CORRIM: Phase I Final Report

Module I

DESIGN OF RESIDENTIAL BUILDING SHELLS - MINNEAPOLIS AND ATLANTA

July 15, 2004

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EXECUTIVE SUMMARY

The objective of this task was to design typical light-frame residential structures for two different climates: a hot and humid climate represented by Atlanta, GA and a cold climate, represented by Minneapolis, MN. The configuration of the structures was based on the most recent surveys conducted by US Census Bureau and National Association of Home Builders. The designs reflected the local building codes valid in pertinent areas, including building envelope design. Alternative steel framing was designed such that the thermal properties matched the ones for the wood frame.

According to recent surveys conducted by US Census Bureau and National Association of Home Builders, the average size of a new house is about 2,225 sq. ft. The predominant type of construction is slab on grade with 56% of new housing starts, followed by basement (29%) and crawl space (11%) designs. The two representative structures were selected to reflect the above surveys.

The Minneapolis structure was designed as a two-story building with a basement, representing a typical construction in the Minneapolis area. All framing members were solid wood with a nominal thickness of 2 in., with the exception of floor joists which were composite I-joists. Wood-based composites (oriented strandboard and plywood) were used as sheathing and pre-engineered roof trusses were used as a roof system. The total floor area of the structure was 2,062 sq. ft. The foundation was designed as 12-in thick concrete masonry block walls. Typical above grade exterior wall composition (from inside to outside, wood frame) was as follows: 1/2 in gypsum sheetrock, 2x6 in wood studs, 16 in on center, fiberglass batt insulation, 7/16 in OSB sheathing (could also use plywood), housewrap, and vinyl siding. The steel-stud alternative had the following composition: 1/2 in gypsum sheetrock, 6 mil poly vapor retarder, 2x4 steel studs, 16 in on center (cold rolled, C channel), fiberglass batt insulation (R-13), 7/16 in OSB sheathing, 1-1/2 in polystyrene foam panel (R-7.5), and vinyl siding.

The Atlanta structure was a grade-on-slab single-story design with the area of 2,153 sq. ft. The building envelope was as follows (from inside to outside, wood frame): ½ in gypsum sheet rock, 2x4 in wood studs, 16 in on center, fiberglass batt insulation, 7/16 in OSB sheathing (could also use plywood), housewrap, vinyl siding. The concrete wall composition was as follows: 1/2 in gypsum sheetrock, 6 mil polyethylene vapor barrier, 2x4 wood studs 24 in on center, fiberglass batt insulation (R-13), concrete block (CMU) (blocks 8x8x16), and traditional 2 layer stucco finish.

The designs serve as a basis for subsequent life cycle analysis of representative structures. The report includes detailed design plans, including dimensions of load-bearing elements. The load-bearing elements such as beams, floor joists or roof rafters can be replaced in the life cycle analysis by elements with comparable capacities. The non-bearing elements, such as siding, can be replaced without consideration of structural capacities but the thermal properties must be considered.

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1.0 INTRODUCTION

The objective of this task was to design typical light-frame residential structures for two different climates: a hot and humid climate. The designs were intended to serve as a basis for subsequent life cycle analysis of representative structures. The report includes detailed design plans, including dimensions of load-bearing elements. The load-bearing elements such as beams, floor joists or roof rafters can be replaced in the life cycle analysis by elements with comparable capacities. The non-bearing elements, such as siding, can be replaced without consideration of structural capacities but the thermal properties must be considered.

2.0 SITE SELECTION

Two sites were selected for the initial life cycle analysis: Minneapolis, MN and Atlanta, GA. The rationale for the selection is as follows:

1. Minneapolis represents the cold climate

2. The University of Minnesota cold climate housing program provided assistance with envelope design for both Minneapolis and Atlanta

3. Atlanta represents the hot and humid climate

3.0 PLANS SELECTION

The configuration of the structures was based on the most recent surveys conducted by US Census Bureau and National Association of Home Builders. The designs reflected the local building codes valid in pertinent areas, including building envelope design.

According to a national survey (Crist 2000), the average size for new home construction is 2,225 sq. ft. (based on US Bureau of Census, www.census.gov). Data from the National Association of Home Builders (NAHB) (Crandel 2000) shows typical designs in the US as indicated in Table 3.1.

Table 3.1. Typical Foundation Designs and their Proportions for Residential Construction in the US.

Design	Proportion [%]
Slab on grade	56
Basement	29
Crawl space	11

Source: Crist 2000, Crandel 2000.

Based on the above table and representativeness of local building practice, slab-on-grade (Atlanta) design and basement design (Minneapolis) were selected.

The design parameters as shown in Table 3.2 were selected for the two structures:

Table 3.2. Design Parameters for Representative Structures

	Total Area (sq. ft)	Number of stories	Foundation type
Atlanta	2,153	1	slab on grade
Minneapolis	2,062	2	basement

4.0 DESIGN

4.1 GENERAL FEATURES

4.1.1 Exterior Wall Systems

The software package SOFTPLAN (Softplan 2000) was used for the design. Softplan, Inc. provided the two designs as an in-kind contribution to the CORRIM work. The two houses have slightly different areas. Three different exterior wall systems were considered:

1. wood frame
2. steel frame
3. concrete masonry

4.1.2 Exterior Siding

According to US Bureau of Census (Crist 2000), the market share of the exterior siding in 1999 was as shown in Table 4.1.

Table 4.1. Market Share of Exterior Siding Used in Residential Construction

Siding	Market share [%]
Vinyl	39
Brick	21
Stucco	18
Wood	14

The exterior siding is nonstructural and can be easily varied to reflect the market share.

4.1.3 Thermal Considerations

The recommended R-values are shown in Appendices 3 and 4. The values were obtained via interactive program available at http://www.ornl.gov/roofs+walls/. The building envelope configuration designed by the University of Minnesota cold housing program is in Appendices 5 and 6. The building envelopes were designed to meet local building codes for all possible materials used in the structures. No consideration of thermal bridges due to the studs was made.

4.2 LOCATION-SPECIFIC DESIGNS

4.2.1 Minneapolis

The Minneapolis structure was designed as a two-story building with a basement, representing a typical construction in the Minneapolis area. All framing members were solid wood with a nominal thickness of 2 in., with the exception that the floor joists were composite I-joists as the base case. Wood-based composites (plywood and oriented strandboard) were used as sheathing and pre-engineered roof trusses were used as a roof system. The total floor area of the structure was 2,062 sq. ft. The foundation was designed as 12-in thick concrete masonry block walls. Typical above grade exterior wall composition (from inside to outside, wood frame) was as follows: 1/2 in gypsum sheetrock, 2x6 in wood studs, 16 in on center, fiberglass batt insulation, 7/16 OSB sheathing (could also use plywood), housewrap, and vinyl siding. The steel-stud alternative had the following composition: 1/2 in gypsum, 6 mil poly vapor retarder, 2x4 steel studs, 16 in on center (cold rolled, C channel), fiberglass batt insulation (R-13), 7/16 in OSB, 1-1/2 in polystyrene foam panel (R-7.5), and vinyl siding. A complete listing of materials is given in Appendix 6.

4.2.2 Atlanta

The Atlanta structure was a grade-on-slab single-story design with the area of 2,153 sq.ft. The building envelope was as follows (from inside to outside, wood frame): 1/2 in gypsum sheet rock, 2x4 in wood studs, 16 in on center, fiberglass batt insulation, 7/16 in OSB sheathing (could also use plywood), housewrap, and vinyl siding. The concrete wall composition was as follows: 1/2 in gypsum sheetrock, 6 mil polyethylene vapor barrier, 2x4 wood studs 24 in on center, fiberglass batt insulation (R-13), concrete block (CMU) (blocks 8x8x16), and traditional 2 layer stucco finish. A complete listing of materials is given in Appendix 5.

5.0 BUILDING PLANS

Building plans are presented in Appendices 1 and 2. The plans contain the geometry of the structures as well as sizes of individual members. Note that the designation of the envelope materials is valid for the particular design and can be easily changed in the life cycle analysis. However, the geometry and sizes of load-bearing elements must be retained. The load bearing elements include

1. wall studs
2. headers above openings
3. floor members
4. roof members
5. foundation

At this stage of the research, most of the load-bearing elements were designed as solid sawn members with the exceptions of certain girders with high loads where wood composite sections or steel members were used.

6.0 FUTURE RESEARCH

The following activities are proposed for the next phase of research:

1. Include more sites across the US to obtain more representative samples
2. Include designs containing wood-based composite materials—OSB, composite I-beams, glulam, and parallel strand lumber.
3. Include additional plans and elevations.
4. Include other non-wood materials such as concrete filled XPS.
5. Include analysis of various systems from the thermal insulation point of view

7.0 LITERATURE CITED

Crist, Dean. 2000. New Home Characteristics. Housing Economics. February 2000:19-21.

Crandel, Jay. 2000. NAHB Research Center. Personal Communications.

Softplan, Inc. 2000. Architectural Design Software. Version 10. http://www.softplan.com SoftPlan Systems, Inc. 214 Overlook Ct. Suite 220 Brentwood, TN

Oakridge National Laboratory web site http://www.ornl.gov/roofs+walls/.

APPENDIX 1.

ONE-STORY DESIGN ATLANTA STRUCTURE

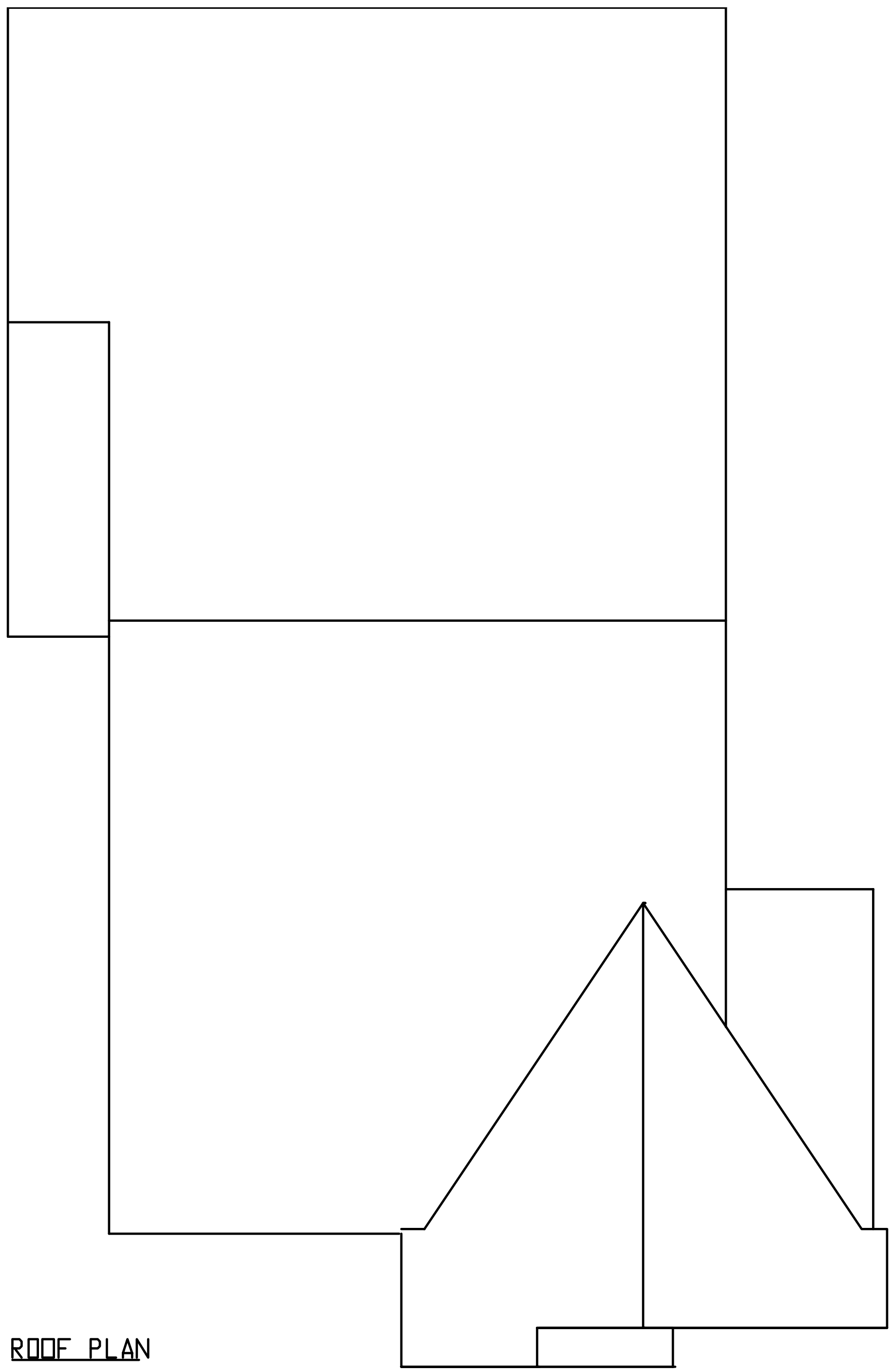


Figure A 1. Atlanta house - roof plan.

