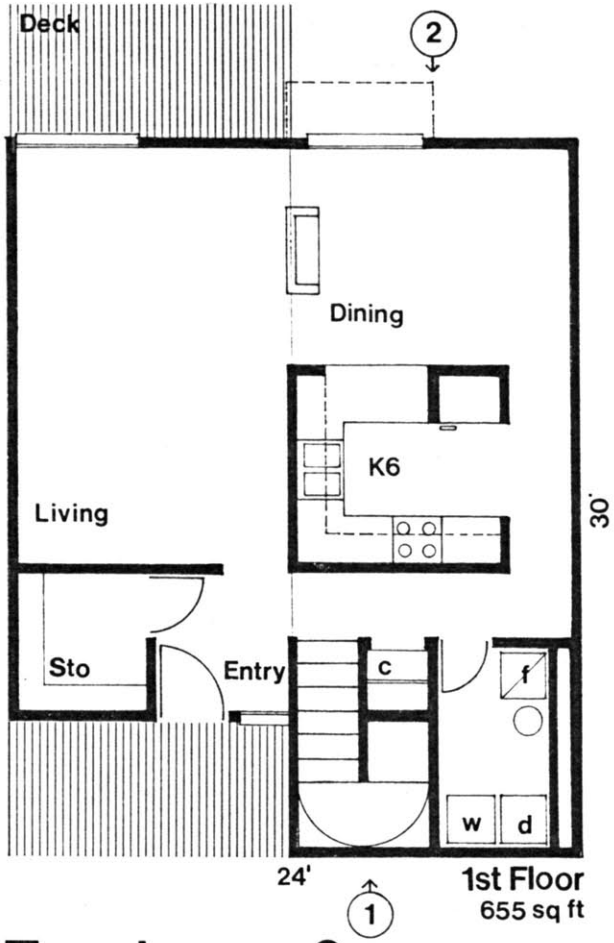
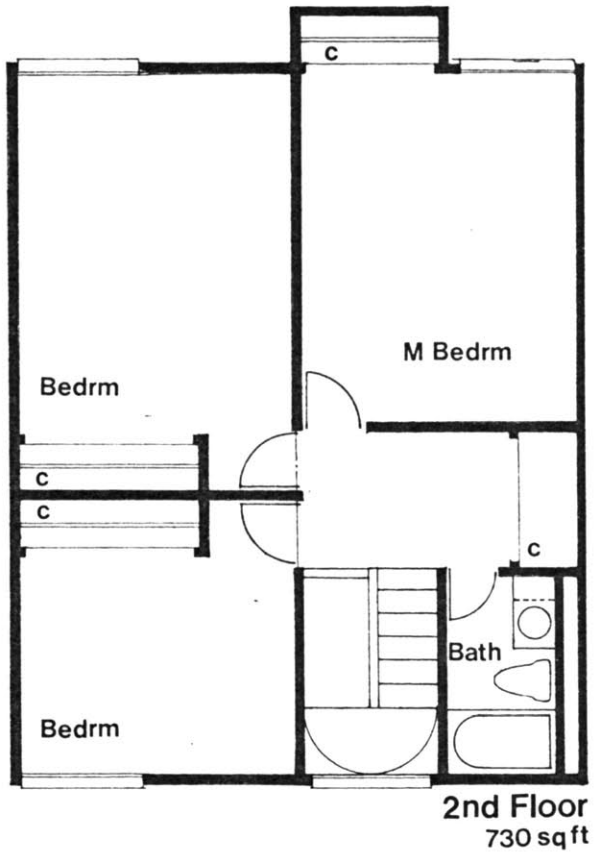
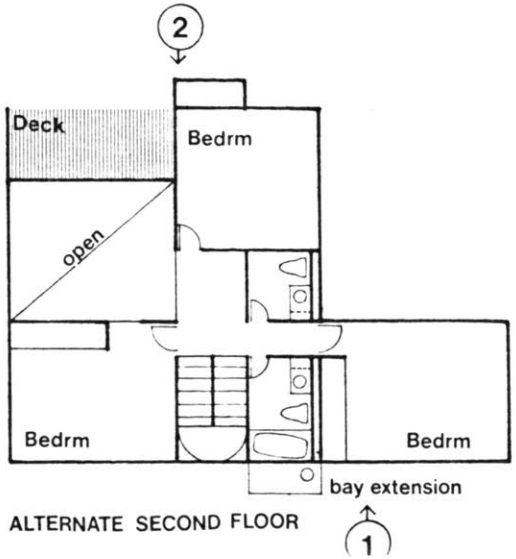


