
Accepted Practices for Post-Frame Building Construction: Metal Panel and Trim Installation Tolerances



NFBA NATIONAL FRAME
BUILDING ASSOC.

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Accepted Practices for Post-Frame Building Construction: Metal Panel and Trim Installation Tolerances

1 Purpose and scope

1.1 Purpose. The purpose of this document is to provide recommended tolerances for installation of metal panel and trim. The information provided is intended to limit the relative orientation and spacing of panel and trim, mechanical fastener placement, and panel and trim surface blemishes. Field experience indicates that adherence to these guidelines will help produce finished buildings that are functional, structurally sound and aesthetically pleasing.

1.2 Scope. Provisions of this document only apply to installation of exterior metal panel and exterior metal trim with a nominal base metal thickness less than 0.05 inches (1.20 mm). Fastener criteria only apply to exposed (a.k.a. through-panel) fasteners. This document does not address the type or quality of metallic coatings and paint finishes. This document does not address gutters, downspouts or related accessories.

1.2.1 Appendices. Provisions in the appendices are for informational purposes only and are not an enforceable part of this document.

1.3 Time-frame for inspection. Provisions of this document apply only to assessments made prior to building use/occupancy or within 90 days of substantial building completion, whichever comes first.

1.4 Governing documents. This document is superseded by all contract documents (this includes building plans and specifications) and applicable building codes. Special jobsite conditions may require alteration of the building plans and specifications. These alterations should only be made after approval of all parties involved.

2 Normative references

The following document contains provisions which, through reference in this text, constitute provisions of this document.

NFBA, *Accepted Practices for Post-Frame Building Construction: Framing Tolerances*

3 Definitions

3.1 accessory: A supplementary building product such as doors, windows, skylights, vents, gutter, etc.

3.2 anode: See *galvanic series*.

3.3 at-grade: Located at the ground level on a building site.

3.4 base metal: The metal underlying the paint and/or *metallic coating* on a piece of coated metal.

The base metal of most wall and roof panels is low carbon steel or aluminum.

3.5 bead mastic: Sealant furnished in a continuous roll, normally used for sealing *roof panel endlaps* and *sidelaps*.

3.6 bimetallic corrosion: See *galvanic corrosion*.

3.7 blemish: Any defect or mark that tends to detract from the appearance of a piece of *paneling* or *trim*. Blemishes seldom affect structural integrity.

3.8 building perimeter: Total distance measured around the outside of a building.

3.9 camber: Edgewise curvature. A lateral departure of a side edge of a *metal sheet*, *panel* or *trim* from a straight line. Often designed into a structural member to offset the anticipated deflection when loads are applied.

3.10 cathode: See *galvanic series*.

3.11 chalking: A fine powder consisting of individual particles of resin and pigment that are left on a painted surface as the paint gradually weathers/deteriorates.

3.12 cladding: The material(s) comprising the exterior and interior surfaces of a building. See *covering*.

3.13 closure strip: A resilient strip, flat on one side and formed to the contour of *corrugated panels* on the other, used to close openings created by joining *corrugated panels* and *trim/flushing*.

3.14 coated metal: Thin *metal sheets*, usually in coil form, which have been covered on one or both sides with paint, enamel, adhesive, anti-corrosive coatings, and/or laminates.

3.15 cold forming: The process of using *press brakes* or *rollformers* to shape steel into desired cross sections at room temperature.

3.16 cool roof: A roof system that is designed to lower the roof surface temperature and minimize the rate of heat transfer from the roof to the building interior.

3.17 contract documents: Documents that are part of a legally binding agreement between two or more parties. Construction contract documents include contract conditions, drawings and specifications.

3.18 corrosion: Gradual chemical or electrochemical degradation of a metal.

3.19 corrugated panel (see Figure 2): A *panel* having a surface with ridges and valleys.

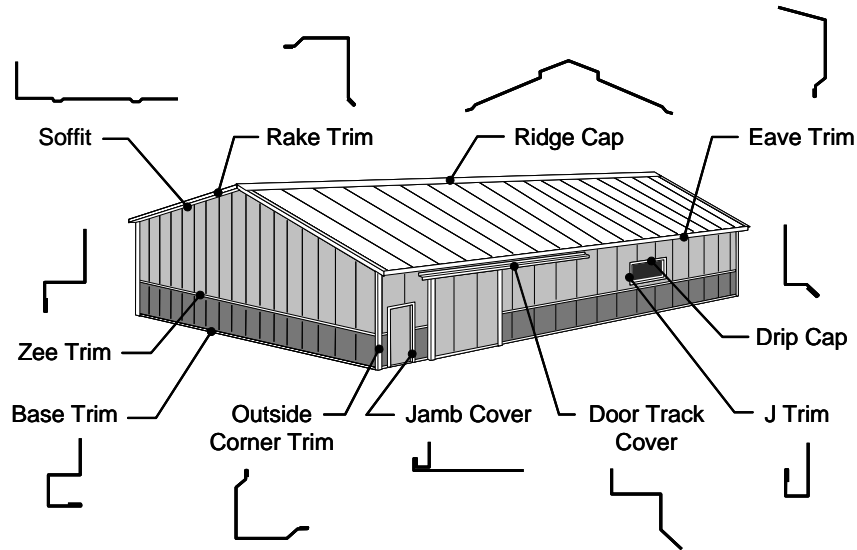


Figure 1 – Examples of common metal trim types.

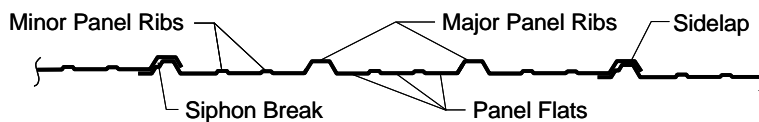


Figure 2 – Metal panel cross-section.

3.20 covering: The material(s) comprising the exterior and interior surfaces of a building. See *cladding*.

3.21 cover width: That portion of a panel's width that remains visible after installation.

3.22 dent: A surface depression caused by striking or pressing. To qualify as a dent, the depression in question must be visible by a majority of normal-sighted individuals when viewed under natural noon-day lighting from an *at-grade* position no closer than fifteen feet to the area in question.

3.23 ding: A relatively small *dent*.

3.24 dissimilar metals: Metals or alloys characterized by *galvanic corrosion*.

3.25 eave: The part of the roof that projects over the sidewalls. In the absence of an overhang, the eave is the line along the sidewall formed by the intersection of the roof and sidewall planes.

3.26 edge kink (See Figure 3). A permanent crease in the overlapping edge of a corrugated panel, which is specifically located between the edge and the first panel bend in from the edge. An edge kink is a severe form of *edge rippling*.

3.27 edge rippling (see Figure 4): Waviness of the overlapping edge of a corrugated panel. An *edge kink* is an extreme type of edge ripple.

3.28 endlap: The lap formed when two *panels* are connected end-to-end to form a longer assembly.

3.29 endwall: An exterior wall orientated normal (i.e., perpendicular) to the horizontal line formed by the building *ridge*.

3.30 exposed fastener: A *fastener* that is still visible in whole or in part after construction is complete. A nail or screw whose head is visible. See also *through-panel fastener*.



Figure 3 - Example of edge kinking.



Figure 4 - Example of edge rippling. The middle wave in the right seam would be classified as an edge kink.

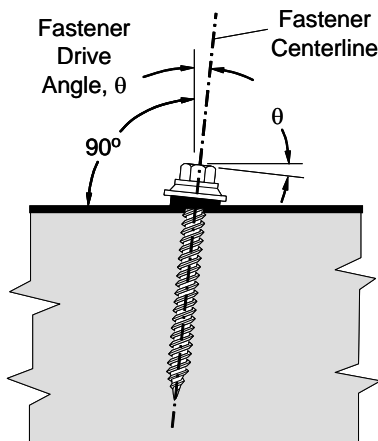


Figure 5 – Fastener drive angle

3.31 fanning: End-to-end variation in the *cover width* of a panel. A panel may be fanned to align its leading edge with a premarked location. Corrugated panels can be fanned by slightly altering the amount of overlap at edge seams, or by forcibly changing the width of the panel. Most standing seam panels can only be fanned by increasing the gap between the base of adjacent panel legs.

3.32 fascia: A member used for the outer face of a *roof overhang*. Metal rake and eave trim is frequently referred to as rake and eave fascia.

3.33 fastener: A device for holding something together. Broad categories include: adhesives, *mechanical fasteners*, and weldments.

3.34 fastener alignment: The degree to which a row or column of *exposed fasteners* form a straight line.

3.35 fastener drive angle (see Figure 5): The angle that the shank of a nail or screw *fastener* makes with a line drawn normal to the *panel* surface. Typically determined by measuring the difference in angle between the *panel* surface and the *fastener* head.

3.36 fastener washer compression level (see Figure 6): The relative thickness to which the sealing washer of a nail or screw *fastener* is compressed. *Fasteners* with sealing washers may be over- or under-driven depending on if the sealing washer is over- or under-compressed, respectively.

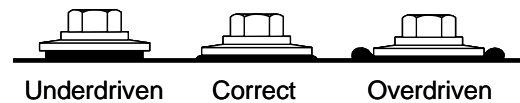


Figure 6 – Fastener washer compression level.

3.37 filler strip: See *closure strip*.

3.38 finish: The final condition of a surface after the last phase of production, fabrication and/or installation.

3.39 flashing: A closure, typically of *sheet metal* or plastic, which functions primarily to provide weather tightness in a structure and secondarily to enhance appearance.

3.40 foil: Metal with a maximum thickness of 0.005 inches. See *metal plate*, *metal sheet*.

3.41 framed opening: Framing (headers and jambs) and flashing which surround an opening of a roof or wall in a building. Used for field installed accessories such as overhead doors, service doors and windows.

3.42 framing: The structure of a building which gives it shape and strength; including interior and exterior walls, floor, roof and ceilings.

3.43 gable: The triangular portion of the *endwall* of a building directly under the sloping roof and above the eave height line.

3.44 gable roof: Roof with one slope on each side with each slope of equal pitch. Gable roof buildings have rakes on the gable facades and eaves on the non-gabled facades

3.45 gage (or gauge): The numerical designation for the thickness of *sheet metal*.

3.46 galvalume: Trademarked name for an aluminum-zinc alloy coating that is 55% aluminum, 43.4% zinc and 1.6% silicon by weight. By volume the coating is 80% aluminum. See *metallic coating*.

3.47 galvanic action: See *galvanic corrosion*.

3.48 galvanic corrosion: Accelerated *corrosion* that occurs when dissimilar metals or alloys are brought into electrical contact (frequently this occurs by immersion in impure water). When electrically connected, one of the metals in the couple becomes the anode and corrodes faster than it would all by itself, while the other becomes the cathode and corrodes slower than it would alone. See *galvanic series*.

3.49 galvanic series (see Table C.1): A list of metals arranged in order of their relative electrical potential. If any two metals are coupled together, the one closer to the anodic (or active) end of the series will be the anode and thus will corrode faster, while the one toward the cathodic (or noble) end will corrode slower. The greater the electrical potential difference between two metals, the more rapidly the anode will corrode when the metals are electrically connected. If a component has a *metallic coating*, the *metallic coating* and not the *base metal* determines the electric potential of the component.

3.50 galvanized: Coated with zinc for *corrosion* resistance.

3.51 hip roof: A roof which rises by inclined planes from all four sides of a building. The line where two adjacent sloping sides of a roof meet is called the hip.

3.52 kink: An unwanted permanent crease or wrinkle resulting from compressive forces that induce stresses beyond the elastic limit of the material. See *edge rippling*, *rib kink*.

3.53 liner panel: A *panel* applied as an interior finish. A *panel* that “lines” the interior of a building.

3.54 mastic: Caulking or sealant normally used in sealing *roof panel* laps.

3.55 mechanical fastener: A device of fixed shape and size that holds components together without chemically bonding to them. Components joined with mechanical fasteners are generally easily separated without damaging the components. Common mechanical fasteners include nails, screws, bolts, rivets, and staples.

3.56 metal burr: A thin ridge or roughness left on a metal edge by such cutting operations as *slitting*, *trimming*, *shearing*, *sawing* or *blanking*.

3.57 metal chip: A small piece of metal. Typically results from a drilling, tapping or deburring operation.

3.58 metal panel (see Figure 2): A thin *metal sheet*, typically *rollformed*, used as wall and roof *covering*.

3.59 metal plate: Metal with a thickness greater than 0.188 inches. See *metal sheet*, *foil*.

3.60 metal sheet: Metal with a thickness between 0.188 and 0.005 inches. See *metal plate*, *foil*.

3.61 metal trim (see Figure 1): Any *trim* made out of metal. Common metal trim types include: outside

corner trim, inside corner trim, rake (a.k.a. gable) trim, eave trim, soffit, ridge cap, drip cap, door track cover, door jamb cover, J-trim (a.k.a. J-channel), Zee trim, base trim.

