



COLD CLIMATE HOUSING RESEARCH CENTER

CCHRC

Construction Manual

Sustainable Northern Shelter Home

Quinhagak, Alaska

Second Edition



Cold Climate Housing
Research Center

December 1, 2012

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Research Center

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IMPORTANT — READ BEFORE BUILDING.

The information contained in this manual was originally developed and published as a reference for experienced building professionals in Quinhagak Alaska who participated in on-site training and construction of the Quinhagak Prototype Home. The manual documents the techniques utilized in the construction of the Quinhagak Prototype Home in order to further enable the experienced building professionals of Quinhagak to incorporate these techniques in future home construction projects. This manual is not a substitute for a detailed architectural plan set or site specific engineering. Any application of knowledge contained in this manual will need to consider site specific issues including but not limited to applicable codes and structural design considerations for soil type, weather, and wind and snow load conditions. It is essential that a structural engineer review the plans to ensure they meet design criteria appropriate to the site. This home has many elements that require specialized knowledge. We strongly recommend that the installation of the spray foam insulation, plumbing and electric work be done by professionals.

Always use proper safety gear and precautions when building.

CCHRC sincerely appreciates its partnership with the Native Village of Kwinhagak in the design, construction, and long-term monitoring of this prototype home.

This training manual will provide an in-depth look at each of the major building components, systems, and processes of this house. This includes

- site preparation
- foundation and floor system
- exterior wall system
- the roof system
- the mechanical system

Cover Photos: *Top Left:* Bryan Jones of Quinhagak, lead carpenter for the Quinhagak Prototype Home project. *Top Right:* The completed Quinhagak Prototype Home in November 2010. *Bottom Left:* Dave Shippey, CCHRC instructor, describes the Quinhagak Prototype Home to a local high school construction class.



Table of Contents

List of Figures.	1
The Quinhagak Project	4
Site Preparation	7
Foundation & Floor System	8
Walls	16
Roof	24
Insulation & Interior Finishes	33
Mechanical & Electrical Systems	39



List of Figures

Figure 1.1	The finished pad measures 88' x 64' and proved adequate to buffer the building footprint	7
Figure 1.2	A laser level set up nearby allows the carpenter to check grade between leveling passes	7
Figure 1.3	A hand-held compass and string line can be used to determine the north-south axis	7
Figure 1.4	Building placement and site orientation are critical	7
Figure 2.1	A plywood template makes laying out reference lines on the pads much easier.	11
Figure 2.2	Dimensioned drawing of pad	11
Figure 2.3	Dimensioned drawing of template.	11
Figure 2.4	drawing of 6x6	11
Figure 2.5	Drilling 3/4" holes in a 6x6 to accept the 3/4" threaded rod on the saddle bracket.. . . .	11
Figure 2.6	Closeup of how the pad and 6x6 and support saddles are oriented in relation to an octagon corner.. . . .	11
Figure 2.7	Photo showing the diagonal string lines being used to orient the pads.	12
Figure 2.8	Setting the first four pads and using string lines to orient the pads in relation to the center and corners of the octagon.	12
Figure 2.9	The center rectangle of the octagon is braced square	12
Figure 2.10	Once the octagon beam framing is completed, strings can be run connecting opposite octagon corners.	12
Figure 2.11	Close-up of the pad arrangement at the corner of the octagon.	13
Figure 2.12	Setting the first four pads and using string lines	13
Figure 2.13	The first two beams (#1 and 2) carrying the floor are nailed together	13
Figure 2.14	The center beams carrying the floor are built up with 3 versalams nailed together	13
Figure 2.15	Joists are laid out two foot on center using the centerline of the floor.. . . .	14
Figure 2.16	A close up of the area where the entry wall beam meets the octagon corner	14
Figure 2.17	There are four joists that fall too close to an inside octagon corner to be supported by a skewed hanger	14
Figure 2.18	3/8 CDX plywood is cut and dropped into the joist bays.	14
Figure 2.19	The middle entry corner must line up with its corresponding octagon corner.	14
Figure 2.20	Framing and squaring the floor system	14
Figure 2.21	A cut line is snapped approximately 1 foot in from the exterior walls	15
Figure 2.22	Once the floor has been sprayed, the subfloor plywood is installed permanently.	15
Figure 2.23	Joist and plywood layout guide	15
Figure 3.1	The main east-west control line is being snapped through the center.	17
Figure 3.2	The carpenter is writing corner and mid-wall heights on the subfloor for each wall section.	19
Figure 3.3	Use the subfloor to test-assemble a roof section before setting the wall	19
Figure 3.4	Edge stops ensure that every stud assembly has the same width, in this case 8 inches.	19
Figure 3.5	The end studs are screwed to stop blocks to ensure all eight walls are built to the same outside dimension.	19
Figure 3.6	With the end studs in place, the top and bottom tracks can be fastened in place.	20
Figure 3.7	The 16-inch-high assembly table walls allow the carpenters to move easily from one part of the layout to the next.	20
Figure 3.8	The outer flange on the window will serve to attach the light gauge angle and siding.	20
Figure 3.9	Header boxes can be pre-built from the prints.	20
Figure 3.10	With the windows close together, the siding can be screwed directly to the window flanges.	20
Figure 3.11	The siding starts flush with the exterior angle to cover the outside of the floor and foundation.	20
Figure 3.12	A slot is cut in the siding in order to tuck the siding underneath the bottom flange of the window for better drainage.	21
Figure 3.13	2"x4" top plates are held flush to the inside edge of the wall and help transfer truss loads.	21
Figure 3.14	Walls can be carried by four people.	21
Figure 3.15	The plywood perimeter shims fastened to the subfloor in the foreground keep these walls level.	21
Figure 3.16	The south wall is plumbed with two adjustable braces.	21
Figure 3.17	Sections of the octagon that face the entry wall are faced with plywood sheathing.	21
Figure 3.18	Trim will cover the exterior corners.	22
Figure 3.19	Buckle bracing ties the corners together and supports the point loads from the hip trusses.	22
Figure 3.20	Gussets cut from scraps tie the octagon corners together.	22
Figure 3.21	The exterior trim, including windows and corners, should be sealed with "outside closure" weather stripping	22
Figure 3.22	Long-term exposure of the wood roof framing to the elements can result in moisture damage.	22
Figure 3.23	Snap centerlines through the octagon that represent the north-south axis and east-west axis.	23
Figure 3.24	Reference inside plate lines from the center point on the floor.	23



Figure 3.25	From the center of the wall, measure left and right the distance required to determine the total inside wall length.	23
Figure 3.26	The plate lines for the initial four outside walls must be parallel to the main north-south and east-west control lines.	23
Figure 3.27	Snap the north, south, east and west wall plate lines first	23
Figure 3.28	As a final step, lines should also be snapped from each outside corner.	23
Figure 4.1	Both hips and all the jack trusses for one roof section were assembled for a test fit	27
Figure 4.2	The timber spreader is centered on the floor layout to support the temporary post.	27
Figure 4.3	The floor layout is transferred to the spreader.	27
Figure 4.4	The primary tension hub has saddles to support the hip trusses on the bottom during assembly.	27
Figure 4.5	The post is braced in two directions and the scaffold is set to help erect the eight hips.	28
Figure 4.6	Plumbing and bracing the first four hips.	28
Figure 4.7	As seen from below, a $\frac{1}{8}$ " to $\frac{1}{4}$ " space should be left between the hip and the backstop in the hub	28
Figure 4.8	Slight discrepancies in wall framing will affect where the hip lands at the corner.	28
Figure 4.9	The vertical laser beam references off the corner to corner layout lines on the floor	28
Figure 4.10	Shims are used to fill the space between backstop and truss in the top hub.. . . .	28
Figure 4.11	Tensioning is done in a diagonal pattern until the back of the truss contacts the backstop in the hub.	29
Figure 4.12	Plywood gussets are sistered on either side of the main roof truss tails to carry the entry rafters.	29
Figure 4.13	Any jack truss tails that extend pass the hips can be marked with a straight edge and trimmed.	29
Figure 4.14	Jack trusses can be installed once the hips are set and the top hub is installed.	29
Figure 4.15	Hip strapping is hammered flat over the hip truss and bent to lap down over back edge of the corner studs.	29
Figure 4.16	Ties should extend to the metal top plate for secure anchoring.	29
Figure 4.17	House wrap is cut in lengths that will reach over the individual facets	30
Figure 4.18	The starting edge of the first course of house wrap is flush with the blocking.	30
Figure 4.19	The roof must stay as dry as possible to protect the truss framing before the foam is applied.. . . .	30
Figure 4.20	Where the jack truss and hip truss furring strips intersect, the jack truss furring must be cut short.	30
Figure 4.21	The first course of peel-and-stick membrane starts at the bottom and is lapped "shingle style"	30
Figure 4.22	In the prototype, the dormer was held back from the edge of the roof.	30
Figure 4.23	The two valley flashings meet at the peak in a woven fashion.	31
Figure 4.24	The membrane reaches to the peak.	31
Figure 4.25	Metal roofing should run as close to the hips as possible.	31
Figure 4.26	Roof penetrations should be sealed with flexible boots and silicone, as for this plumbing vent.	31
Figure 4.27	Roof penetrations should be sealed with flexible boots and silicone	31
Figure 4.28	Seen from the bottom, the roof circle is cut and stitched to the pitch of the roof.	32
Figure 4.29	A conventional chimney cap covers the inside pipe.	32
Figure 4.30	The compressible foam weather strip is also used down both sides of every hip cap	32
Figure 4.31	A ring of compressible gasket spans the vent to the roof.	32
Figure 4.32	A dab of silicone can be applied to the exposed fasteners for additional protection.	32
Figure 4.33	The vent space blocking is flush with the metal cladding	32
Figure 5.1	The first "flash coat" of foam is applied over all interior surfaces to insulate and seal the structure for heating.	34
Figure 5.2	It is easier to install the chimney before the foam is sprayed.	34
Figure 5.3	The structural screws (or plates) that anchor jack trusses to hips must be in place before spray foaming	34
Figure 5.4	The bracing must remain in place until the interior has been coated with several lifts of foam.	36
Figure 5.5	The center of the roof, where the upper hub and trusses meet, must be well-insulated.	36
Figure 5.6	The carpenter on the right is using a straightedge to check for high spots and overspray.	36
Figure 5.7	As seen on the left, horizontal blocking should be added to fully support the short edges of the ceiling sheets	36
Figure 5.8	The two middle runs of furring straddle the hub and clear the saddles that carry the hips	36
Figure 5.9	"Outside closure" weather stripping must be added behind the corner trim.	36
Figure 5.10	Sheathing the ceilings in the bedroom areas before framing the walls simplifies both operations	37
Figure 5.11	Floor layout is transferred to the ceilings and then the ceiling track is installed	37
Figure 5.12	A control line is snapped for the center starter course to keep the rows straight	37
Figure 5.13	The end joints of the ceiling panels must be supported both in the field and along the edges	37
Figure 5.14	The plate lines are snapped in place	37
Figure 5.15	Kitchen sidewalls must be laid out square and parallel to fit the counter top	37
Figure 5.16	Once one side of a wall is covered in plywood, it can be soundproofed with friction-fit soundproof batting	38
Figure 5.17	The batten strips should miss all ceiling penetrations, such as the can lights shown	38



Figure 5.18	The flooring is modular for ease of application in the octagonal floor plan	38
Figure 5.19	The cement board hearth extends in front of the stove for fire protection.	38
Figure 5.20	The completed kitchen.. . . .	38
Figure 6.1	The HRV unit in the utility room.	41
Figure 6.2	HRV supply air ducting in the pantry.	41
Figure 6.3	A long pilot bit is used in the hole saw to locate the hole center on the inside.	41
Figure 6.4	Holes should be located at a height that seals well to the contours of the metal wall cladding.	41
Figure 6.5	Duct runs are tight.	41
Figure 6.6	A 7" flex duct insulation jacket being slipped over 6" hard pipe.	41
Figure 6.7	Supply air is delivered through the ceilings	42
Figure 6.8	The exhaust diffuser in the bathroom is in the ceiling of the toilet alcove.	42
Figure 6.9	A low-sone bathroom fan provides spot ventilation.	42
Figure 6.10	The HRV condensate is plumbed into the waste pipe above the macerating pump.	42
Figure 6.11	The makeup-air exits mid-wall in the pantry.	42
Figure 6.12	A 6" makeup-air duct is installed behind the refrigerator.	42
Figure 6.13	A soffit is installed in the pantry where the HRV supply air and the passive makeup-air vent exit out the exterior wall.	43
Figure 6.14	Modern take on the traditional "qingok".	43
Figure 6.15	Exterior view of where the supply air for the HRV (top) and the passive makeup-air vent exit the wall (bottom).	43
Figure 6.16	Finished dryer vent opening.	43
Figure 6.17	All waste plumbing must enter the macerating pump.	45
Figure 6.18	The sink drain enters the pump from the left side.	45
Figure 6.19	The washer drain line runs behind the raised tub platform.	45
Figure 6.20	The tube is raised so the tub drain will to meet the toilet drain.	45
Figure 6.21	Vanity supply and waste water run along the exterior wall to the utility room.	45
Figure 6.22	The vanity plumbing lines are covered by a half wall.	45
Figure 6.23	Washer vent.	46
Figure 6.24	The washer vent and shower/toilet/vanity vent meet towards the center of the roof before exiting.	46
Figure 6.25	An air admittance valve is used to vent the sink to avoid venting through the interior walls.	46
Figure 6.26	The domestic water tank has a site-built surround that will catch any water.	46
Figure 6.27	The water tank fill and vent pipes are located in the wall to the right of the electrical service.	46
Figure 6.28	The domestic water lines are insulated to prevent condensation from forming.	46
Figure 6.29	The Unistrut® used to support the panel and mast is fastened through the siding.	47
Figure 6.30	The feeder wire is protected by a section of angle iron cut into the foam.	47
Figure 6.31	Can lights are marked on the floor using a screw covered with red tape.	48
Figure 6.32	Weather-resistant exterior outlets.	48
Figure 6.33	All the can lights should be laid out so they lights do not interfere either with the batten strips	48



The Quinhagak Project

A 2009 survey of the homes in Quinhagak, Alaska, showed that many were unhealthy: mold was visibly present in the walls, high humidity and poor indoor air quality were noted, and many houses exhibited structural deterioration. Community leaders and the local housing authority determined that 55 of the homes in this village of approximately 700 residents must be replaced. This presented a real challenge to the community.