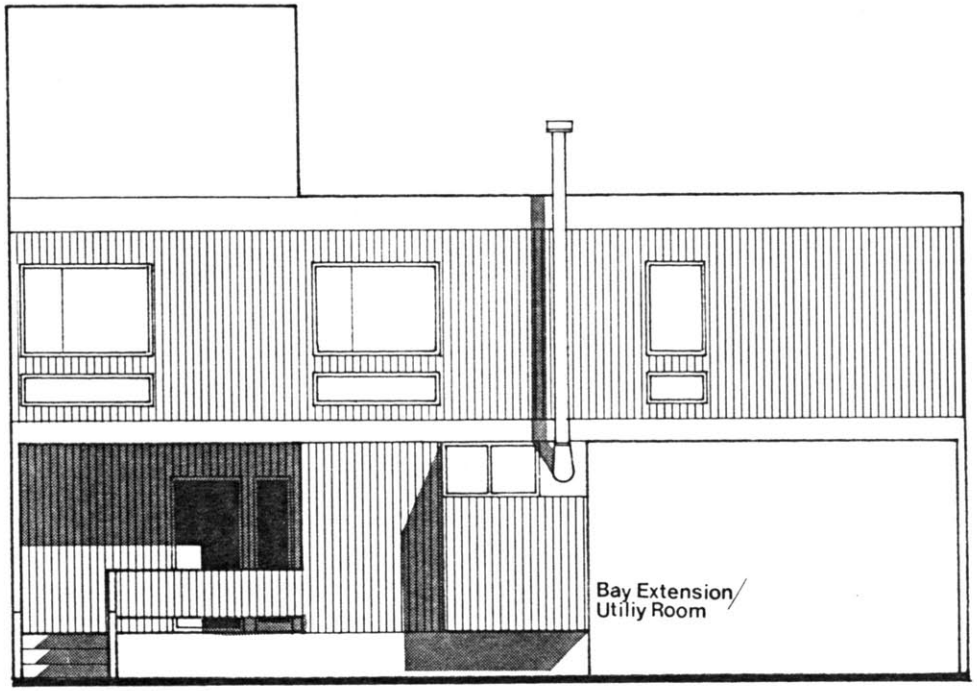


Townhouse 2

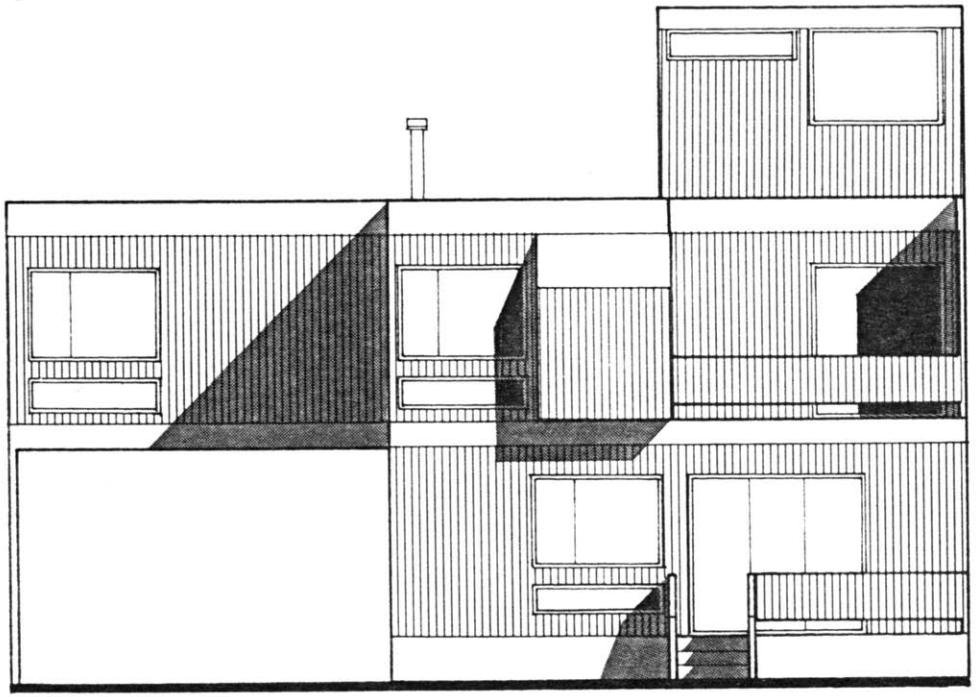
Total – 1385 sq ft



ALTERNATE SECOND FLOOR