3.62 metallic coating: Thin metal coating applied to a base metal to protect it from rapid corrosion. Common metallic coatings include zinc (see *galvanizing*), aluminum and aluminum-zinc alloys. Trademarked names of aluminum-zinc alloy coatings include *galvalume*, *zincalume*, *zintro-alum*, *galfan* and *galval*.

3.63 molding: A strip of material, frequently ornamental, used to enhance building appearance and/or conceal surface or corner joints. See *trim* and *flashing*.

3.64 offset: The setting back of one part from another.

3.65 oil canning: Waviness in the flat areas of *metal panels* and *trim*.

3.66 panel: A thin, large-surface building part. See *metal panel*.

3.67 panel flat (see Figure 2): Any unformed, flat area of a *metal panel* that lies in the plane of contact between the panel and underlying framing.

3.68 panel length: Distance between panel ends as measured along the centerline of the panel. Generally equal to the average overall length of the two side edges.

3.69 panel rib (see Figure 2): Raised portion of a *rollformed metal panel*. If a *panel* contains two different rib sizes, the larger ribs are called major ribs and the smaller ribs are called minor ribs.

3.70 panelized perimeter: Length of the *building perimeter* that contains wall panels for at least 25% of the wall height.

3.71 plumbness: The orientation of a line or element relative to a truly vertical plane or line. An element that is off plumb or out-of-plumb will tend to lean to one side.

3.72 prepainted coil: Coil steel which receives a paint coating prior to the forming operation.

3.73 press brake: A machine used in *cold-forming metal sheet* into desired shapes.

3.74 rake: The part of a roof that projects over the endwalls. In the absence of an overhang, the rake is line along the endwall formed by the intersection of the endwall and roof planes.

3.75 rib kink (see Figure 7): A compression failure of a major panel rib which occurs when panel bending forces exceed panel bending strength.

3.76 ridge: Highest point on the roof of a building which creates a horizontal line running the length of the building.



Figure 7 - Example of a rib kink.

3.77 rollformer: Machine that uses a progressive series of rollers to *cold-form* thin-metal coils in a continuous process. Common rollformed products include *roof and wall panels*, Cee and Zee purlins, metal studs and jambs, and *metal trims*.

3.78 roof overhang: That portion of a roof that extends beyond the endwall or sidewall of a building.

3.79 roof panel: A *panel* used for covering a roof.

3.80 roof panel overhang: The distance a roof panel extends beyond the eave trim/*fascia*, measured along the edge of the *panel*.

3.81 rope sealant: See *bead mastic*.

3.82 sandwich panel: See *structural insulated panel*.

3.83 sawtooth: The jagged edge appearance that occurs when the ends of adjacent panels are slightly *offset*.

3.84 scrape (see Figure 8): Any removal of surface paint that (1) reveals the underlying *metallic coating* and/or *base metal*, and, (2) is not categorized as a *deep scratch*. This includes scores in the surface that are too wide to be categorized as *deep scratches*, and any area containing multiple, similarly-shaped, closely-spaced, *deep scratches*.

3.85 scrape area: The approximate area of material removed by a *scrape*. If a *scrape* consists of several *deep scratches*, the scrape area is the area enclosed by the *scratches* that define the outer borders of the scraped area.

3.86 scratch (see Figure 8): A single line with a width no greater than 0.04 inches (1.0 mm) that has been etched into a painted surface. The line may be any configuration: straight, curved, jagged, serpentine, etc. Two or more scratches that are similar in shape

and closely spaced would be classified as a *scuff* or *scrape*.

3.86.1 shallow scratch: A *scratch* that does not reveal the underlying *metallic coating* and/or *base metal*. To qualify as a shallow scratch, the line in question must be visible by a majority of normal-sighted individuals when viewed under natural noonday lighting from an *at-grade* position no closer than fifteen feet to the line in question.

3.86.2 deep scratch: A *scratch* that reveals the underlying *metallic coating* and/or *base metal*.

3.87 scratch length: Length of a *scratch* as measured along the centerline.

3.88 scuff (see Figure 8): Any removal of surface paint that (1) does not reveal the underlying *metallic coating* and/or *base metal*, and (2) is not categorized as a *shallow scratch*. A scuff frequently consists of multiple, similarly-shaped, closely-spaced, *shallow scratches*. To qualify as a scuff, the area in question must be visible by a majority of normal-sighted individuals when viewed under natural noonday lighting from an *at-grade* position no closer than fifteen feet to the area in question.

3.89 scuff area: The approximate area of material removed by the *scuff*. If the *scuff* consists of several *shallow scratches*, the scuff area is the area enclosed by the *scratches* that define the outer borders of the scuffed area.

3.90 sealant: Any material which is used to close up cracks or joints to prevent leaks.

3.91 seamer: A mechanical device used to lock or seal the *sidelaps* of a *standing seam roof*.

3.92 self-drilling screw: A screw that drills and taps (thread forms) its own hole. Generally used when one or more of the components to be fastened is metal with a thickness greater than 0.03 inches.

3.93 self-tapping screw: A screw that taps its own threads in a predrilled hole.

3.94 self-piercing screw: A self-tapping (thread forming) screw that does not require a pre-drilled hole. Differs from a self-drilling screw in that no material is removed during screw installation. Used to connect light-gauge metal, wood, gypsum wallboard and other "soft" materials.

3.95 sheet metal: See *metal sheet*.

3.96 sidelap (see Figure 2): The lap occurring at the side or lengthwise direction of *panels*.

3.97 sidewall: An exterior wall orientated parallel to the horizontal line formed by the building *ridge*.

3.98 siphon break (see Figure 2): A small groove to arrest the capillary action of two surfaces in direct contact. Usually found at a *roof panel sidelap*.

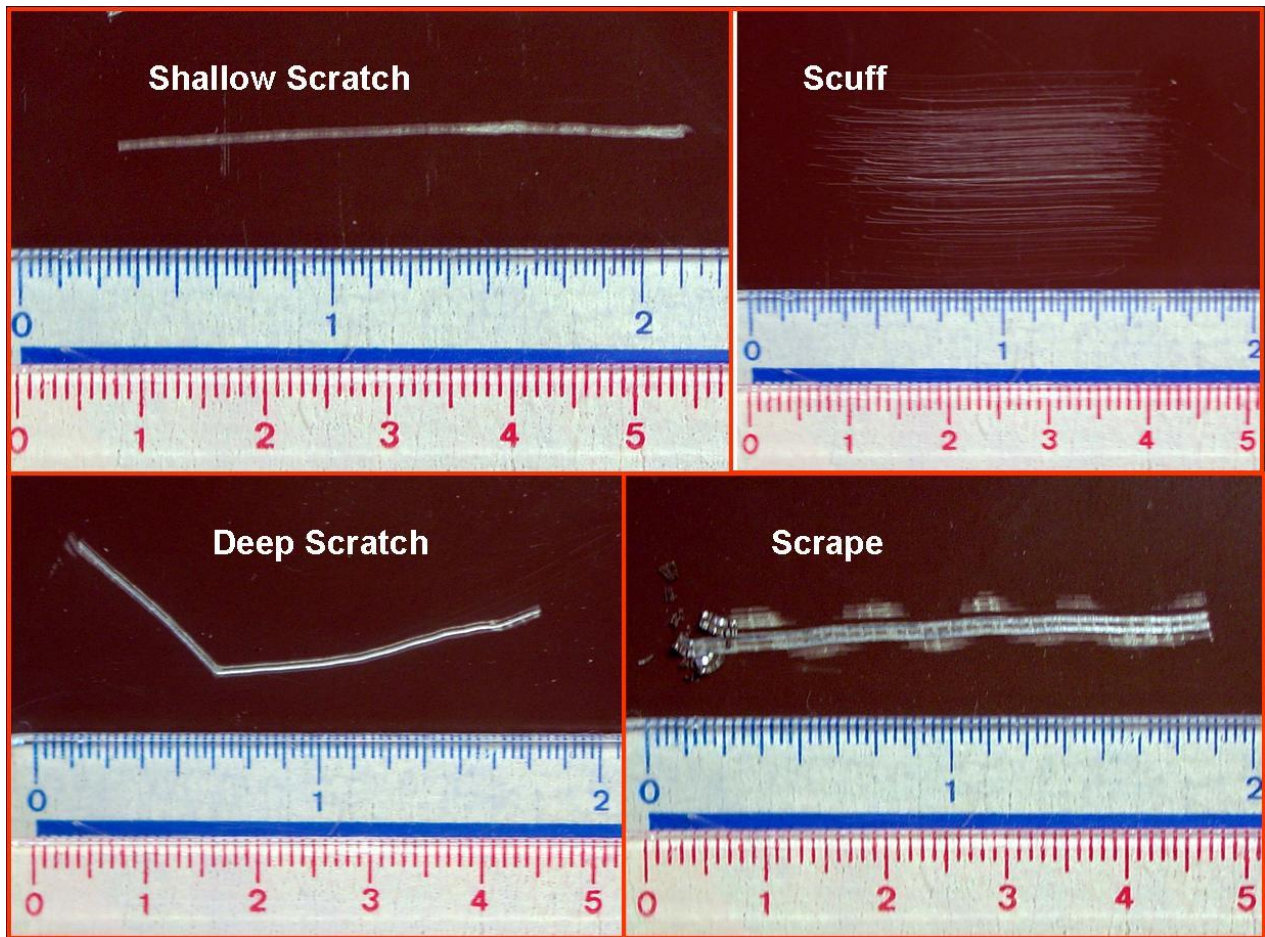


Figure 8 - Example scratches, scuffs and scrapes.

3.99 slitting: Cutting of a *metal sheet* into a smaller *strip*.

3.100 standing seam roof: A roof consisting of *metal panels* with interlocking *sidelaps* or *sidelaps* that are covered with battens. The panels are generally attached to framing with clips hidden from view inside the *sidelaps*.

3.101 stitch (or seam) fasteners: *Fasteners* used to connect *panels* together at the *sidelap*.

3.102 strip: *Metal sheet* less than 24 inches wide.

3.103 structural insulated panel (SIP): A composite panel consisting of a core of insulation material (foam, fiberglass, etc.) laminated between front and back facings. Facing material is generally *sheet metal*, wood paneling, and/or fiber reinforced plastic.

3.104 surface blemish: Any surface imperfection including, but not limited to, *scratches*, *scuffs*, *scrapes*, *dents* and *kinks*.

3.105 through-panel fastener: A *fastener* that requires and/or produces a hole through the panel that it is attaching.

3.106 tape sealant: See *bead mastic*.

3.107 tolerance: A fractional allowance for variations from the specified standard weight, dimensions, etc., in construction.

3.108 trim: The finish materials on/in a building, such as *moldings* and *flashings* applied around door and window openings, and at intersections between different wall, roof, floor and ceiling surfaces. Trims are used to enhance building appearance, and most play a critical role in weather tightness of a structure. See *metal trim*.

3.109 wainscot: A lower wall surface that contrasts with the wall surface above.

3.110 wainscot panel: A *metal panel* that comprises a lower wall surface that differs from the wall surface above.

3.111 wall panel: A *panel* used for covering a wall.

3.112 washer compression level: See *fastener washer compression level*.

4 Metal panel positioning

4.1 Plumbness (see Figure 9).

4.1.1 Individual panel. No wall panel edge should deviate from plumb more than 1.0%. A panel specifically designed to be installed out-of-plumb shall be positioned so that no edge deviates from its specified slope an amount greater than 1.0%.

4.1.2 Adjacent panels. The slopes of any two adjacent wall panels shall not differ by more than 0.3%.

4.1.3 Fanning. No edge/rib of a panel shall differ in slope from another edge/rib on the same panel by more than 0.3%.

4.2 End-to-end alignment of wall panels (see Figure 10). Corresponding ribs of an upper wall panel

and a wainscot panel shall not be offset by more than 3/8 inch (9.5 mm).

4.3 End offset of adjacent panels (sawtooth).

4.3.1 Overhanging roof panels. Edges of adjacent roof panels shall not be offset by more than 0.38 inches (9.5 mm) unless so designed. Ninety-five percent (95%) of all such offsets on a given building shall be less than 0.24 inches (6.0 mm).

4.3.2 Visible wall panel ends (see Figure 10). Visible ends of adjacent panels shall not be offset by more than 0.20 inches (5.0 mm) unless so designed. Ninety-five percent (95%) of all such offsets on a given building shall be less than 0.12 inches (3.0 mm). A visible wall panel end is any panel end that is not covered by trim or otherwise hidden from view.

4.4 Panel edge-to-trim spacing (see Figure 9). The slope of a visible field-cut panel edge shall not deviate from the slope of the adjacent trim by more than 0.5%.

