Lesson A3–9

Framing Agricultural Structures

Unit A. Mechanical Systems and Technology

Problem Area 3. Construction Systems

Lesson 9. Framing Agricultural Structures

New Mexico Content Standard:

Pathway Strand: Power, Structural and Technical Systems

Standard: **VIII:** Plan, implement, manage, and/or provide support services to facility design and construction; equipment design, manufacture, repair, and service; and agricultural technology.

Benchmark: **VIII-A:** Design machinery and equipment including vehicles, implements, building, and facilities (e.g., feeding, feed storage).

Performance Standard: **1.** Analyze site/equipment/permit requirements. **2.** Develop drawings. **3.** Estimate material needs and costs. **4.** Operate Computer Aided Drafting Design (CADD) Software.

Student Learning Objectives. Instruction in this lesson should result in students achieving the following objectives:

1. Discuss designing for building strength.
2. Discuss and compare building shapes.
3. Discuss and compare framing systems.
4. Explain how to identify building framework components.
5. Explain how to lay out rafters.

List of Resources.

The following resources may be useful in teaching this lesson:

Recommended Resources. One of the following resources should be selected to accompany the lesson:

Hometime Video. *Framing*. Sponsored by Chevrolet Trucks.

Johnson, Donald M., et al. *Mechanical Technology in Agriculture*. Danville, Illinois: Interstate Publishers, Inc., 1998. (Textbook, Chapter 18)

Phipps, Lloyd J., et al. *Introduction to Agricultural Mechanics,* Second Edition. Upper Saddle River, New Jersey: Prentice Hall Interstate, 2004. (Textbook, Chapter 11)

Using The Carpenter's Square. University of Illinois: Information Technology & Communication Systems (U3009a).

List of Equipment, Tools, Supplies, and Facilities

Writing surface
Overhead projector
Transparencies from attached masters
Copies of student lab sheets
Framing square
Tape measure
One 2 × 4—14 for each class member

Terms.

The following terms are presented in this lesson (shown in bold italics):

Band joists
Bird's mouth
Block plate or sill plate
Bridging
Clear-span buildings
Collar tie
Concrete block building
Curved half-arch buildings
Dead loads
Fascia
Floor joists
Full-arch type building
Gable-type building
Gambrel-type roof
Girts
Header
Hip-type roof
Jack studs

Light wood-frame (stud) construction
Live loads
Lower cripples
Lower plate
Lower plumb line
Overhang length
Pole buildings
Purlins
Rafter tail
Rigid arch building
Rise
Roof pitch
Rough sill
Run
Shed-type building
Sill sealer
Slope triangle
Soffit
Span
Subfloor
Trimmers
Truss
Upper chords
Upper cripples
Upper plate
Upper plumb line
Wall sheathing

Interest Approach. Use an interest approach that will prepare the students for the lesson. Teachers often develop approaches for their unique class and student situations. A possible approach is included here.

Ask students to name the different types of agricultural building framing systems. Show pictures of buildings that are sway-back or leaning. Ask students why buildings fail (fall down). In this lesson students will learn the types of building framing systems, the parts of a building framework, construction procedures used to strengthen a building, and how to lay out a common rafter.

Summary of Content and Teaching Strategies

Objective 1: Discuss designing for building strength.

Anticipated Problem: What can be done to prevent building failures?

I. Buildings are designed in the opposite order that they are built. The first decision is the type of roof, then what type of side construction is to be used, and finally the kind of foundation or support that will be used to anchor the building in the ground. The type of roof and side walls affect the appearance and the use of the building, while the foundation is dependent upon the style and weight of the building selected. Before starting to build, it is important that you get a complete set of plans showing construction details and a bill of materials. Use the grade and type of materials called for in the specifications. Build according to the plan and local building codes.

A. Buildings that are poorly designed or improperly built will lean or become sway-back. Usually the weakest points are where two or more members are joined together. The critical joints are: (1) where the wall meets the foundation, (2) where the roof meets the wall, and (3) at the point of the roof. To avoid failure, the joints should be as strong as the structural members. Another common cause of building failure is an inadequate foundation. The footing must be deep enough to avoid the results of shrinking and swelling of the soil due to freezing, thawing, and moisture changes. The footing must also be wide enough to support the weight of the building on your particular soil. The same principle also applies to poles used in a pole-type structure, plus they must also be deep enough to resist overturning when the wind blows against the side of the structure.

B. Where the wall meets the foundation, anchor bolts are installed in the concrete blocks and through the wooden plate to fasten the wall in place. Currently, tornado straps are becoming popular to tie the wall and foundation together. With pole buildings, the poles are set in holes that go below the frost line. Forty-five pounds of concrete are placed around the base of the pole before backfilling the hole with soil. If the concrete is attached to the pole it helps prevent poles from sinking and the strong winds from lifting the poles out of the ground.

C. Where the wall meets the roof, several nails should be used or a metal bracket can be used. In pole buildings, trusses or rafters can be fastened with pole nails (ring shanked nails), bolted to the pole, attached with plywood gussets, or reinforced with knee braces.

D. At the peak of the roof a collar tie can be used. A ***collar tie*** is a 2 × 4 nailed into both rafters to strengthen the joint and help prevent the roof from sagging over time. Most buildings today are built with trusses rather than rafters. A ***truss*** is a set of rafters with bracing used to increase the strength and a lower chord that is used to serve as ceiling joists.

E. Designing a safe durable structure requires an understanding of the nature and types of loads and stresses to which the framing will be subjected. There are two types: dead loads and live loads.