1



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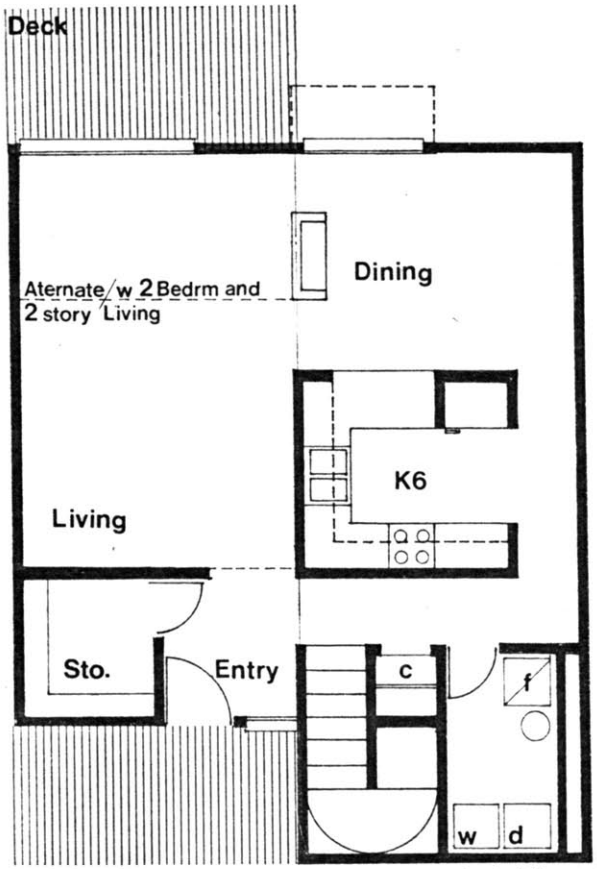
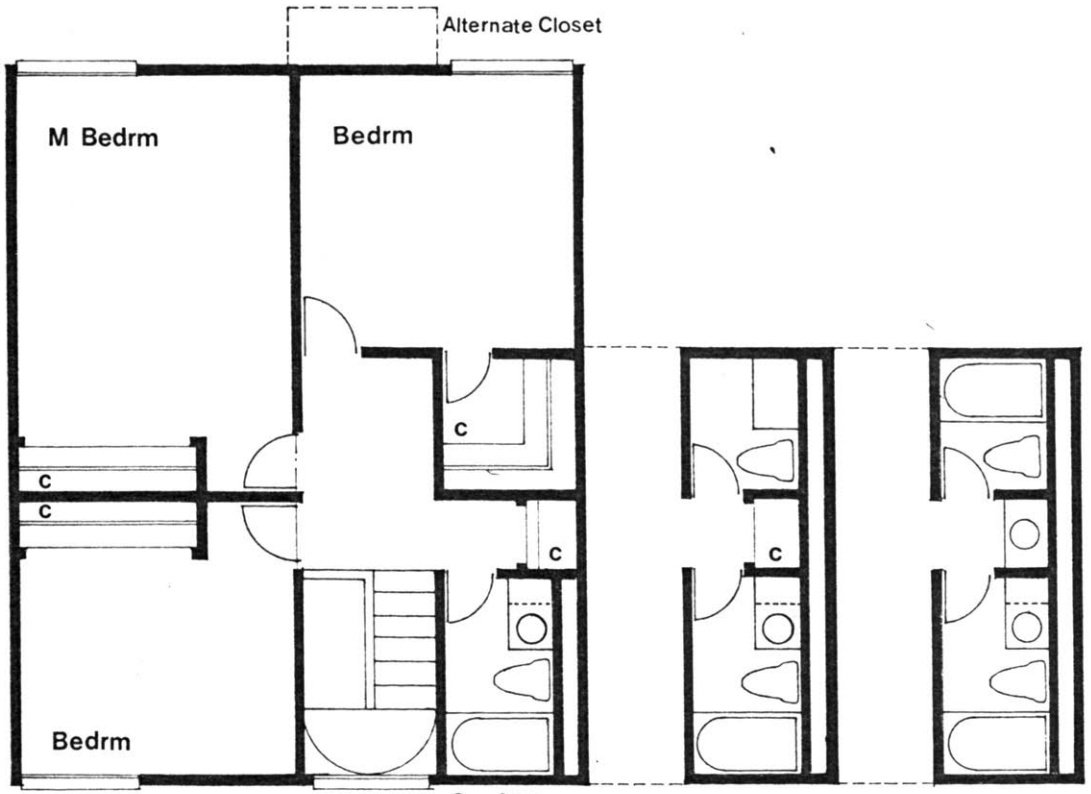