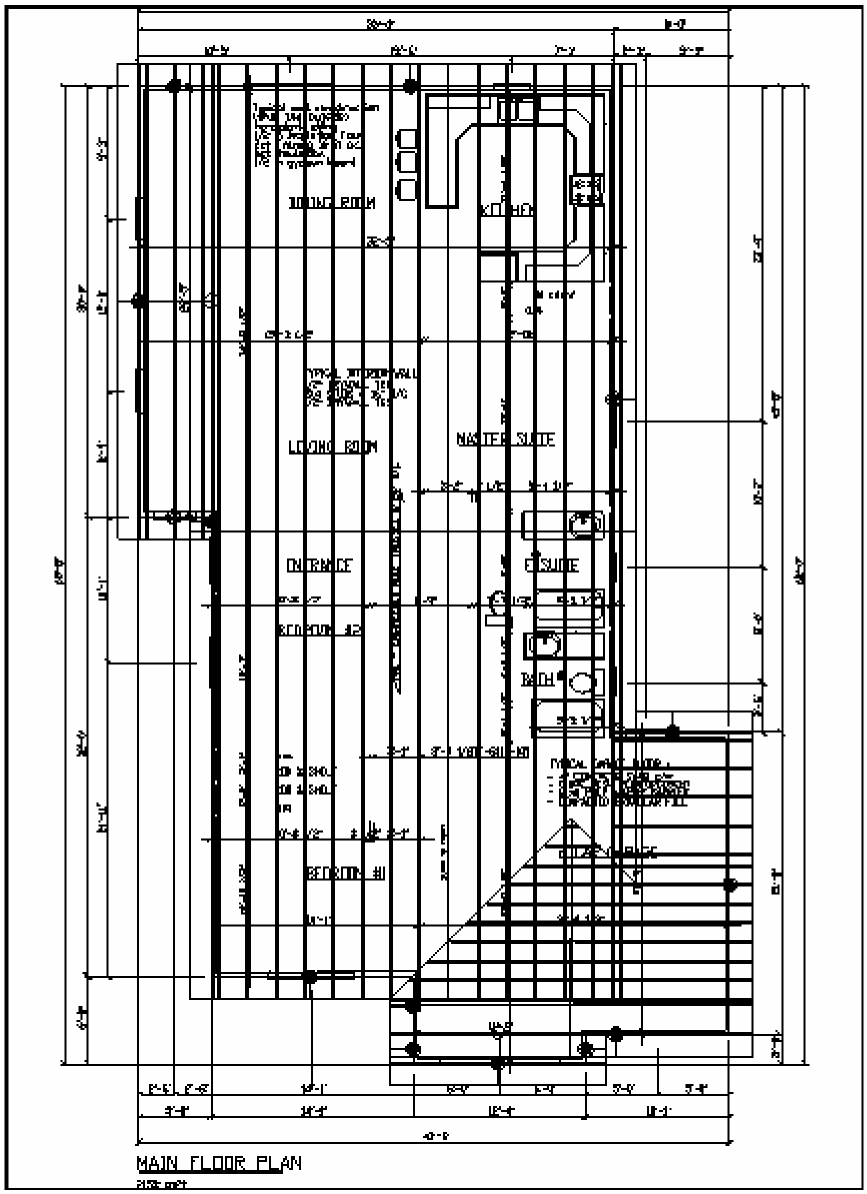


Figure A 2. Atlanta house - floor joists.

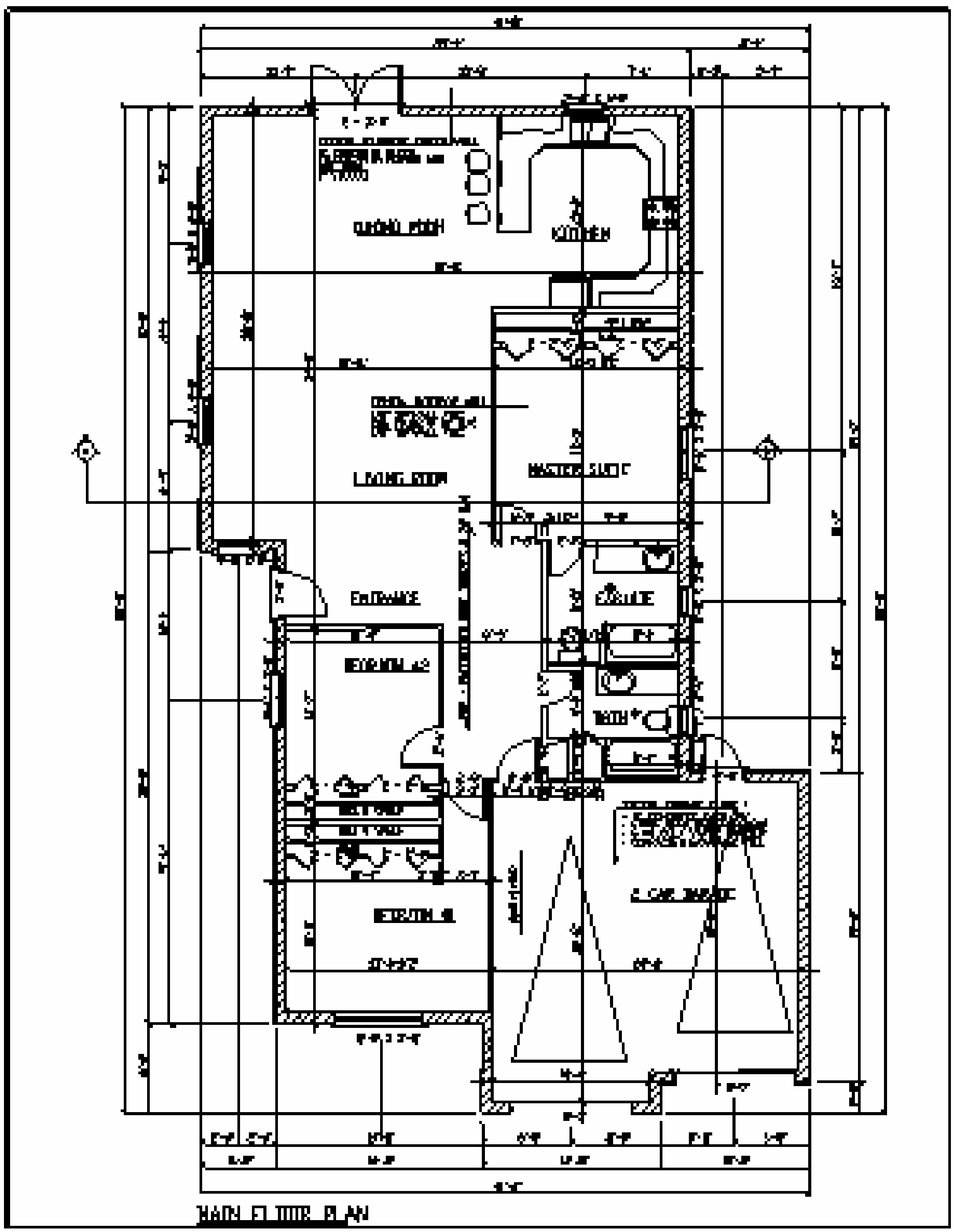
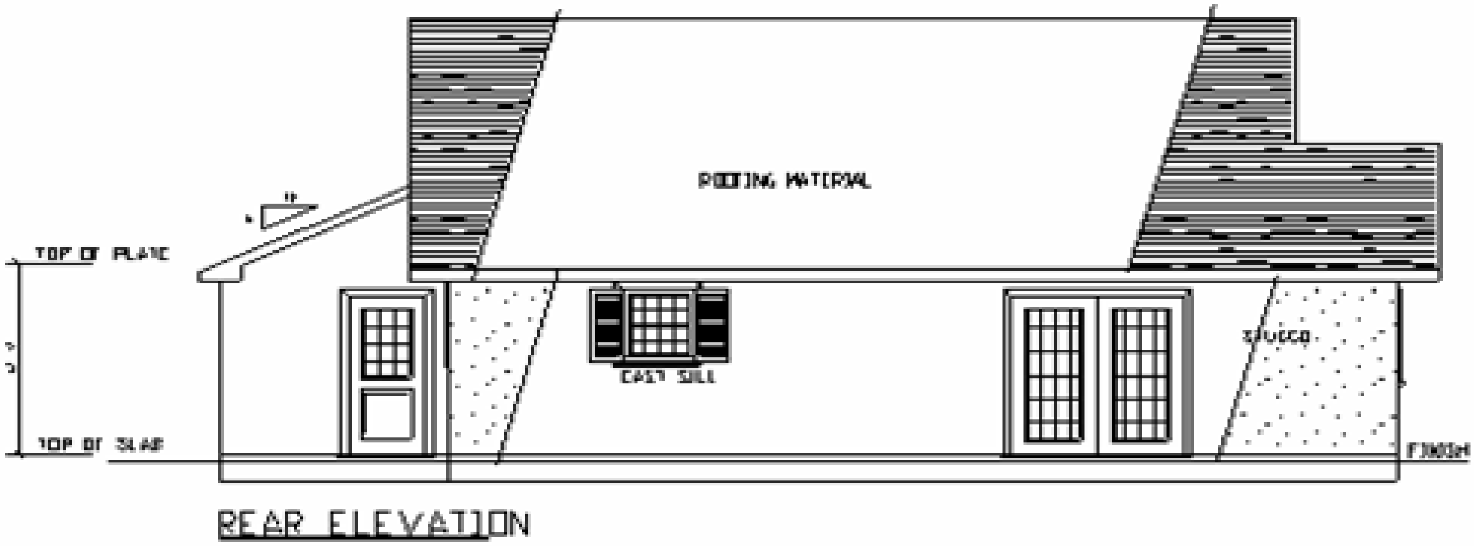


Figure A 3. Atlanta house - main floor plan.

Figure A 4. Atlanta house - elevations.



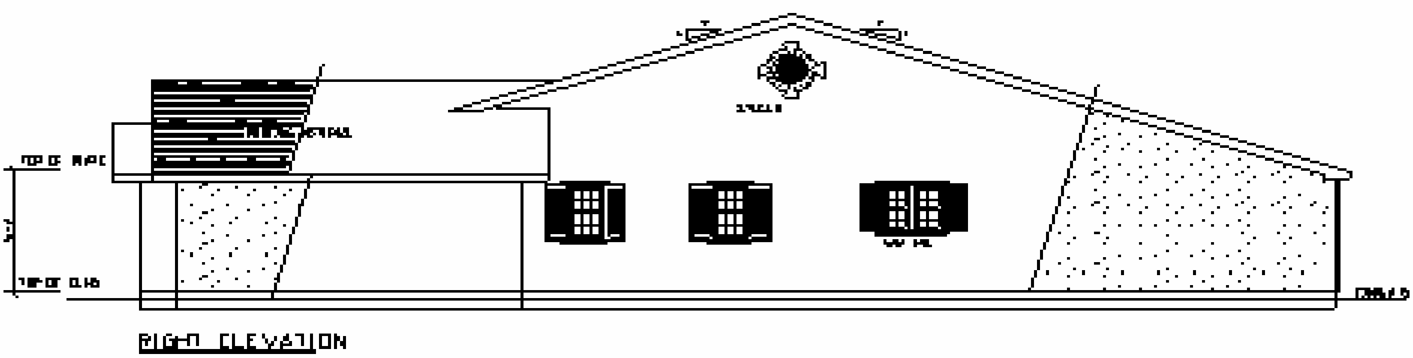


Figure A 5. Atlanta house - elevations.