In late 2009, the Native Village of Kwinhagak and the NVK Housing Authority approached CCHRC to work with the residents of Quinhagak to design an energy-efficient, cost-effective and healthy home. Subsequently the Rural Alaska Community Action Program (RurAL CAP) awarded CCHRC a grant to incorporate elements of the USDA Mutual Self-Help Housing program in this effort.



History

An inclusive approach to designing and building in rural Alaska was pioneered by CCHRC and members of the community of Anaktuvuk Pass, Alaska, the summer of 2008. Following design development and review by the community members and partners, the first prototype home was built with a local workforce and housing authority in 2009. The construction cost reduction, extreme energy efficiency and livability of the home have been remarkably successful. As was the case in Anaktuvuk Pass, Quinhagak residents had specific needs and cultural expectations that are reflected in the design. Combining what CCHRC has called “indigenous wisdom with twenty-first century technology” a refreshing new direction to designing and building in Alaska’s isolated and diverse communities has been initiated.

Both the Anaktuvuk and Quinhagak homes were built collaboratively—CCHRC staff worked side-by-side with local village residents. What has grown from this dynamic has proven to be of mutual benefit and far-reaching. The CCHRC team has gained invaluable knowledge from the local people who themselves have developed adaptive techniques and an intimate understanding of physical conditions that can only be gained by living in a challenging environment for many years. In turn, the CCHRC team shares a knowledge base that is focused on innovations in building science and energy-efficient construction practices derived from its continuously evolving research as well as its relationships with a resource pool of like-minded industry and professional communities.



Rural Alaska faces unique challenges. Most rural villages in the state do not have road access. When building, this means that all materials must be shipped by barge or air freight. Freight and shipping often adds up to 40% of the cost of construction in rural Alaska. By comparison, the same home built in Anchorage for \$180,000 would cost approximately \$250,000 off the road system, especially if the materials in the design did not take weight and volume into consideration (which is often the case). If skilled labor is not available locally, those workers move to the village temporarily, where they receive per diem, transportation and lodging costs in addition to wages. In 2008, when the last 1,200 sq. ft. home was built in Quinhagak, the building cost \$430,000. During that time a similar new home for Anaktuvuk Pass was quoted at \$750,000.

There are several key goals of the Sustainable Northern Communities prototype home:

- to design a home that uses materials that substantially reduce the cost of shipping;
- to produce a home that is healthy to live in;
- to design a home that honors the cultural heritage of the community and suits the lifestyle of the inhabitants;
- to build a home that is at least 50% more energy-efficient than current housing stock; and
- to build this home for close to half the cost of current new construction.

Quinhagak Prototype Home

The first design charrette was held in the village in November 2009, and several more planning sessions over the ensuing months were held in Quinhagak to guide the design process. A design for the prototype home was developed by the following March. NVK Housing Authority, village residents and CCHRC staff all worked together to finalize the design, select and order the proper materials and choose the home site. The Quinhagak Prototype Home was built in October and November 2010.

The Quinhagak Prototype Home has been designed for the environment of the Yukon-Kuskokwim Delta of Alaska, where wind-driven rain and snow are common causes of building failure. A limited cash economy and mostly seasonal employment opportunities demanded the home have very low operating costs and be quickly and economically constructed.

Features of the home include:

- light gauge steel wall framing members and a complete monolithic thermal envelope, employing high-density spray-foam insulation in the floor, walls and roof;
- an octagonal shape that significantly reduces the amount of snow drift and surface area in relation to volume;
- a design that is informed by traditional knowledge of building in the area, including elements of open design and large, insulated and functional “arctic entry;”
- a complete thermal envelope with high insulated value ;
- simple and efficient heating and ventilation systems ; and
- estimated energy use less than 200 gallons of fuel oil a year.

Perhaps even more importantly, both homes have been built by CCHRC instructors with local village residents whose new skills will be put to use in future home building projects. Besides providing well-paying jobs to local residents, this will drastically reduce the cost of construction.

The Quinhagak home was built in seven weeks. A family of five moved into the prototype in 2011. Sensors in the home collected data on fuel usage, temperature, indoor air quality, water infiltration and electrical usage for the first two years of occupancy. The results from the first two years of data collection can be found on the CCHRC website at http://cchrc.org/docs/reports/NREL_DEC2011_Quinhagak.pdf In 2012 the community Tribe proceeded with the construction of four additional units. A new foundation strategy was implemented for the second phase of units. The updated



foundation module is outlined in this Second Edition of the Quinhagak Construction Manual. Two CCHRC instructors supervised the new foundation module over the course of two weeks. The second generation homes were built by an all-local crew in fall/winter 2012.

House Plans and Manual

Please note that plans and a full materials list for the design are available.

In this manual, you will find instructions for the octagonal prototype home on an adjustable above-grade foundation. The First Edition Construction Manual, with the on-grade foundation module on a built-up gravel pad, is available through CCHRC upon request. This design is most appropriate for experienced builders.



Site Preparation

Overview

The Quinhagak prototype home is sited on a built-up gravel pad over a geotextile fabric placed on native soils. The finished pad on the prototype home site measured 88' x 64' and proved adequate. The pad should be large enough to accommodate the building footprint with enough space remaining on all sides to safely erect scaffolding, protect the house from perimeter erosion, and allow comfortable walk-up access to the entry without crowding the pad edges. Ideally, the finished pad should be within two inches of level and raked smooth. It is preferable to let the pad sit one winter before building. If the pad is new, a compactor should be used during leveling, in order to reduce future settling. Discrepancies in pad height greater than two inches will require more foam to level the floor system and more edge fill later to cover that foam. It is essential that the finished grade allow drainage away from the building in all directions.

Sequence and Considerations

1. Shoot grades on existing pad, compact and level as necessary.
2. Using a compass, establish a north-south line in a place where either end will be visible beyond the house foundation to help orient the floor system.



Figure 1.1 The finished pad dimensions measure 88' x 64' and are adequate to protect the building footprint against perimeter erosion. Enough space was available in front for easy entry access and on the other sides for some storage. A compactor was available to help minimize future settling.



Figure 1.2 A laser level set up nearby allows the carpenter to check grade between leveling passes. The equipment shown in the picture was available in this village and is oversized. Smaller equipment, such as a Bobcat®, would be better suited for site leveling.



Figure 1.3 Building placement and site orientation are critical. Knowing the local declination to true south will optimize passive solar gain and daylighting.



Figure 1.4 Determine the north-south axis. The three living room windows should face within a few degrees of true south to maximize solar gain.



Foundation & Floor System

A Note on the Second Edition

The first Quinhagak Prototype Home was built on an Insulated Raft Foundation that sat directly on the top of the gravel pad. The First Edition of the Quinhagak Construction Manual outlines the step-by-step construction of that foundation and is available to the public. In this Second Addition of the construction manual, an adjustable raised foundation is incorporated. No other aspect of the design has changed. For this reason, photos of later stages of construction may be from the original prototype.

Overview

Discontinuous permafrost can and will destroy conventional foundations. Heat transfer from the building to the thaw unstable soil underneath can cause it to heave and slump, compromising the structure and leading to premature building failure. Often, the most common and economical solution is to isolate the building from the ground by raising it several feet using post and pad construction. As unstable soils typically are subject to some movement, the foundation supporting the raised structure must have a means for adjustment. The Quinhagak foundation uses commercially available Simpson hardware consisting of adjustable post bases, which are set in treated wood bearing pads in order to provide adjustment to the bearing points under the structure. The foundation described below is a rigid wood frame diaphragm designed to thermally isolate the building from the soil, span inevitable movement, and have the ability to be leveled over time.

Once the roof is in place and the entire structure is dried in, then soy-based spray-foam insulation is applied between the floor joists. After the insulation is applied, the framing is covered by a plywood subfloor. Demilec's HEATLOC SOY® is a high-density closed cell, 2 lb per-cubic-foot insulation that is resistant to both liquid water and water vapor infiltration and provides additional rigidity to the building shell. Other foams may be appropriate as well, but properties of other products should be similar to the Demilec product.

Sequence and Considerations

In order to take advantage of passive solar gain, determine the house location and orientation on the pad using the previously established north-south line as a reference. As shown in Figure 2.1, an east-west line has also been established for reference in front of the due south face. Establishing an accurate outline of the octagon on the ground will save labor in shooting grades and setting the pads. One way to draw the octagon would be to draw a square first that is roughly 33'-9" on each side and then draw the remaining four sides of the octagon inside the square. The building perimeter can be drawn in the gravel or spray paint can be used to establish the rough perimeter outline for the octagon and the entryway.

Use a builder's level to determine the highest and lowest pad locations on the site. Ideally, there should be no more than 2 inches height variation across the site. Assuming a height discrepancy of only a few inches between the highest and lowest pad, it is generally easier if all pads are set to the height of the lowest pad. The gravel around the higher pads will need to be excavated slightly to bring them to the same level as the lowest (reference) pad.



The pads: The octagon pads are constructed of two layers of treated 4x12 timbers, with three timbers side-by-side per layer. The two layers are oriented perpendicular to one another and fastened together with 6" timber screws. Care should be taken that the pads are assembled square. Completed pad dimensions will be approximately 34 1/2" x 34 1/2" x 7" thick (See Figure 2.2)

A total of 13 pads will be required to support the entire structure including the octagon corners (8), floor beams (2), and entryway corners (3). (See Figure 2.12)

REFERENCE LINES:

Make a plywood template as shown in figure 2.1 to draw reference lines on the top surface of each pad. Legs 30 3/4" & Corner to Point 30 3/4", The reference lines on the finished pad should look like figure 2.3. These reference lines will be used in combination with string lines to properly orient the pads so that they are diagonally centered in relation to the octagon corners, and to center the 6x6 supporting timber post on the pad.

PAD ORIENTATION:

The first pads to be set are those four octagon perimeter pads, which will be required to support the center floor rectangle of the octagon. See figure 2.8. All other pads will be set using these four pads as a reference. Later, all floor framing will reference off of the floor rectangle framing that is supported by the first four pads. The simplest way to set and properly orient the first four pads is to use string lines. Using the reference lines drawn on the pads in figure 2.3, set a screw or nail on the point representing the octagon corner of each pad and stretch the strings in the pattern as shown in figure 2.8. The pads can be squared to one another using the dimensions supplied below, and in figure 2.8

The distance between opposing octagon faces (ie - North to South) is 33'- 9 9/16"

The distance between opposing corners is 36' - 7"

The legs of an equilateral triangle with a 14' hypotenuse are 9' - 10 13/16"

The corners are 14 feet apart.

Once the first four pads have been leveled and properly oriented, the remaining 4 octagon perimeter pads can be set in place using the first four pads as a reference. The two pads that carry the beams supporting the center of the floor can now be set as well. figure 2.9

It will be easiest to fine-tune the remaining 3 pads supporting the entryway corners once all of the octagon floor perimeter beams are set and braced in place. At that point, measurements taken from the completed octagon perimeter beam framing can be used to set the entry pads.

When all 10 octagon pads are set and leveled (including the 2 pads supporting the floor beams in the center), the 6x6 treated timbers can be drilled to receive saddle brackets and then centered and fastened to the pads using the layout lines on the pads. A centerline drawn around the 6x6 timber is used to center the timber on the centerline of the pad. figure 2.5 & 2.6.

Distance between holes on saddles for the 8 6x6 timbers carrying the octagons is 19" (9 1/2" each side of center). Holes are centered in the middle of the 6x6 @ 2 3/4"

2.11

FLOOR FRAMING: After the 10 6x6 treated timbers supporting the octagon are set in place, the saddles can be installed and leveled to receive the floor beam framing. The first step in the floor framing is to



build the center rectangular portion of the octagon, measure diagonals, and brace it square as shown in figure 2.9

Once the center floor rectangle is framed and braced, the remaining 6 perimeter beams needed to complete the octagon can be fastened in place. The 6 perimeter beams are set by measuring from the perimeter rectangle. Once the octagon perimeter is framed, string lines running across all corners can be used in combination with diagonal measurements to ensure the octagon floor is symmetrical. All string lines should cross at the same point in the center of the floor. See Figure 2.20

After the octagon floor beams are squared and braced, the three entry pads and entry perimeter beam framing can be installed, using measurements taken from the octagon beam framing as a reference. The middle pad in the entry must be in line with the corresponding octagon corners. This will ensure that the entry hip rafter will carry through to the octagon hip truss in a straight line. Figure 2.19

Once all beam framing is completed, the joist hangers and floor joists can be nailed in place.

ADDITIONAL NOTES ON FLOOR FRAMING:

Space the intermediate entry beam double saddle hanger as far right of the octagon corner as the post base bracket will allow.

Use the single LVL hanger to attach the south gable wall entryway double LVLS. Hang the inner LVL with the single hanger and fasten the outer LVL to it. The single hanger is needed to allow room to nail both flanges securely. If a double hanger were used, the left side flange of a double hanger would extend too far past the octagon corner to be properly attached. Figures 2.13 & 2.14

The four joists that land next to the octagon corners will not be able to accept a hanger due to their proximity to the corner. Instead, the web area will need to be filled on both sides of each joist and then the joist can be fastened to the perimeter beam with structural screws. Figure 2.17

There is no center joist, however, joist layout is taken from the center point of the floor and joists are spaced 2 foot on center in either direction of the centerline Figure 2.23 All joist layout is 2 foot on center and the first joists to the left and right of the centerline can be used to provide layout for the rest of the floor framing. 3/8" plywood sheathing will need to be cut and fitted against all the bottom flanges of the joists to provide backing for the spray foam insulation which will be applied from above once the structure is safely dried in.

Subfloor installation: Subfloor plywood starts parallel to the north wall, and the edge of the first sheet splits on the first joist to the northwest of the core rectangle Figure 2.23.

NOTE: The spray foam in between the floor joists must be applied out of the weather in controlled, dry conditions. The safest way to ensure that the floor can be dried and will stay dry after it has been insulated, is to spray the floor foam once the entire structure is dried in. Once the structure is safe from the elements, then the floor, ceiling, and walls can be sprayed at the same time. In order to spray the floor at this later time, the subfloor plywood is initially installed with a minimum number of screws to allow it to be taken up again when the time comes to insulate. The only part of the subfloor that can be glued and nailed in place permanently is roughly the first foot around the perimeter which includes the inaccessible portion under the exterior walls. When the time comes to insulate the floor, a chalk line can be snapped roughly 9 inches in from the inside edge of the exterior wall plates. A skill saw with the blade set to the thickness of the subfloor is then used to cut around the perimeter chalk line so the center of the subfloor can be removed in order to apply the foam. As the sheets of subfloor are removed, they should be labeled sequentially so that they can be reinstalled in the same manner once the floor has been insulated.