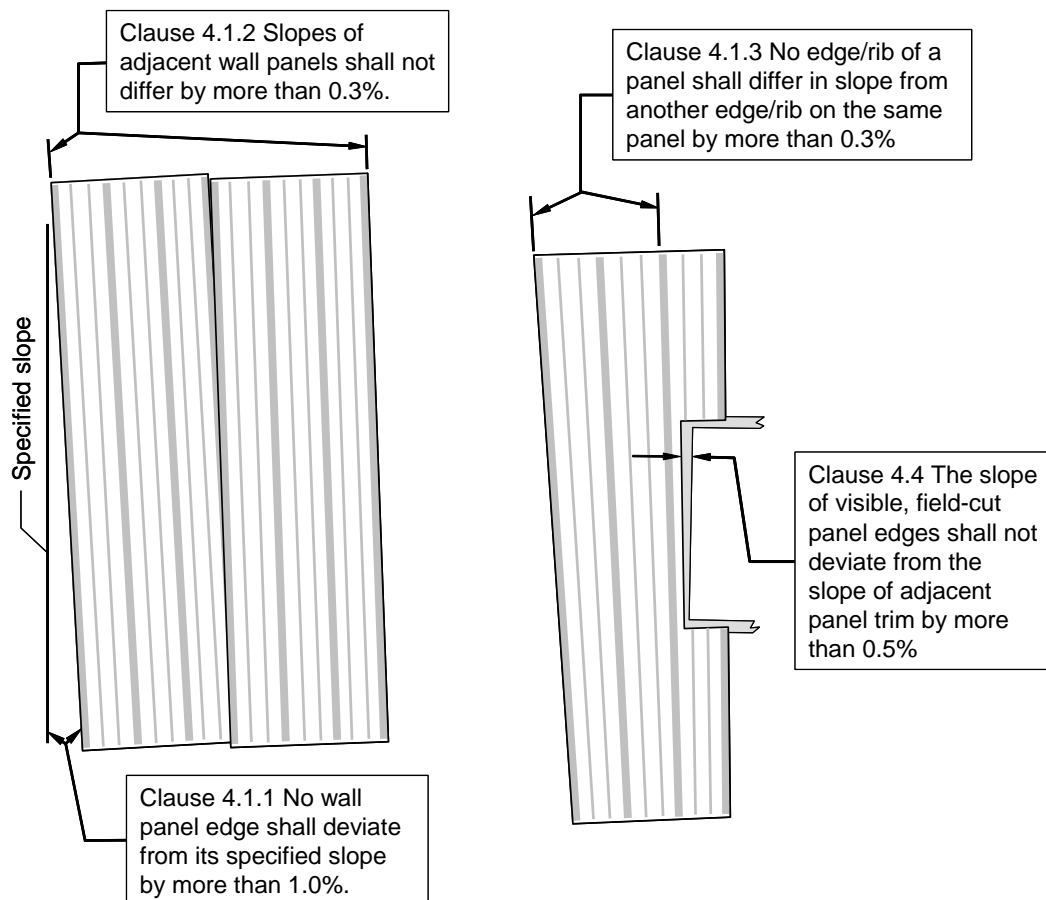


Figure 9 – Wall panel plumbness criteria.

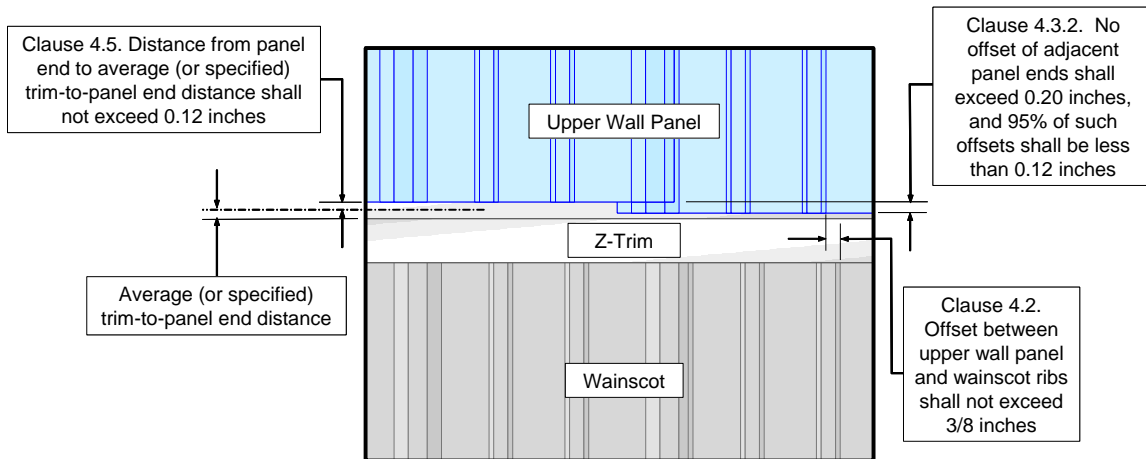


Figure 10 - Wall panel positioning criteria.

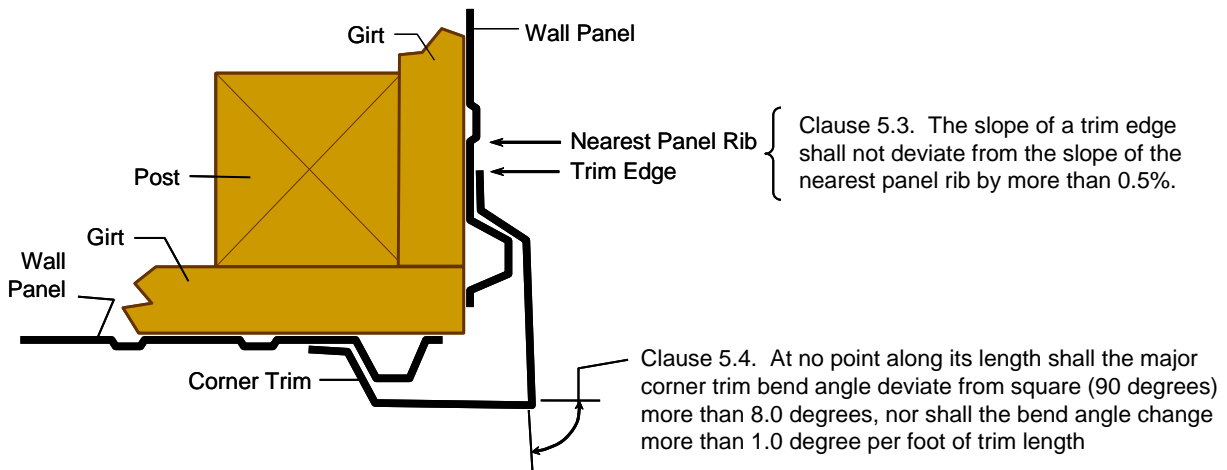


Figure 11 – Trim positioning criteria.

4.5 Panel end-to-trim spacing (see Figure 10). Where the visible cut end of several panels butt up against the same piece of trim, the space between the trim and an individual panel shall not vary in distance from the average or specified spacing by more than 0.12 inches (3.0 mm).

4.6 Roof panel overhang. The overhang of an individual roof panel shall not deviate from the average roof panel overhang by more than 0.75 inches (19.0 mm).

5 Metal trim positioning

5.1 Orientation. Trim orientation should not vary from the specified orientation more than 1.0% (See

Figure A.1(a)).

5.2 Camber. The deviation of a trim edge from a line drawn between any two points on the edge shall not exceed the lesser of (a) 0.3% of the distance between the two points, or (b) 0.5 inches (see Figure A.1(b)).

5.3 Trim edge-to-panel rib spacing (see Figure 11). The slope of a trim edge shall not deviate from the slope of the nearest panel rib by more than 0.5%.

5.4 Corner trim bend angle (see Figure 11). At no point along its length shall the major corner trim bend angle deviate from square (90 degrees) more than 8.0 degrees, nor shall the bend angle change more than 1.0 degree per foot of trim length (1.0 degree per 30 cm of trim length).

6 Fastener installation

6.1 Wall fastener alignment.

6.1.1 Horizontal alignment. Alignment of fasteners within a given horizontal row is checked by drawing a line parallel to the row. The distance between each fastener and the line is measured, and the average fastener-to-line distance calculated. Fasteners can be considered properly aligned if it is possible to position a 12-foot line such that the distance between any one fastener and the 12-foot line does not deviate from the calculated average by more than 0.38 inches (9.5 mm). Additionally, the vertical difference (offset) between adjacent fasteners in the same row shall not exceed 0.38 inches (9.5 mm).

6.1.2 Vertical alignment (parallel-to-rib alignment). Vertical alignment of fasteners is checked using the adjacent rib/seam. The distance between each fastener and the rib/seam is measured, and the average fastener-to-rib/seam distance calculated. The distance between an individual fastener and the rib/seam shall not deviate from the calculated average by more than 0.38 inches (9.5 mm).

6.2 Washer compression. Each fastener shall be driven so that its sealing washer is compressed to the manufacturer's recommended level. Under-driven fasteners shall be driven to proper depth. Any fastener whose washer sealing ability has been compromised by over-driving shall be replaced.

6.3 Drive angle. Fastener drive angle shall not exceed the manufacturer's specified limit. Where such a limit does not exist, the fastener drive angle shall not exceed 15 degrees unless it can be shown that an adequate seal is still formed between fastener head and cladding at a greater drive angle.

6.4 Penetration into wood framing. To ensure a proper and long lasting seal, a fastener must penetrate wood framing a distance of 0.75 inches (19 mm) or 75% of the specified embedment depth, whichever is greater. A fastener that does not meet this requirement must be removed. If the fastener cannot be redriven through the same hole such that it simultaneously meets the aforementioned penetration requirement and the drive angle requirements of Clause 6.3, the installer can (1) install a fastener in the panel hole that penetrates a special wood block or steel washer/backer plate, or (2) install a special corrective fastener (generally an oversized screw) into the hole. No more than 3 such repairs are allowed per 1000 square feet of building area. Note that the aforementioned penetration requirements may be superseded by stricter connection strength requirements.

6.5 Irregular fastener pattern. Fasteners shall be placed in accordance with contract documents.

6.6 Missing sealing washer/assembly. Any fastener that is missing a component that is critical to proper sealing shall not be used in construction. If during installation, a fastener loses a component critical to proper sealing, that fastener shall be removed and replaced.

7 Surface and edge blemishes

7.1 Shallow scratches. Aggregate length of all shallow scratches on trim and wall panels shall not exceed 0.5 inches per foot of panelized perimeter (4.0 cm per meter of panelized perimeter).

7.2 Deep scratches. Aggregate length of all deep scratches on trim and wall panels shall not exceed 0.25 inches per foot of panelized perimeter (2.0 cm per meter of panelized perimeter). No single deep scratch on a wall panel, roof panel or piece of exterior trim shall exceed 4.0 inches (10 cm) in length. The preceding requirements must be met prior to the application of any touch-up paint.

7.2.1 Deep scratch repair. All deep scratches on wall and roof panels and exterior trim shall be touched-up using materials and application procedures approved by the supplier/manufacturer of the panels/trim.

7.3 Scuffs. Total area of all scuffs on trim and wall panels shall not exceed 0.02 square inches per foot of panelized perimeter (0.4 square centimeters per meter of panelized perimeter).

7.4 Scrapes. Total area of all scrapes on trim and wall panels shall not exceed 0.005 square inches per foot of panelized perimeter (0.1 square centimeters per meter of panelized perimeter). No single scrape on a wall panel, roof panel or piece of exterior trim shall expose more than 0.1 square inches (0.65 square centimeters) of the underlying metallic coating and/or base metal. The preceding requirements must be met prior to the application of any touch-up paint.

7.4.1 Scrape repair. All scrapes on wall and roof panels and exterior trim shall be touched-up using paint approved by the supplier/manufacturer of the panels/trim.

7.5 Dents. Total number of wall panel dents shall not exceed 1 per 100 feet (30 m) of panelized perimeter, nor shall the maximum dimension of a wall panel dent exceed 1.0 inches (2.5 cm), nor shall the maximum depth of a wall panel dent exceed 0.12 inches (3 mm). Any roof or wall panel with a dent that is characterized by cracked paint must also be replaced. Scratches, scuffs and scrapes associated with a dent are controlled by the provisions of Clauses 7.1, 7.2, 7.3 and 7.4.

7.6 Rib kinks. A panel with a rib kink shall not be installed on the building unless the rib kink will be covered by another component, and will not affect building structural integrity after construction is complete. A panel with a rib that has been accidentally

kinked during or after installation shall be replaced unless the kink will be covered by another component, and will not affect building structural integrity after construction is complete.

7.7 Edge kinks. Total number of edge kinks on wall panels shall not exceed 1 per 100 feet (30 m) of panelized perimeter.

7.8 Panel side cut exposed. The panel edge that is outwardly visible at the overlap between two panels shall not be field cut.

7.9 Removal of metal chips. Any metal chips resulting from drilling or cutting operations or from the

installation of self-drilling and/or self-tapping screws shall be immediately removed from metal panel and trim surfaces.

7.10 Cutting with abrasive blade. Cutting with an abrasive blade is not recommended. Any metal panel or trim edge or end that will be in any way visible after building completion shall not be cut with an abrasive blade.

7.11 Oil canning. To minimize waviness in panel flats, all panels shall be installed in accordance with manufacturer recommendations.

COMMENTARY

Accepted Practices for Post-Frame Building Construction: Metal Panel and Trim Installation Tolerances

1 Purpose and scope

All building components are assumed to have specific dimensions, and the locations of the components are dimensioned on drawings to a theoretically exact position either relative to each other or relative to one or more datum points. In reality, all component dimensions and positions vary somewhat. The acceptable amount of this variation is the *tolerance* of the component dimension or installed position.