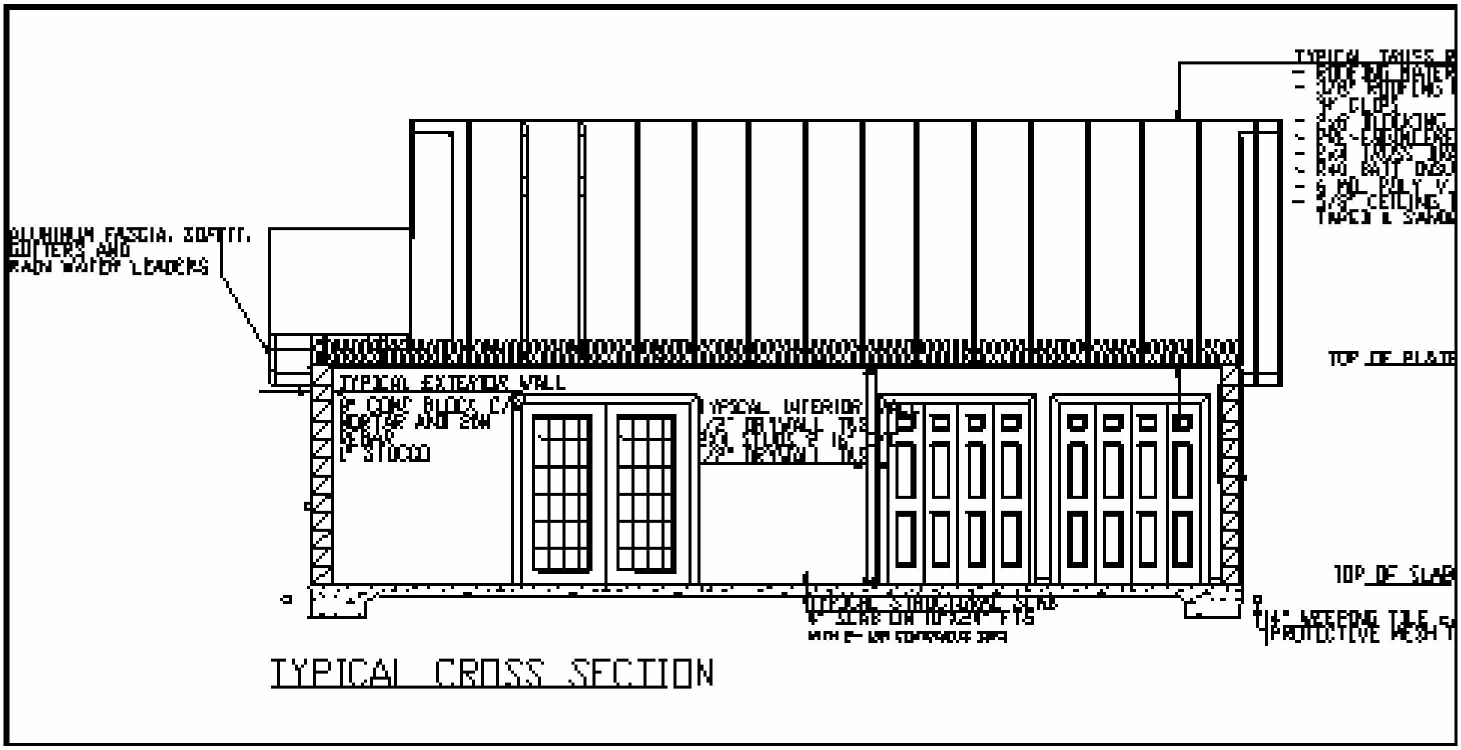
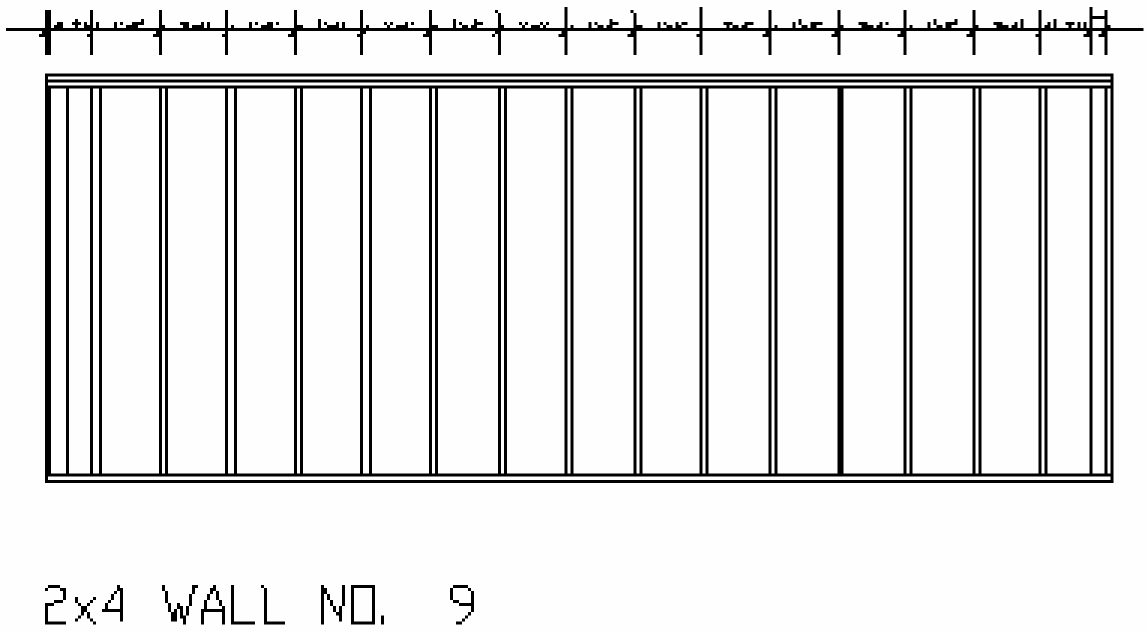


Figure A 6. Atlanta house - elevations.



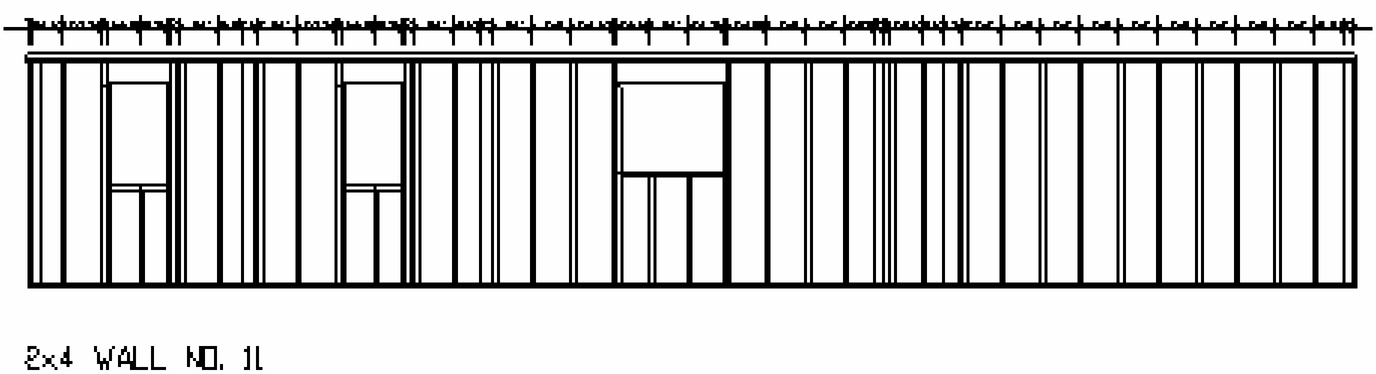


Figure A 7. Atlanta house - typical wall framing diagrams.

Figure A 8. Atlanta house - wall framing diagrams.

APPENDIX 2.

TWO-STORY DESIGN - MINNEAPOLIS STRUCTURE

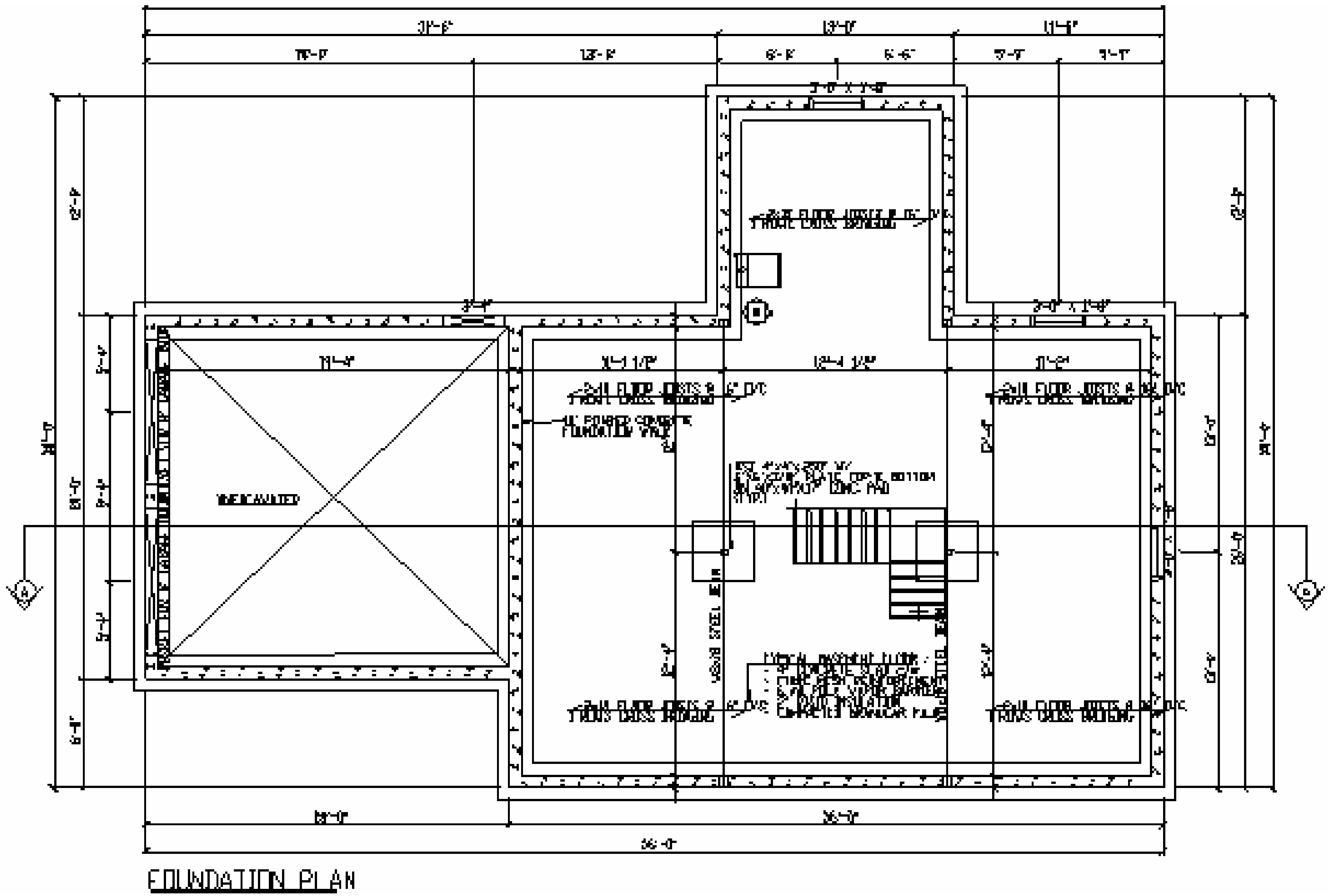


Figure B 1. Minneapolis house - foundation plan.

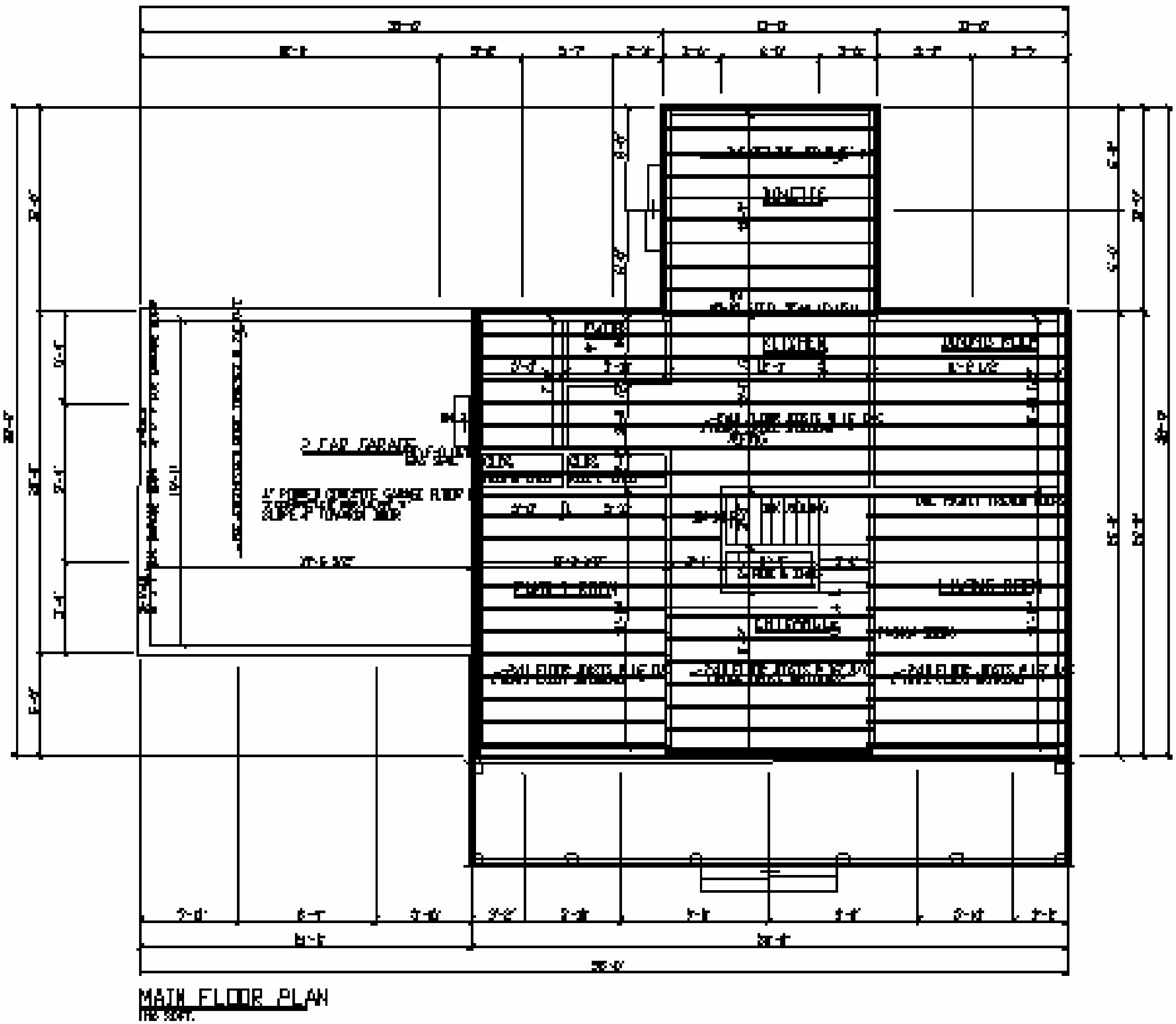


Figure B 2. Minneapolis house - main floor plan with floor framing.