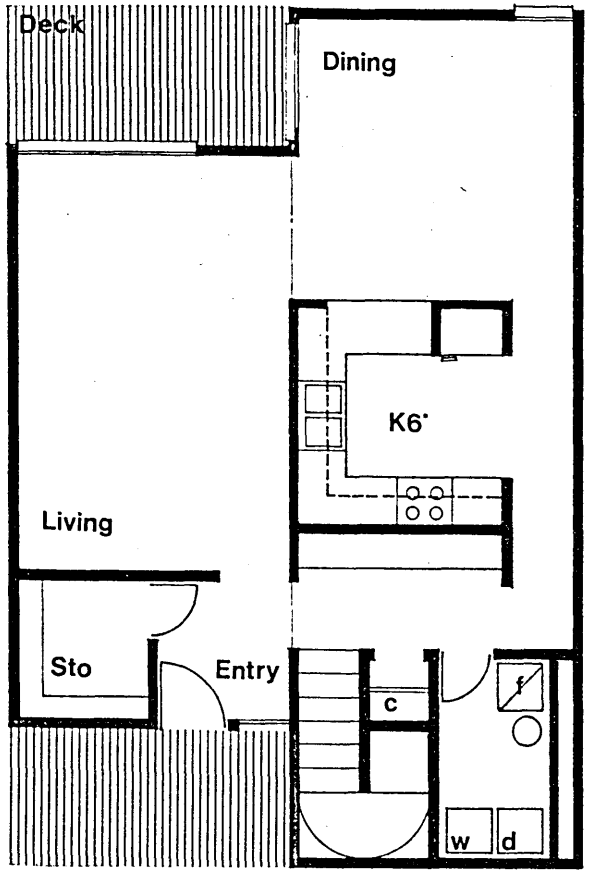
1st Floor
650 sq ft



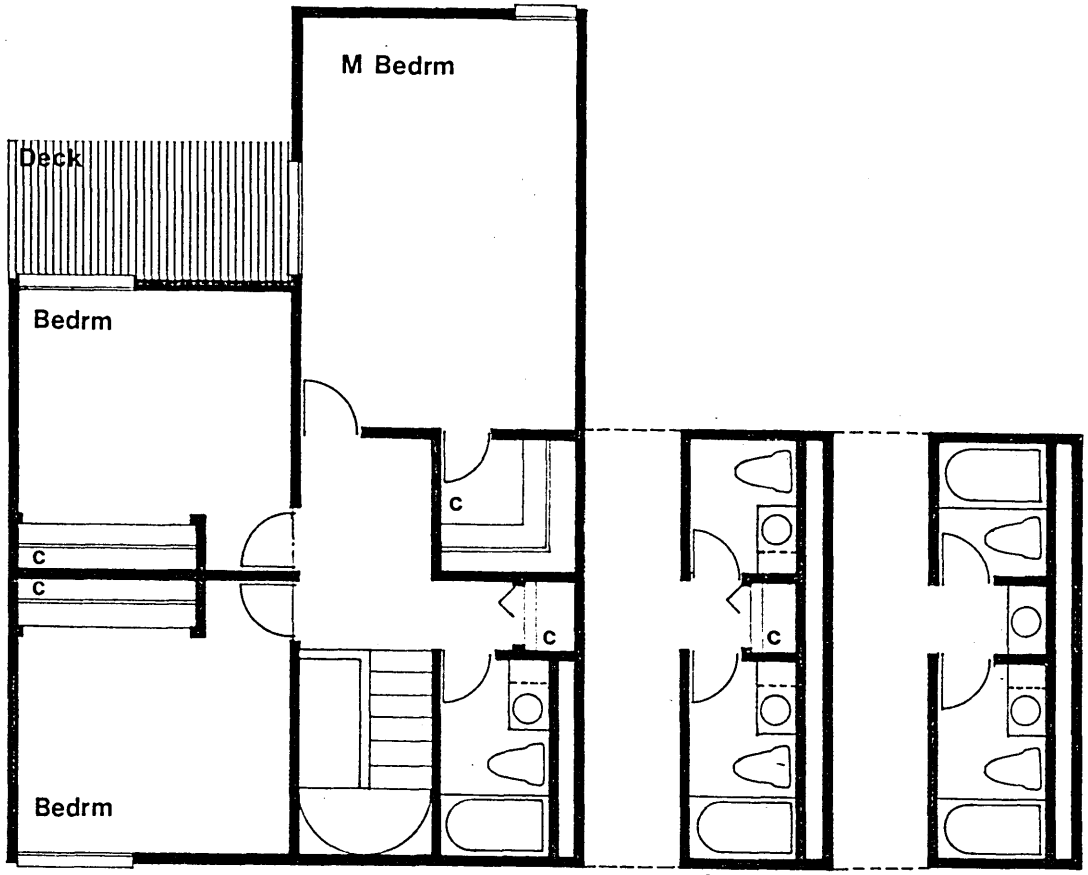
2nd Floor
720 sq ft

Townhouse

Total – 1370 sq. ft.