1. ***Dead loads*** are those that are constant and are a permanent part of the structure. They consist of the combined weight of the building materials in the roof structure.
2. ***Live loads*** are temporary loads that move, or can be moved, without altering the structure. The most important ones are wind and snow loads. In most sections of the country, wind is the worst load you have to deal with. Snow, in areas of heavy snowfall, can add enough weight to cause a poorly designed or poorly built building to collapse.

Assign students to read the suggested chapters in the recommended textbooks. Show students sway-back and leaning buildings (in the community or in pictures). Talk about the reasons buildings fail and identify potential building weak points. Discuss procedures that can be used to prevent building failures. Talk about design elements and construction procedures that can be used to strengthen buildings. Use TM: A3–9A to emphasize the weak points of a building and TM: A3–9B to summarize loads and stresses.

Objective 2: Discuss and compare building shapes.

Anticipated Problem: What are the building shapes that can be used?

II. Once you determine the size of building you need, the next step is to select the type of building that will best serve your purpose.

A. The ***shed-type building*** has a roof sloping in only one direction with the front side commonly open. These buildings are limited to narrow widths and lack protection from rain and snow on the open entrance side unless equipped with doors.

B. The ***gable-type building*** has one roof angle on each side with the peak of the roof in the middle. Siding extends up on the ends of the building to the peak.

C. The ***hip-type roof*** is similar to the gable-type except the roof is brought down to the height of the side wall at the ends. Many houses have this type of roof.

D. The ***gambrel-type roof*** has two different slopes on each side, with the lower often being steeper than the upper. The roof forms half of an octagon. In past years large gambrel-type red barns were common on farms. Today many gambrel-type red barn utility buildings are found in homeowner's backyards.

E. The curved ***full-arch type buildings*** are metal prefabricated steel buildings with an end entrance. This design is strong with high wind resistance. In the past these buildings have been used mainly as a shop or machine shed. ***Curved half-arch buildings*** are half of the full arch design. They can have either an end or side entrance. Full-arch and half-arch buildings have decreased in popularity due to the curved short side walls.

The suggested chapters in the recommended texts contain more complete information on the content of this objective. Have students read them to gain a more complete understanding. Use the TM: A3–9C to show the various building shapes and roof designs.

Objective 3: Discuss and compare framing systems.

Anticipated Problem: What are the framing systems that could be used for agricultural buildings?

III. ***Clear-span buildings*** are buildings made without inside posts or beams. The use of wood-trussed rafters makes clear-span buildings possible without increasing the costs excessively.

A. ***Light wood-frame (stud) construction*** uses a continuous poured concrete or concrete block foundation and 2 × 4 or 2 × 6 vertical members called studs spaced at 16 inch centers to frame the wall. This framing system is the system used to build a house.

B. ***Pole buildings*** use poles spaced 10 to 14 feet apart along the length of the building with heavy-duty trusses bolted or nailed to the pole. Instead of a continuous footing or foundation, the pole building uses concrete around the base of each pole. The recommended depth of the pole and the amount of concrete to use should be included with the building plans. The difference between a pole and post building is that poles are round and posts are square (4 × 4, 6 × 6, 8 × 8) or rectangular (4 × 6, 6 × 8). The pole building is generally roofed and sided with metal sheeting. These buildings are relatively inexpensive to build and are popular as shops and machine sheds.

C. ***Rigid arch building*** construction can be a metal or wooden framework with the roof framing and wall framing all fastened together as one unit. When metal is used, the framing members are usually prefabricated at the factory. These buildings have a high ceiling providing space for hay storage or tall machinery. If wood framing is used, the roof framing and wall framing are connected together with plywood or metal gussets.

D. ***Concrete block building*** construction has concrete block walls with rafters or trusses to form the roof. This design offers high fire resistance but is much more expensive to build than a pole building.

Each of the recommended texts contains complete information on this topic. Assign students to read the suggested chapters. Compare the framing systems that are being used with agricultural buildings today. Look at buildings in the community or use TM: A3–9D with this objective.

Objective 4: Explain how to identify building framework components.

Anticipated Problem: What are the parts of a building framework?

IV. Knowing the names of the parts of a building are essential in order to communicate with designers and builders.

A. Light wood-frame building construction starts with the footing, foundation, and floor framing. Many agricultural buildings have a concrete floor. If the building will be a house or agribusiness office, it will probably have a wooden floor. If a wooden floor is installed the ***block plate*** or ***sill plate*** is bolted onto the foundation. A ***sill sealer*** of compressible foam is used between the sill and the foundation to stop air leaks. ***Floor joists*** placed on edge and spaced on two foot centers are the beginning of the framing. The ***band joist*** is

the joist where the ends of the floor joist are nailed. ***Bridging*** is bracing placed between floor joists to prevent warping and twisting of joists as well as a way of strengthening the floor. A ***subfloor*** of wafer board is commonly glued and nailed to the floor joists. On top of the subfloor some type of flooring is installed (finished plywood, then tile or congoleum, carpet, etc.). Wall framing begins with a horizontal ***lower plate*** attached to the vertical wall members called studs. The ***upper plate*** is the horizontal nailer at the top of the stud wall. The upper plate is normally doubled with an attempt to stagger the joints in the two plates resulting in a stronger, stiffer wall. Window and door openings are framed into the wall. The ***header*** is the horizontal support at the top of the openings. ***Jack studs*** are the vertical supports in the door opening between the door header and the subfloor. The ***rough sill***, or sill as it is commonly called, is the horizontal support at the bottom of the window opening. ***Trimmers*** are the vertical supports in the window opening between the header and the sill. ***Lower cripples*** are the vertical supports above the window and door headers in non-load bearing walls. ***Upper cripples*** are the vertical supports placed between non-load bearing headers and the upper plate. The stud walls are covered with ***wall sheathing*** (sheeting) that is wafer board at the corners and insulation board between the corners. Some type of siding is installed over the wall sheathing. Roof framing is almost always a factory built truss. Trusses are covered with wafer board roof sheathing, then roofing felt, and then rolled roofing or shingles. The ***fascia*** is the board, often covered with aluminum, that is nailed to the ends of the rafters. The ***soffit*** is the material, wood or aluminum, that goes from the fascia to the wall of the building.