Fig 2.1 A plywood template makes laying out reference lines on the pads much easier. The point in the center of the template represents the location of an octagon corner.

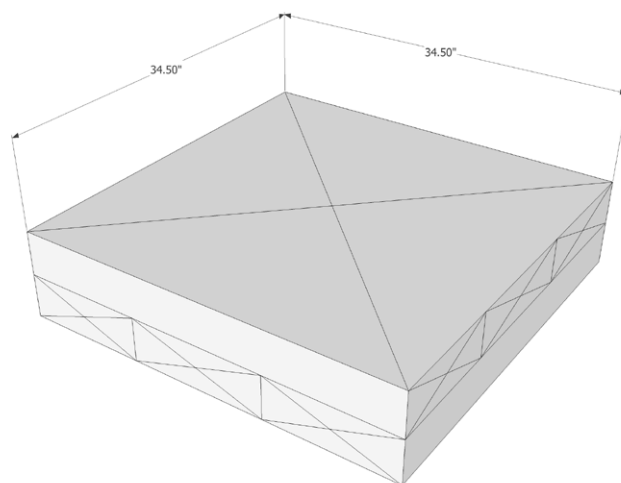


Fig 2.2 Dimensioned drawing of pad

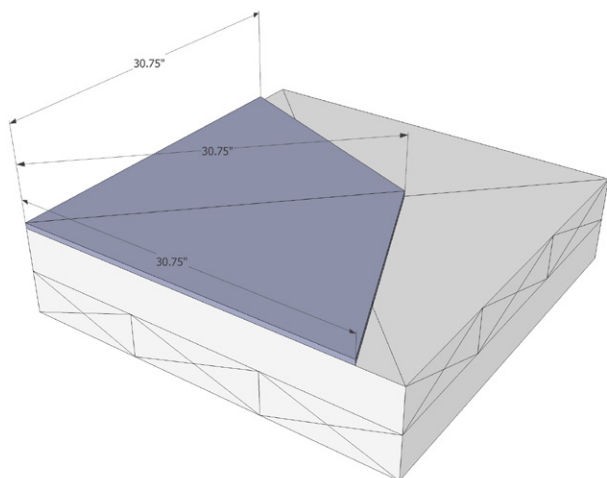


Fig 2.3 Dimensioned drawing of template

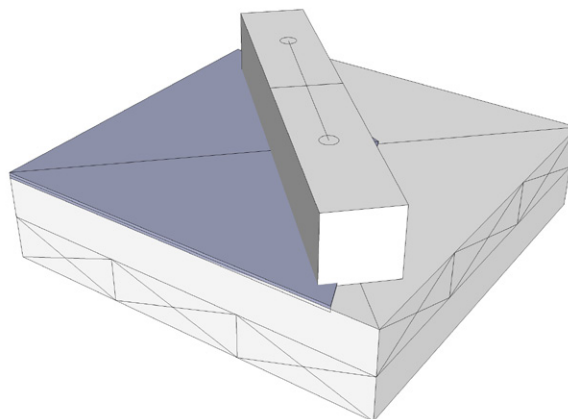


Fig 2.4 Drawing of 6x6



Fig 2.5 Drilling $\frac{3}{4}$ " holes in a 6x6 to accept the $\frac{3}{4}$ " threaded rod on the saddle bracket. Note that a speed square is being used to help keep the auger bit plumb.



Fig 2.6 Closeup of how the pad and 6x6 and support saddles are oriented in relation to an octagon corner. As shown, the 6x6 should be centered diagonally in one direction on the pad, while the octagon corner should be centered diagonally in the other. The two saddles carrying the beams should be equally spaced from the octagon corner. The layout lines on both the pad and the 6x6 will help to make this arrangement accurate.

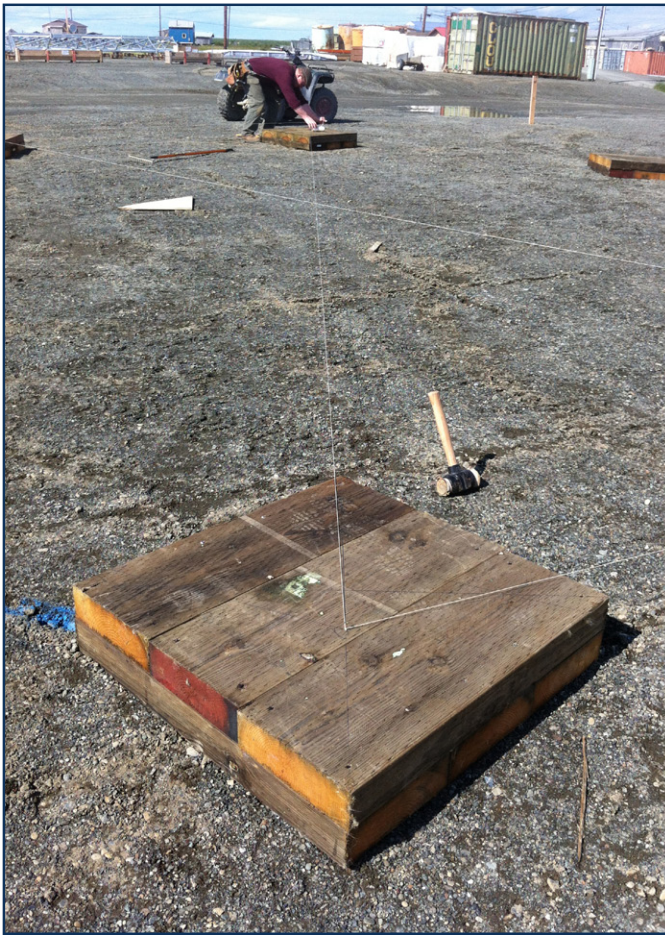


Fig. 2.7 The diagonal string lines are used to orient the pads.

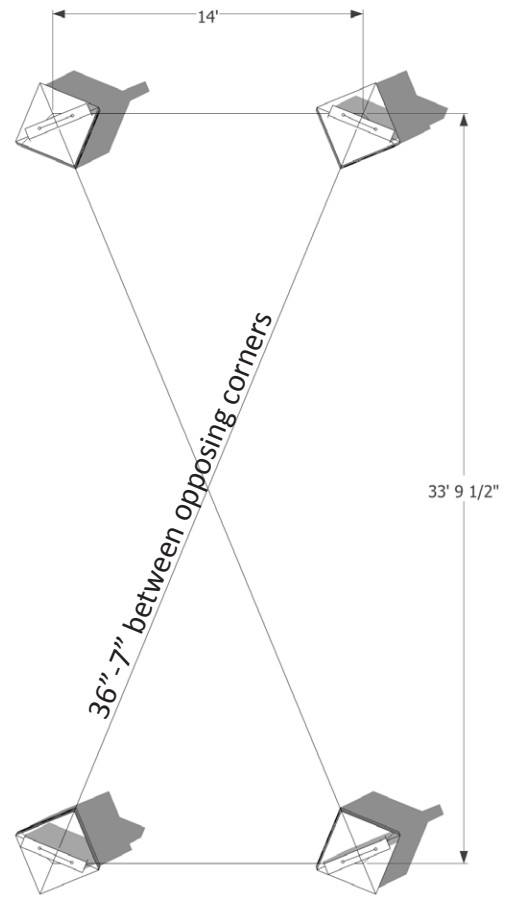


Fig 2.8 Setting the first four pads and using string lines to orient the pads in relation to the center and corners of the octagon. Reference dimensions are provided to ensure the first four pads are properly oriented and installed to produce a center floor rectangle. These dimensions can also be used to help orient the other octagon pads.



Fig. 2.9 The center rectangle of the octagon is braced square and becomes the reference point for installing and squaring the remaining 6 sides of the octagon. Note the two string lines that run the length of both the center beams. When the rectangle is being braced, the string lines ensure that the center beams are also braced straight as well as square.



Fig 2.10 Once the octagon beam framing is complete, strings can be run connecting opposite octagon corners to ensure the structure is symmetrical. It is critical that all string lines cross at the same point in the center of the floor as this will allow the corners and center of the floor framing to be used as accurate reference points for the roof framing.



Fig 2.11 Close-up of the pad arrangement at the corner of the octagon.

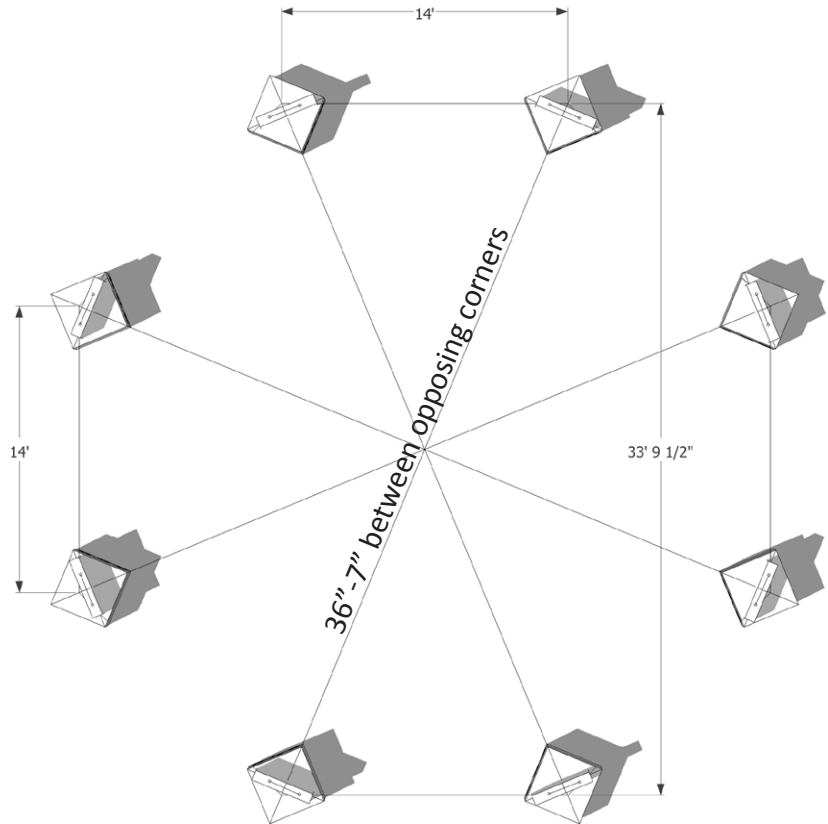


Fig 2.12 Setting the first four pads and using string lines to orient the pads in relation to the center and corners of the octagon. Reference dimensions are provided to insure the first four pads are installed square. These dimensions can also be used on the other octagon pads.



Fig 2.13 The first two beams (#1 and 2) carrying the floor are nailed together and then dropped into the double hanger. The third beam (#3) is then nailed alongside the first two on the face furthest away from the corner. The third beam is cut slightly short and rabbeted along its face to make room for the hanger and the hanger nails.



Fig. 2.14 The center beams carrying the floor are built up with 3 versalams nailed together. A double joist hanger is used to support the beams where they meet the outside corner. Be sure to hold the beams far enough away from the corner so that the nailing flange from the hanger doesn't extend into the corner. Also Shown in previous figure 2.13



Fig 2.15 Joists are laid out 2 foot on center using the centerline of the floor, rather than pulling edge layout from an outside starting point. This keeps the joist arrangement symmetrical and simplifies both the layout and cutting joists to length. In relation to the centerline of the floor, the joist layout falls 1 foot to the left and right of the centerline.



Fig 2.16 A close-up of the area where the entry wall beam meets the octagon corner. The entry beam is hung off of the octagon beam by a single width hanger as the flanges on the left side of a typical double width hanger would extend too far past the corner to allow for proper fastening. The octagon corner will not interfere nailing flange on a single width hanger if the hanger is attached to support the inner of the two entry wall beams. The outer beam can be face nailed to the inner beam, once the inner beam is fastened in place in the hanger.



Fig 2.17 There are four joists that fall too close to an inside octagon corner to be supported by a skewed hanger. Instead, the joists can be cut at 45 degrees and accurately fitted in place. The web space on either side of the joist is filled with solid blocking, thereby allowing the joist to be fastened to the face of the beam with 3 structural screws (ie Timberlok or Headlok).



Fig 2.18 3/8" CDX plywood is cut and dropped into the joist bays and rests on top of the lip created by the bottom flange of the I joists. Once the plywood is set in place, it can be permanently secured with nails from a finish gun.



Figure 2.19 The middle entry corner must line up with its corresponding octagon corner. Thus the entry hip rafter will carry through to the hip truss in a straight line.



Figure 2.20 Framing and squaring the floor system using the dimensions and illustrations presented in this manual will make finding the center of the floor easier when the time comes to set the post that supports the tension hub. Be sure to verify that the octagon corners project through the center of the floor with string lines. If all strings meet in the center during the floor framing stage, then finding the center of the floor once the floor is sheathed is just a matter of snapping chalk lines through opposing corners.



Fig 2.21 A cut line is snapped approximately 1 foot in from the exterior walls to allow removal of the subfloor and access to the joists.



Fig 2.22 Once the floor has been sprayed, the subfloor plywood is installed permanently. Pieces should be numbered sequentially when they are removed to simplify their reinstallation.