The provisions of this document only apply to light-gage, exterior, metal panel and trim that are directly attached to framing with nails and/or screws. The provisions of this document apply regardless of the framing material to which the metal panel and trim are attached. Consequently, although this document was developed for wood-frame buildings, it can be applied to steel-frame structures.

The thickness limit of 0.05 inches in Clause 1.2 corresponds to 18 gage steel. Although corrugated metal panels of this thickness are available, they are seldom used as exterior cladding on wood-frame structures.

Clause 1.2.1 states that provisions in the appendices are for informational purposes only and are not an enforceable part of this document. That said, builders would be wise to adopt panel fabrication tolerances similar to those recommended in Appendix B, as it is difficult to achieve the installation tolerances in Sections 4 and 5 of this document if panel fabrication tolerances don't meet those recommended in Appendix B.

Clause 1.3 requires that measurements taken for assessment of construction quality be made prior to building use/occupancy or within 90 days of substantial building completion, whichever comes first. This clause is included because the greater the elapsed time between construction and field assessment, the more difficult it is to separate deviations and damage associated with normal structural use and aging from those associated with initial component placement. Note that the relative position of panel and trim components will change as the underlying frame moves. Frame geometry will vary over time as: (1) wood absorbs and desorbs moisture, resulting in changes in the size and shape of members, (2) anticipated and unanticipated loads temporarily and/or permanently deform the structure, and (3) changes occur in unstable or nonconsolidated soils.

The tolerances contained in this document are primarily based on field measurements reported by Bohnhoff and Cockrum (2004). The Bohnhoff and Cockrum study involved 52 buildings, all with corrugated steel

wall and roof panels. All panels had a nominal width of 3 feet. Approximately half the buildings featured panels with a major rib spacing of 9-inch, the other half featured panels with a 12-inch major rib spacing.

2 Normative references

The *NFBA Accepted Practices for Post-Frame Building Construction: Framing Tolerances* document (a.k.a. the *NFBA Framing Tolerances* document) is established as a normative reference because it helps define post-frame building terminology, influences post-frame building component selection, and contains tolerances appropriate to post-frame building construction. If provisions established in the *NFBA Framing Tolerances* document are not met, it becomes exceedingly difficult for builders to meet some of the panel and trim installation requirements in Sections 4 and 5 of this document.

As previously stated, wood framing members will change in shape and size as they absorb and desorb moisture. For this reason, the *NFBA Framing Tolerances* document makes allowances for a certain amount of lumber warping. It is important to realize that warped framing is often accentuated by the application of metal paneling. Even through warped framing may make installed cladding less attractive, the installation is still acceptable as long as tolerances in this document and in the *NFBA Framing Tolerances* document are met. In some cases, steps can be taken to lessen the impact of lumber warping on cladding appearance. For example, Figure 12 shows a situation where a cupped girt resulted in noticeable depressions around screw fasteners. These depressions would likely not have appeared if the girt had been installed with its convex side facing outward.

3 Definitions

Section 3 contains definitions associated with fabrication, installation and durability of metal panels and trim. Although some words defined in Section 3 do not appear elsewhere in this document, they have been included because they help define terminology that is likely to be used in discussions associated with this document.

Some of the definitions appearing in Section 3 are based on definitions given in the *Metal Building Systems* book published by the Building Systems Institute (1990). The Building Systems Institute is a coalition of allied trade organizations that promotes low-rise, non-residential construction with steel.



Figure 12 - Panel attachment to a cupped girt results in noticeable depressions around fasteners.

Definitions for scratch (shallow and deep), scuff, scuff area, scrape, and scrape area are unique to this document and essential to document application. In general, a scratch is a surface blemish caused by a single sharp point. Scuffs and scrapes are surface blemishes resulting from another surface or edge being drawn over the surface. To qualify as a shallow scratch or scuff, the blemish must be visible by a majority of normal-sighted individuals when viewed under natural noonday lighting from an at-grade position no closer than fifteen feet to the blemish in question. In practice, this requires that a line be drawn all the way around the building 15 feet from each exterior wall surface. If a majority of normal-sighted individuals spot the blemish on their own (i.e., without assistance from others) without ever entering inside the 15-foot offset boundary, then the blemish meets the visibility criteria. The fifteen foot distance was not arbitrarily selected for this document, but was taken from a document published in 1981 by the Indiana Chapter of NFBA.

Three other surface blemishes that have been categorized, uniquely titled, and defined in this document are *edge rippling*, *edge kink* and *rib kink*.

4 Metal panel positioning

It is very difficult to judge the plumbness of a component with the naked eye unless the component abuts or is very near to a component known to be plumb. For this reason, builders and building owners are frequently more concerned with how a panel aligns with nearby building elements (e.g. posts, door jambs) than whether or not it is perfectly plumb. Clause 4.1 recognizes this relative importance by allowing an

individual panel to deviate from plumb (or its specified orientation) by 1.0%, but placing a stricter limitation of 0.3% on (1) the difference in slopes between adjacent panels, and (2) the difference in slopes of ribs/edges of the same panel. The 1.0% value is identical to that permitted for the deviation of posts from specified values (NFBA, 1999). Consequently, a wall panel will be within tolerance if it is perfectly aligned with a post that is within its placement tolerance. Fanning of panels is effectively controlled with the 0.3% restrictions in Clauses 4.1.2 and 4.1.3.

Clause 4.2 limits misalignment of wainscot and upper wall panel ribs to 3/8 inch (9.5 mm) – an offset which was exceeded 1% of the time in the Bohnhoff and Cockrum study (2004). To obtain a good alignment of wainscot and upper wall panel ribs, builders will first install upper wall panels. This is because upper wall panels are longer than wainscot and therefore more difficult to adjust if the “run-out” on the upper wall panels and wainscot panels differ.

End-to-end alignment of panel ribs is less important the greater the distance between panel ends, and the further the panel ends are from view. For these two reasons, alignment of roof panel ribs with wall panel ribs is seldom controlled during panel installation. This statement is supported by the Bohnhoff and Cockrum (2004) research, and explains why this document does not contain a tolerance requirement for the alignment of roof panel ribs with those of wall panels. In cases where there is no eave overhang, and roof and wall panels ends are not separated by horizontal eave trim/fascia, an offset tolerance similar to that in Clause 4.2 may be appropriate for the alignment of roof and wall panel ribs.

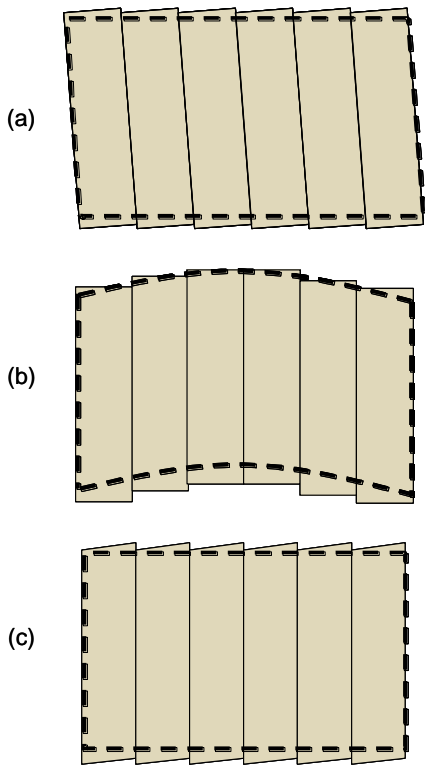


Figure 13 - Conditions that lead to greater panel end offset include (a) racked framing, (b) curved framing, or (c) panel end cuts that are not square.

Clause 4.3 places limits on the end offset (i.e. saw-tooth) of adjacent panel ends. As Figure 13 shows, it becomes considerably more difficult to consistently eliminate such offsets when (1) attaching panels to a racked frame, (2) attaching panels to a curved frame, and/or (3) using panels with end cuts that are not square. Clause 4.3.1 for overhanging roof panels, and Clause 4.3.2 for visible wall panel ends, each contain two limits which are based on data from the Bohnhoff and Cockrum (2004) study. Specifically, the 0.38- and 0.24-inch limits for overhanging roof panels were met 99.8% and 94.8% of the time, respectively, and the 0.20- and 0.12-inch limits for visible wall panel ends were met 99.5% and 95.5% of the time, respectively, in the Bohnhoff and Cockrum (2004) study. The Metal Construction Association (MCA) *Preformed Metal Wall Guidelines* limit end offset to 0.19 inches at the panel base, to 0.25 inches for panel laps below 40 feet, and to 0.50 inches for laps above 40 feet.

Clause 4.4 is intended to control the fit of wall paneling edges along the sides of trimmed-out wall openings. This clause does not apply to panel edges that are hidden from view by the trim. The 0.5% limit in Clause 4.4 was selected to match the limit established in Clause 5.3 for trim edge-to-panel rib spacing.

Spacings between the visible cut ends of wall panels and a piece of horizontal trim (e.g., zee trim, base trim) are controlled by Clause 4.5. This clause recognizes that it is not the magnitude of the spacings, but the consistency of the spacings that is important. For example, if gaps between the center of each of four wall panels and a piece of trim are 0.36, 0.52, 0.60, and 0.48 inches, the average gap will be 0.49 inches, and the absolute deviations from the average for these four panels will be 0.13, 0.03, 0.11, and 0.01 inches, respectively. In this case, the deviation associated with the first panel (0.13 inches) exceeds the 0.12 inch maximum allowed by Clause 4.5.

Clause 4.6 limits variations in the distance that roof panels overhang eave trim. Data collected by Bohnhoff and Cockrum (2004) showed that variations in this distance had less to do with misalignment of the ends of adjacent panels (i.e., panel end offsets), and more to do with eave shape or eave trim attachment. Stated more specifically, roof panel overhang variations were significantly greater than roof panel end offsets. This would imply that either (1) eave trim gets further and further from (or closer and closer to) roof panel ends as one moves down the eave, or (2) eave trim curves or snakes along the length of the building while roof panel ends remain in a straight line.

Proper panel positioning is more difficult when panel profiles vary slightly. Variations in panel profile are typically due to variations in steel coils and to the use of different roll-formers. Although less likely, profile variations can result from improper handling or storage (i.e., a large force flattens all or a portion of some panels). Note that the use of different roll formers is more likely when different colored wall panels are used on the same building, and frequently explains why the run-out of upper wall panels and wainscot differ.

5 Metal trim positioning

Limits on the deviation of trim orientation from that specified in contract documents is established at 1.0% in Clause 5.1. This maximum allowable deviation is equal to that established for individual wall panels in Clause 4.1.

Clause 5.2 controls trim edge straightness by limiting the deviation from a line drawn between any two points on the edge to the lesser of 0.5 inches (13 mm) or 0.3% of the distance between the two points. Because 0.5 inches is equivalent to 0.3% of 167 inches (6.56 m), the 0.5 inch limit controls once the distance between the two points exceeds 167 inches. Limiting deviations to 0.3% of the distance between two points is equivalent to a displacement limitation of $L/333$, where L is the distance between the two points.

Clause 5.3 limits the difference in slopes between a trim edge and the nearest panel rib to 0.5%. This clause is of primary importance when installing corner

trims and jamb flashing. In the study by Bohnhoff and Cockrum (2004), 88% of corner trim edges had a slope within 0.5% of the slope of the adjacent panel rib.

Side jambs and casings of many prehung doors and windows are designed to fall in panel flats. Likewise, edges of corner and rake trims are designed to fall on the panel flats (as shown in figure 1) and not on major ribs. When wall panels are not correctly positioned, the major corner trim bend angle is generally forced open or closed to keep the trim edge in the wall panel flat. Clause 5.4 limits the extent to which a piece of corner trim can be distorted in this manner.

6 Fastener installation

Roof fasteners are exempted from the fastener alignment criteria of Clause 6.1 as they are seldom visible when viewed from an at-grade position near the building. Additionally, the goal when locating a roof fastener is to target the center of the underlying wood framing member as this decreases the likelihood of missing the framing member, especially when the fastener is driven into the narrow face of the framing member. When fasteners are targeted to align with the centerline of a framing member, fastener alignment will depend on the curvature of the installed framing.

Horizontal alignment criteria for wall fasteners is based on research by Bohnhoff and Cockrum (2004) who used a 12-foot aluminum bar to assess fastener alignment. Limiting horizontal alignment investigations to 12-foot lengths will permit gradual curvature of a long fastener row. This gradual curvature is generally only detectable when sighting down along (i.e., parallel to) a wall. Clause 6.1.1 states that wall fasteners can be considered properly aligned if it is possible to position a 12-foot line such that the distance between any one fastener and the 12-foot line does not deviate from the calculated average by more than 0.38 inches (9.5 mm). In the Bohnhoff and Cockrum study, 99% of the fasteners met this requirement for proper alignment. Clause 6.1.1 also requires that the vertical difference (offset) between adjacent fasteners in the same row not exceed 0.38 inches (9.5 mm). Without this clause, adjacent fasteners could be offset by as much as 0.75 (19 mm) as one fastener could be 0.38 inches above a best fit line, and the adjacent fastener positioned 0.38 inches below the same best fit line. In the Bohnhoff and Cockrum study, 99% of the vertical offsets between adjacent fasteners were less than 0.38 inches.