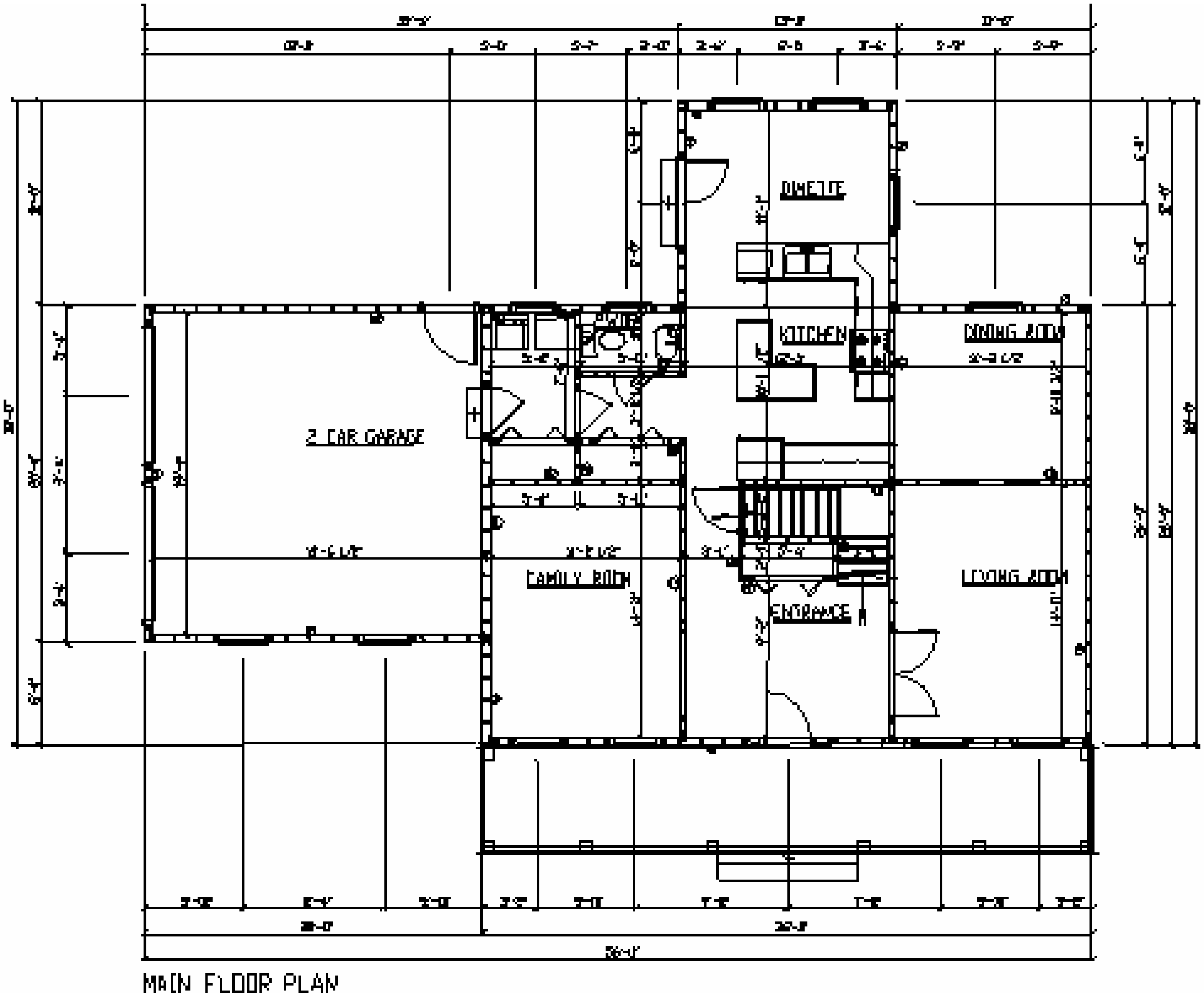


Figure B 3. Minneapolis house - main floor plan.

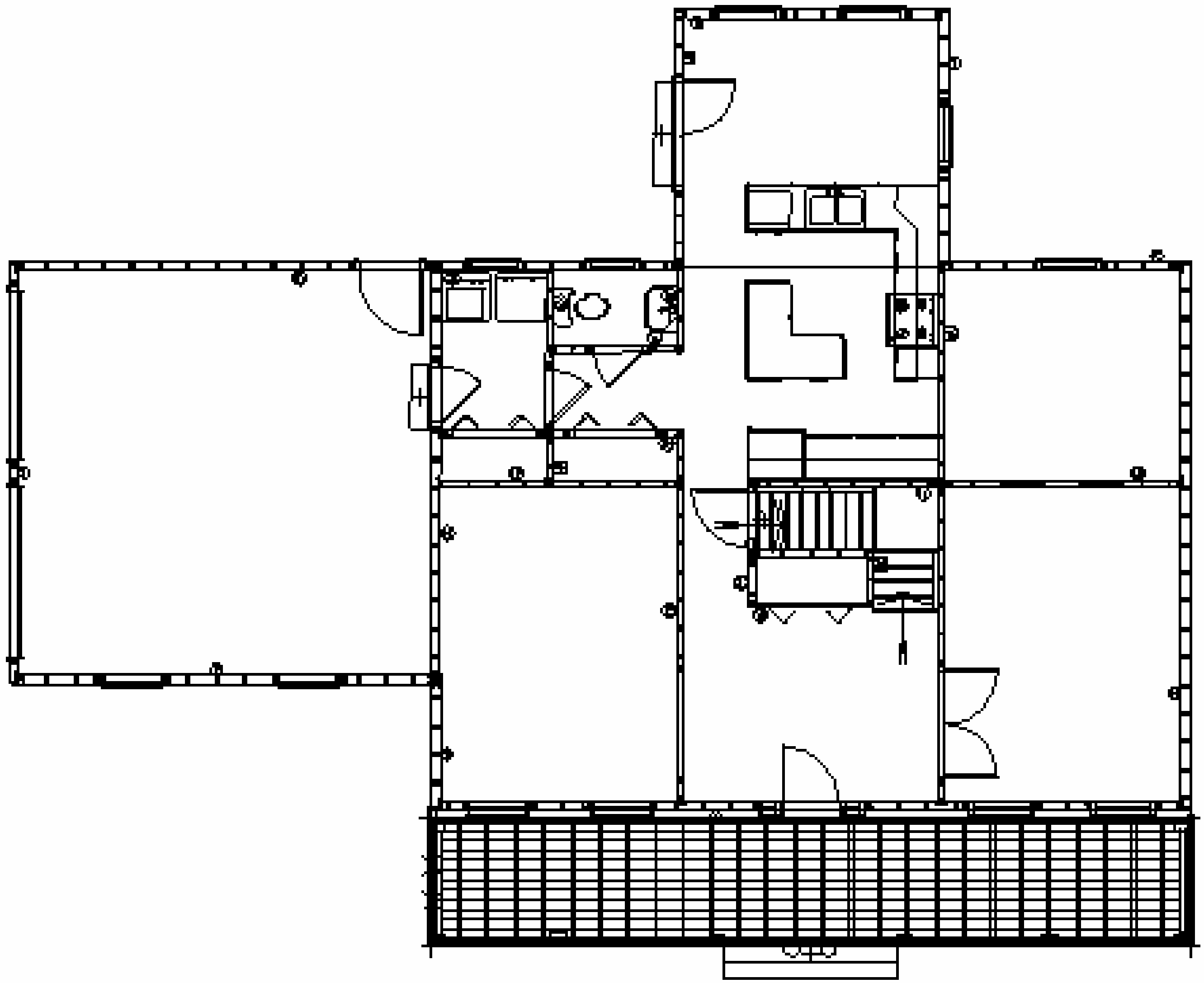


Figure B 4. Minneapolis house - main floor plan.

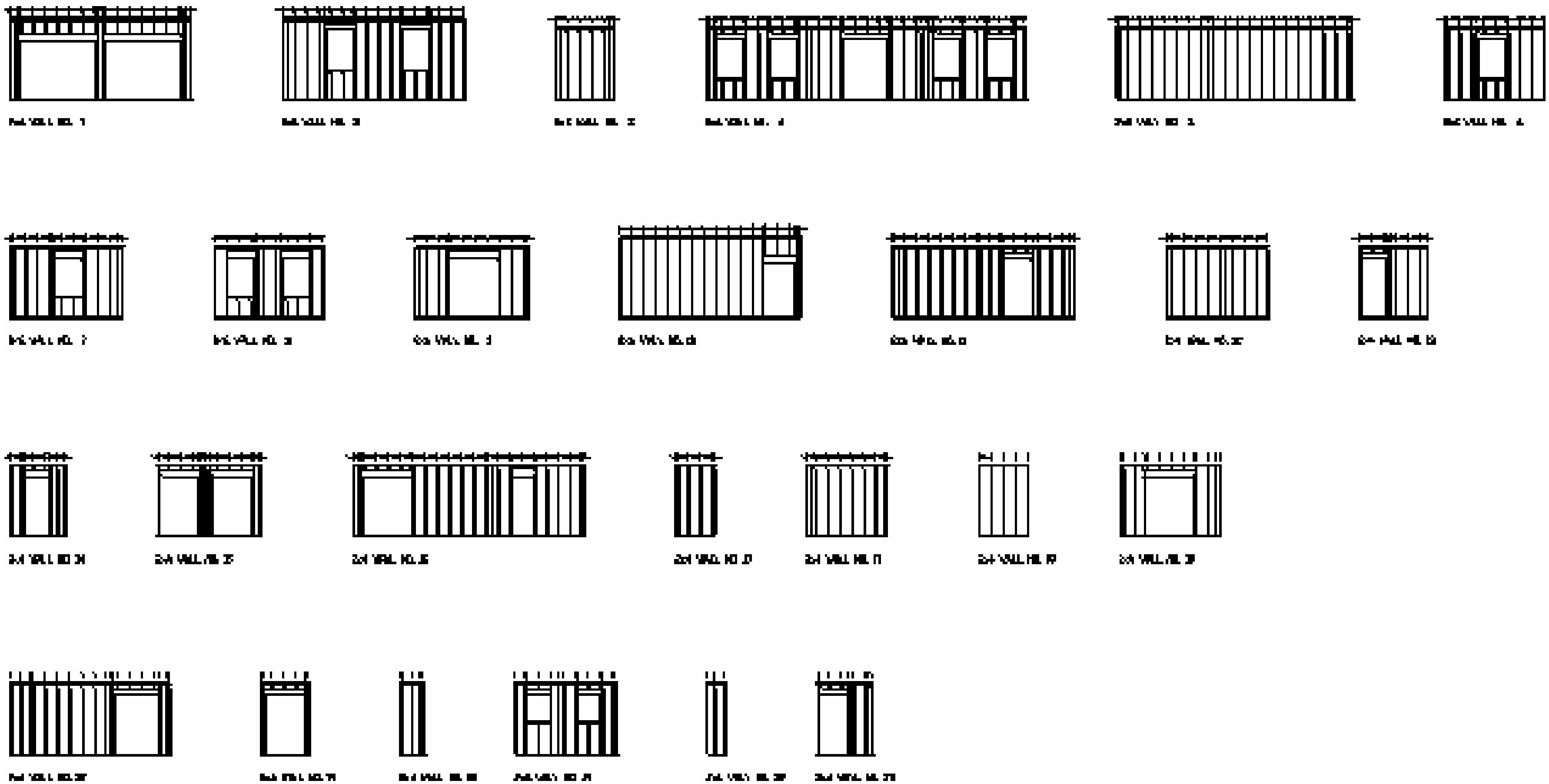


Figure B 5. **Minneapolis house - wall-framing plans.**

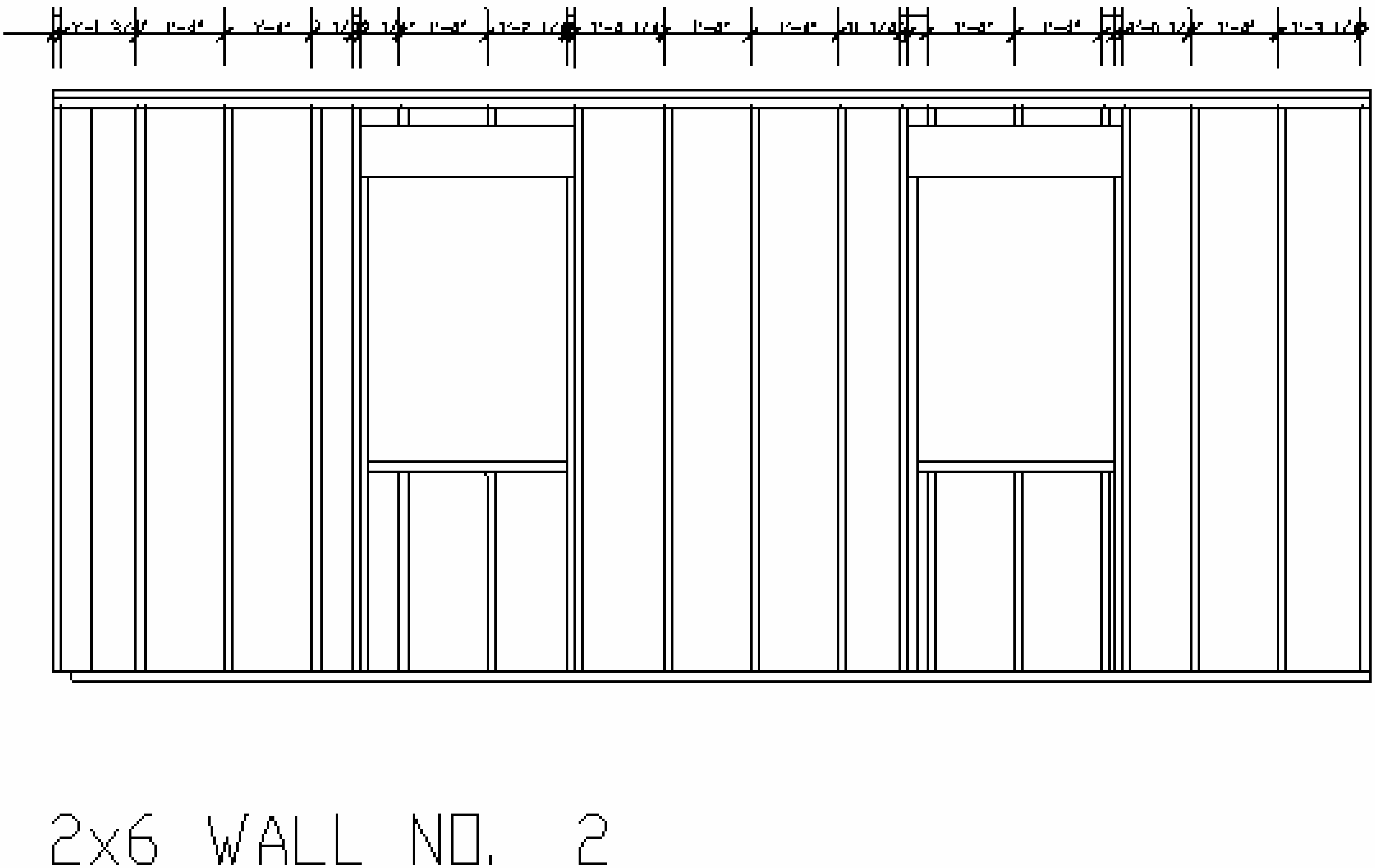
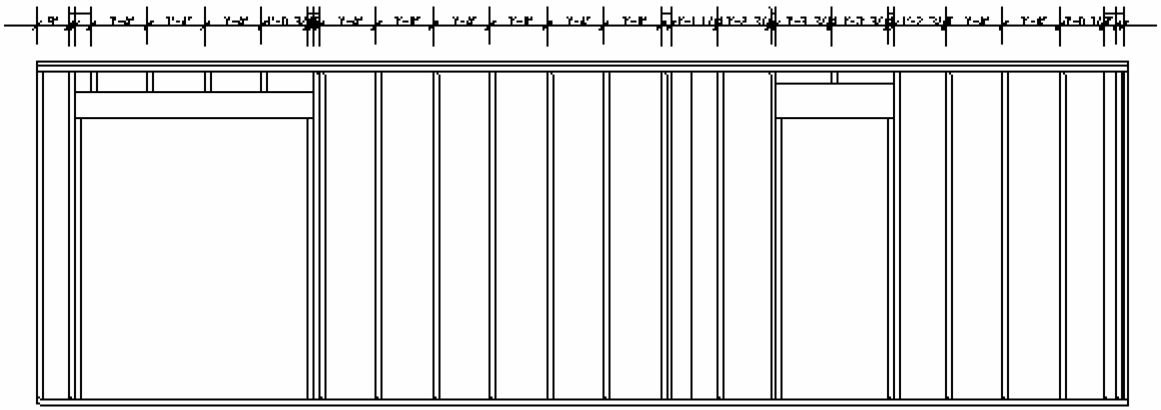