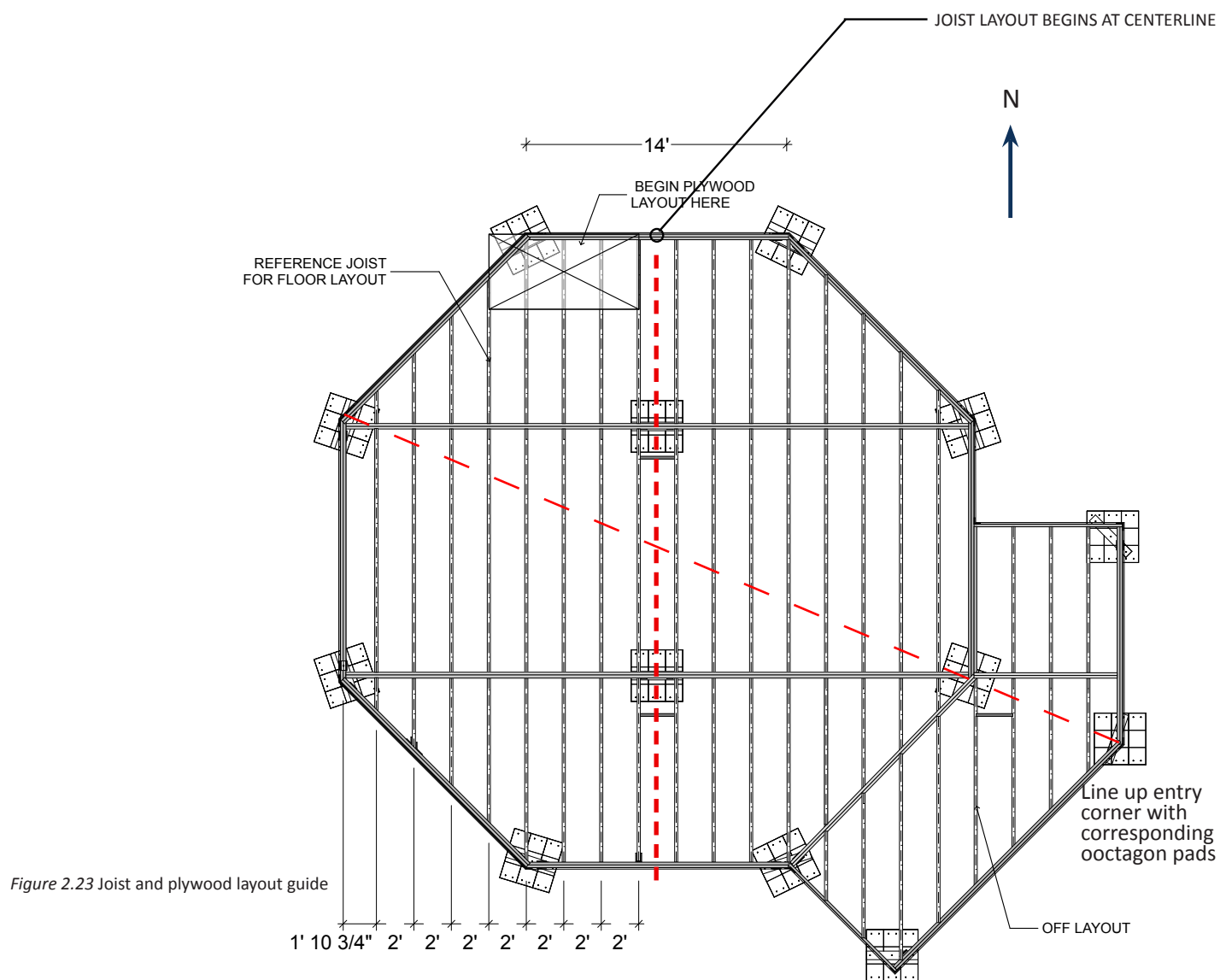


Figure 2.23 Joist and plywood layout guide



Walls

Overview

The exterior walls are composed primarily of light-gauge steel components and are constructed in a thermal-break-offset-wall design which reduces conductive heat losses and is moisture-resistant. Steel studs were chosen to reduce shipping costs: they are light, nest together, and do not warp or degrade in the weather. Steel does conduct heat much more than wood, however, which makes the thermal break offset very important. All the components needed to build the exterior portion of the wall, including the studs, headers, and plates, can be precut and assembled in advance. To simplify the process, the walls, including the windows and siding, are built on an assembly table. For improved weather resistance in extreme environments, metal roofing is used as exterior siding. The finished walls are light enough that each section can be carried and raised by four people. Once all walls are raised and the roof is in place, the entire shell can be insulated from the inside with the same high density spray foam insulation used in the floor. Half-inch A/C plywood is used to cover the interior wall surfaces. The plywood provides the necessary structural rigidity and is coated with a base layer of fire-proof paint to meet fire codes (see “Interior Insulation and Finishes”). The overall wall thickness is approximately 8” and yields an R-value of 40+.

Sequence and Considerations

Wall Layout

1. The exterior walls are set to inside plate lines, as is typical. With the floor deck completely sheathed and trimmed, snap centerlines through the octagon that represent the north-south axis and east-west axis (Figure 3.23). These lines will produce a center point for the floor and will be used to reference inside plate lines for exterior wall layout as well interior partitions later in construction. (Figures 3.1 and 3.24).
2. The distance from the center point to the center of the inside plate lines for the north, south, east, and west wall plates can now be determined (Figure 3.24). From the center of each of the four walls, measure left and right the distance required to determine the total inside wall length (Figure 3.25). The plate lines for the four outside walls must be parallel to the main north-south and east-west control lines which determine the center of the floor and also provide square reference points (Figure 3.26).
3. Once the north, south, east, and west wall plate lines have been snapped, the remaining four walls (NE, NW, SE, SW) can be snapped between them (Figure 3.27).
4. As a final step, lines should also be snapped from each outside corner on the octagon (where the inside plate lines of two walls meet), through the center point to the opposite corner (Figure 3.28). These lines will be used later with a plumb bob or laser to set the hip trusses accurately on the top plates.



Figure 3.1 The main east-west control line is being snapped through the center. It is square to the north-south line, which was snapped first.

Building Walls

1. It is very important that the wall plates be level so that the wall and roof system can be built plumb and square. When foam is sprayed under the joists, curing and expansion will inevitably cause some movement. Each of the eight octagon corners and the entry corners should be shot for level and the walls should be shimmed level with the highest point in the exterior wall perimeter (Figure 3.2). Plywood shims of varying thicknesses can be cut to the width of the plates and screwed to the subfloor to support the walls as necessary, both in the corners and under the rest of the wall.
2. The stud length in the prototype home is 8 feet. A 16-foot, 1½"x4" metal stud can be cut in half to produce two wall studs. A metal cutting chop saw with an abrasive blade and a site-built cutting bench will greatly speed up the cutting process for all the wall components. **IMPORTANT: Metal studs are a full 4" thick (dimensional lumber is 3½"). This will affect window jamb extensions and other aspects of construction.**
3. An assembly table insures accurate construction. It must be built square, the pony walls braced plumb, and the floor shimmed level. The table floor dimensions are 8'x16' and the pony walls are 16 inches high. The low pony wall allows carpenters to step over studs in the wall to easily attach fasteners from all directions (see Figure 3.7).
4. Since all eight of the main octagon walls are the same length (14 feet), stop blocks can be screwed onto the table to guarantee that each wall will be cut square during construction (Figure 3.5).
5. Before any wall framing takes place, two of the adjacent layout lines (established in Step 4) which represent the centerlines of the hips, can be used as reference points to test-assemble a roof section on the floor deck (Figure 3.3). Also see Step 2 in the roof framing chapter.
6. Stud layout is 2 feet on center, and to ensure consistency, is done from left to right in all walls. Layout starts at the short point on the inside of the wall, but the end studs are held back from the corner 1 inch to allow enough room for spray foam to be applied in this area (Figure 3.5).



7. To create the offset wall, a length of $1\frac{1}{2}$ "x $1\frac{1}{2}$ " light gauge angle (also referred to as a "shiny 90") is used to attach the metal siding to the wall exterior. The angle is held away from the stud wall using vinyl or plastic spacers cut out of a 4'x8' sheet of garden lattice. In the prototype home, the space between the stud wall and the light gauge angle is 4 inches (Figure 3.6). As a result, the space between the flanges on the double-flanged windows must also be 4 inches in order for the window to be properly installed in the wall (Figure 3.8).
8. A jig (made using stop blocks) helps locate the three spacers and the angle in relation to the stud and ensures that all wall stud assemblies are identical (Figure 3.4).
9. Including the studs and the sheeting, the overall wall thickness is 8 inches. An 8-inch wall filled with high-density spray-foam produces an R-value of between 40 and 50, considered adequate for the Yukon-Kuskokwim Delta. In future installations of this wall system, the plastic spacer can be cut to varying thicknesses, producing thicker or thinner walls. However, to maintain a thermal break at least a 2-inch space is desired between the studs and the offset light gauge angle.
10. The light gauge metal angle that supports the exterior siding extends past the top and bottom plates of the stud wall in both directions. On the bottom, the angle extends down an additional $10\frac{1}{2}$ inches which includes the subfloor, the rim joist, and the 4 inches of spray foam under the floor (Figure 3.5). On the top, the angle extends past the metal top track $10\frac{1}{2}$ inches to cover the 2"x4" top plate and the exposed energy heel on the truss. The distance the angle extends in both directions should be verified with each new floor to take into account any variations in floor or truss thickness.
11. With the two outer studs and the top and bottom tracks attached, the remaining in-fill framing can be done (Figures 3.5 and 3.7). As mentioned in step 6 and shown in Figure 3.6, the end studs are held in from the corner 1 inch to allow the spray foam to be applied into the corner once the walls are tied together.
12. Window headers are built in advance and the window openings are framed a half-inch oversize in both directions. This leaves one-quarter inch of space on all sides when the window is installed. The headers are constructed in an open design to allow the spray foam to reach everywhere in this area (Figure 3.10).
13. In the south wall, three windows are set close together. The galvanized angle is attached directly to the window flanges (Figures 3.8 and 3.10).
14. The siding starts flush with the bottom of the offset light gauge angle, in this case $10\frac{1}{2}$ " to cover the floor and foundation foam (Figure 3.12). Each upper course of siding overlaps the course below it on the wall. Each subsequent course of siding overlaps the previous course, creating a "shingle style" drainage plane.
15. The windows are sealed around the vertical flanges with foam weather stripping covered with a bead of caulking on both front and back (Figure 3.12). The weather stripping ("wiggle mold") is available in two variations: "inside closure" or "outside closure," and is contoured to match the corrugations in the siding. For the windows, the "inside closure" is used to seal the space between the window flange and the siding. The "outside closure" is used to seal between the corner trim and window trim and the siding. On the top and bottom, the window flanges can be caulked directly to the siding. A slot is cut in the metal siding so that it can tuck behind the bottom flange of the window, creating a shingle style drainage plane. The edges of the slot are sealed with caulking from both sides. The exposed bottom flange is hidden by the window trim which can be added during wall assembly or when the completed wall is raised (Figure 3.18).
16. Once the wall is completed, a wood 2"x4" plate is added to the top of the wall. This plate provides a nailing surface for the wooden trusses and helps transfer point loads from the individual trusses to the studs in the wall (Figure 3.13).
17. The finished walls are light enough to be carried and raised by four people, as in Figure 3.14. All necessary floor shims must be in place before the walls are raised (see step 1 and Figure 3.15).
18. Each of the walls is held plumb with two adjustable braces ("turnbuckle form aligners"), as in Figure 3.16.
19. The portions of the two exterior house walls that are protected by the entryway are sheathed in plywood rather than metal siding (Figure 3.17).



20. On the exterior, the wall siding will not meet at the corners (Figure 3.18). This gap is covered with trim and sealed with outside-closure weather stripping before spraying.
21. On the interior, six gusset plates must be added where corner studs meet in each of the eight octagon corners. This bracing ties the corners together to support the loads of the hip trusses and the roof while still allowing enough of a gap for the spray foam applicator to spray insulation in the corner. Three braces should be installed on the front edge of the studs, and three braces should also be installed on the back edge. To reach the back edges, a 90-degree right angle drill will be required (Figure 3.19).
22. The top plates on the walls must be tied together at the corners with gussets and screws (Figure 3.20).
23. The exterior trim, including windows and corners should be sealed with “outside closure” weather stripping to prevent water from entering at these locations (see step 20 and Figure 3.21).



Figure 3.2 The carpenter is writing corner and mid-wall heights on the subfloor for each wall section. Shims are cut to these heights and to the width of the bottom track and fastened to the subfloor in their designated locations.



Figure 3.3 Use the subfloor to test-assemble a roof section before setting the walls.



Figure 3.4 A stud-assembly jig ensures that every stud offset has the same width, in this case 8 inches.



Figure 3.5 The end studs are screwed to stop blocks to insure all eight walls are built to the same outside dimension. The chop saw bench in the background is long enough to support cutting 16-foot studs in half. The light gauge metal angle that carries the siding extends past the top and bottom of the wall to cover the floor on one end and the truss heel on the other.

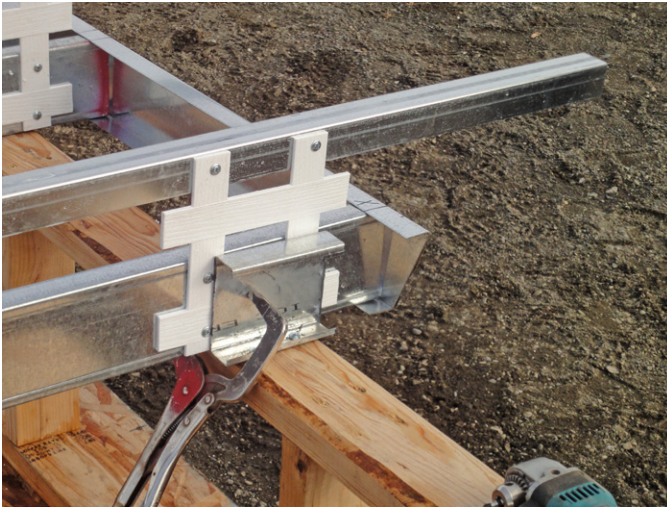


Figure 3.6 With the end studs in place, the top and bottom tracks are fastened in place, making a square frame for all other in-fill framing. The outermost stud is brought in 1" from the corner to allow enough room for spray foam to be applied into the inside corners.



Figure 3.7 The 16-inch-tall assembly table walls allow the carpenters to move easily from one part of the layout to the next.



Figure 3.8 The outer flange on the window will serve to attach the light gauge angle and siding. The inner flange attaches the window to the stud framing. Double check the distance between flanges with the stud jig before framing.



Figure 3.9 Header boxes can be pre-built from the prints. The 2"x4" plate above the header adds additional support for point loads from any trusses that may be installed over the window opening. Open-truss headers allow for foam to be sprayed in the header.



Figure 3.10 With the windows close together, the siding can be screwed directly to the window flanges.



Figure 3.11 The siding starts flush with the exterior angle to cover the outside of the floor and foundation.



Figure 3.12 A slot is cut in the siding in order to tuck the siding underneath the bottom flange of the window for better drainage. The exposed flange will be covered by window trim.



Figure 3.13 2"x4" top plates are held flush to the inside edge of the wall and help transfer truss loads.



Figure 3.14 Walls can be carried by four people.



Figure 3.15 The plywood perimeter shims fastened to the subfloor in the foreground keep these walls level over low spots in the subfloor (also see Figure 3.2).



Figure 3.16 The south wall is plumbed with two adjustable braces. The power for the floor outlet is routed through the bottom plate in the wall as it is raised.



Figure 3.17 Sections of the octagon that face the entry wall are faced with plywood sheathing. The siding on the right wall extends far enough to cover the exposed foundation.