B. Pole or post buildings begin with digging and placing the preservative treated poles or posts. The concrete footing pad under the pole is the footing. These buildings have horizontally spaced nailers attached to the poles or post. These horizontal wall nailers used for attaching wooden or metal siding are called ***girts***. At the top of the poles a set of horizontal plates called girders are attached to the inside and outside of the poles to support the rafters or roof trusses. Roof framing is fastened with pole nails, bolts, tie down metal brackets, wooden gussets, or knee braces. A truss is composed of a set of ***upper chords*** (rafters), a set of lower chords across the bottom which can serve as ceiling joists, and a set of braces between the upper and lower chords (often the shape of a W). Horizontal roof nailers for attaching metal roofing are called ***purlins.*** Roofing and siding are generally galvanized steel sheets.

C. Rigid arch buildings that are made from metal often come pre-assembled from the factory and are raised into place with a boom lift or crane. Wooden arch buildings are often assembled by the builder using plywood gussets glued and nailed on the rafter and wall framing pieces. Metal rigid arch buildings are usually large and wooden arch buildings are usually small in size.

D. Concrete block buildings generally have trusses mounted on the concrete block walls.

Utilize student readings of the recommended textbooks to provide students with the information to fully understand the content of this objective. Use TM: A3–9E to show the parts of a stud frame building construction and TM: A3–9F to show the parts of a pole-frame building construction. Use LS: A3–9A and

LS: A3–9B to test the students knowledge of the building parts. Use the Hometime Framing video to show the construction of the building framing.

Objective 5: Explain how to lay out rafters.

Anticipated Problem: How is a common rafter marked out?

V. If common rafters are to be used in the building framing, the builder needs to know the ***span*** of the building (full width), the ***run*** (half of the width of the building), and the ***rise*** (total height increase from the wall to the peak of the roof). The ***roof pitch*** is defined as the rise or span. The ***slope triangle*** is the inches of rise or foot of run.

A. Look at the common rafter table on the framing square. Look under the inch mark that represents the rise or foot of run for the building in question. Multiply that number by the total run. Divide the answer by 12 to get the rafter length in feet. The rafter length is marked out on a marking line (1½ inches from the bottom of a 2 × 4 or 2 inches from the bottom of a 2 × 6). The ***upper plumb line*** is the marked angle at the top of the rafter. It is marked using the rise or foot of run and the number 12. Measure where the upper plumb line intersects with the marking line at the upper end of the board along the marking line to the length that was calculated. That location will be the point of the bird's mouth. The ***bird's mouth*** is the notch in the rafter where it sets on the wall. The angled cut at the lower end of the rafter is called the ***lower plumb line***. The ***rafter tail*** is the rafter from the bird's mouth to the lower plumb line.

B. When the rafter is in place on the roof, the horizontal distance from the bird's mouth notch to the lower plumb line is called the ***overhang length***. To calculate the rafter tail length that is marked on the board, take the number on the rafter table under the rise or foot of run and multiple it by the desired overhang length. All rafter cuts are marked using the rise or foot of run and the number 12. For example, the rafter for a 5–12 building would be marked using the numbers 6 and 12. If the building total run was 10 feet and the overhang was 2 feet, then using the number 13.00 inches found under the 5 in the rafter table would result in a rafter length of 130 inches or 10 foot 10 inches (13 × 10) and a overhang length of 26 inches or 2 foot 2 inches (13 inches × 2). If a ridge piece is used between a pair of rafters each rafter must be shortened by half of the width of the ridge piece.

Assign students to read the appropriate chapters in the recommended texts. The texts will supply students with more complete detail on this topic. The Cutting Rafters section in Chapter 11 of Introduction to Agricultural Mechanics presents excellent information on this objective. Use the framing square and a 2 × 4 to demonstrate how to lay out a rafter such as the example above. Use LS: A3–9C to calculate common rafter problems. Give each student a framing square, a 2 × 4, and LS: A3–9D to lay out a common rafter.

Review/Summary. Review why some buildings fail while others stand for years and years. Stress the importance of proper design with dead and live loads considered. Compare roof designs

and framing systems using the transparencies. Use the transparencies to review the parts of the building and the lab sheets as a way of reviewing the information of the transparencies. Visit a construction site and identify the parts of the building under construction. Calculate more rafter problems and lay out another rafter to be sure students understand the process.

Application. Use the accompanying lab sheets to identify the parts of the building, to calculate rafter problems, and to lay out a rafter.

Evaluation. Take the written test and grade the work done with the lab sheets.