Figure B 6. Minneapolis house - typical wall framing.



2x4 WALL NO. 16

Figure B 7 **Minneapolis house - typical wall framing.**

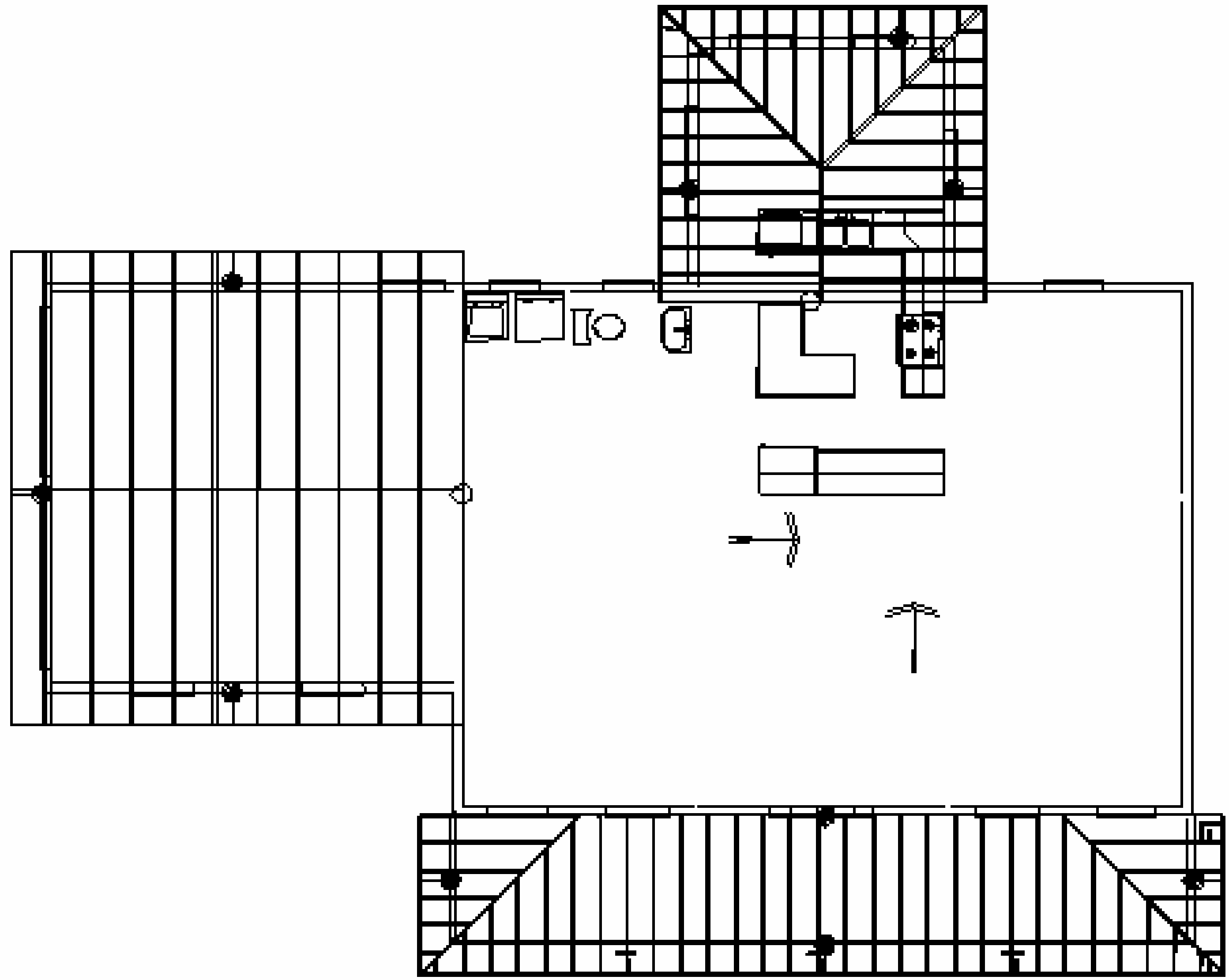


Figure B 8. Minneapolis house - main floor plan with roof and floor framing.

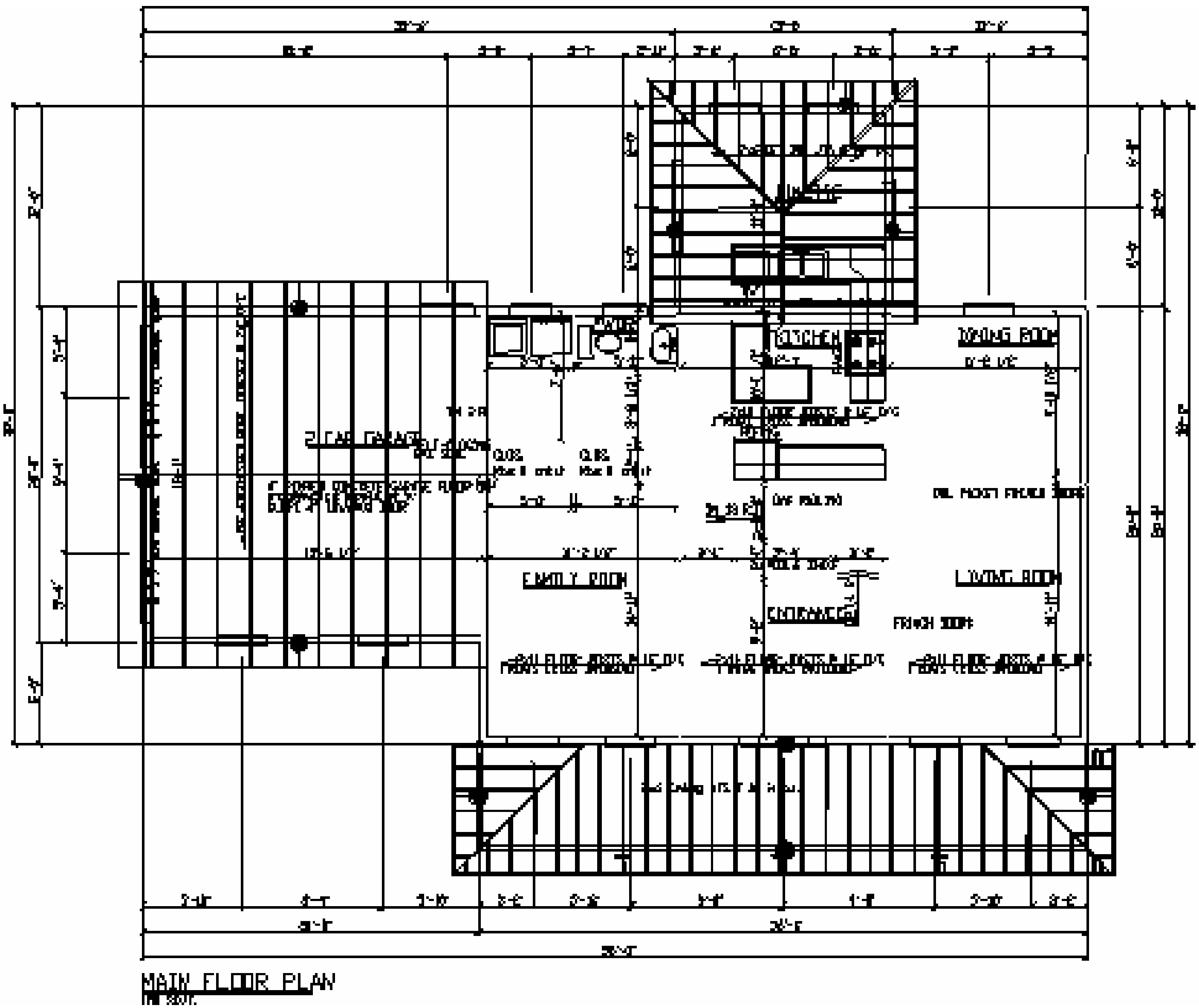


Figure B 9. Minneapolis house - main floor plan with roof and floor framing.

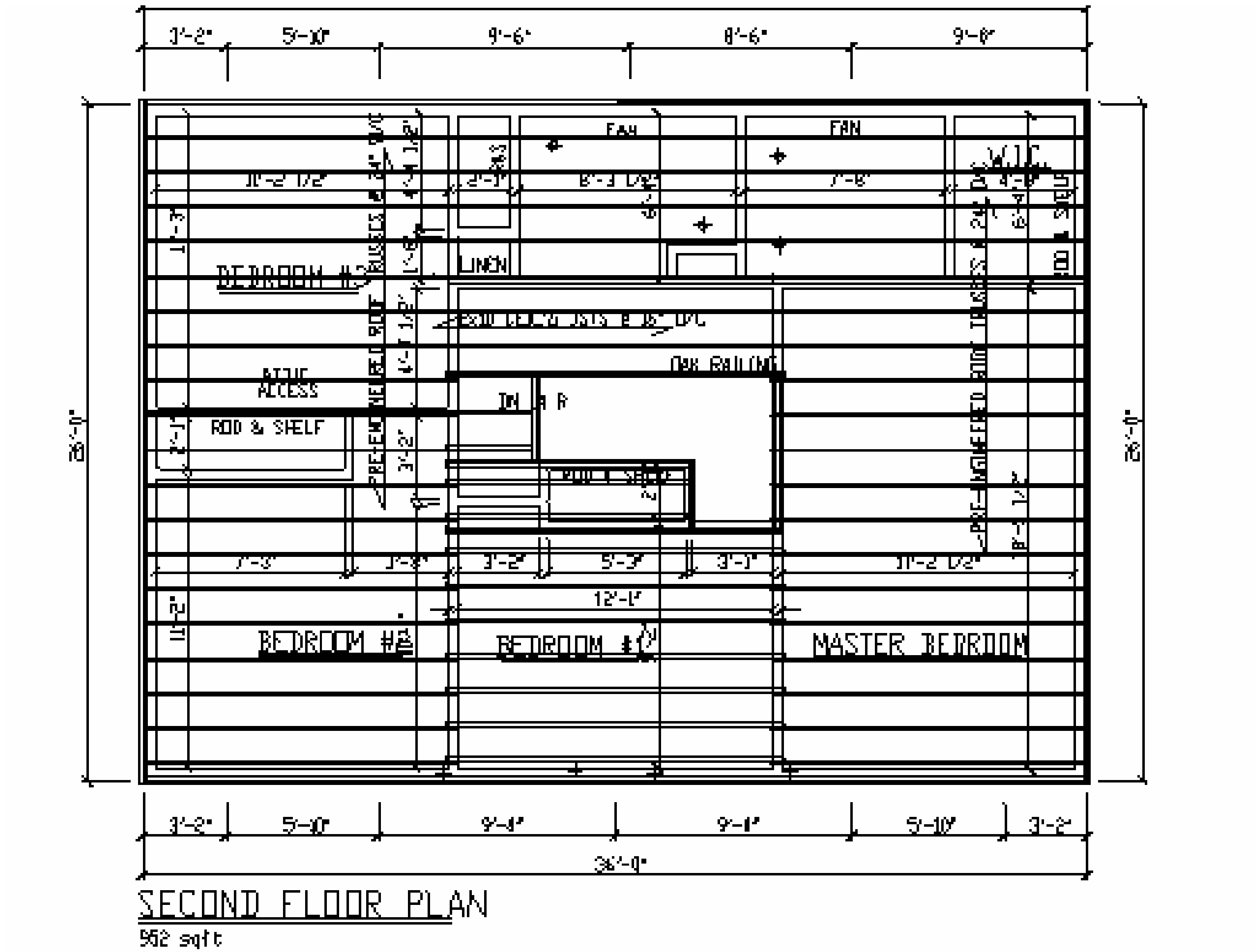


Figure B 10. Minneapolis house - 2nd floor joist framing.