Figure 3.18 Trim will cover the exterior corners. A drainage plane is created by the exposed bottom window flange. This will also be covered with trim.



Figure 3.19 Buckle bracing ties the corners together and supports the point loads from the hip trusses. Three large plates are installed on the inside edge, and three straps tie the back edges together in the same place.



Figure 3.20 Gussets cut from scraps tie the octagon corners together at the top. The greatest point loads in the roof will fall on these spots via the hip trusses.



Figure 3.21 The exterior trim, including windows and corners, should be sealed with "outside closure" weather stripping to prevent water from entering at these locations.



Figure 3.22 Before soffits were installed, the crew noticed a potential weak spot in the exposed overhang of the roof. It is recommended that soffits be built into the overhang to avoid the situation above.

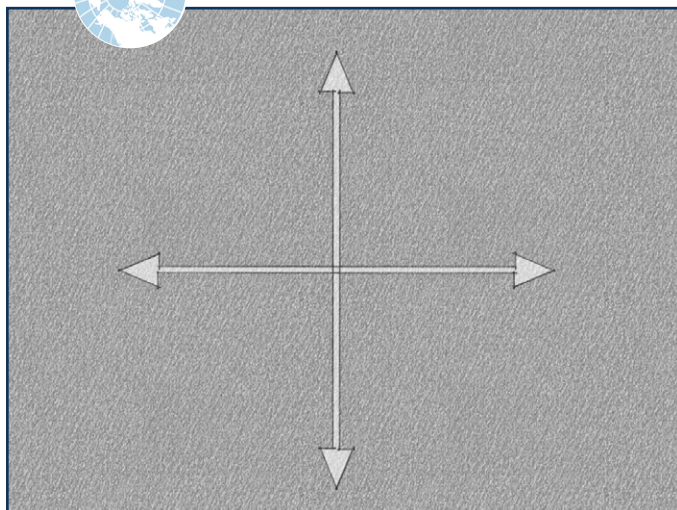


Figure 3.23 Snap centerlines through the octagon that represent the north-south axis and east-west axis.

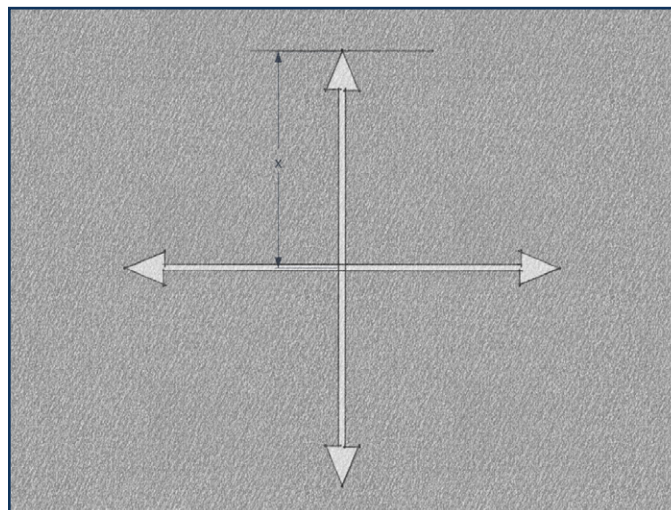


Figure 3.24 Reference inside plate lines from the center point on the floor.

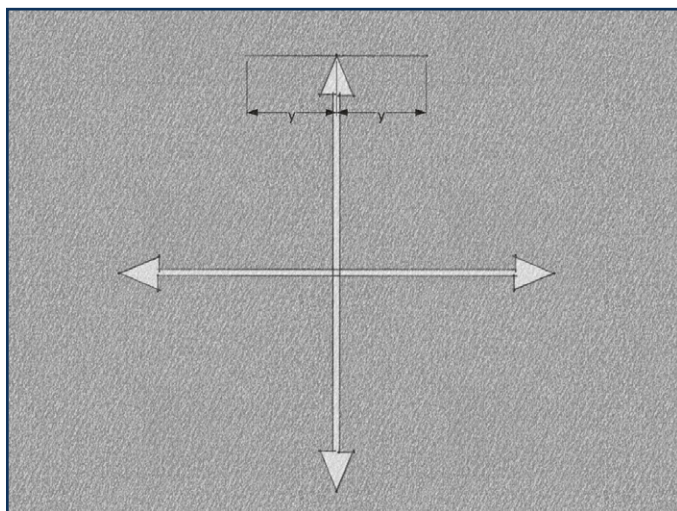


Figure 3.25 From the center of the wall, measure left and right the distance required to determine the total inside wall length.

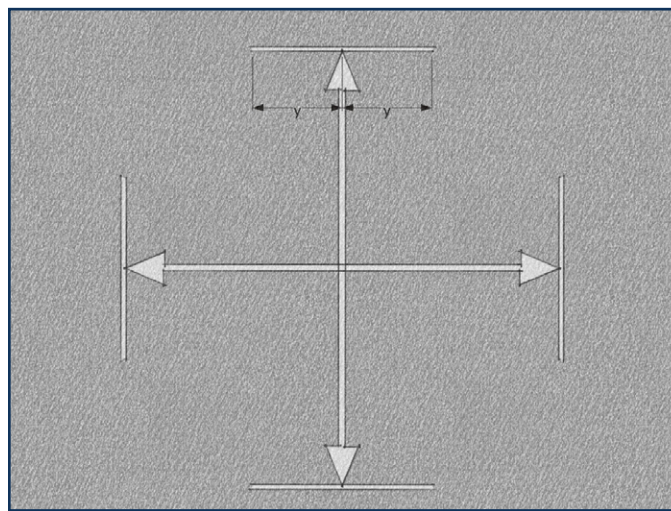


Figure 3.26 The plate lines for the initial four outside walls must be parallel to the main north-south and east-west control lines which determine the center of the floor and also provide square reference points.

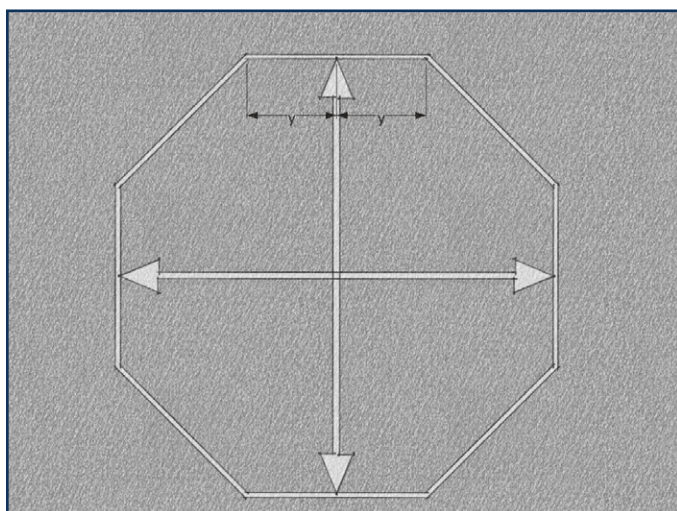


Figure 3.27 Once the north, south, east and west wall plate lines have been snapped, the remaining four walls can be snapped between them.

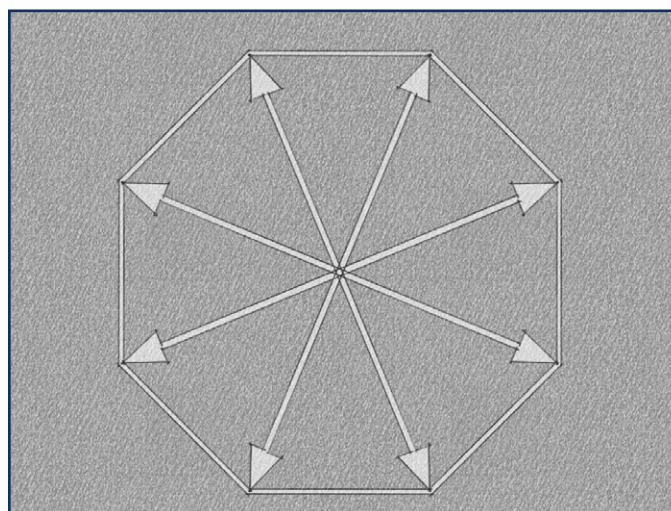


Figure 3.28 As a final step, lines should also be snapped from each outside corner on the octagon through the centerpoint to the opposite corner. These lines will be used later with a plumb bob or laser to set the hip trusses accurately on the top plates.



Roof

Overview

The roof system is comprised of wooden trusses configured in an octagon shape. A primary doubled hip truss rests on each of the eight corners of the exterior walls. These eight trusses extend radially to the corners from a common center point, which forms the peak of the roof. In the center, the bottom chords of the hip trusses are held together in tension by a steel hub custom-fabricated to hold the trusses and the associated tensioning hardware. A second hub holds the top chords of the trusses in compression, balancing the loads and allowing for an open floor plan without columns or load-bearing interior walls. This design was chosen to reduce the weight of the individual roof members so that every component could be lifted by hand in remote locations where heavy lifting equipment is not available. A series of common trusses laid out two-foot-on-center (also called “jack trusses”) spans the wall section between each pair of hips. Although the roof system has many individual members, the number of different trusses is kept to a minimum, and the same combination repeats itself in each of the eight sides in order to simplify assembly. The roof has a 1½-inch ventilated space in each truss bay which allows air to flow from openings at the eaves to a center chimney-type vent. This vented space provides a drying path, should any water enter the roof and reach the wood framing underneath. This drying path is particularly important as the entire top chord of the trusses in the roof assembly is encased in spray-foam insulation from underneath. Spray-foam insulation is applied to the walls and roof from the interior, once the building shell is dried in. The foam extends down to the bottom of the foundation via the 4-inch space created by the offset wall, thereby creating a virtually unbroken thermal envelope.

Sequence and Considerations

1. Two custom-fabricated hubs (Figure 4.4) provide the critical connecting point in the center of the roof. They are designed to tie the eight hip trusses together at the top and the bottom. Once the hardware is installed between the hubs and the trusses and properly tightened, the entire roof becomes self-supporting in the center (Figure 4.11). Although the hub is custom-fabricated, all the hardware and related fasteners are readily available off-the-shelf.
2. During construction, one of the eight facets of the roof truss system, including the center hub, was temporarily assembled and braced on the subfloor (Figure 4.1). This was done before the walls were set, but right after the eight layout lines representing the center of each hip were snapped on the floor. (see step 4 on page 15) (Figure 3.28). The test fit was conducted to ensure accuracy in fabrication and layout for both the trusses and the hub on the ground, directly on layout lines, where potential problems would be easier to identify. Assembling one roof section also makes it possible to determine exactly where the various jack trusses intersect the hip trusses. The layout for these intersecting points can then be transferred to the top edge and sides of all eight hip trusses while they are still on the ground and easily accessible. This will significantly speed up roof assembly.
3. Begin framing the roof by placing a timber spreader in the center of the floor to carry the weight of the temporary center post. This will carry the hub and roof weight until the trusses are tensioned. The spreader can also be built out of stacked dimensional lumber, if necessary. The spreader should extend several feet to either side of the center point to distribute the roof load directly to the joists and can be laid out with center lines to correspond with those already on the roof deck, as in Figures 4.2 and 4.3.
4. Once the spreader is set and the floor center lines are transferred to the spreader, the temporary post that supports the lower hub can be braced in place (Figure 4.5). The hub should be set so the hip trusses are level.



5. The first four hips are set perpendicular to each other, plumbed, and then braced off to stabilize the hub (Figure 4.6). **IMPORTANT: A space of $\frac{1}{8}$ " to $\frac{1}{4}$ " or slightly larger should be left between the backstop and the vertical member of the hip. None of the hips should be jammed tight against backstops in the hub (Figure 4.7).** This allows the hips to be drawn together and tensioned and also provides some free play when installing the upper hub.
6. On the wall end, minor discrepancies in the framing may cause the hip trusses to not line up perfectly with some of the plates (Figure 4.8). Slight deviations (ideally less than $\frac{3}{8}$ ") are acceptable here, since keeping the roof square and symmetrical takes precedence over appearance and lining the hip up with the corner joint in the wall framing. The layout on the floor that goes from corner to corner is used to determine the centerline location of the hips. Hips are easy to center using a plumb laser (Figure 4.9).
7. The upper hub should be installed once all eight hips have been set, plumbed, and securely braced. The hub should be placed far enough below the top edge of the hip truss that the structural screws holding it in place do not cause splitting in this area. A right-angle drill or driver will be needed to drive the screws. All holes should be pre-drilled with an appropriate undersize bit to prevent splitting. Since the top functions in compression rather than tension, shims should be driven into any space between the truss and the backstop (Figure 4.10).
8. After the top hub is installed, the jack trusses can be set. To speed assembly, initially the jack trusses can be face nailed directly against the hips. Ultimately however, either Oly log screws or nail plates will need to be installed to reinforce this connection (Figure 4.14). With these in place, the bottom hub will be ready for initial tensioning. The trusses should be numbered to help keep track of the tightening sequence, which should be done in a diagonal or star-shaped pattern, similar to that used in mounting automotive wheels. This helps insure that tensioning forces are being engaged evenly. Once the last truss has been tensioned, the roof should raise slightly as the trusses are drawn together and the space between the trusses and backstop in the hub begins to close up. A gap will form where the bottom hub is resting on the support post as the center of the roof draws together and forms a slight camber. The tensioning process will require several tightening passes around the hub (Figure 4.11). After the roof framing has been completed and the sheathing installed, the tensioning bolts should be checked for tightness.
9. The roof framing over the entry can proceed once the jack trusses have been set and the bottom hub in the main roof has been tensioned. To maintain the layout for sheathing, install the rafters over the entry walls in line with the main roof members using plywood gussets and glue (Figure 4.12).
10. Blocking must be installed between all rafters and trusses to help provide lateral bracing. The blocking must be installed at the edge of the siding, not over the stud wall, as the siding represents the edge of the thermal envelope, where the spray foam ends (Figures 4.13 and 4.18). Not all the tails on the jack trusses may line up. Before the rough fascia (fascia backer) is installed, a steel stud spanning from hip truss to hip truss can be used to determine if any jack truss tails need to be trimmed (Figure 4.13). A 22½-degree bevel may need to be cut on the hip trusses if this was not done at the factory. The fascia needs to extend above the tops of the trusses far enough to include the thickness of the furring and sheathing that will be added later (Figure 4.18).
11. Perforated strapping bolsters the structural connection between the roof and the walls to resist wind and seismic stresses. The strapping must be in place before any house wrap is installed, since it will then be inaccessible. Each hip is anchored with a perforated strap wrapped over the hip and bent to attach to the back edge of the corner studs on either side (Figure 4.15). The strapping should lap over the studs by at least 16 inches and is screwed into the back edge of the studs using a right angle drill. At this stage, hold-downs can also be attached to all of the jack trusses (Figure 4.16).
12. After the strapping has been installed to anchor the hips, the roof can be closed in. Depending on the size of the crew, different sides of the roof can be worked on simultaneously. The first step is to install the house wrap over the tops of all trusses, starting at the edges of the roof. The house wrap serves multiple purposes. It creates the barrier that keeps the spray foam out of the ventilated spaces. Once the roof is completed, the house



wrap also helps prevent any water leakage from reaching the trusses, which will dry slowly once they are encased in foam. Cut the house wrap. Install over individual roof sections so that it stretches tightly between the hips and overlaps into the next section by several feet (Figure 4.17). Avoid wrinkles in the house wrap, as they may interfere with the spray foam when it is applied from underneath.