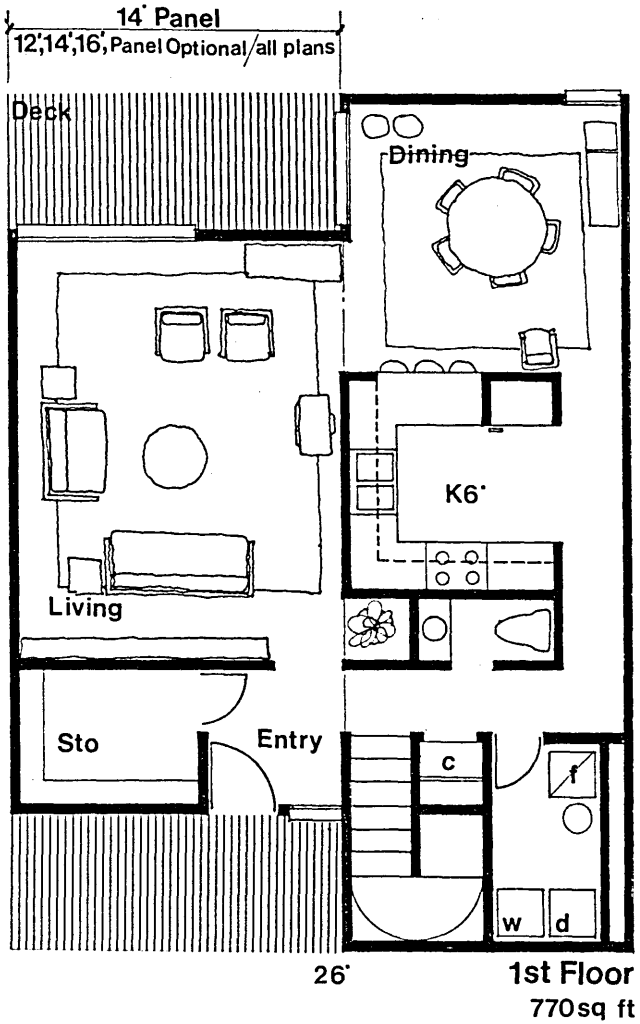
1st Floor
720 sq ft



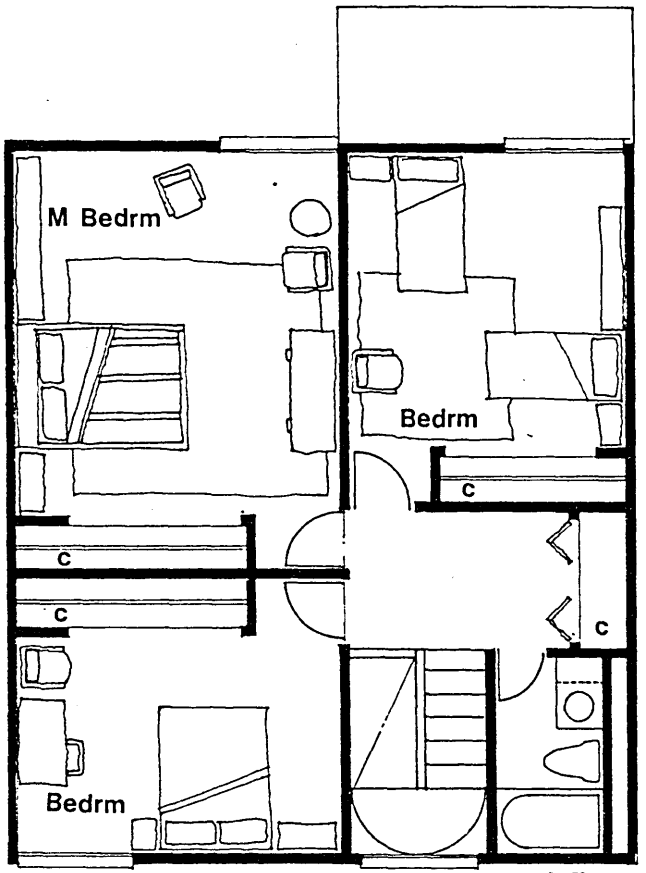
2nd Floor
720 sq ft

Townhouse 3

Total 1440 sq ft