Answers to Sample Test:

Part One: Matching

1 = c, 2 = g, 3 = i, 4 = f, 5 = h, 6 = j, 7 = b, 8 = e, 9 = d, 10 = a

Part Two: Completion

1. purlins, girts
2. dead, live
3. lower chord, upper chord, web braces, gussets
4. sill sealer
5. floor joists, bridging
6. slope, pitch
7. span, run, rise
8. bird's mouth
9. rafter length
10. rise/foot or run, 12

Part Three: Short Answer

1. a. lean-to roof
   b. gable roof
   c. hip roof
   d. gambrel
   e. half arch
   f. full arch
2. Foundation-wall joint: anchor bolts, brackets
   Wall-roof joint: metal brackets, bolts, knee braces, plywood gussets
   Roof ridge joint: ridge piece and collar tie, truss with web bracing

Sample Test Name _____

Test

Lesson A3–9: Framing Agricultural Structures

Part One: Matching

Instructions. Match the term with the correct response. Write the letter of the term by the definition.

a. concrete block building
b. header
c. jack stud
d. light-wood-frame construction
e. lower cripple
f. pole building
g. rigid arch building
h. rough sill
i. stud
j. trimmer

_____ 1. The framing member that supports a door header.

_____ 2. Building framing system where the roof and wall framing members are together as a unit.

_____ 3. Framing member between the lower plate and upper plate.

_____ 4. Building framing system that uses trusses attached to poles set in the ground.

_____ 5. Horizontal framing member at the bottom of a window opening.

_____ 6. Framing member at the side of a window opening.

_____ 7. Horizontal framing member support at the top of the window or door opening.

_____ 8. Vertical framing member under the window opening.

_____ 9. Building framing system that uses 2 × 4 stud walls and a continuous concrete footing.

_____ 10. Building framing system that uses a concrete footing and concrete block wall.

Part Two: Completion

Instructions. Provide the word or words to complete the following statements.

1. The horizontal nailers on top of the trusses of a pole building are called _____. The horizontal nailers on the walls are called _____.
2. Loads that are a permanent part of the building, such as the weight of the roof, are called _____ loads while loads that are temporary, such as the wind and snow, are called _____ loads.

3. The parts of a truss are the _____ _____, _____ _____, _____ _____, and _____ _____.
4. The _____ _____ is placed between the top of the foundation and the block or sill plate to stop air leaks.
5. On top of the block or sill plate the supports for the floor are called _____ _____. Between the floor supports bracing in the shape of an x called _____ is used.
6. Roof _____ is the rise/foot of run while _____ is the rise/span.
7. The _____ is the width of the building while the _____ is half the width of the building. The _____ is the total height increase from the wall to the peak of the roof.
8. The _____ _____ is then notch in a rafter where it rests on the wall.
9. The _____ _____ is defined as the distance from the upper plumb line to the corner of the bird's mouth.
10. When marking a bird's mouth use the _____or _____ and the number _____.

Part Three: Short Answer

Instructions. Provide information to answer the following questions.

1. Name and draw 6 common building roof shapes:

2. List at lease five techniques that could be used to strengthen the potential weak points of a building (foundation-wall joint, wall-roof joint, and roof ridge joint):

TM: A3–9A

POTENTIAL BUILDING WEAK POINTS

- **Foundation-wall joint—Points where the walls and foundation meet.**
- **Wall-roof joint—Points where the walls meet the roof.**
- **Roof ridge joint—Point where the roof peaks.**

TM: A3–9B

DESIGNING BUILDING THAT WILL WITHSTAND LOADS AND STRESSES

Dead Load

… constant permanent load

… parts of the structure such as the weight of the roof inside

Live Load

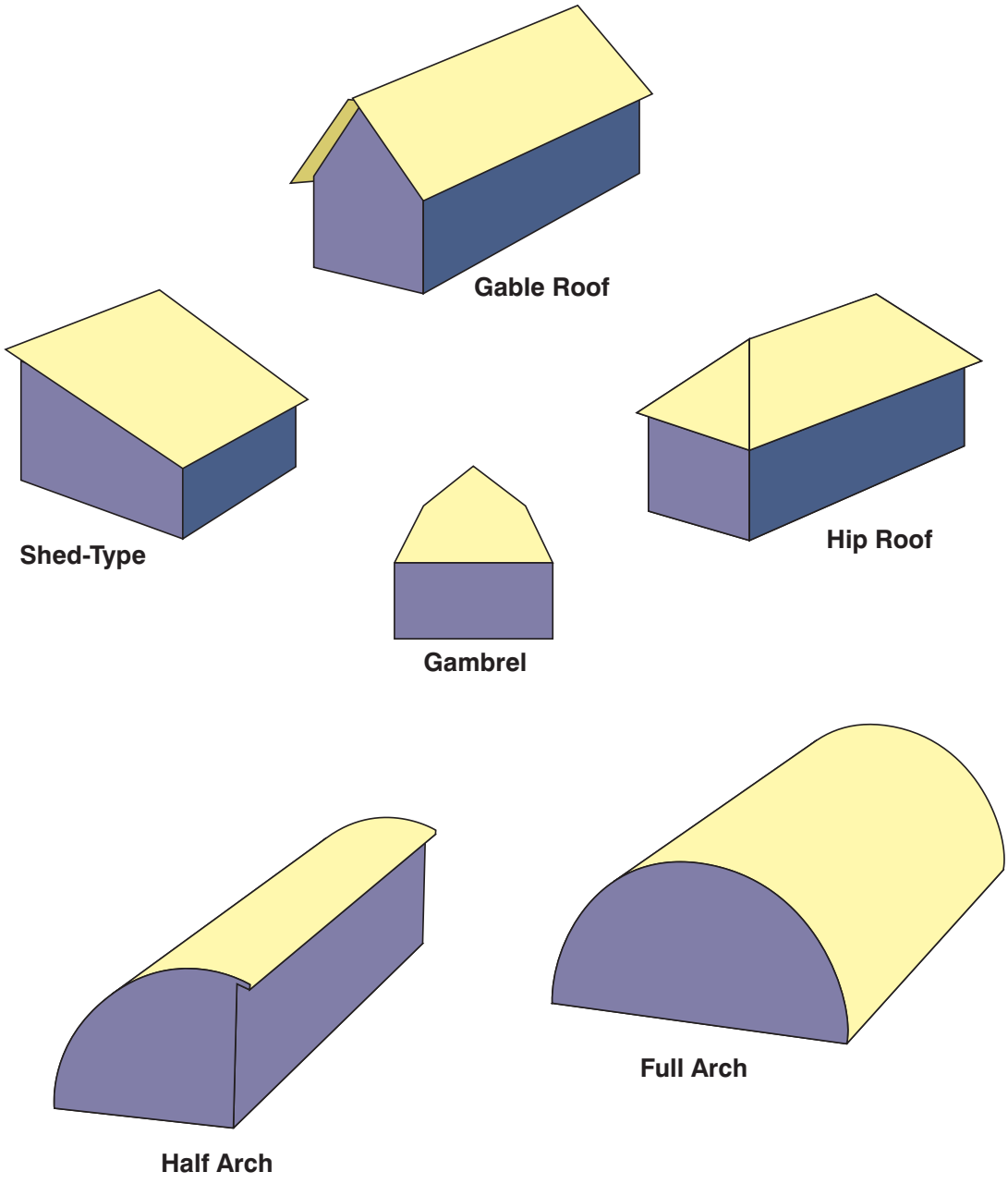
… temporary loads that can be moved without altering the structure