13. The first course of 2"x2" furring starts at the bottom, butted against the fascia board, and is nailed down with 16d framing nails. The house wrap starts flush with the blocking and must be stapled down tightly all along the blocking edge so the foam cannot lift it away in this area (Figure 4.18). If the house wrap is 9 feet long and the 2"x2" furring is 8 feet long, the second course of house wrap can lap over the first without interference.
14. Plywood can be installed over the first course of house wrap and furring and will provide a standing surface to install the second course. **IMPORTANT: In those areas where the furring on the jack and hip trusses intersect, the furring must be cut approximately 8 inches short to keep the ventilation path to the ridge open (Figure 4.20).**
15. For extra protection, a patch of peel-and-stick membrane is used to reinforce the peak since it is directly below the peak vent. Hold the furring strips away roughly 6 inches from the peak as this area will be cut away later to install the roof vent (Figure 4.20).
16. Keep the roof as dry as possible. Drape reinforced poly over unprotected portions during construction (Figure 4.19).
17. Apply peel-and-stick membrane over the plywood to provide an extra layer of long-term protection under the metal roofing (Figures 4.21 and 4.24).
18. The dormer is framed with "California valleys" and is completely separate from the roof underneath. The dormer should extend flush to the edge of the roof so that all fascia boards are in plane (Figure 4.22). If desired, the dormer can be omitted and replaced with a series of snow stops to protect the entrance below. The important issue is that the exterior walls of the entry must be tall enough to allow a conventional pre-hung exterior door to be installed (typically a rough opening height of 82½"), and the roof overhangs should not interfere with head room in this area.
19. The valley flashings should be woven together at the peak and the joint covered by a layer of peel-and-stick roofing membrane. As mentioned earlier regarding the dormer framing, the valley flashing should extend to the end of the roof to simplify the metal roofing installation (Figure 4.23).
20. Metal roofing should be applied in the same pattern on the six identical faces to minimize waste. Off cuts from one face can be used on other faces. To keep the roofing square to the fascia, a control line extending to the peak should be snapped perpendicular to the roof edge. The roofing edges should meet as closely as possible at the hips, but not overlap (Figure 4.25).
21. Until the foam contributes to compressive strength and the interior plywood contributes to shear strength, the wall is not operating at its full capacity. For this reason, all wall bracing should remain in place until the spray foam has filled the wall cavities to the point that it reaches the studs and the builder is ready to clad the inside with AC plywood.
22. Roof penetrations can be sealed with flexible boots and silicone. These can be cut in later when their locations can best be determined from underneath (Figures 4.26 and 4.27).
23. The roof vent is made out of a 5-foot-wide piece of flat stock (also called "coil stock") cut in a circle with a 2-foot, 6-inch radius. A straight cut is made from the edge of the circle to the center, allowing it to wrap around itself and conform to the roof pitch. The easiest way to determine the pitch is to take the flashing on the roof and set it on the peak. Mark the position where the two edges of the circle overlap. These points can be screwed together to maintain the correct pitch. At this point, a 6-inch pipe can be inserted over a corresponding hole cut into the center of the circle (Figure 4.28). The pipe is then covered by a conventional chimney cap on the outside. On the inside the pipe should be held ¾ inch below the top of the cap to allow air to escape. An additional band can be added outside the cap to act as a windbreak (Figure 4.29).



24. At the roof peak, a roughly 6-inch-diameter hole is cut into the vent space. It is important that each of the passages on the eight sides has an opening where air can escape. If necessary, a 1¼-inch spade bit or similar can be used to drill down the length of the furring strips to widen the opening. The overlapping hip caps should be well sealed in this area with silicone and compressible foam gasketing. **IMPORTANT: Compressible gasketing should also be used along the entire length of both sides of every hip cap to keep wind-driven rain from intruding into this area via the spaces created by the ridges in the roofing (Figure 4.30).**
25. Once the opening is cut and properly sealed, use silicone to attach an additional piece of compressible gasket around the perimeter to seal the vent to the roof (Figure 4.31).
26. The vent is fastened to the roof with a series of stitcher screws around the perimeter (Figure 4.32).
27. The vent represents the top of the air space in the roof (exit point), while the ½" gap at the blocking (Figure 4.33) represents the bottom of that airspace (entry point).
28. To prevent wind uplift, four ground anchors must be attached to the tails of the hips. See the detail drawings for reference.



Figure 4.1 Both hips and all the jack trusses for one roof section were assembled for a test fit on the subfloor before the walls were set.



Figure 4.2 The timber spreader is centered on the floor layout to support the temporary post. This carries the hub and helps avoid point loads on the floor diaphragm.

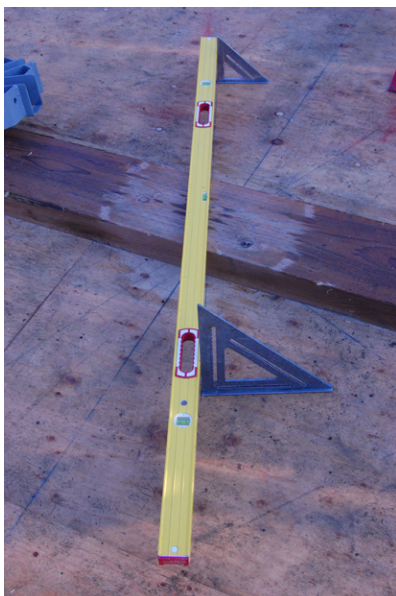


Figure 4.3 The floor layout is transferred to the spreader. See figure something something for a closeup of the floor layout. See Fig 2.24 in the Floor and Foundations Section

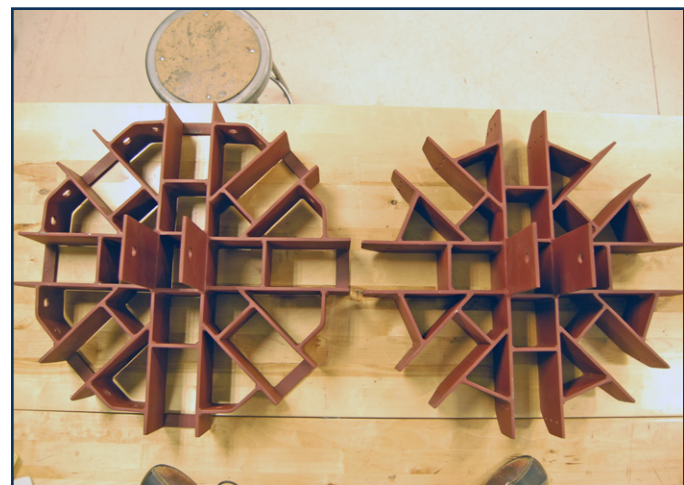


Figure 4.4 On the left is the primary tension hub which has saddles to support the hip trusses on the bottom during assembly. The right hub does not have holes for tension bolts and acts in compression at the top of the trusses. Do not notch the trusses to fit the saddles flush on the bottom hub.



Figure 4.5 The post is braced in two directions and the scaffold is set to help erect the eight hips.



Figure 4.6 Plumbing and bracing the first four hips.



Figure 4.7 As seen from below, a $\frac{1}{8}$ " to $\frac{1}{4}$ " space should be left between the hip and the backstop in the hub to allow for tensioning.



Figure 4.8 Slight discrepancies in wall framing will affect where the hip lands at the corner. **The floor layout takes precedence.**



Figure 4.9 The vertical laser beam references off the corner to corner layout lines in order to on the floor to center the hips on the walls.



Figure 4.10 Shims are used to fill the space between backstop and truss in the top hub.



Figure 4.11 Tensioning is done in a diagonal pattern until the back of the truss contacts the backstop in the hub.



Figure 4.12 Plywood gussets are sistered on either side of the main roof truss tails to carry the entry rafters.



Figure 4.13 Any jack truss tails that extend past the hips can be marked with a straight edge and trimmed.



Figure 4.14 Jack trusses can be installed once the hips are set and the top hub is installed.



Figure 4.15 Hip strapping is hammered flat over the hip truss and bent to lap down over back edge of the corner studs at least 16".

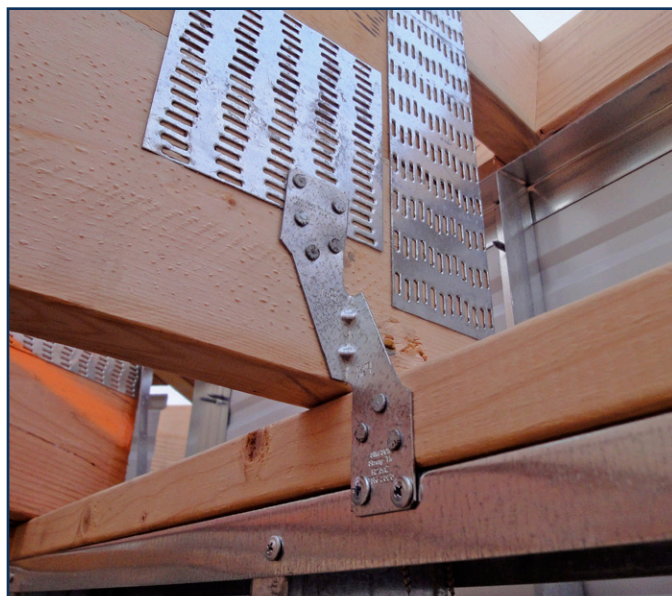


Figure 4.16 Hold-downs should extend to the metal top plate for secure anchoring.



Figure 4.17 House wrap is cut in lengths that will reach over the individual facets and lap past the hip into the adjoining roof section by several feet.



Figure 4.18 The starting edge of the first course of house wrap is flush with the blocking. It should be stapled down tightly along this edge to prevent being lifted by the spray foam insulation.



Figure 4.19 The roof must stay as dry as possible to protect the truss framing before the foam is applied. Reinforced poly can be draped over vulnerable areas.



Figure 4.20 Where the jack truss and hip truss furring strips intersect, the jack truss furring must be cut short to allow air flow to reach the peak.



Figure 4.21 The first course of peel-and-stick membrane starts at the edge of the roof and is lapped "shingle style" by successive courses.



Figure 4.22 In the prototype, the dormer was held back from the edge of the roof. On future homes, the dormer should extend to the edge of the roof. This will simplify both the valley flashing and roofing installations.

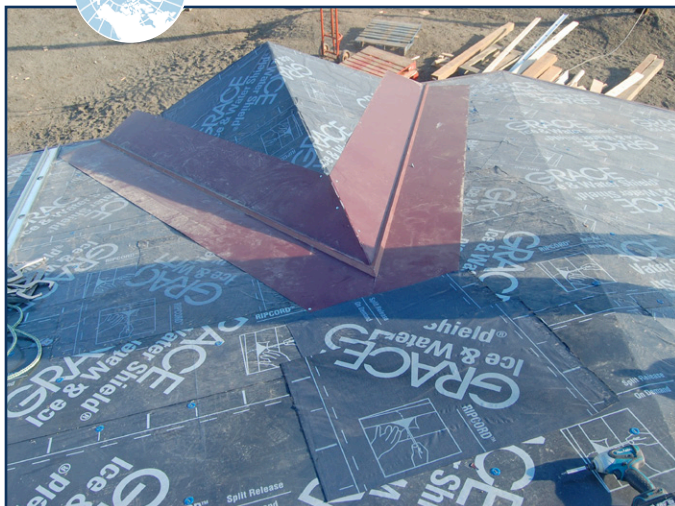


Figure 4.23 The two valley flashings meet at the peak in a woven fashion where the upper sides of the flashing lap over one another. A patch peel-and-stick membrane is then applied over the joint.



Figure 4.24 The membrane reaches to the peak. However, no fasteners should be in the plywood or furring within 6 inches of the peak underneath as this area will be cut away later for the roof vent.



Figure 4.25 Metal roofing should run as close to the hips as possible. The points at the peak can be trimmed during the roof vent installation.



Figure 4.26 Roof penetrations should be sealed with flexible boots and silicone, as for this plumbing vent. It should be turned down to protect from wind and weather.

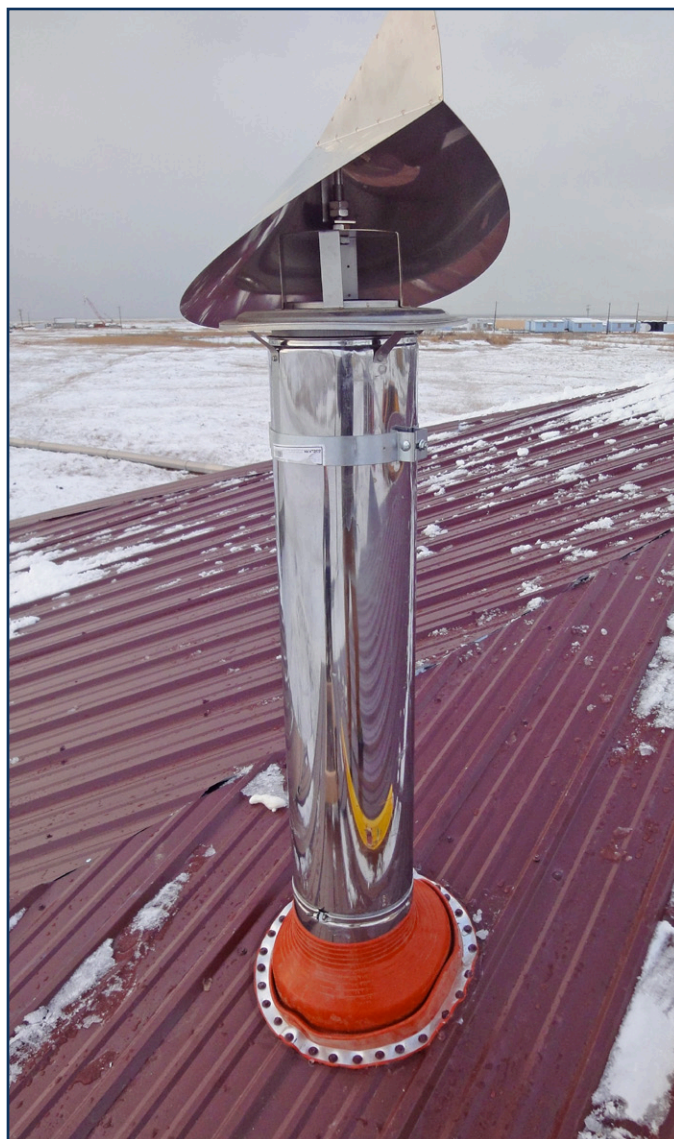


Figure 4.27 Roof penetrations should be sealed with flexible boots and silicone, as with this wood stove chimney with wind-directional hood.