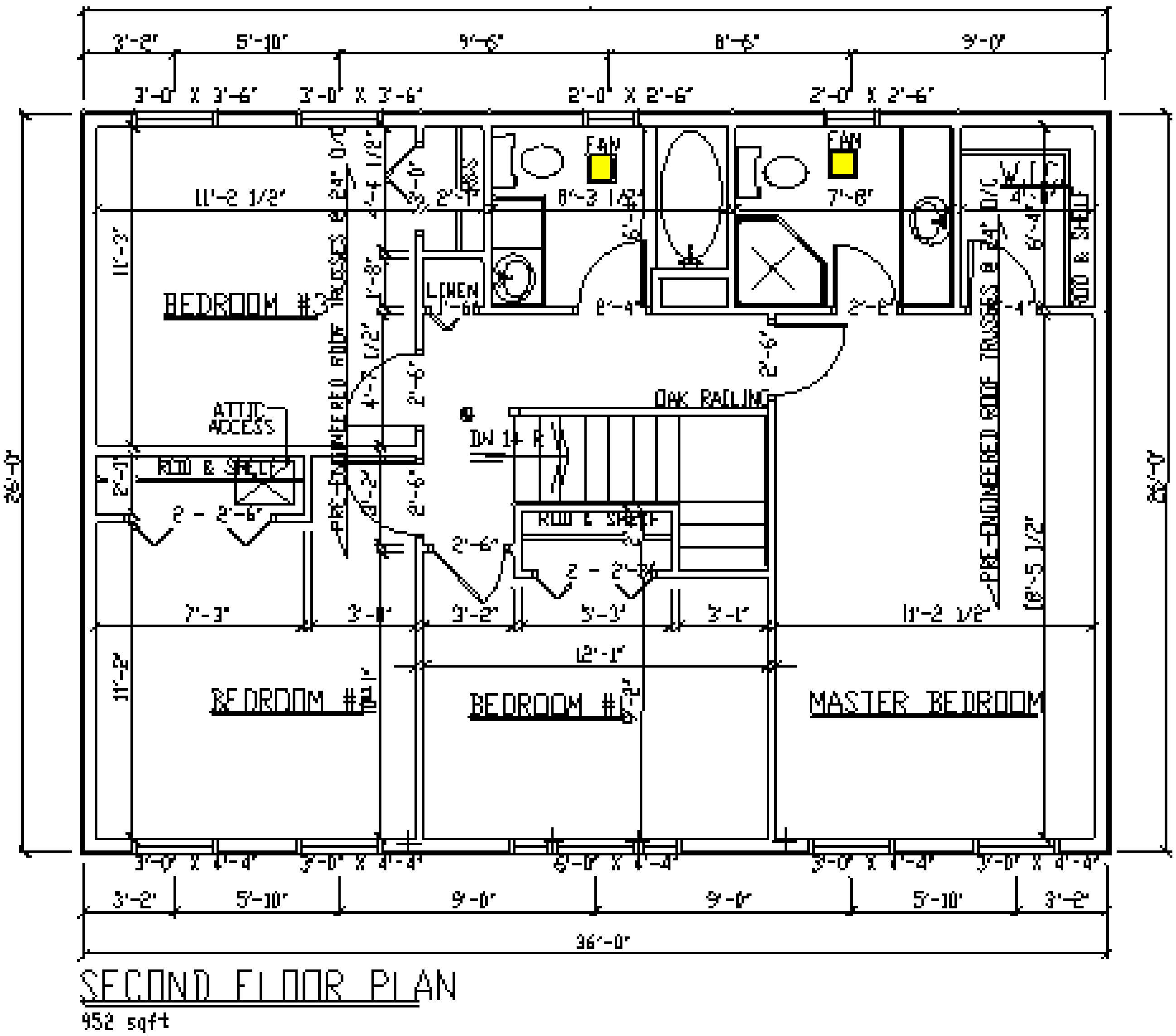


Figure B 11. Minneapolis house - 2nd floor framing plan and wall topology.

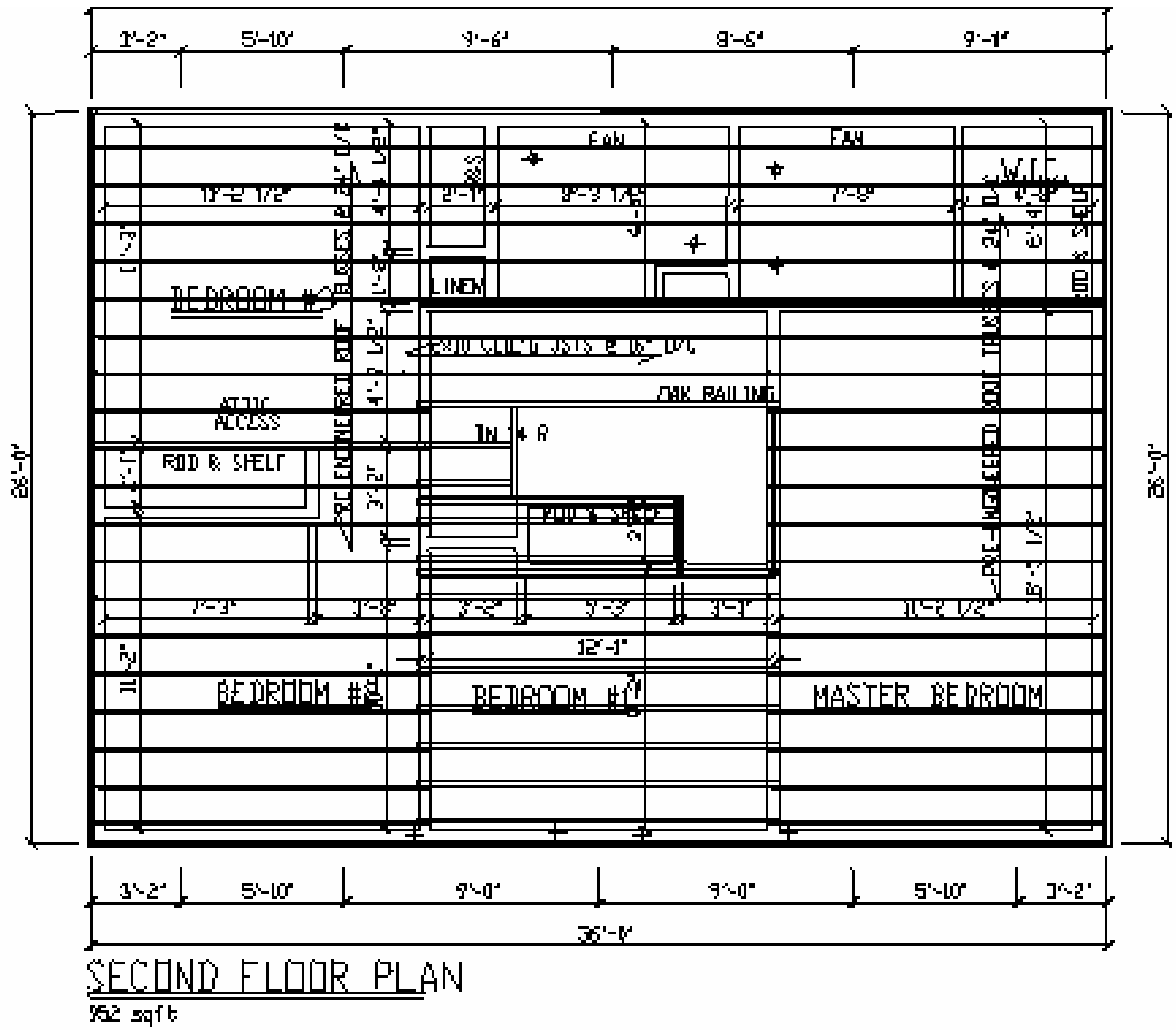


Figure B 12. Minneapolis house - 2nd floor framing diagram.

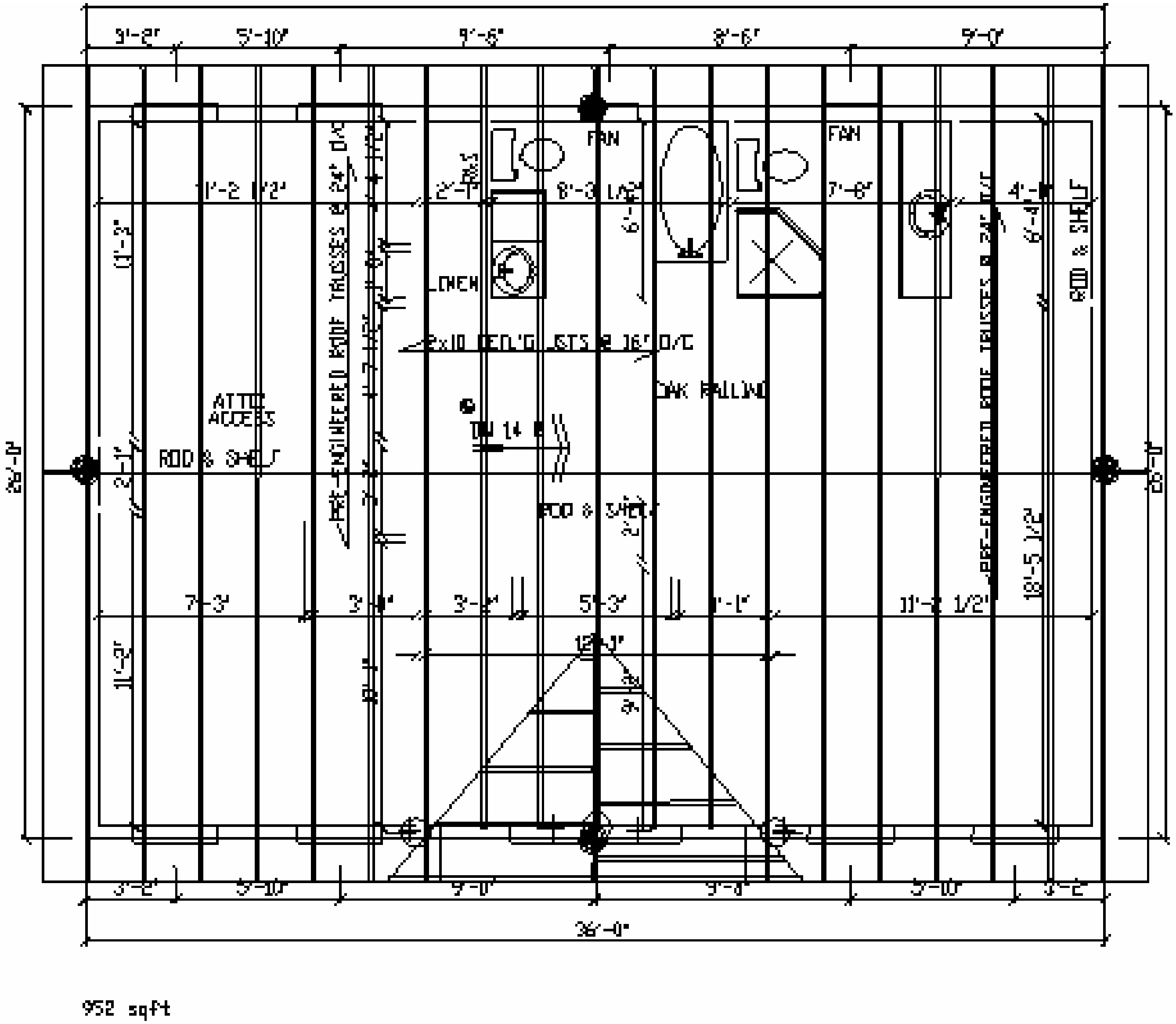


Figure B 13. Minneapolis house - roof plan.