Wall fastener location is generally established by predrilling, center-punching, or marking the panels in some other manner while they are still stacked in a horizontal position (the indentation left by the punch helps keep screw points from “walking” and thus marring the panel surfaces during drive commencement). Given that these marks are the same distance from the bottom edge of each panel, those installing

the panels only need to ensure that the ends of adjacent panels are not offset in order to guarantee compliance with Clause 6.1.1. Obviously any upward or downward shift of a premarked panel relative to the adjacent premarked panel will affect the horizontal alignment of fasteners an amount equal to the offset.

Fasteners need to be driven to a depth that properly compresses the sealing washing. Overdriving of some fasteners can squeeze the sealing washer out from under the fastener head. When this occurs, the fastener must be replaced. Figure 14 shows the numerical scale used by Bohnhoff and Cockrum (2004) to quantify screw and nail fastener drive depths. For the fasteners shown in this figure, those with depths between -1 and +3 would be considered acceptable, those with depths between -2 and -5 require additional driving, and those at depths of +4 and +5 should be replaced.

Fastener sealing washers are designed to seal even when the fastener is driven at a slight angle. Maximum drive angle will vary from one fastener type to another. Factors affecting this maximum include: sealing washer composition and size, whether the sealing washer is bonded or unbonded to the fastener head, and whether a metal washer is used between the fastener head and sealing washer. In the absence of a fastener manufacturer specified limit, Clause 6.3 limits fastener drive angle to a maximum of 15 degrees unless it can be shown that an adequate weather-tight seal can be formed between the fastener head and cladding at a greater drive angle. Bohnhoff and Cockrum (2004) found that fastener drive angle was lowest, on average, for fasteners within 3 to 6 feet of grade. This is not surprising as fasteners within 3 to 6 feet of grade can be installed from an at-grade position without stooping or reaching.

A fastener that does not properly penetrate wood framing is more likely to loosen, thus compromising the watertight seal. Clause 6.4 helps ensure a proper and long lasting seal by requiring that every fastener penetrate wood framing at least 0.75 inches (19 mm) or 75% of the minimum specified depth, whichever is greater. A fastener that does not meet this requirement can be removed and re-driven at a different angle through the same hole in an attempt to meet the penetration requirement. Obviously the new drive angle must meet the requirement of Clause 6.3. If this does not work, the installer can plug the hole with a special corrective screw (a.k.a. a goof screw) or by driving a fastener through the hole and into a special wood block or steel washer/backer plate that has been placed on the backside of the panel for this specific purpose. It is not recommended to seal a panel hole with sealant. Regardless of the method used to obtain a proper seal, steps must be taken to ensure that strength requirements of the panel-to-framing connection are still met. This is best accomplished by properly installing another fastener near the location of the first.

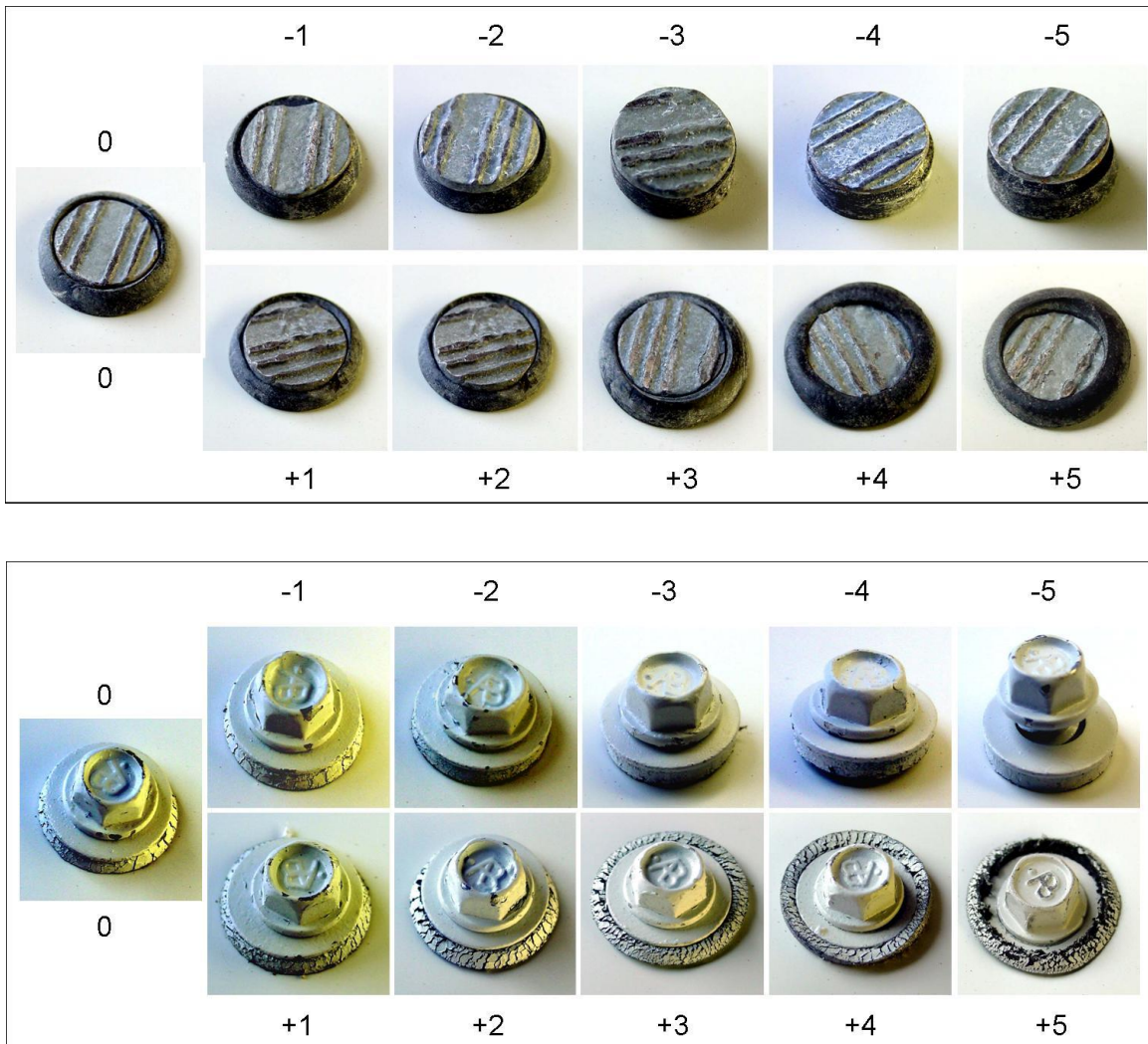


Figure 14 - Numerical scales used by Bohnhoff and Cockrum (2004) to quantify screw and nail fastener drive depths.

7 Surface and edge blemishes

Maximum allowances for scratches, scuffs, scrapes and dents are based on the length of panelized perimeter. Panelized perimeter (and not panelized wall area) was selected as the basis for allowable surface blemishes for two reasons. First, it is easier to calculate, especially when there are numerous small wall openings and when wall height varies as it does on most endwalls. Second, the number of surface blemishes is found to be more directly related to building perimeter than building wall area. This is because surface blemishes increase with increases in the number of wall openings, the number of wall panels, the number of trim pieces, and the length of horizontal base and zee trims. Each of these factors is more a function of perimeter length than wall area.

Panelized perimeter is defined by Clause 3.71 as the length of building perimeter containing wall panels for at least 25% of the wall height. Consequently, a rectangular building with a 50-foot width, a 100-foot length, a 16-foot eave height, three service doors, eight 4- by 4-foot windows, and two 16-foot wide and 14-foot high overhead doors in one of the sidewalls, would have a panelized perimeter of 268 feet (300 feet minus 32 feet). The 32 feet subtracted from the gross perimeter of 300 feet is the aggregate width of the overhead doors, which because of their height, leave less than 25% of the total wall height covered by wall panels.

The aggregate length of all shallow scratches on trim and wall panels is limited by Clause 7.1 to 0.5 inches per foot of panelized perimeter. This is equivalent to 134 inches for building with a total panelized perime-

ter of 268 feet. It is important to note that the location of these scratches is not restricted. This means that the allowable 134 inches of shallow scratching for the example building could be on the same wall panel or piece of trim. However, if the 134 inches is exceeded, scratched wall paneling and/or trim would have to be replaced with less-blemished components to bring the total under 134 inches.

In accordance with Clause 7.2, the allowable aggregate length of deep wall scratches is limited to 0.25 inches per foot of panelized perimeter, which is half that allowed for shallow wall scratches. This is equal to 67 inches for a building with a total panelized perimeter of 268 feet. This maximum must be met before any touch-up paint is applied. If not met, wall panels/trim with deep wall scratches must be replaced to bring the total under the maximum allowed. In addition to this limitation, no single deep scratch on the entire metal-clad exterior of the building (this includes roof panels) can be longer than 4.0 inches. Any panel/trim with a longer scratch must be replaced. All deep scratches that remain on the walls and roof of the building must be repaired with touch-up paint so that no underlying base metal or metallic coating is visible. The materials and application procedures used for this purpose must be approved by the supplier/manufacturer of the panel.

Requirements for scuffs and scrapes are similar to those for shallow and deep scratches, respectively, except that scuff and scrapes restrictions are expressed as an allowable area (not length) per unit length of panelized perimeter.

Clause 7.5 restricts the number and size of dents on wall panels and trims. There are no such restrictions on roof panel dents. However, any panel, whether it be on the roof or wall, must be replaced if the action causing the dent has cracked the paint – an indication that more severe damage to the panel's protective coating(s) has possibly occurred. Frequently, the action causing the dent has removed surface paint. In such a case, the resulting scratch, scuff or scrape is treated like any other scratch, scuff or scrape and is subject to the restrictions and corrective measures established in Clauses 7.1, 7.2, 7.3 and 7.4.

Many dents and scratches are associated with fastener installation. Dents are frequently due to poor or worn sockets that slip off screw heads during driving. Scratches result from screws points that fail to pierce paneling (when downward pressure is applied and the screw gun is triggered) and instead “walk” across the panel surface. It is not uncommon to come across a batch of screws that are difficult to get started, and hence of poor quality.

The most blemished areas in the Bohnhoff and Cockrum study (2004) were the top surfaces of base and zee trim (Figure 15). Avoiding scratches, scuffs

and scrapes in these areas is not difficult. Figure 16 illustrates the option employed by most experienced builders, that is, to use the back side of another piece of trim to protect the finished surface of a piece of zee or base trim. Another option is to slide trim up behind wall panels and fasten them in place after all but the bottom row of fasteners have been installed in the panels. Aligning the base of panels when trim is not yet installed is probably best accomplished by attaching a straight wood member to the wall as a temporary support ledger for the wall panels.

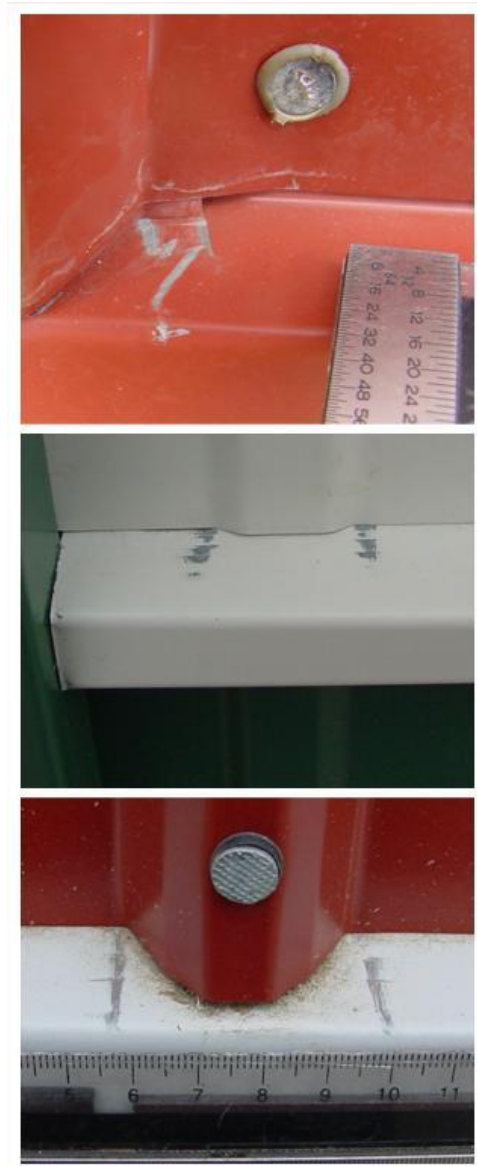


Figure 15 - Scratches and scrapes are frequently found on zee and base trim.