Figure 4.28 Seen from the bottom, the roof circle is cut and stitched to the pitch of the roof. A 6" hole is cut in the center for the vent stack. Tabs in the hole bend upwards to attach the pipe on the inside.

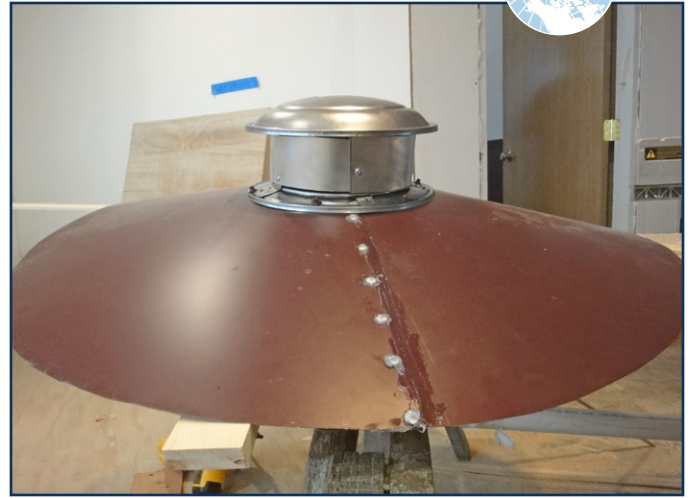


Figure 4.29 A conventional chimney cap covers the inside pipe. The pipe is held three-quarters inch below the top of the cap on the inside to allow air to escape, but keep water out. The middle portion of the chimney cap is banded to further reduce wind infiltration, leaving enough space at the top to allow air to exit.



Figure 4.30 The compressible foam weather strip in the picture is also used down both sides of every hip cap to keep rain from entering through the gap created by the ridges in the roofing.



Figure 4.31 A ring of compressible gasket spans the vent to the roof.



Figure 4.32 The vent is fastened to the roof with a series of stitcher screws around the perimeter. A dab of silicone can be applied to the exposed fasteners for additional protection.



Figure 4.33 The vent space blocking is flush with the metal cladding (not the studs) and has a $\frac{1}{2}$ " gap made with plywood spacers covered by a 1"x4" for airflow.



Insulation & Interior Finishes

Overview

The construction sequence involved in building a home of this type offers significant advantages in wet climates. The integrated assembly processes for the walls and roof produce a fully dried building shell in a short amount of time. All of the spray-foam insulation needed to complete the thermal envelope is applied from the inside, under controlled conditions. Since the building shell already has windows placed, the wall corners are sealed with outside closure weather stripping, and roof is covered in house wrap, air leakage heat losses are relatively minor. The interior can be temporarily heated with a large space heater to insure that all areas affected by the spraying will dry sufficiently enough to be covered in spray foam. In preparation for spraying the foam, the interior surfaces can be brought to a workable temperature relatively quickly. Additionally, the spray equipment and drums of insulation product will be in a temperature-stable environment. As the insulating process may take several days, an initial “flash coat” of foam should be applied to all exterior surfaces, allowing the building to hold heat with relative ease for the duration of the insulating process. It is extremely important that the drums and spraying mechanism are stored in a warm environment before application. If at any time the drums get too cold or are allowed to freeze, the foam will be compromised.

The interior walls are covered in half-inch AC plywood, which serves two purposes.

- Plywood sheathing provides the required structural rigidity for the exterior walls.
- If it doubles as an interior cladding it not only saves on shipping costs but also is a more durable and moisture tolerant material than drywall.

Because drywall serves as an ignition barrier, CCHRC chose to coat all of the exposed plywood with low-VOC intumescent paint. Deciding whether or not a fire retardant paint is required may vary from region to region, and ultimately falls under the jurisdiction of the local code authorities.

Sequence and Considerations

Pre-Insulation Prep Work

Once the exterior work has been completed and the building shell is dried in, any interior prep work required before the spray foam is applied should be completed:

1. Wiring for outlets in the exterior walls. (Figure 5.1)
2. Install chimney, if possible. The chimney can be installed later and sealed with spray foam, however, this will likely be more time-consuming (Figure 5.2).
3. Any structural reinforcing hardware not yet installed in the regions to be sprayed should be added at this stage (Figure 5.3).
4. Any areas where the house wrap hangs down into the rafter bays should be trimmed so it does not interfere with the foam (Figure 5.3).
5. Control lines should be sprayed on the various trusses to give a visual reference for final foam depth (Figure 5.3).
6. Outside corners with outside closure weather stripping must be installed before the inside is sprayed, otherwise foam overspray will leak out of this area (Figure 5.9).



Figure 5.1 The first “flash coat” of foam is applied over all interior surfaces to insulate and seal the structure for heating. All wiring in the exterior walls should be completed at this point.



Figure 5.2 It is easier to install the chimney before the foam is sprayed. Manufacturer’s clearances to combustibles must be followed.



Figure 5.3 Since the spray foam completely wraps the wood framing, the structural screws (or plates) that anchor the jack trusses to the hips must be in place. The house wrap above has been trimmed to avoid interfering with the foam. An orange control line is sprayed for reference on the trusses to gauge the final depth of the foam.



Interior Finish

7. As in the floor, the foam is applied in approximately 2-inch lifts. The wall bracing must remain in place until enough foam is applied to stiffen the structure (Figure 5.4).
8. The center of the roof, where the upper hub and trusses meet, is a critical spot due to (a) its complexity; and (b) the conductive nature of the steel. Care must be taken to ensure that this area is completely covered and sealed (Figure 5.5).
9. **IMPORTANT: Once the insulation has been completed, the structure will be extremely air tight. Keeping several windows on opposing walls slightly open during working hours provides cross-flow ventilation to reduce indoor humidity levels and ensure that fresh air is available to the crew.**
10. Some overspray onto the stud edges is inevitable and will need to be scraped away after all the spraying is completed. The walls should be checked with a straightedge, and any high spots in the stud bays must be trimmed flush as well (Figure 5.6). If simple dish soap is applied to the stud before spraying, any overspray will be easier to remove.
11. The 1"x4" furring is applied on the ceiling every 2 feet on-center, parallel with the master bedroom (NE) and the entry doorway (SW) walls. Orienting the furring in this direction makes it easier to build a square attic access in the master bedroom, and to install the chimney in the living room. The easiest way to lay out the furring is to snap all the furring lines on the floor and then transfer them to the ceiling using the plumb laser. The furring can be attached with 2-inch framing staples or similar (Figure 5.7).
12. A control line is snapped to keep the first (center) run of ceiling plywood straight. **Do not stagger the joints in adjoining runs: this will require more trim work later** (Figure 5.12).
13. The plywood is fastened to the walls using 1¼" self-tapping bugle head drywall screws, or similar. Install sheets vertically, and trim the vertical seams with ¾"x1½" batten strips after painting. The screws must be held as close to the edges as is structurally feasible to ensure that they will be covered by trim later. Screws in the field must be recessed below the surface of the plywood, as they will be filled with spackling compound before painting.
14. Since the 1"x4" furring is in line with the trusses in one direction, it will clear the saddles in the lower hub where they extend below the bottoms of the trusses (Figure 5.8).
15. All edges of the plywood must be supported to prevent sagging. Backing strips are also added between the end joints and the exterior walls where necessary (Figure 5.13).
16. Much of the ceiling must remain open until all of the mechanical work in the attic is completed. The bedroom areas can be covered, as wiring and ducting here is minimal. Covering the bedroom ceilings with plywood first greatly simplifies the installation of the wall framing (Figure 5.10).
17. Plate layout for the interior partitions is snapped out on the subfloor using the reference lines established in the "Walls" section. Floor layout can then be transferred to the ceilings using a plumb laser (Figures 5.11 and 5.17).
18. The most important layout is the kitchen. The counter is U-shaped and, as a result, the side walls must be parallel and square. The window must also be centered over the sink. Filler strips can be used between the upper and lower cabinets to help with centering. It is often best to draw out cabinet and appliance layout on the floor to ensure that all components and the counter will fit in the allotted space (Figure 5.15).
19. Sound batting is installed in all the walls once the wiring and mechanical work is finished. Use batting designed to fit between metal studs (Figure 5.16).
20. Once the walls have been painted, the batten strips can be installed to cover all inside and outside corners as well as exposed seams (Figure 5.17).
21. When the doors are installed, the jambs should be held up 5/16" to allow the flooring to tuck underneath. The flooring consists of durable 18"x18" interlocking rubber tiles, which can be removed and replaced should they ever become damaged (Figure 5.18).



Figure 5.4 The bracing must remain in place until the interior has been coated with several lifts of foam.



Figure 5.5 The center of the roof, where the upper hub and trusses meet, must be well-insulated.



Figure 5.6 The carpenter on the right is using a straightedge to check for high spots and overspray.

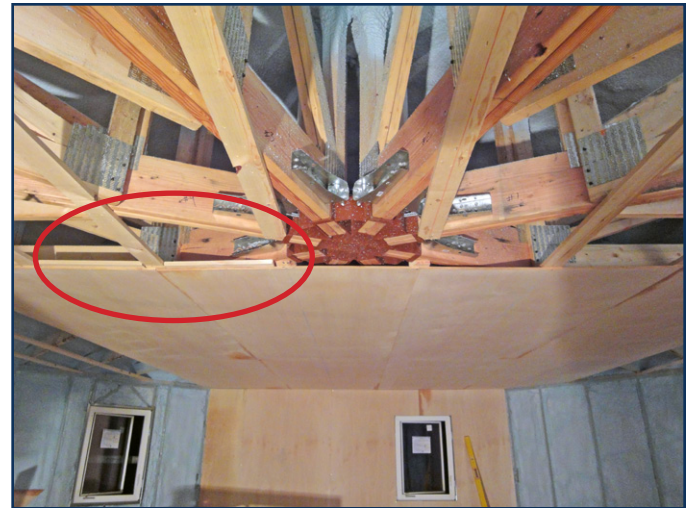


Figure 5.7 As seen on the left, horizontal blocking should be added to fully support the short edges of the ceiling sheets.

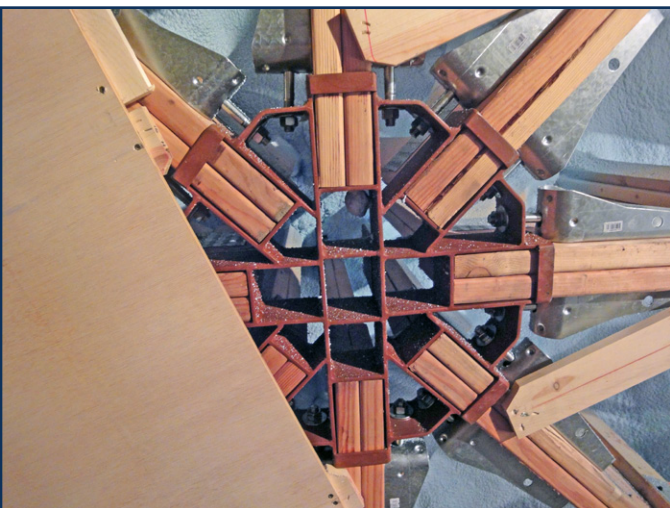


Figure 5.8 The two middle runs of furring straddle the hub and clear the saddles that carry the hips and extend below the bottom of the trusses.



Figure 5.9 Outside closure weather stripping must be added behind the corner trim. It will keep weather out and prevent the spray foam from leaking out.



Figure 5.10 Sheathing the ceilings in the bedroom areas before framing the walls simplifies both operations



Figure 5.11 Floor layout is transferred to the ceilings and then the ceiling track is installed.



Figure 5.12 A control line is snapped for the center starter course to keep the rows straight. Do not stagger the joints in the rows. This creates more work trimming out the seams.



Figure 5.13 The end joints of the ceiling panels must be supported both in the field and along the edges.



Figure 5.14 Once the edges and ends of the ceiling plates have been transferred from the floor with the laser, the plate lines can be snapped.



Figure 5.15 Kitchen sidewalls must be laid out square and parallel to fit the counter top. To simplify the installation of the counter, the utility room wall on the right was held back half-inch wider than the counter, and then moved in tight once the counter was installed.



Figure 5.16 Once one side of a wall is covered in plywood, it can be soundproofed with friction-fit soundproof batting. Insulation designed to fit between steel studs is wider than that required for wood.



Figure 5.17 The batten strips should miss all ceiling penetrations, such as the can lights shown. When the end seams in the rows of ceiling plywood are lined up, this produces a visually pleasing 4'x8' grid pattern.



Figure 5.18 The flooring is modular for ease of application in the octagonal floor plan. Replacing damaged sections is also made easier, and more cost-effective, using this technique.



Figure 5.19 The cement board hearth extends in front of the stove for fire protection.



Figure 5.20 The completed kitchen.



Mechanical & Electrical Systems

Overview

For the most part, the prototype home employs mechanical systems and installation processes that are typical to residential construction. This means that the plumbing, electrical, and ventilation systems can be installed with readily available components and be adapted to meet specific requirements relatively easily. There are a few additional considerations, however.

As the entire structure is encased in an unbroken envelope of spray foam insulation, it is extremely air tight. This translates to a very high level of energy efficiency, but it also makes adequate and reliable sources of ventilation critical to occupant health. A heat recovery ventilation system (HRV) in the utility room is the primary source of fresh air. Because this house is dependent on a dedicated source of fresh air, the HRV must remain on, and the supply air diffusers in the bedrooms must remain open. Secondary to the HRV, a 6" passive air duct leading directly outside has been installed behind the refrigerator. This passive air duct is designed: (a) to provide make-up supply air when exhaust systems such as the kitchen exhaust or the clothes dryer are in operation; and (b) to supply air to the woodstove as needed. This duct **MUST** remain open at all times and is not to be considered an adequate substitute for the HRV. In the kitchen a direct-vent exhaust with an in-line fan allows humid air to escape through the roof.