a. Wind Load (maximum PSI expected)

b. Snow Load (maximum PSI probably)

TM: A3–9C

COMMON BUILDING SHAPES

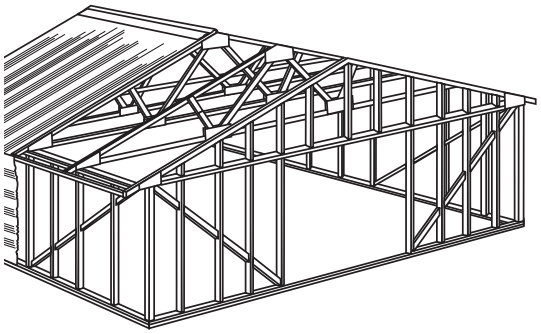


(Courtesy, Interstate Publishers, Inc.)

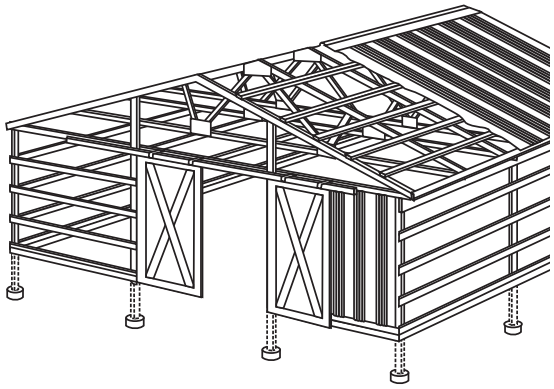
TM: A3–9D

FRAMING SYSTEMS

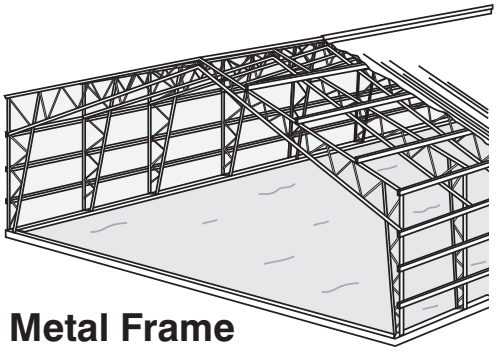
Light-Wood-Frame (Stud) Construction



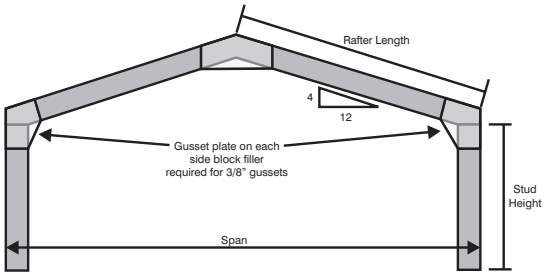
Pole or Post-Frame Construction



Rigid Arch-Frame Construction

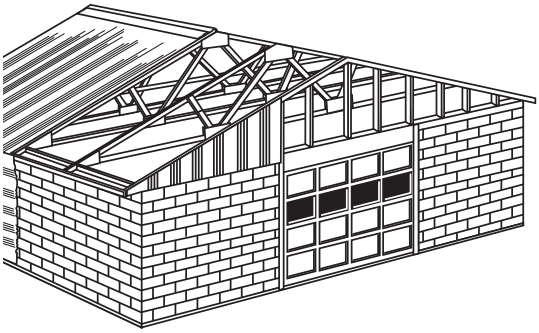


Metal Frame



Wood Frame

Concrete Block Building Construction