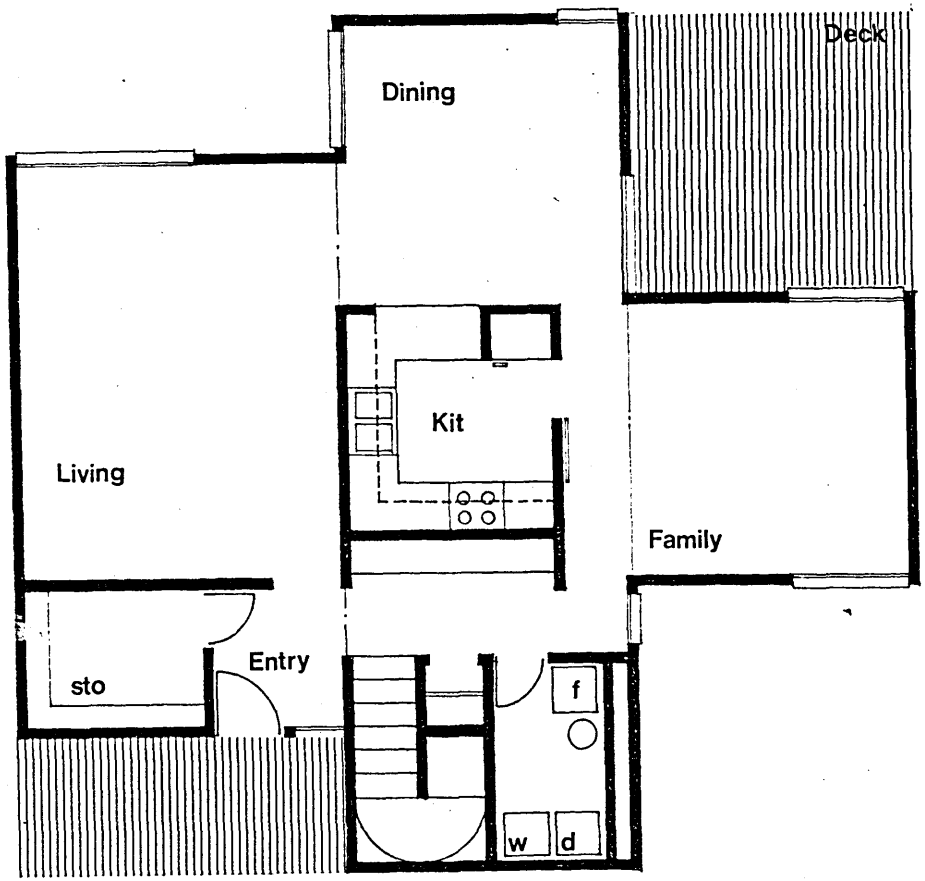
1st Floor
770sq ft



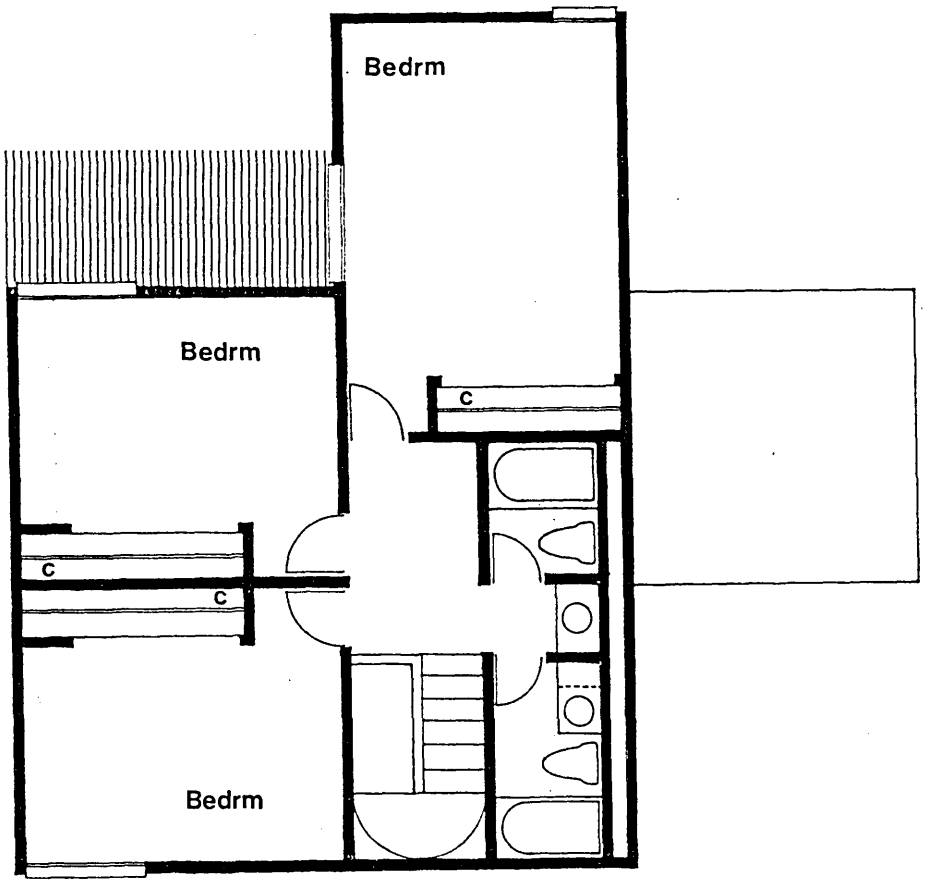
2nd Floor
780sq ft

Townhouse

Total–1550 sq ft