In future homes, some changes to the ventilation system design should be considered. The HRV can be counted on to provide all of the exhaust ventilation in the bathroom by means of a manually operated boost control. A direct-vent exhaust with an inline fan should be installed in the kitchen to remove cooking odors and excess humidity. This fan would exhaust straight up and through the roof. In the northern regions this type of ceiling ventilation was called a Qingok (Figure 6.14) and a passive version was common in many traditional homes. The advantage to this arrangement is that in addition to the HRV, a strictly manually controlled ventilation system would be available in an area of the house where its presence would help insure that it gets used. The in-line fan in the kitchen would still depend on the passive make-up air vent behind the fridge to supply fresh outside air when it is operating.

The core of the home's wastewater disposal system consists of a macerating pump and lift station assembly, which are located in the utility room and connected to the toilet through a common wall. This type of system was chosen to meet a series of site-specific waste disposal challenges. The current sewage collection arrangement consists of a "flush-and-haul" system whereby the home's wastewater is deposited into an external insulated storage tank. This tank is then pumped out on a routine schedule by the village wastewater treatment department. Because the house rests directly on grade, rather than on the elevated piling systems common to the community, the wastewater cannot feed into the tank using gravity alone. A pumping system is required. In the future, the home will be connected to a village piped-in sewage and water system which will change the current wastewater disposal configuration. The type of water and sewer infrastructure in the village, combined with the foundation type available on each specific site, will determine changes in the affluent discharge and potable water supply to the house. CCHRC recommends that a professional plumber be consulted early in the planning process to make any necessary change to the plans that might be affected by these variables.



Sequence and Considerations

Ventilation

1. The prototype home is extremely air tight, which improves energy efficiency but also makes the need for a dedicated source of fresh air very important for occupant health. A heat recovery ventilation system (HRV) was chosen to meet the home's primary ventilation needs. The HRV is situated in the utility room and supplies fresh air to the living room and bedrooms through a 6" round duct and diffusers. Exhaust air is removed from the bathroom and kitchen by means of the same duct arrangement. An exhaust diffuser is also installed in the attic to ensure that air does not become stale in this area (Figure 6.1). The HRV in the prototype home operates using the latest generation of programmable "smart" controls. The advantage of this type of system is that, in conjunction with user inputs, it will adjust its ventilation schedule based on a combination of indoor humidity, indoor temperature, and outdoor temperature.
2. Holes for supply and exhaust air ducting can be drilled into the exterior walls from both sides using a hole saw. Once the ducting is installed, seal the remaining gap between the ducting and the hood wall insulation with spray foam. Exhaust and supply hoods must be 10 feet apart on the wall to ensure that no stale exhaust air is reentering the house.
3. The exterior hoods are sealed to the wall with closure strips and silicone. They should be drilled at a height that doesn't make sealing the exterior opening difficult (Figure 6.2).
4. The ducting installation is difficult in the attic, so much of the ceiling should be left open until this work is completed. See also "Insulation and Interior Finish."
5. Ducting to the outside must be insulated. Insulated flex duct should be avoided, as it can significantly reduce airflow. Instead, 6" hard pipe can be insulated by removing the insulation jacket from 7" flex duct and sliding it over the 6" pipes. With some types of 7" flex duct, the core has a large enough diameter that it does not have to be removed. The easiest approach is to assemble and insulate the ducting in advance, then take apart in sections and reinstall in the attic (Figure 6.6).
6. Supply air is delivered through the bedroom and living room ceilings. The diffusers should be located in areas where the cooler air will cause the least amount of occupant discomfort. The supply air should also be located away from doorways to prevent "short-circuiting" the air flows and to ensure good air mixing (Figure 6.2).
7. Exhaust air is also picked up through diffusers in the ceilings. The bathroom, kitchen, and attic should each have an exhaust air diffuser (Figure 6.7).
8. The condensate drain from the HRV can be plumbed into the waste piping above the macerating pump. It must have a trap (Figure 6.10).
9. A low-sone bathroom fan was installed in the bathroom of the prototype to provide spot ventilation as needed. The fan also houses a ceiling light (Figure 6.9). The exhaust ducting is hard-piped out the utility room wall. It may be preferable to rely on the HRV booster for the bathroom and instead place an in-line fan in the kitchen ceiling. This decision is up to the housing authority or homeowner. However, CCHRC recommends at least one mechanical exhaust route separate from the HRV system installed in the home.
10. A 6" passive makeup-air vent is installed behind the refrigerator to provide supply air when exhaust appliances such as the bathroom/kitchen fan or the dryer are turned on. It also provides supply air for the wood stove. To avoid problems with backdrafting combustion appliances such as the wood stove or the furnace, this duct must remain open. The makeup-air is not designed to meet occupant needs (Figure 6.11).
11. The makeup-air duct must be insulated. It enters the attic above the refrigerator, drops back down in the pantry and exits mid-wall in the neutral pressure zone (Figures 6.12 and 6.13).
12. The pantry ducting is hidden by soffit once it is completed (Figure 6.13).
13. A 4" dryer vent runs from the bathroom into the attic and exhausts out the utility room wall (Figure 6.16).



Figure 6.1 The HRV unit in the utility room. The hard pipe for all four ducts ends at the ceiling and short sections of flex duct make the connection to the HRV. This is easier to install and reduces noise transmission through the warm-side ducting.



Figure 6.2 HRV supply air ducting in the pantry.



Figure 6.3 A long pilot bit is used in the hole saw to locate the hole center on the inside.



Figure 6.4 Holes should be located at a height that seals well to the contours of the metal wall cladding.



Figure 6.5 Duct runs are tight. The ceiling paneling should be left off in all areas except the bedrooms to allow easier access.



Figure 6.6 A 7" flex duct insulation jacket being slipped over 6" hard pipe.



Figure 6.7 Supply air is delivered through the ceilings and should be located in areas that will cause the least amount of occupant discomfort.



Figure 6.8 The exhaust diffuser in the bathroom is in the ceiling of the toilet alcove.



Figure 6.9 A low-sone bathroom fan provides spot ventilation. A short section of flex duct makes the transition from the fan to the attic space.

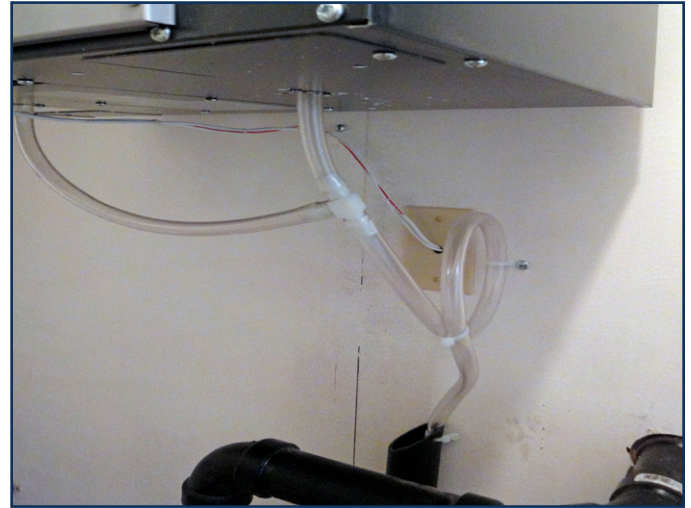


Figure 6.10 The HRV condensate is plumbed into the waste pipe above the macerating pump.



Figure 6.11 The makeup-air exits mid-wall in the pantry.



Figure 6.12 A 6" makeup-air duct is installed behind the refrigerator. This duct must remain open and be insulated to avoid attracting condensation.



Figure 6.13 A soffit is installed in the pantry where the HRV supply air and the passive makeup-air vent exit out the exterior wall.



Figure 6.14 Modern take on the traditional “qingok.” This kitchen ventilation system incorporates a fan.



Figure 6.15 Exterior view of where the supply air for the HRV (top) and the passive makeup-air vent exit the wall (bottom).



Figure 6.16 Finished dryer vent opening.



Plumbing

1. The tank housing the macerating pump and lift station is installed directly behind the bathroom wall in the utility room and connected to the toilet through the wall. The waste lines from all other sources must also be plumbed into the pump (Figures 6.17 and 6.18).
2. The plumbing runs from the washer tees into the toilet drain line which then enters the pump. The tub drain must also connect at this point (Figure 6.19).
3. The tub is raised in order for the tub drain line to meet the toilet drain line at the proper level (Figure 6.20).
4. The vanity waste and supply lines run along the exterior wall and then are hidden by a furred-out half wall (Figures 6.21 and 6.22).
5. The vent line from the washer is run separately and connected to the tub/toilet/vanity vent in the attic (Figure 6.23).
6. All vents travel toward the center of the roof and then neck up to a 3" pipe that exits the roof (Figure 6.24).
7. On the outside, the main vent is turned down to prevent weather related issues from affecting the vent system (Figure 4.26)
8. Due to space considerations, the vent for the kitchen sink uses an air admittance valve (AAV) in lieu of a traditional vent. AAV supply lines and the drain line are cut through the back of the cabinet (Figure 6.25).
9. A 200 gallon vertical water tank holds domestic water. The tank has a surround built underneath it using 2"x2" lumber to create a shallow bowl lined with a piece of rubber membrane. If the cold water in the tank causes the tank to attract condensation, the floor will remain protected by the membrane (Figure 6.26).
10. The fill and vent pipes for the water tank are located on the exterior wall shared by the kitchen (Figure 6.27). Fill pipe fittings should be selected to be compatible with fittings used by the water delivery service.
11. The domestic water lines are insulated to prevent condensation from forming on the cold water side and to prevent standby losses on the hot water side (Figure 6.28).



Figure 6.17 All waste plumbing must enter the macerating pump.



Figure 6.18 The sink drain enters the pump from the left side.



Figure 6.19 The washer drain line runs behind the raised tub platform.



Figure 6.20 The tube is raised so the tub drain will meet the toilet drain.



Figure 6.21 Vanity supply and waste water run along the exterior wall to the utility room.



Figure 6.22 The vanity plumbing lines are covered by a half wall. The vent for the shower/toilet/vanity is located in the plumbing wall between the toilet and the tub. Avoid placing plumbing lines in exterior walls wherever possible as doing so displaces spray insulation and takes more effort to access for repairs in the future.

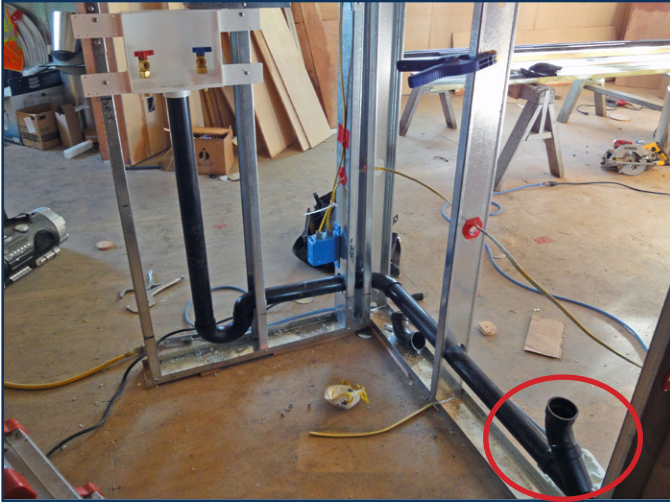


Figure 6.23 Washer vent.



Figure 6.24 The washer vent and shower/toilet/vanity vent meet towards the center of the roof before exiting.

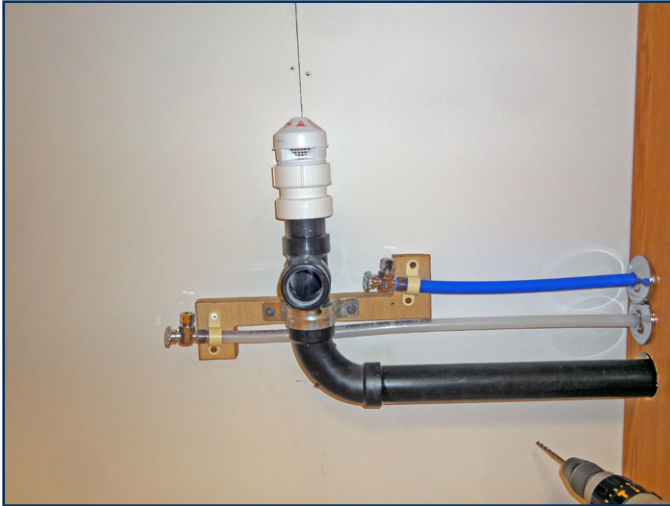


Figure 6.25 An air admittance valve is used to vent the sink to avoid venting through the interior walls.



Figure 6.26 The domestic water tank has a site-built surround that will catch any water if the outside of the tank attracts condensation.



Figure 6.27 The water tank fill and vent pipes are located in the wall to the right of the electrical service.



Figure 6.28 The domestic water lines are insulated to prevent condensation from forming on the cold water side and to prevent standby losses on the hot water side.



Electrical

1. Overhead power is brought in through the utility room wall next to the entryway.
2. The feeder wire that travels from the back of the outside panel through the wall to the inside panel is protected by a piece of angle iron recessed into the foam (Figure 6.30).
3. The can lights in the ceiling use retrofit cans. This allows the electrician to rough in the wiring to the approximate location and then reach the wires after the holes have been located in the ceiling. The layout for the can lights is done on the floor and marked with a screw covered by tape for easy reference (Figure 6.31). Once the plywood is installed on the ceiling, the layout can then be transferred to the ceiling using a plumb line or laser.
4. Holes for can lights should be placed so they do not intersect the batten strips that cover the seams in the plywood (Figure 6.33) or conflict with the ceiling joists.



Figure 6.29 The Unistrut® supporting the panel and mast is fastened through the siding and the light gauge angle behind it using #14 self-tapping screws. Screw penetrations are sealed with a dab of silicone.



Figure 6.30 The feeder wire is protected by a section of angle iron cut into the foam where it travels from the outside panel through the wall and upward.



Figure 6.31 Can lights are marked on the floor using a screw covered with red tape. This layout can then be transferred to the ceiling once the plywood has been installed.



Figure 6.32 Weather-resistant exterior outlets.



Figure 6.33 All the can lights should be laid out so they do not interfere either with the batten strips that cover the seams in the plywood, or the trusses underneath.