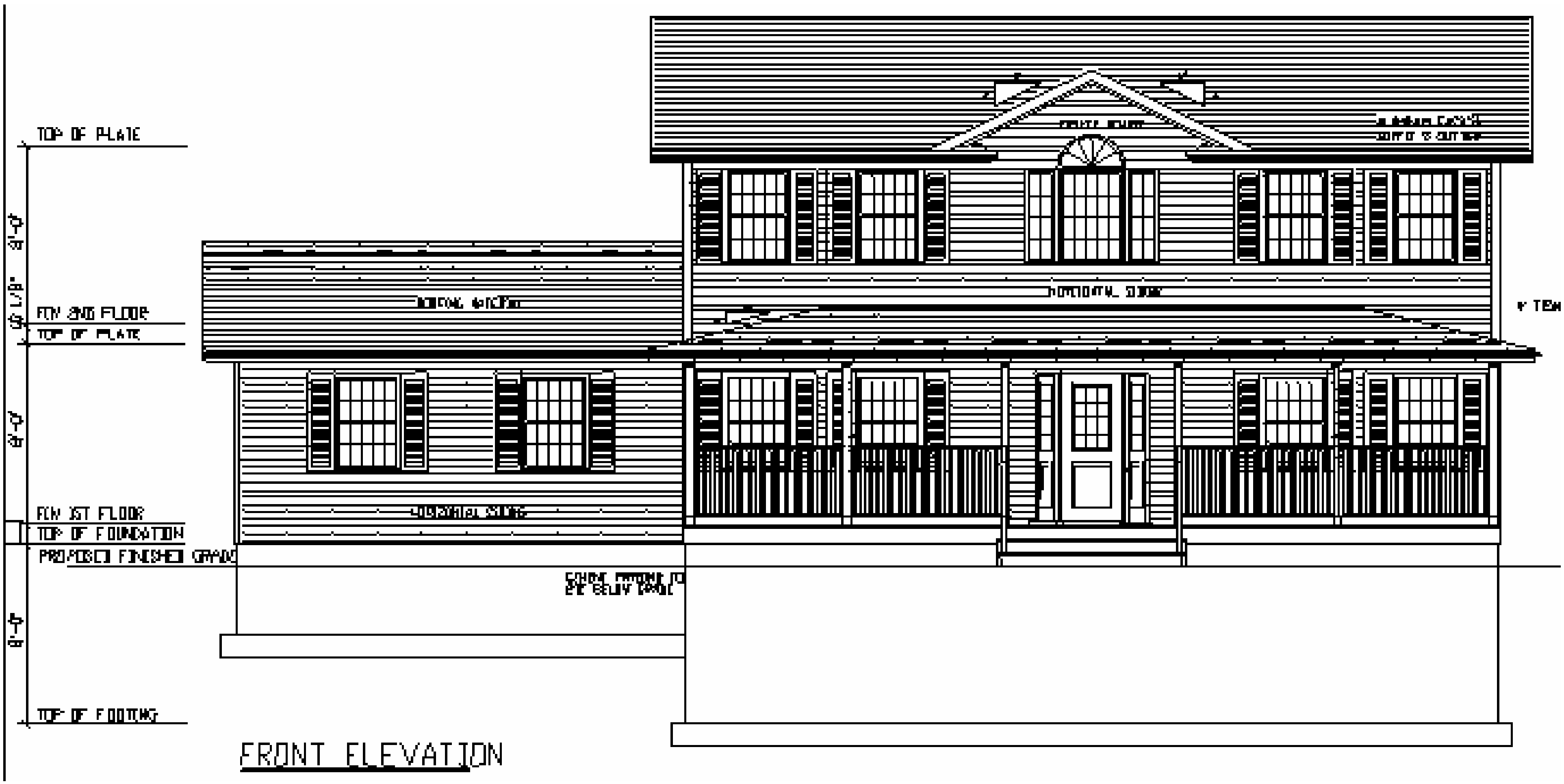


Figure B 14. Minneapolis house - front elevation.

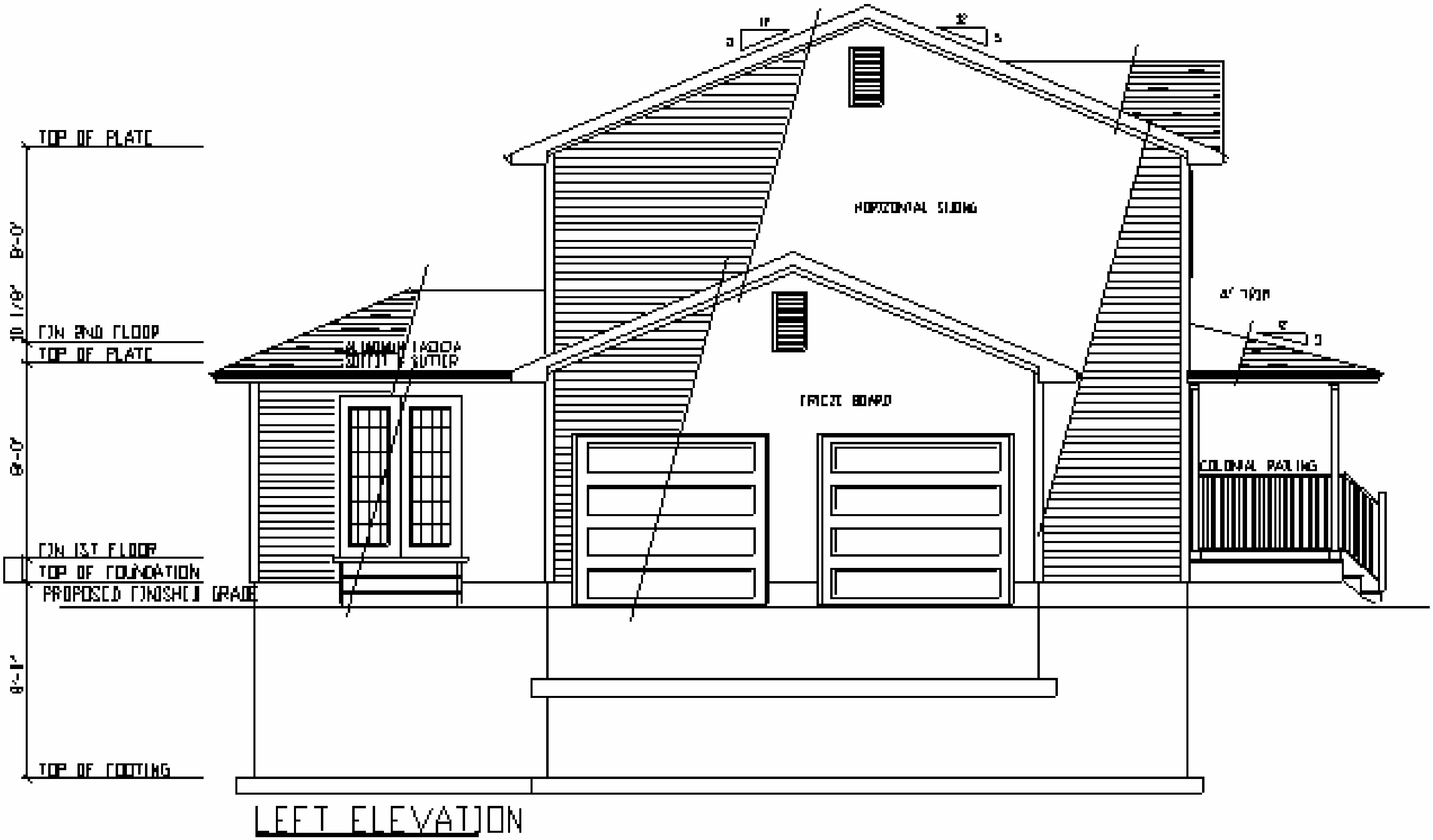


Figure B 15. Minneapolis house, - left elevation.

Figure B 16. Minneapolis house - rear elevation.

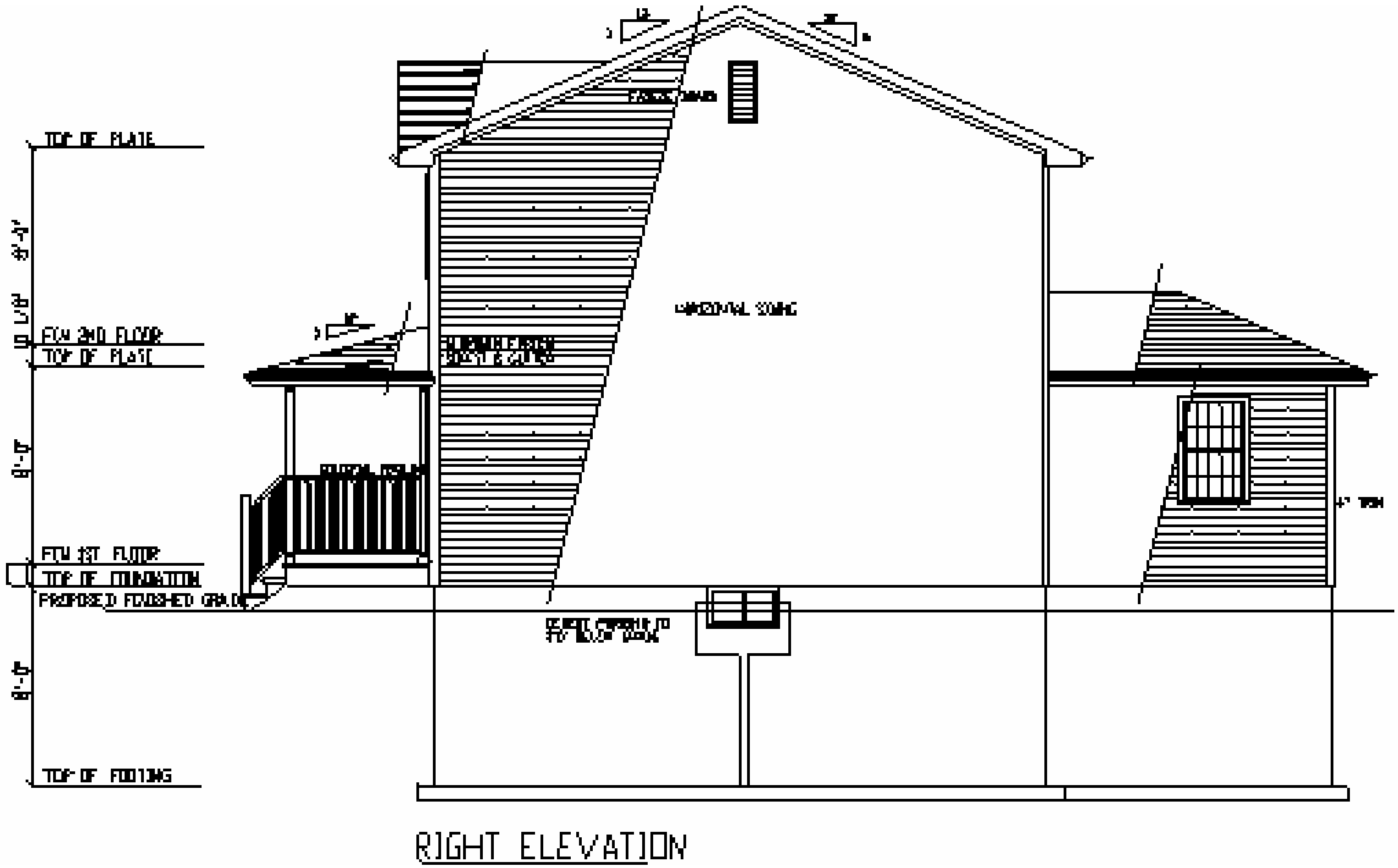


Figure B 17. Minneapolis house - right elevation.

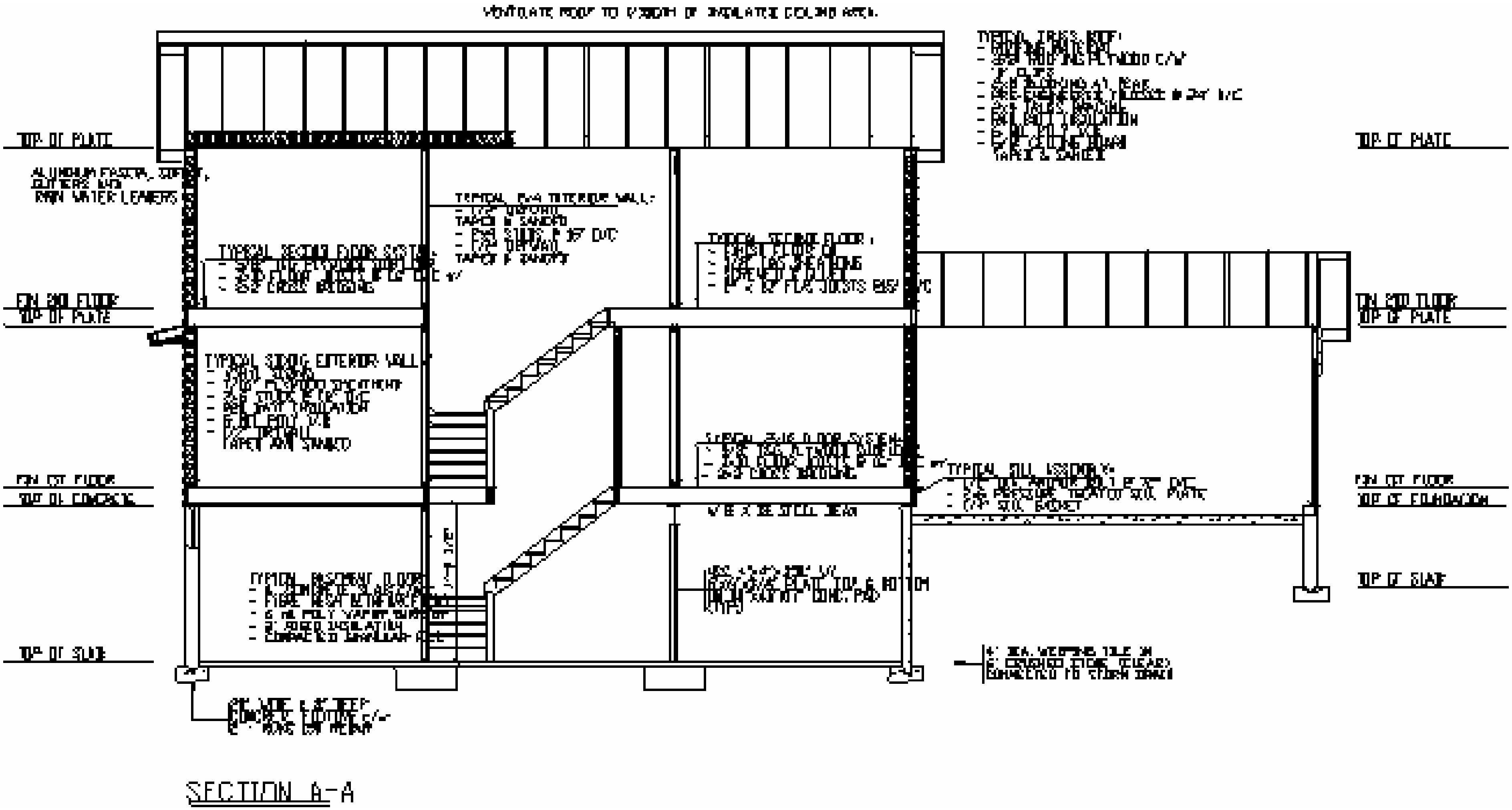


Figure B 18. Minneapolis house - section A-A.