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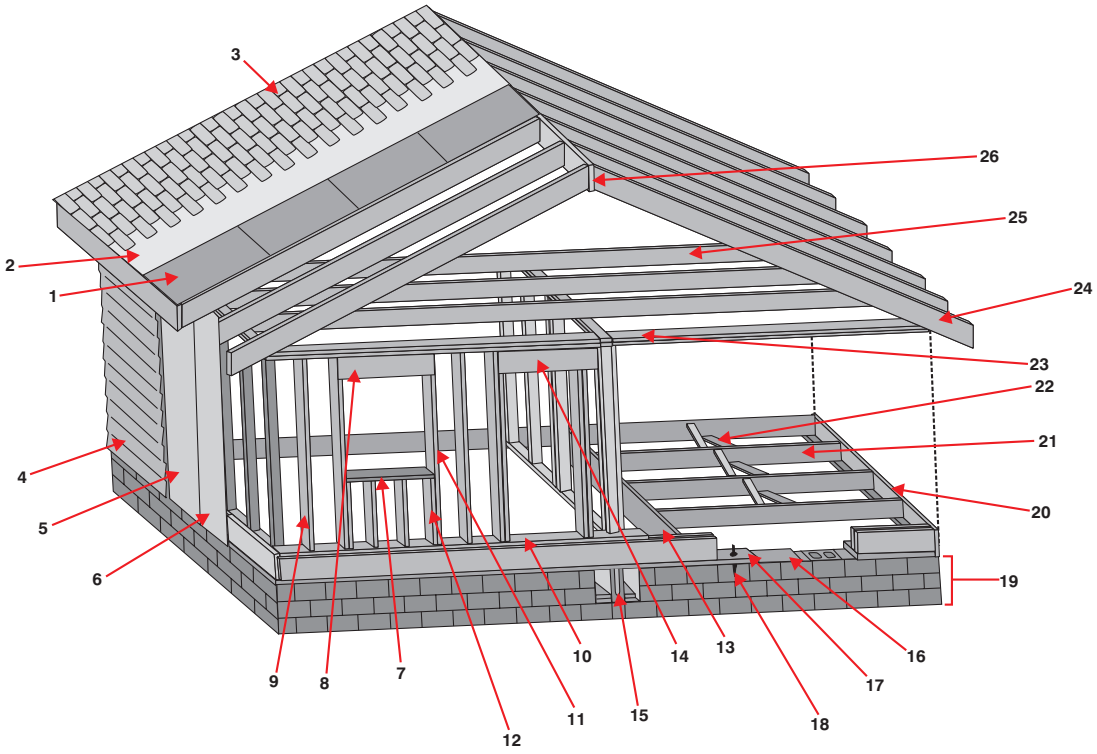
TM: A3–9E

SELECTED PARTS OF STUD FRAME BUILDING CONSTRUCTION WITH TRUSSED ROOF

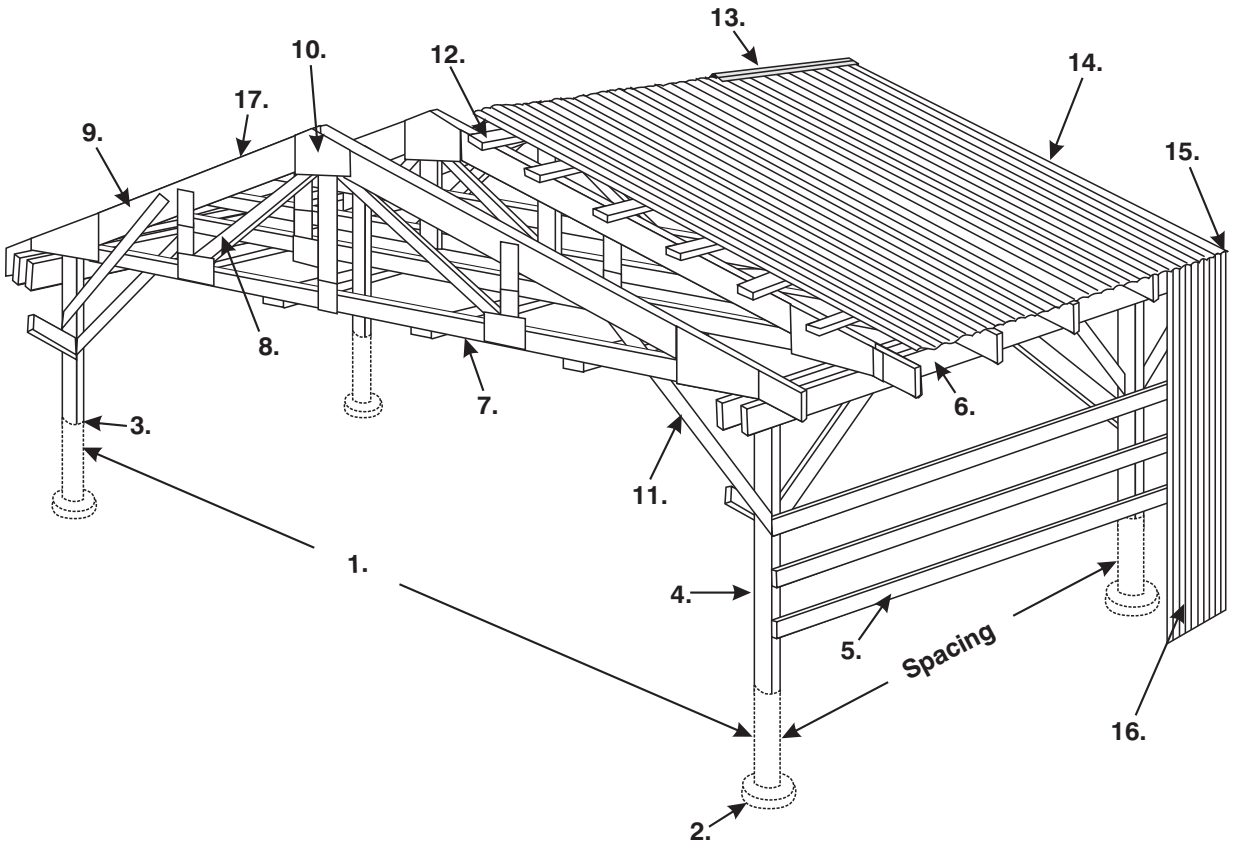


1. Roof sheeting
2. Roofing felt
3. Shingles
4. Siding
5. Insulation wrap
6. Wall sheeting
7. Rough sill
8. Header
9. Stud
10. Lower plate
11. Trimmer
12. Lower cripples
13. Subfloor
14. Header
15. Girder
16. Sill sealer
17. Sill plate
18. Anchor bolt
19. Foundation
20. Band joist
21. Floor joist
22. Bridging
23. Upper plate
24. Rafter
25. Ceiling joist
26. Ridge piece

(Courtesy, Interstate Publishers, Inc.)