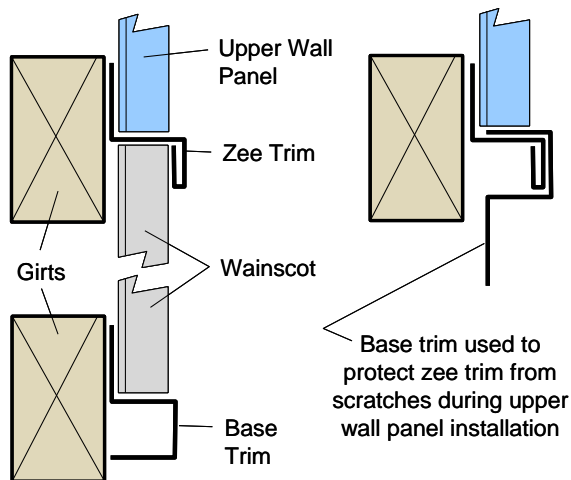


Figure 16 - Using a piece of base trim to protect zee trim during upper wall panel installation.

When cutting an opening in a panel as it lies on another panel, it is important to protect the lower panel with cardboard or some other barrier. Failure to do this is characterized by scratches on the panels that frame wall openings and/or on the panels that are adjacent to panels that frame openings. Workers must also be careful of sheared edges when stacking or unstacking panels. Unless special protection is used, sheared edges of shorter panels (e.g., gable end panels) may scratch the surface of adjacent longer panels.

Clause 7.6 prohibits a panel with a kinked rib from being installed or remaining on a building unless the kink will be covered by another component and will not affect building structural integrity after construction is complete. A rib kink is compression failure of a major panel rib which occurs when panel bending forces exceed panel bending strength. It follows that any panel with a rib kink is no longer capable of sustaining its published design loads. In this respect, a rib kink is considerably more critical than any other surface blemish. Long narrow components that are not properly supported during transportation and final positioning can easily incur a rib kink. A long panel that is lifted/carried only by its ends while in a flatwise

position is almost guaranteed to incur a rib kink. For this reason, long panels are lifted by their edges and transported in a vertical position. Alternatively, a long panel can be rolled such that its edges are literally touching. This not only protects one side of the panel during transport, but it also enables a single person to carry a long panel very effectively. Avoiding rib kinks in roof panels requires that they be moved onto a roof with care, and that higher concentrated loads not be applied between panel supports and/or directly on a high rib. Note that the greater the support spacing, the easier it becomes to kink a major rib by applying a force to the panel.

Edge rippling (Figure 6) can be caused by panel fabrication processes (see Appendix B.5 Oil canning), mishandling of a corrugated panel, and/or installation of a corrugated panel on a convex surface. In its most severe form, edge rippling is characterized by edge kinks. Edge kinks are most likely due to panel mishandling, and can occur when long panels are lifted in the center when panel ribs are facing upward, or when long panels are lifted at the ends when panel ribs are facing downward. With most corrugated panels, either of these two actions will compress the extreme edge of the overlapping rib. The edge kinks shown in Figure 3 are identical in location, and thus likely occurred when a stack of panels was inappropriately lifted. Clause 7.7 restricts edge kinks on wall panels to one per 100 feet of panelized perimeter. This document places no other restrictions on edge rippling.

Metal filings, drillings, cuttings and other metal debris should never be left on panel and trim surfaces, as they generally corrode and cause rust stains. Such particles should be removed from painted roof panels as soon as possible since walking on them can damage a paint film.

Field cutting of metal panels and trim is best accomplished with a sharp shears/nibblers or a circular saw with a special carbide-tipped metal-cutting blade. Cutting with an abrasive disc should be avoided to prevent damage to paint and metal coatings. Be aware that hot metal particles thrown from spinning blades/discs can easily embed themselves in nearby panels/trim.

Appendix A - Measurement Equivalencies

Many allowable deviations (i.e., tolerances) in this document are expressed as a percent slope. To calculate such a deviation, the actual location or orientation of the component edge in question must first be identified. In Figure A.1(a), this location is labeled as the *reference line*. Note that the reference line may be the edge of another component, the edge of a carpenter's level or framing square, etc. The deviation of the component edge from this reference line is identified with the variable X . The distance from where X is measured, to the point where the component edge and the reference line intersect, is identified as distance D . Percent slope is equal to 100 times X divided by D . The angle between the reference line and the slope of the component is equal to the arctangent of X divided by D .

Relationships between deviation X , distance D , the deviation slope in %, and the deviation angle in degrees are compiled in Table A.1. This table shows, for example, that a deviation of 0.80% is equal to an angle of 0.46 degrees, and to a deviation of 0.288

inches in 3 feet, or a deviation of 0.768 inches in 8 feet, etc.

Restrictions on component camber (Figure A.1(b)) place limits on the maximum deviation, X , between the component's edge and a line drawn between two selected points on the component's edge. This deviation is generally limited to some fixed value or to some percentage of the distance L between the two selected points. For example, Clause 5.2 restricts camber in a piece of installed trim to the lesser of 0.5 inches or 0.3% of the distance L . Instead of expressing the limitation on camber as a *percentage* of the distance L , one can express it as a *fraction* of the distance L . For example, 0.5% of L is numerically equivalent to $L / 200$. Note that the latter method is more commonly used to express limitations on component deflections where L is the distance between component supports. Percents of L and fractions of L appear in the first and last columns, respectively, of Table A.1.

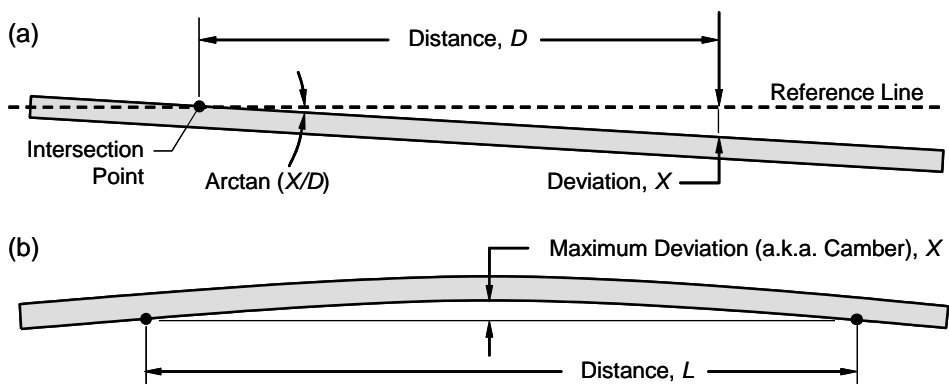


Figure A.1 – Measurement nomenclature for (a) deviation of a component edge from a reference line, (b) component camber.

Table A.1 – Equivalency Table

Slope, Percent	Angle, Degrees	Deviation, X , in inches when D (or L) is:					Camber
		2 ft	3 ft	4 ft	8 ft	10 ft	
0.20	0.11	0.048	0.072	0.096	0.192	0.240	$L/500$
0.30	0.17	0.072	0.108	0.144	0.288	0.360	$L/333$
0.40	0.23	0.096	0.144	0.192	0.384	0.480	$L/250$
0.50	0.29	0.120	0.180	0.240	0.480	0.600	$L/200$
0.60	0.34	0.144	0.216	0.288	0.576	0.720	$L/167$
0.80	0.46	0.192	0.288	0.384	0.768	0.960	$L/125$
1.00	0.57	0.240	0.360	0.480	0.960	1.200	$L/100$
1.20	0.69	0.288	0.432	0.576	1.152	1.440	$L/83$
1.50	0.86	0.360	0.540	0.720	1.440	1.800	$L/67$
2.00	1.15	0.480	0.720	0.960	1.920	2.400	$L/50$

Appendix B - Recommended Panel Fabrication Tolerances

If variances from specified panel dimensions are not controlled during panel fabrication, it can be difficult, if not impossible for those erecting the building to meet requirements of Sections 4 and 5. For this reason, it is important for builders to establish panel fabrication tolerances. To guide builders in this effort, recommended tolerances for fabricated panel length, end cut, cover width and edge camber are given in this Appendix. Similar controls on panel fabrication appear in the Metal Construction Association (MCA) *Preformed Metal Wall Guidelines* and in the Steel Deck Institute (SDI) *SDI Design Manual*. Tolerances in the *SDI Design Manual* are for steel roof deck, and consequently, are not as tight as those published for wall panel by MCA. Although developed completely independent of each other, the following recommended fabrication tolerances are similar in magnitude to those published in the *MCA Preformed Metal Wall Guidelines*. Slight differences between the two are discussed in the following paragraphs.

Recommended panel fabrication requirements are illustrated in Figure B.1. Note that measurements used to check these requirements should always be made with panels positioned without restraint and with support that does not influence the magnitude of the quantity being determined.

B.1 Panel length. [Recommended tolerance: *The average manufactured length (corrected to 65°F) of all panels produced for a given specified length, shall be within 0.30 inches (7.5 mm) of the specified value. No single manufactured panel shall have a length that deviates from the average manufactured panel length by more than 0.20 inches (5 mm).*]

MCA allows individual manufactured panel length to deviate from the specified length by +/- 3/8 inches. This allows, in theory, for two panels from the same run to differ by as much as 0.75 inches (19 mm). Such a difference could cause problems in certain wall and roof paneling applications. The recommended tolerance recognizes this shortcoming by requiring that no single panel deviate from the average manufactured panel length by more than 0.20 inches (5 mm). This means that no two panels from the same run can differ in length by more than 0.40 inches (10 mm). Additionally, the recommended tolerance requires that the average manufactured panel length for a given run – not the length of one specific panel – be within 0.30 inches (7.5 mm) of the specified panel length. This means that an individual panel length could differ from the specified panel length by +/- 0.50 inches (0.30 inches + 0.20 inches). In this regard, the recommended tolerance for panel length is more liberal than the MCA requirement.

B.2 Panel end cut. [Recommended tolerance: *Panel ends specified to be square shall be cut within 0.5%*

of square. Panel ends specified to be tapered shall be cut within 1.0% of the specified slope.]

This recommendation sets the maximum allowable tolerance on a panel end cut to 0.5% of square for panel ends that are specified to be square. This equates to 0.19 inches (4.8 mm) for a panel with a 38-inch overall width. When panel ends are specified to be cut at an angle other than 90 degrees, this tolerance allows the cut to be off by as much as 1.0% - double the allowance for a square end cut. The MCA fabrication tolerance on panel end squareness is 0.5% of the panel width. In addition, MCA limits the total deviation at one end to one-eighth inch (3.1 mm). MCA does not have fabrication tolerances for ends cuts that are specified to be something other than 90 degrees.

B.3 Panel edge camber. [Recommended tolerance: *The deviation of a panel edge from a line drawn between any two points on the edge shall not exceed 0.16% of the distance between the two points.*]

This recommendation limits the deviation of a panel edge, from a line drawn between any two points on the edge, to 0.16% of the distance between the two points. This deviation is equivalent to a deflection criteria of $L/625$ (see Appendix A). The MCA tolerance on panel camber is 3/16 inches (4.8 mm) per 10 ft (3.05 m) length, which is equivalent to a deflection criteria of $L/640$.

B.4 Panel cover width. [Recommended tolerance: *At no point along its length shall the fabricated cover width of a corrugated panel deviate from the specified cover width by more than 0.20 inches (5 mm). At no point along its length shall the fabricated cover width of a standing seam panel deviate from the specified cover width by more than 0.10 inches (2.5 mm).*]

Including a panel cover width tolerance is critical to ensuring proper panel spacing and alignment without excessive distortion during installation. Because corrugated panel width is easier to alter during installation than is standing seam panel width, it is recommended that the allowable cover width deviation for corrugated panels be twice that for standing seam panels. The *MCA Preformed Metal Wall Guidelines* do not address fabricated panel width.

B.5 Oil canning. [No recommended tolerance]

Manufacturing processes can result in noticeable waviness in the flat areas of manufactured panels and trims. This waviness is not uncommon and can be caused by residual stresses induced during master coil production. As a result of these stresses, the edges of a coil may be longer than the center of the coil, or the center longer than the edges. In some cases, the residual stresses on one side of the coil

are different than on the other side, resulting in a coil that displays camber when unrolled. Slitting of a master coil to produce narrower coils can release and redistribute residual stresses. Additionally, roll form-

ing can redistribute residual stresses and induce new stresses. Oil canning is difficult to quantify, and thus no recommended tolerances for its control are herein provided.