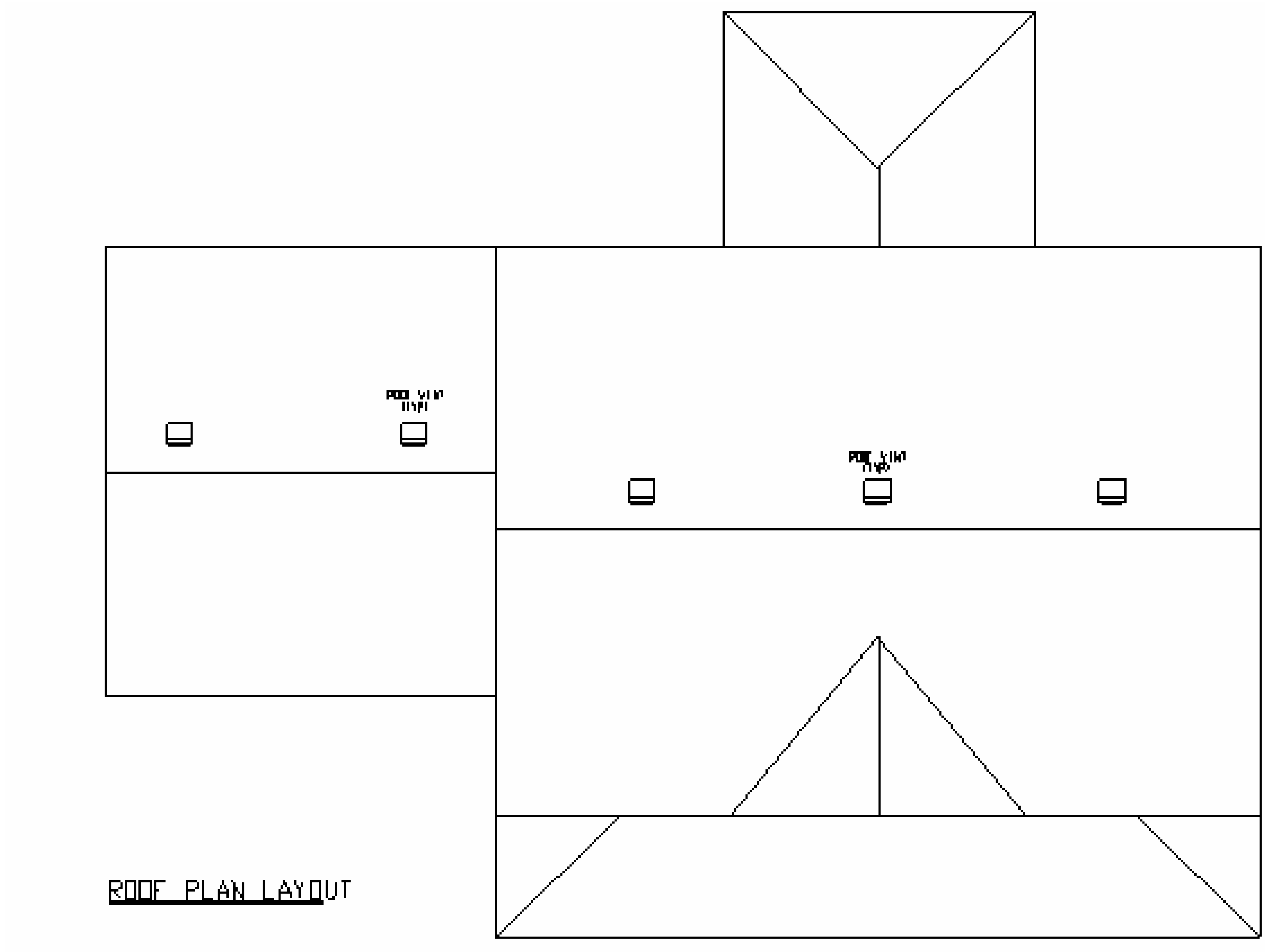


Figure B 19. Minneapolis house - roof plan.

APPENDIX 3.

R-VALUE RECOMMENDATIONS FOR ATLANTA STRUCTURE

DOE/CE-0180
September 1997

Department of Energy
Assistant Secretary
Energy Efficiency and
Renewable Energy

R-Value Recommendations for New Buildings

Heating System: Heat Pump
Cooling System: Electric Air Conditioning
First 3 digits of ZIP code: 303
Location: Atlanta, GA

Wood-Framed Building		
Insulation Location	**R-Value***	**Notes**
Attic	49	-
Cathedral ceiling	38	-
Floor	25	Over unheated, uninsulated space.
Wall cavity	13	-
OVE wall cavity	19	This recommendation assumes that a 2x6 wall can be built for the same cost as a 2x4 wall, using a careful design procedure called Optimum Value Engineering (OVE). Discuss this option with your builder.
Concrete or masonry wall	11.4	Insulation should be placed on the interior side of an above-grade wall.
Band joist	30	A band joist is a part of a floor joist system (see Fig. 1). This part of the exterior wall must be insulated before the floor is installed.

Basements and Foundations		
Insulation Location	**R-Value***	**Notes**
Slab edge	8	-
Crawl space wall	19	Crawl space walls are only insulated if the crawl space is unvented and the floor above the crawl space is uninsulated. See the *Builder's Foundation Handbook.*
Basement wall exterior	8	Exterior insulation on a below-grade wall is used only if you choose not to insulate the interior side of your basement wall.
Basement wall interior	11	Interior insulation on a below-grade wall is used only if you choose not to insulate the exterior side of your basement wall.

Metal-Framed Building *The recommended insulation levels for metal frames will not necessarily give you performance as good as the recommended levels for a wood-framed building. Please see the discussion about heat loss paths associated with metal frames.*		
Insulation Location	**R-Value***	**Notes**
Floor	25	Over unheated, uninsulated space.
Attic cavity	49	-
Wall sheathing	5	It is important to use both the insulative sheathing and cavity insulation recommended. Insulative sheathing may be placed outside of wood sheathing product, or special braces may be used.
Wall cavity	13	-

* R-values have units of F-ft^2-h/Btu. The recommended R-values were produced using the ZIP-Code computer program. The recommendations are based on an analysis of cost effectiveness, using average local energy prices, regional average insulation costs, equipment efficiencies, climate factors, and energy savings for both the heating and cooling seasons.

Building Envelope Research
Oak Ridge National Laboratory

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Revised: August 28, 1998

APPENDIX 4.

R-VALUE RECOMMENDATIONS FOR MINNEAPOLIS STRUCTURE

DOE/CE-0180
September 1997

Department of Energy
Assistant Secretary
Energy Efficiency and
Renewable Energy

R-Value Recommendations for New Buildings

Heating System: Heat Pump
Cooling System: Electric Air Conditioning
First 3 digits of ZIP code: 554
Location: Minneapolis, MN

Wood-Framed Building		
Insulation Location	**R-Value***	**Notes**
Attic	49	-
Cathedral ceiling	38	-
Floor	25	Over unheated, uninsulated space.
Wall sheathing	5	It is important to use both the insulative sheathing and cavity insulation recommended. Insulative sheathing may be placed outside of wood sheathing product, or special braces can be used.
Wall cavity	13	-
OVE wall sheathing	5	It is important to use both the insulative sheathing and cavity insulation recommended. Insulative sheathing may be placed outside of wood sheathing product, or special braces can be used.
OVE wall cavity	19	This recommendation assumes that a 2x6 wall can be built for the same cost as a 2x4 wall, using a careful design procedure called Optimum Value Engineering (OVE). Discuss this option with your builder.
Concrete or masonry wall	11.4	Insulation should be placed on the interior side of an above-grade wall.
Band joist	30	A band joist is a part of a floor joist system (see Fig. 1). This part of the exterior wall must be insulated before the floor is installed.

Basements and Foundations		
Insulation Location	**R-Value***	**Notes**
Slab edge	8	-
Crawl space wall	19	Crawl space walls are only insulated if the crawl space is unvented and the floor above the crawl space is uninsulated. See the *Builder's Foundation Handbook.*
Basement wall exterior	15	Exterior insulation on a below-grade wall is used only if you choose not to insulate the interior side of your basement wall.
Basement wall interior	11	Interior insulation on a below-grade wall is used only if you choose not to insulate the exterior side of your basement wall.

Metal-Framed Building

The recommended insulation levels for metal frames will not necessarily give you performance as good as the recommended levels for a wood-framed building. Please see the discussion about heat loss paths associated with metal frames.

Insulation Location	**R-Value***	**Notes**
Floor	25	Over unheated, uninsulated space.
Attic cavity	49	-
Wall sheathing	7	It is important to use both the insulative sheathing and cavity insulation recommended. Insulative sheathing may be placed outside of wood sheathing product, or special braces may be used.
Wall cavity	13	-

* R-values have units of F-ft^2-h/Btu. The recommended R-values were produced using the ZIP-Code computer program. The recommendations are based on an analysis of cost effectiveness, using average local energy prices, regional average insulation costs, equipment efficiencies, climate factors, and energy savings for both the heating and cooling seasons.

Building Envelope Research
Oak Ridge National Laboratory

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Revised: August 28, 1998

APPENDIX 5.

ONE-STORY DESIGN BUILDING ENVELOPE - ATLANTA STRUCTURE

ATLANTA STRUCTURE

One-story design building envelope built to code. Bungalow slab on grade, 2153 sq. ft. (200 sq. m.). All house types include the following components (inside to outside):

Ceiling/Roof Systems

5/8 inch gypsum board
polyethylene sheet
engineered wood trusses 24 in. o.c.
blown cellulose insulation (R30)
7/16 inch OSB sheathing
15# rolled asphalt impregnated roofing paper
240# asphalt shingles

Floor (concrete slab construction)

concrete monolith footings and reinforced 4 inch thick slab floor
6 mil polyethylene sheet
gravel

Walls–Wood Frame

1/2 inch gypsum sheetrock
polyethylene vapor barrier sheet
2x4 wood studs, 16 inch o.c.
fiberglass batt insulation (R-13)
7/16 inch OSB sheathing
15# rolled asphalt impregnated roofing paper
vinyl siding

Walls-Concrete block (CMU)

1/2 inch gypsum sheetrock
polyethylene sheet?
2x4 studs 24 inch o.c.
fiberglass batt insulation (R-13)
concrete block (CMU) (blocks 8x8x16)
traditional 2 layer stucco finish

Walls-Partition (for both wood and concrete house)

1/2 inch gypsum sheetrock both faces
2x4 wood studs, 16 inch o.c.

Windows (use same types for all)

Double glaze, low E argon filled, vinyl frame

APPENDIX 6.

TWO-STORY DESIGN -BUILDING ENVELOPE - MINNEAPOLIS STRUCTURE

MINNEAPOLIS STRUCTURE

Two-story design envelope built to code. Full basement house with 2062 sq.ft. floor area (192 sq.m). All house types will include the following components (inside to outside):

Ceiling/Roof Systems

5/8 inch gypsum sheetrock
6 mil polyethylene sheet
wood engineered trusses 24 in. o.c.
blown cellulose insulation (R44)
1/2 inch OSB sheathing
15# rolled asphalt impregnated roofing paper
240# asphalt shingles

Basement walls and Floor

8 inch x 20 inch concrete footings
12 inch concrete masonry block walls
vapor retarder installed on block wall (typically 6 mil poly)
2x4 in wood stud frame wall (24 o.c.) on treated plate
R13 fiberglass batt insulation
6 mil flame retardant poly vapor retarder
4 inch concrete floor over sand

1st and 2nd Floor(wood)

I-joist equivalent to 2x10" solid wood joists 16" o.c.
19/32" plywood decking (Sturdi-floor type product, although minimum thickness it can span 20")

1st and 2nd Floor(steel)

Steel 18 ga. C joist at 12" o.c.
19/32" plywood decking (Sturdi-floor type product) (this is minimum approved thickness for sturdi-floor which eliminates the need for particleboard underlayment)

Walls–Wood Frame (above grade)

1/2 inch gypsum sheetrock
6 mil poly vapor retarder
2x6 inch stud, 16 o.c.
5 1/2inch fiberglass batts (R19)
7/16 inch OSB sheathing
15# rolled asphalt impregnated paper
vinyl siding

Exterior Walls—Wood Frame (below grade)

1/2 inch gypsum sheetrock
6 mil polyethylene vapor barrier
2x4 wood stud, 24 inch o.c.
fiberglass insulation batt (R-13)

Partition Walls-Wood Frame

1/2 inch gypsum sheetrock both sides
2x4 wood studs, 16” o.c.

Walls-Steel Frame (above grade)

1/2 inch gypsum sheetrock
6 mil poly vapor retarder
2x4 20 ga. steel studs, 16 inch o.c. (Cold rolled, C channel)
fill with fiberglass batt insulation (R13)
1-1/2 inch polystyrene foam (XPS) panel (R7.5)
7/16 inch OSB sheathing
15# rolled asphalt impregnated paper
vinyl siding

Exterior Walls -- Steel Frame (below grade)

1/2 inch gypsum sheetrock
6 mil polyethylene vapor barrier
2x4 25 ga. steel C studs, 24 inch o.c.
glass insulation batt (R-13)

Partition Walls -- Steel Frame

1/2 inch gypsum sheetrock both sides
steel 25 ga. “C” studs 16 inch o.c.

Windows

Double glaze, low E argon filled, vinyl frame