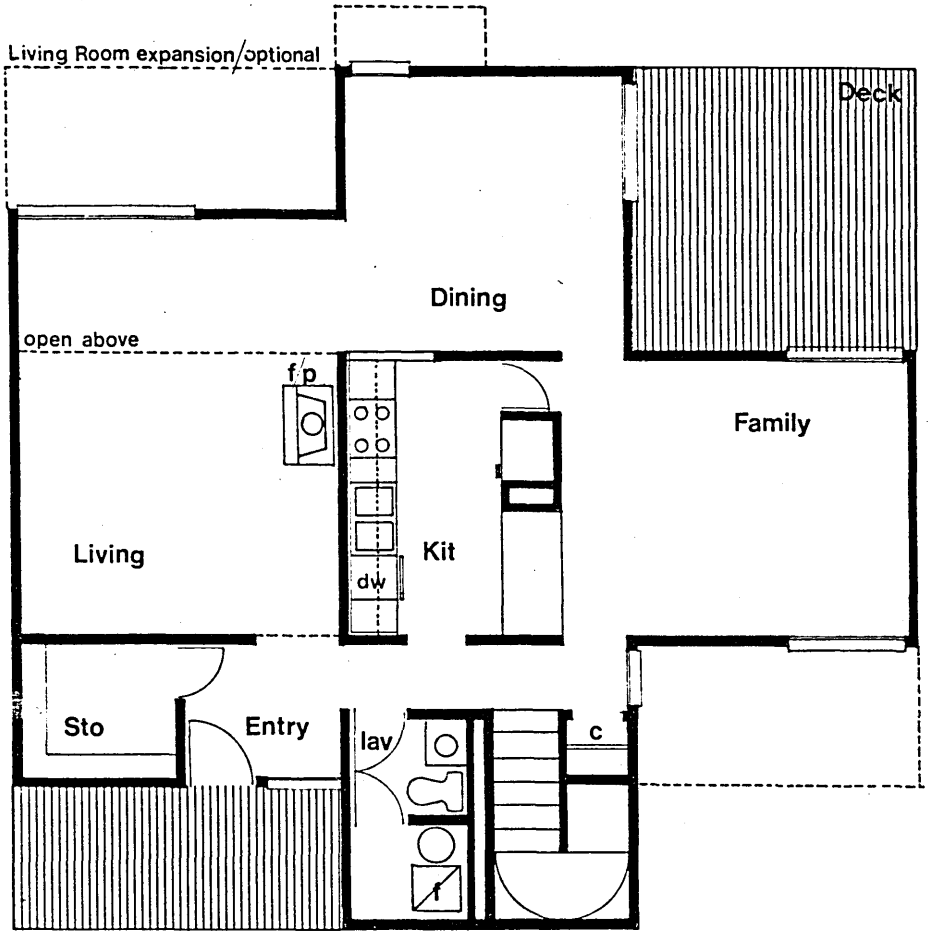
1st Floor
915 sq ft



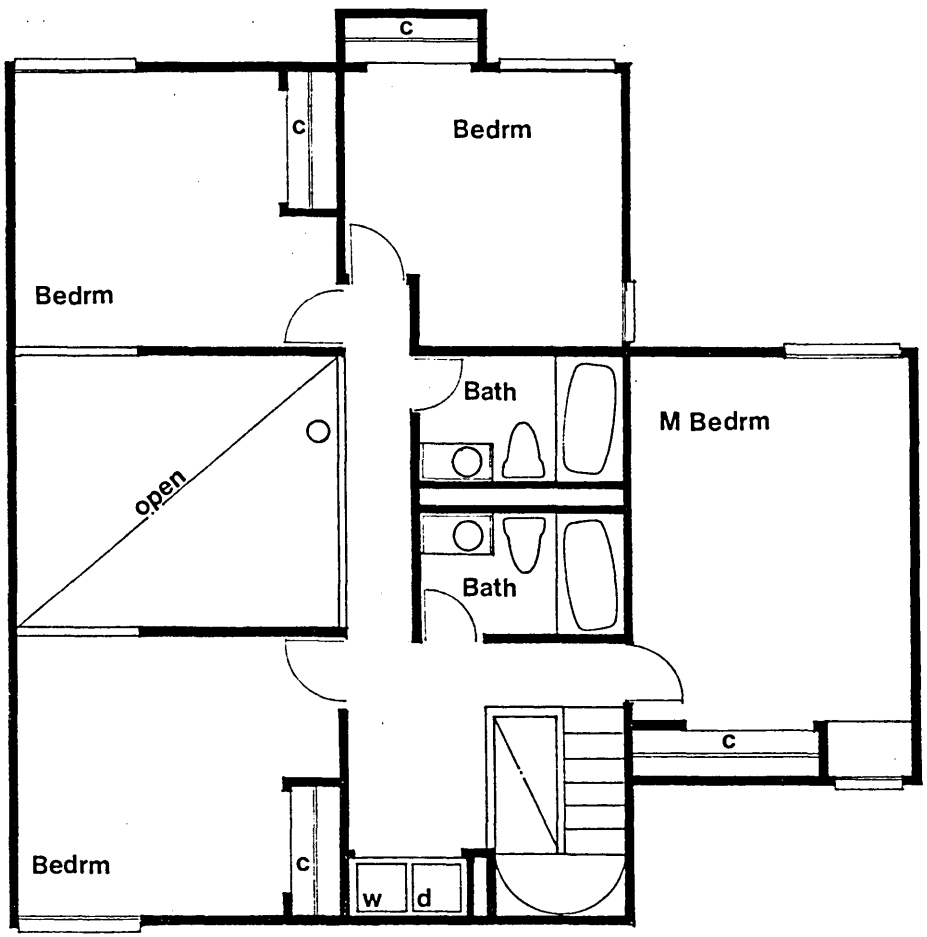
2nd Floor
770 sq ft

Townhouse

Total – 1685 sq ft