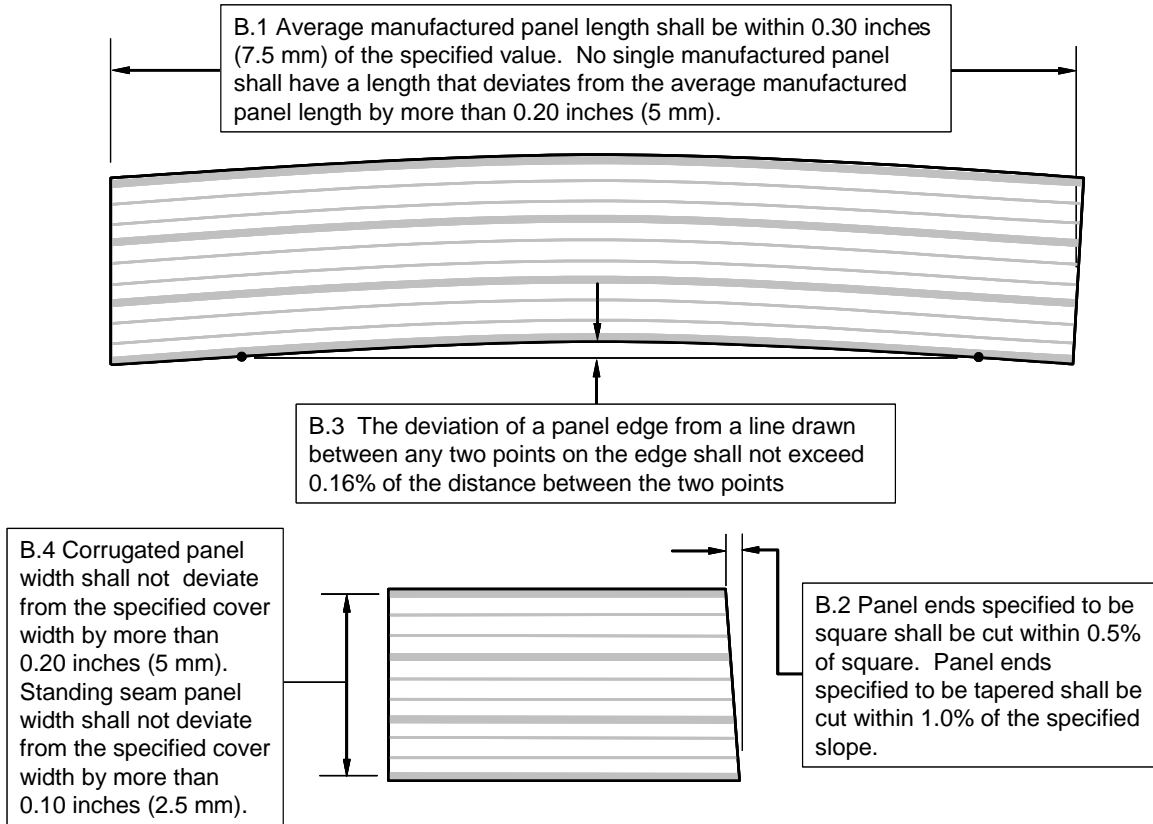


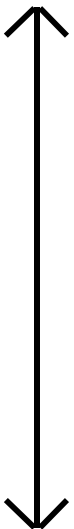
Figure B.1 - Recommended panel fabrication requirements.

Appendix C - Galvanic Corrosion

Galvanic corrosion is a common form of corrosion that occurs when dissimilar metals or metal alloys are brought into electrical contact by immersion in a conductive electrolyte. In the case of building materials, this conductive electrolyte is generally impure water (e.g., rainwater, groundwater). When electrically connected, one of the dissimilar metals becomes the anode and corrodes faster than it would all by itself in the conductive electrolyte, while the other metal becomes the cathode and corrodes slower than it would alone in the conductive electrolyte. Because minimization of galvanic corrosion plays a critical role in panel, trim and fastener selection, it is covered in detail in this Appendix.

C.1 Galvanic series. Which metal becomes the anode and which becomes the cathode depends on their relative electrical potential within the conductive electrolyte. Table C.1 contains a list of the electrical potentials of metals in flowing seawater. When arranged in order of their electrical potential, the list of metals is referred to as a galvanic series. Within a galvanic series, the metal closer to the anodic (or active) end of the series will be the anode and thus will corrode faster, while the one toward the cathodic (or noble) end will corrode slower. The greater the electrical potential difference between two metals, the more rapidly the anode will corrode when the metals are electrically connected.

Table C.1 – Galvanic Series (in Flowing Seawater)
(Source: Stephen Dexter, University of Delaware Sea Grant Marine Advisory Service)

	Metal or Metal Alloy	Electrical Potential Range of Alloy vs. Reference Electrode, volts*
<p style="text-align: center;">Anodic or Active End</p>  <p style="text-align: center;">Cathodic or Noble End</p>	Magnesium	-1.60 to -1.63
	Zinc	-0.98 to -1.03
	Aluminum Alloys	-0.70 to -0.90
	Cadmium	-0.70 to -0.76
	Cast Irons	-0.60 to -0.72
	Steel	-0.60 to -0.70
	Aluminum Bronze	-0.30 to -0.40
	Red Brass, Yellow Brass, Naval Brass	-0.30 to -0.40
	Tin	-0.29 to -0.31
	Copper	-0.28 to -0.36
	Lead-Tin Solder (50/50)	-0.26 to -0.35
	Admiralty Brass, Aluminum Brass	-0.25 to -0.34
	Manganese Bronze	-0.25 to -0.33
	Silicon Bronze	-0.24 to -0.27
	Stainless Steel – Type 410, 416**	-0.25 to -0.36
	90-10 Copper-Nickel	-0.21 to -0.28
	80-20 Copper-Nickel	-0.20 to -0.27
	Stainless Steel – Type 430	-0.20 to -0.32
	Lead	-0.19 to -0.25
	70-30 Copper-Nickel	-0.13 to -0.22
Silver	-0.09 to -0.14	
Stainless Steel – Types 302, 304, 321, 347	-0.05 to -0.10	
Stainless Steel – Type 316, 317 **	-0.00 to -0.10	
Titanium and Titanium Alloys	+0.06 to -0.05	
Platinum	+0.25 to +0.18	
Graphite	+0.30 to +0.20	

* These numbers refer to a Saturated Calomel Electrode. Measured in seawater with flow rates between 8 and 13 ft/s and temperatures between 50 and 80 F (10-27 C)

** Values listed are for a passive state. In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V

The electrical potential given in Table C.1 for each metal is the potential measured between the metal and a saturated calomel electrode when both were inserted in 50 to 80 F seawater flowing between 8 and 13 ft/s. Changing the reference electrode (saturated calomel) and the type and properties of the aqueous solution (seawater) will produce different electrical potentials for the metals. That said, the ratios between electrical potentials of different metals, and hence the order of the metals within the galvanic series, will generally not change significantly when the seawater is replaced with a similar aqueous solution (e.g. rain water, tap water) and/or the reference electrode is changed.

C.2 Minimizing galvanic corrosion. Galvanic corrosion is minimized by (1) using metals that are not dissimilar, (2) preventing dissimilar metals from becoming electrically connected, and (3) keeping small anodes from contacting large cathodes. With respect to the latter, rate of corrosion is dependent on the surface area of the anode relative to the cathode. The smaller the surface area of the anode relative to the cathode, the more concentrated the flow of electrons at the anode (i.e., the higher the current), and the faster the rate of corrosion. Conversely, the larger the anode's surface area in relation to the cathode, the more spread out the flow of electrons and the slower the rate of corrosion. For example, if there is a window frame made of stainless steel and it is attached with carbon steel screws, the screws will probably corrode. If the window frame is made of carbon steel and it is attached with stainless steel screws there will be very little, if any, corrosion.

C.3 Sacrificial coatings and barriers. Application of a metallic coating to a panel is done to protect the base metal from oxidation. When the coating is measurably more active/anodic (i.e., higher up on the galvanic series) than the base metal, it will provide galvanic protection to the base metal. Such is the case with a zinc-coated (a.k.a. galvanized) steel panel. When steel is exposed by cutting or scratching of the panel, galvanic corrosion will take place with the anodic zinc moving to cover the exposed cathodic steel. A coating that protects base metal in this manner is referred to as a sacrificial coating. The extent to which a sacrificial coating can continue to protect base metal is directly proportional to the amount (i.e., thickness) of the coating. Metallic coatings that are not sacrificial can only protect base metal by preventing moisture and oxygen from reaching the base metal. Such metallic coatings, along with paint, are referred to as barrier coatings. Prevention of base metal oxidation by sacrificial and barrier coatings is important. Not only is such oxidation unsightly, but it compromises panel strength and eventually weather tightness.

Application of paint coatings to metallic surfaces, or placement of plastic or other non-metallic barriers between dissimilar metals, can significantly reduce galvanic corrosion. When protecting an underlying

metallic coating or base metal with a paint coating, it is important to realize that a small accidental scratch in the coating can result in rapid corrosion of the newly exposed metal if the exposed metal becomes the anode in a reaction with a nearby dissimilar metal that has a large surface area.

C.4 Panels in contact with trims/flashings. In high moisture environments, components that are in direct contact should not have an electric potential difference (from Table C.1) that exceeds 0.20 volts. Metals listed in Table C.1 have been color-coded into groups that fall within the potential difference range of roughly 0.20 volts. Using this as a guideline, there should be no problem with zinc coated panels contacting aluminum flashings, nor a problem with tin and copper components contacting each other. Conversely, allowing a zinc- or aluminum-coated panel to contact copper or tin will result in more rapid degradation of the zinc and aluminum coatings. Lead should not be used in any construction where Galvalume® or aluminum-coated sheet is utilized. Note that if a component has a metallic coating, the metallic coating and not the base metal determines the electric potential of the component.

Materials should be selected so rainwater does *not* flow from the cathode in a metal pair to the anode in a metal pair. For example, in a metal pair of copper and galvanized steel, copper is the cathode and galvanized steel (i.e., zinc) is the anode. Water from a copper roof will contain dissolved copper that will result in unwanted corrosion of a galvanized steel gutter. Alternatively, water runoff from a galvanized steel roof will not corrode a copper gutter.

C.5 Fasteners in contact with panels and trim. Due to their small surface area relative to the materials they fasten, fasteners that take on the role of the anode will be at risk of rapid corrosion and thus should be avoided. Table C.2 contains a guideline for selection of fasteners based on galvanic action. In general, zinc-coated fasteners should only be used to connect galvanized and aluminum-zinc alloy coated steel. Do not use zinc- or aluminum-coated fasteners to attach copper or stainless-steel panels. Whenever possible, match the surface metal on the fasteners with that on the panels and trim they will attach.

C.6 Fasteners in preservative treated wood. Most waterborne wood preservatives contain copper. This includes chromated copper arsenate (CCA), alkaline copper quat (ACQ), copper azole (CA), and ammoniacal copper zinc arsenate (ACZA). To avoid galvanic corrosion in wood containing a copper-based treatment and used in a moist condition, use fasteners that are comprised of, or coated with: copper, a material more noble than copper such as silicon bronze and types 304 and 316 stainless steel, or plastic (Baker, 1992). Do not use aluminum fasteners or aluminum-coated fasteners in lumber containing copper-based wood treatments (Baker, 1992; AWC, 2004). Fasteners with a sufficient zinc coating (i.e., fasteners that meet ASTM A153 Class D for hot-dip galvanizing) can

generally be used in wood containing copper-based treatments as long as the wood is not regularly exposed to moisture or other environments considered extremely corrosive. This means that any fastener with only an electrodeposited coating of zinc (e.g., an electro-plated screw) should not be used in wood containing copper-based treatments if the wood is regularly exposed to moisture or an environment considered extremely corrosive.

C.7 Panels and trim in contact with treated wood.
Do not allow aluminum, aluminum-coated, and Galvalume®-coated panels and trim to come into direct

contact with wood preservatives containing copper, mercury or fluorides. Galvanized steel is generally compatible with chromated copper arsenate (CCA) treatments but not with alkaline copper quat (ACQ) and copper azole (CA) in damp conditions. Avoid direct contact between bare metal panels and treated lumber where (1) condensation will frequently form on the metal surface in contact with the lumber, and (2) the wood treatment is more noble (cathodic) than the metal surface. Direct contact between metal panels and treated lumber can be avoided by separating them with a barrier proven suitable for the application.

Table C.2 – Common Fastener Recommendations from Manufacturers

Panel/Trim Surface Material	Fastener Metal					
	Electro-Plated Screws*	Hot-Dip Galvanized Nails **	Zinc Capped Screws ***	Aluminum	Copper	Stainless Steel
Zinc (Galvanized)	Yes	Yes	Yes	No	No	Yes
Aluminum-Zinc Alloy (e.g. Galvalume®)	No	Yes	Yes	No	No	Yes
Aluminum	No	No	No	Yes	No	Yes
Copper	No	No	No	No	Yes	Yes
Stainless Steel	No	No	No	No	No	Yes

* Screws with an electrodeposited coating of zinc applied in accordance with ASTM B633.

** Nails with a zinc coating that meets or exceed ASTM A153 Class D thickness specifications.

*** ASTM B633 electroplated screws with a special zinc or zinc-aluminum alloy cap.

Appendix D - Panel and Trim Design/Selection Considerations

The quality of metal panel and trim installation is influenced, in part, by overall building design and component selection. To this end, knowledge of metal panel and trim design/selection considerations is fundamental to discussions involving installation quality, and is included here for that purpose.