TM: A3–9F

PARTS OF A POLE FRAME BUILDING CONSTRUCTION



1. Span
2. Concrete pad
3. Grade (ground level)
4. Pressure Treated Pole
5. Girder
6. Girder plate
7. Lower chord
8. Web brace
9. Upper chord
10. Gusset
11. Knee brace
12. Purlins
13. Ridge vent
14. Roofing
15. Eave
16. Siding
17. Truss

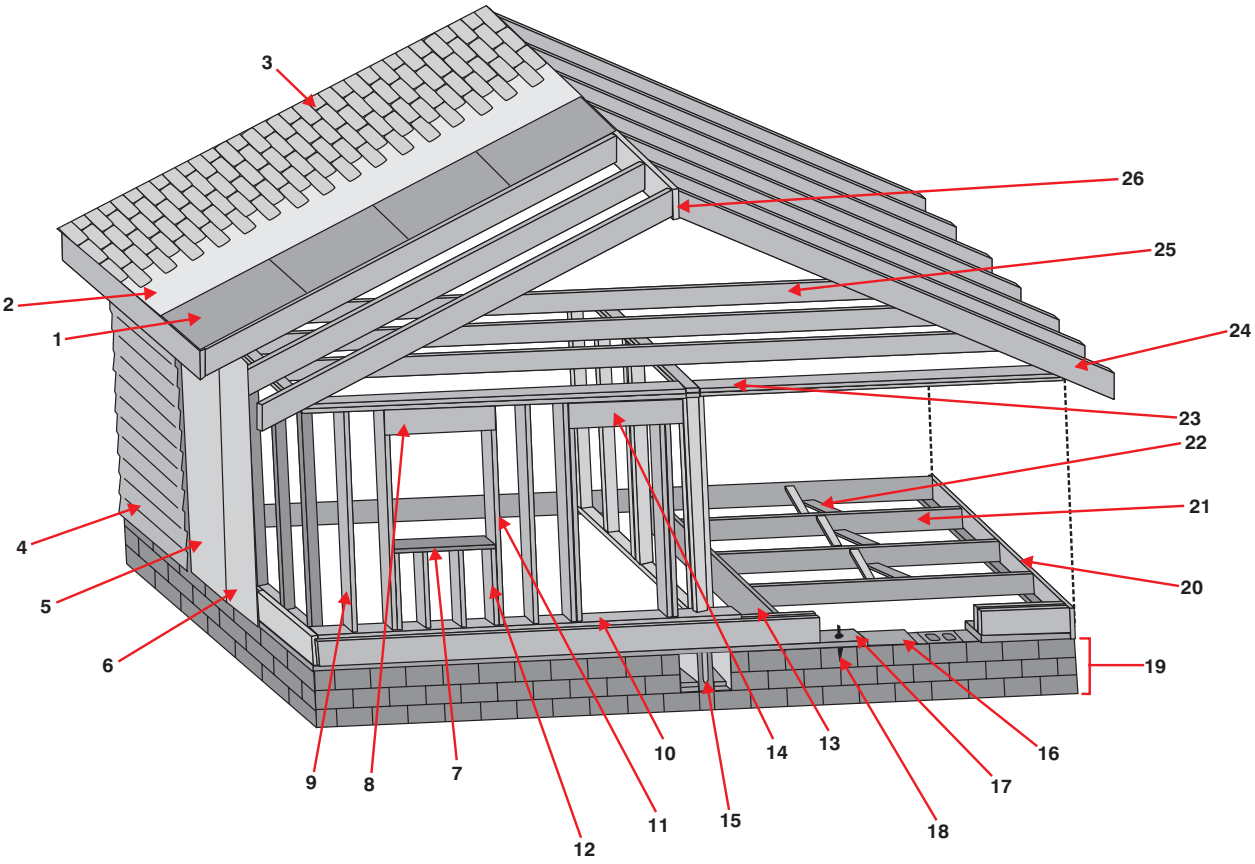
(Courtesy, Interstate Publishers, Inc.)

LS: A3–9A Name _____

Lab Sheet

Stud Frame Building Construction
Parts Identification

Label the parts of the building:



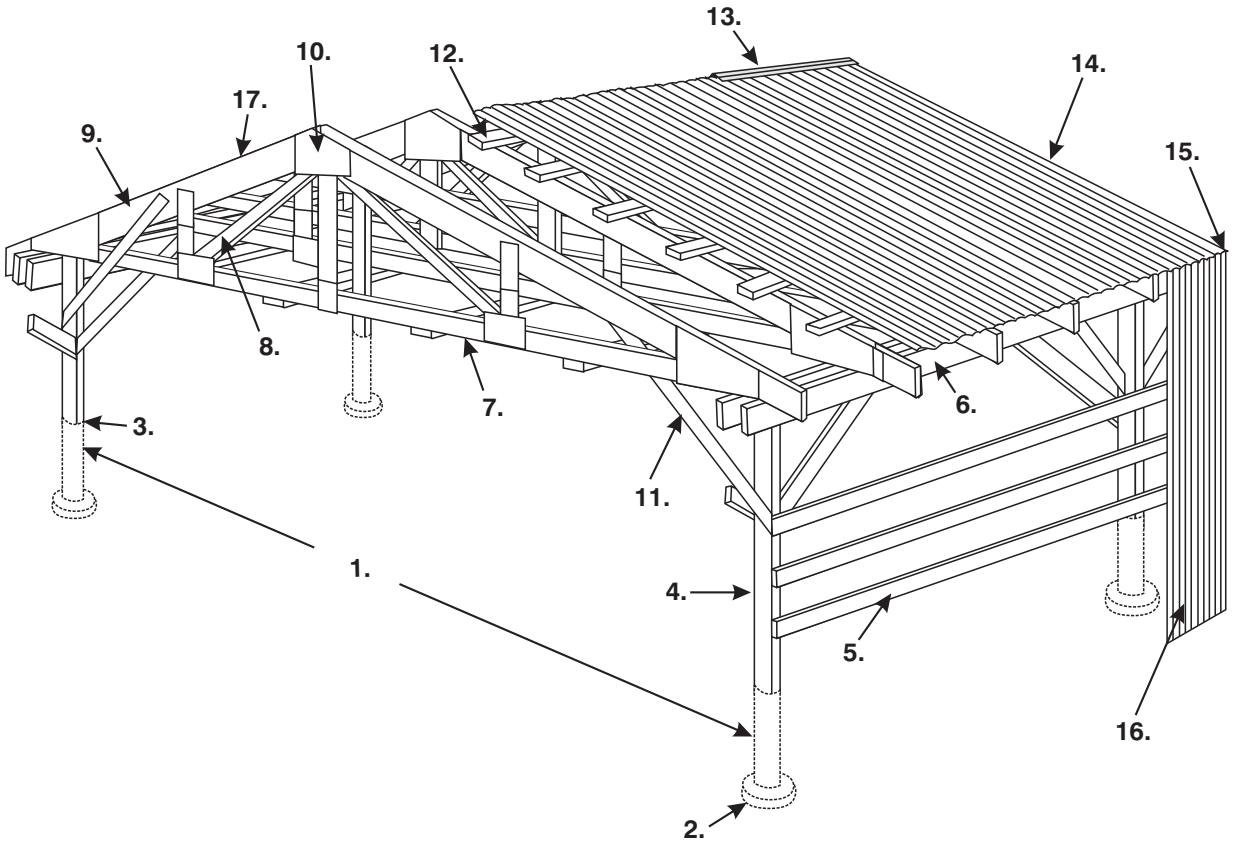
1 _____	10 _____	19 _____
2 _____	11 _____	20 _____
3 _____	12 _____	21 _____
4 _____	13 _____	22 _____
5 _____	14 _____	23 _____
6 _____	15 _____	24 _____
7 _____	16 _____	25 _____
8 _____	17 _____	26 _____
9 _____	18 _____	

LS: A3–9B Name _____

Lab Sheet

Pole Frame Building Parts Identification

Label the parts of the building:



1 _____	7 _____	13 _____
2 _____	8 _____	14 _____
3 _____	9 _____	15 _____
4 _____	10 _____	16 _____
5 _____	11 _____	17 _____
6 _____	12 _____	

Name _____

Lab Sheet

Common Rafter Calculations

… show your work

1. Given information: 8–12 roof slope, 10 foot run, 2 foot overhang
   a) rafter length

   b) numbers used to mark upper plumb line, bird's mouth, and lower plumb line _____ and _____

   c) rafter tail length

   d) length of 2 × 4 that must be purchased for this rafter _____

2. Given information: 4–12 roof slope, 12 foot run, 2 foot overhang
   a) rafter length

   b) numbers used to mark upper plumb line, bird's mouth, and lower plumb line _____ and _____

   c) rafter tail length

d) length of 2 × 4 that must be purchased for this rafter _____

3. Given information: roof slope 6–12, 14 foot run, 3 foot overhang

a) rafter length

b) numbers used to mark upper plumb line, bird's mouth, and lower plumb line _____ and _____

c) rafter tail length

d) length of 2 × 4 that must be purchased for this rafter _____

Name _____

Lab Sheet

Laying Out a Common Rafter

Given information:

Rise/foot of run 4 inches
Run 9 foot
Overhang 2 foot
Dressed ridge piece (1½ inch thick)

_____ 1. Calculate the rafter length (look in the common rafter table under the inch mark that represents the rise/foot of run, multiply that number by the run, and divide by 12 to get the length in feet.

_____ 2. Put a the marking line on the 2 × 4 (use the tongue of the framing square to mark the line 1½ inch from the bottom edge of the board).

_____ 3. Use the rise/foot of run and 12 to mark the upper plumb line near the top end of the 2 × 4.

_____ 4. Measure the calculated rafter length from where the upper plumb line intersects with the marking line. The end of the measured length is the location of the bird's mouth. Use the rise/foot of run and 12 to mark the bird's mouth (the marking line sets the depth of the bird's mouth).

_____ 5. Make the rafter length correction for half of the thickness of the ridge piece. If this case, half of the thickness of a dressed ridge piece would be ¾ inch so re-mark the upper plumb line ¾ inch down from its original location.

_____ 6. Calculate the length of the rafter tail (look in the common rafter table under the inch mark that represents the rise/foot of run, multiply that number by the overhang length, and divide by 12 to get rafter tail length in feet).

_____ 7. Measure the rafter tail length from the corner of the bird's mouth toward the lower end of the 2 × 4. Mark on the marking line. Use the rise/foot of run and the number 12 to mark the lower plumb line.

_____ 8. Hold the marked rafter up until vertical lines are perpendicular to the ground and the base line on the bird's mouth is parallel to the ground. If the upper plumb line, lower plumb line, and the back of the bird's mouth are not parallel to each other re-figure and re-mark.