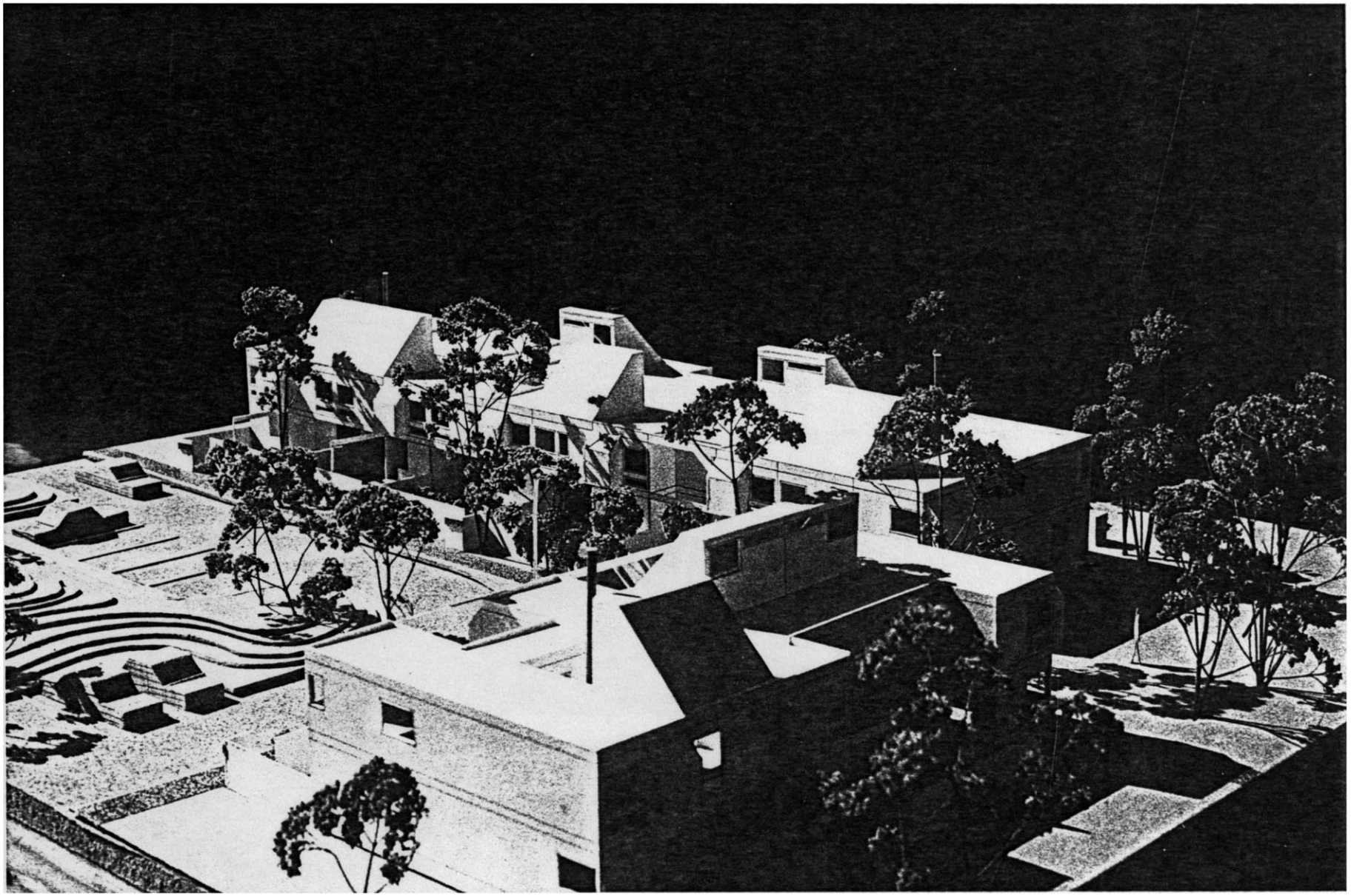
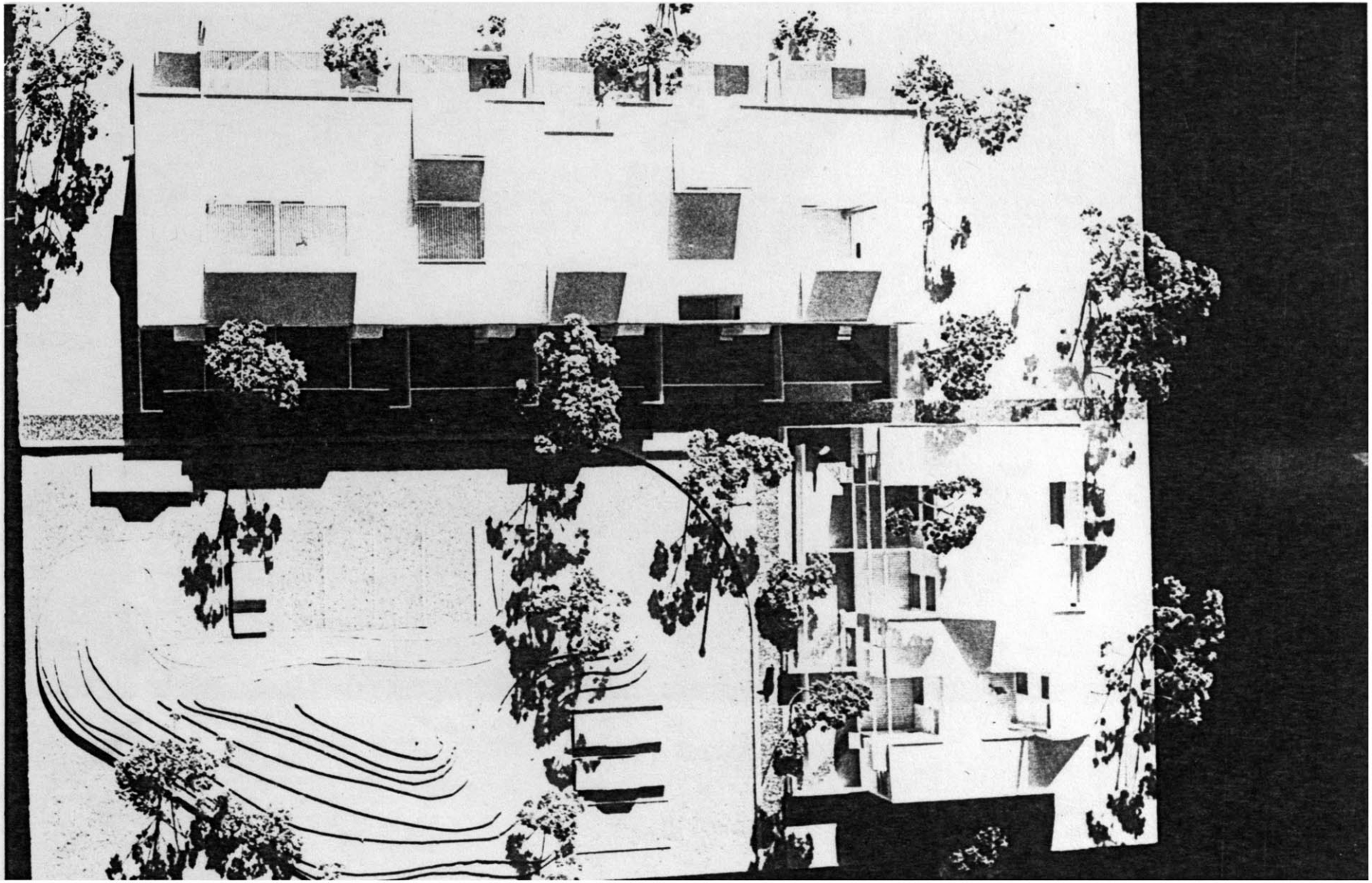
1st Floor
910 sq ft



2nd Floor
1090 sq ft

Townhouse

Total – 2000 sq ft



TOWNHOUSE CLUSTER