D.1 Base metal. The two most common base metals are low carbon steel and aluminum. Although low carbon steel is used in the majority of applications, aluminum performs better in high moisture content environments. The disadvantages of aluminum are that it has a coefficient of thermal expansion that is approximately twice that of steel and it does not have the strength of steel – a combination of factors that make slotting of long panels by through-panel fasteners (and hence roof leaks) more likely in aluminum. Additionally, in typical thicknesses, aluminum panels will dent and crimp more easily than steel, and thus greater care must be taken during aluminum panel installation.

D.2 Thickness. Thickness of steel sheets is commonly denoted by the *Manufacturers' Standard Gage for Sheet Steel* given in Table D.1. Note that because of allowable manufacturing tolerances, the actual thickness of a panel can be less than the nominal thickness of the next smaller gage size. For example, a 26 gage panel can have a minimum thickness of 0.0159 inches which is less than the nominal thickness of a 27 gage panel (i.e., 0.0164 inches). Thicknesses of aluminum sheet were formerly designated by the *American or Brown &*

Sharpe Wire Gage but are now specified in decimals or fractions of an inch. Steel panels for commercial use are typically 24 or 26 gage, although some architectural type panels may be thicker. Twenty-nine gage is the most common steel thickness for agricultural applications. Base metal strength can vary considerable. The 29-gage steel used by most major builders has a relatively high yield strength (i.e., a yield strength in excess of 80 ksi).

D.3 Metallic coatings. Metallic coatings are used to protect base metal from corrosion. This is accomplished by providing a sacrificial metal (galvanic protection as discussed in Appendix C) and/or by creating a physical barrier that prevents moisture and oxygen from reaching the base metal. The most common sacrificial coating for low carbon steel is pure zinc. A panel with G-90 galvanizing has 0.9 ounces of zinc per square foot (this is the total on both sides). This coating is about 0.76 mils thick per side. A G-60 panel has 0.6 ounces per square foot (two-thirds that for a G-90 panel). The galvanic protection provided by zinc increases linearly with coating thickness. The most common metallic barrier coat for low-carbon steel is aluminum. Coating weights for aluminized steel are typically 0.65 ounces per square foot (designated as T2-65) total both sides with a thickness of 1.1 mils per side. Because the application of pure aluminum to steel only provides barrier protection (i.e., the coating is not sacrificial), cut edges, drill holes and any other place where base steel is exposed to moisture and oxygen will corrode.

Table D.1 – Bare Sheet Steel Thicknesses and Nominal Weights

Gage	Nominal Thickness,* inches	Thickness Tolerance,** inches	Minimum Thickness, inches	Maximum Thickness, inches	Nominal Weight ***	
					lbm/ft ²	oz/ft ²
18	0.0478	+0.004	0.0438	0.0518	1.999	31.98
19	0.0418	+0.004	0.0378	0.0458	1.748	27.97
20	0.0359	+0.003	0.0329	0.0389	1.501	24.02
21	0.0329	+0.003	0.0299	0.0359	1.376	22.01
22	0.0299	+0.003	0.0269	0.0329	1.250	20.01
23	0.0269	+0.003	0.0239	0.0299	1.125	18.00
24	0.0239	+0.003	0.0209	0.0269	0.999	15.99
25	0.0209	+0.003	0.0179	0.0239	0.874	13.98
26	0.0179	+0.002	0.0159	0.0199	0.749	11.98
27	0.0164	+0.002	0.0144	0.0184	0.686	10.97
28	0.0149	+0.002	0.0129	0.0169	0.623	9.97
29	0.0135	+0.001	0.0125	0.0145	0.565	9.03
30	0.0120	+0.001	0.0110	0.0130	0.502	8.03

* *Manufacturers' Standard Gage for Sheet Steel*

** Restricted thickness tolerances for cold-rolled sheet (carbon and high-strength, low-alloy steel) from ASTM A568/A568M-05

*** Based upon a mass density of 41.82 lbm per square foot per inch of thickness

Combination zinc-aluminum coatings that provide both galvanic and barrier protection are available. The most common is manufactured under the trade name Galvalume® and contains about 45% zinc and 55% aluminum by weight. Coating weights for Galvalume roofing are typically 0.55 ounces per square foot (total both sides), which translates to a coating thickness of 0.9 mils per side. Due to the combination of protection mechanisms, Galvalume® has a longer service life in most applications than does G90 galvanized sheets. For cattle and pig confinement buildings, Galvalume® sheet (bare or prepainted) is not recommended due to rapid corrosive attack of the aluminum-zinc alloy coating. For these applications, aluminum sheet or heavily zinc-coated galvanized sheet (G185 or heavier) should help provide reasonable service life. For poultry confinement buildings, the corrosivity is less severe than that of cattle or pig confinement buildings, but still more severe than non-confinement agricultural buildings. For these applications, Galvalume® sheet will exhibit cosmetic pinpoint rust-staining earlier than G90 galvanized sheet, but over time, can be expected to provide about the same service life.

D.4 Paint coatings. Paint coatings provide color and an additional layer of protection from moisture and corrosive gases. Coating properties vary and are dependent on the adhesion to the substrate (for one-coat systems) or to the primer (for two-coat systems). Based on a five point scale with 5 being excellent and 1 being poor, National Coil Coating Association (NCCA) ratings for coating weathering resistance (gloss retention, color retention, resistance to chalking) are: fluoropolymers (5); siliconized polyesters (4); polyesters, acrylic latexes and polyurethanes (3-4); and plastisols (2-3). Using the same five point scale, NCCA ratings for resistance to industrial pollutants and acidic/caustic conditions are: plastisols (5); fluoropolymers (4); acrylic latex (3-4); and siliconized polyesters, polyesters and polyurethanes (3). For corrosion resistance (salt spray) NCCA ratings are: plastisols, siliconized polyester, polyester and polyurethanes (4); and fluoropolymers and acrylic latexes (3). NCCA ratings for flexibility/drawability are: plastisols (5); fluoropolymers and polyurethanes (4); polyesters and acrylic latexes (3); and siliconized polyesters (2). Based on their overall characteristics, fluoropolymers are considered the premium coating for corrugated metal panels. Hylar® 5000 and Kynar® 500 based coatings are fluoropolymer coatings.

D.5 Structural loads. Wind and snow loads will dictate base metal thickness, panel profile and panel support spacing. In addition, panel fastener type and spacing is frequently controlled by the magnitude of wind forces drawing the panel away from the structural frame. Self-straining forces, which includes forces induced by differential settlement and changes in component temperature, frequently affect selection of panel type and attachment, especially on larger buildings. Changes in panel temperature alter panel

size, and can cause problems depending on the relative length of the panel and how free it is to move. Through-panel fasteners restrict the movement of panels relative to the frame, and consequently, can induce large panel forces when panels and underlying framing expand/contract at different rates. This is frequently the case when insulation placed between panels and framing results in large temperature differences between panels and framing. Through-panel fasteners will generally cause slotting of the panels where there is severe differential expansion/contraction between the panels and framing. In such cases, an attachment system that allows such differential expansion/contraction is recommended.

D.6 Panel profiles. Corrugated panels are characterized by the profile of their ribs and standing seam panels by the profile of their legs. These profiles, along with base metal thickness, determine panel bending strength and stiffness. In general, the more material required to form a rib/leg and/or the greater the rib/leg height, the greater the panel's bending strength and stiffness. Panel strength and stiffness can dictate panel support spacing – a design variable that is the engineer's responsibility to establish. Producers of commercially-available panels publish strength and stiffness properties for their panels. These values are generally computed in accordance with the American Iron and Steel Institute (AISI) *Specification for the Design of Cold-Formed Steel Structural Members*. Weather-tightness is controlled by panel seam profile. The higher a standing seam panel leg, the less likely it is for rainwater to enter. Side laps of corrugated panels are designed so that when two panels are lapped, a continuous anti-siphon drain channel is formed at the side seam.

D.7 Diaphragm design. Engineers will frequently rely on the in-plane strength and stiffness of diaphragms to resist structural loads. Diaphragms are the large roof, wall and ceiling "plates" that are formed when cladding is attached to the structural frame. Since the manner in which cladding is attached to a structural frame will influence diaphragm strength and stiffness, engineers relying on diaphragms for strength much specify the manner in which panels are attached. Diaphragm design generally requires the use of through-panel fasteners.

D.8 Panel end laps. Although it is always best to minimize panel end laps, they are inevitable as slope length (i.e., eave-to-ridge distance) gets large. This is because most manufactures limit individual panel length to around 30 feet for handling reasons (note that longer panels can be transported, but they seldom exceed the typical flatbed trailer length of 48 feet. Panels longer than 50 feet would be roll-formed on the job site). End laps of standing seam panels are generally made with the use of special steel backer plates.

D.9 Lap sealant. Sealant should be used in accordance with the recommendations of the panel

manufacturer. In general, sealant is not used in wall panel sidelaps unless specified for control of air infiltration. Need for sealant in roof panel endlaps is primarily dependent on roof slope and the amount of overlap between panel ends. Need for sealant in roof panel sidelaps depends on roof slope, rib height, siphon break geometry, distance from the ridge, rain intensity, and inside-to-outside pressure differential. As a rule of thumb, side laps and end laps of corrugated panels should be sealed on roofs with slopes less than 2.0-in-12. This becomes more important the greater the slope length. Sealing is almost always done with an elastomeric butyl rubber (a.k.a. polyisobutylene-isoprene) tape that has been extruded onto a special release paper. Release paper keeps application clean and enables uniform application thickness, which reduces roof leak potential. Tape for side lap sealing is generally 3/32 inches thick and 3/8 inches wide and commonly available in roll lengths up to 45 feet. Butyl rubber tape for end lap sealing is generally 1/8 inch thick and 1 inch wide. Tape should be cut, not pulled apart as the latter results in necking down and non-uniform application. In addition, the tape should be placed on the "wet" side of the fasteners to prevent wind blown rain from leaking through fastener holes in the bottom panel.

D.10 Cool roofs. Cool roofs are promoted, and in some cases required, as a means to reduce costs associated with summer-time cooling in warmer climates. At the heart of cool roof design is the use of roofing materials which reflect the sun's radiant energy before it penetrates into the building interior. By reflecting solar energy back into space, reflective materials also help keep the building's environment (e.g., the city) cool and thus lessen the "heat island effect" in populated areas. The ratio of reflected solar radiation flux to incident solar radiation flux is defined as the reflectivity of a material and is determined in accordance with ASTM E903, ASTM E1918 and ASTM C1549. Conventional white materials, specially formulated pigmented finishes, and unpainted metal roofs have high reflectivity. Use of a special class of inorganic pigments known as CICIP's (Complex Inorganic Color Pigments) has resulted in the manufacture of premium finishes for metal roofing that have reflectivities in excess of 0.65 – high enough to meet U.S. EPA Energy Star and other regulatory and code requirements. Besides high solar reflectance, a surface with high emissivity can benefit a cool roof. Emissivity is defined as the ratio of radiant heat flux emitted by a material to that emitted by a blackbody radiator at the same temperature. Emissivity is a measure of a material's ability to emit heat (via infrared radiation) to its surroundings, and is determined in accordance with ASTM C1371 and ASTM E408. Painted surfaces generally have significantly higher emissivities than do bare metals. The data in Table D.2 shows how the high reflectivity and high emissivity of a white pre-painted metal roof result in a much

cooler roof surface. In addition to reduced heat transfer to the building interior, a lower roof surface temperature means less overall stress in the roof system due to thermal expansion.

Table D.2 - Roof Surface Temperatures in Oak Ridge, TN August 14, 2000

Material	Reflectivity	Emissivity	Maximum Surface Temperature (°F)
White pre-painted metal roof	0.64	0.83	123 – Cool
Unpainted metal roof	0.64	0.08	142 – Warm
Asphalt shingle	0.09	0.91	164 – Hot

D.11 Metal trim properties. Metal trim/accessories should be as durable as the corrugated metal panels to which they are attached. This means specifying a base metal type, thickness and strength; metallic coating type and thickness, and paint finish type that are at least the equivalent of those specified for the panels.

D.12 Vent and closure strips. Where trims attach to corrugated panel ends, special vent or closure strips are generally used. Vent strips enable air infiltration but block insect and snow infiltration. Closure strips will also block air infiltration. Vent strips are recommended at the ridge of all buildings (unless the ridge is open) and at the eaves of buildings without vented soffits. Closure strips are generally used at the eave of buildings with vented soffits and to seal openings formed between trims and wall panels. To function properly, closure and vent strips should be cut to match the panel's profile. A closure or vent strip may be manufactured from plastic (e.g. polyurethane, polyethylene) or rubber (e.g. neoprene, EPDM). Molded rubber closure strips are more expensive than plastic closures but they are also more effective against rodents. Currently, the most commonly used closure strips are those laminated from die-cut pieces of closed-cell, cross-linked polyethylene foam.

D.13 Gutters. Gutters are problematic in climates with substantial ice and snow, and require continual cleaning if filled with leaves/needles. Large roofs require large gutters and large or closely spaced downspouts. In cold climates, gutters must be designed to carry eave ice loads, which can be significant. In general, gutters are only specified over service entrances where water from the roof, especially when frozen, raises safety concerns. Snowguards are specified on roofing directly above service entrances to reduce dangers presented by sliding snow.

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