Wood framing has become increasingly popular in the construction of commercial offices and multi-family dwellings with heights of three to four stories. The material offers an economical alternative to concrete and steel frame construction for these relatively low structures. However, this rising use of multi-story wood frame construction, combined with the specification of brick veneer as a façade finish/component, has resulted in an increase in observed problems due to vertical differential movement between the two materials.

Prescriptive requirements for the design and detailing of masonry veneer over wood framing have been included in the various model building codes for decades. The current edition of the International Building Code (IBC) also contains these requirements by referring to American Concrete Institute (ACI) 530-02/American Society of Civil Engineers (ASCE) 5-02/The Masonry Society (TMS) 402-02, Building Code Requirements for Masonry Structures (hereafter referred to as ACI 530).

In the past, prescriptive code requirements focused on limiting the height of masonry veneer construction over the framing, and dictating specific tie size and spacing requirements between the veneer and the supporting wood.

As an example, Table 1 (page 48) lists the requirements taken from previous editions of the model Building Officials and Code Administrators (BOCA) Code dating back through 1975.

It is interesting to note how veneer height limits have evolved over the years. Until the 1993 BOCA Code, the average height of nominal 102-mm (4-in.) thick veneer over wood framing was limited to 7.6 m (25 ft) above supports. In 1993, the BOCA Code was revised to permit a maximum veneer height of approximately 9 m (30 ft), after which independent support was required at each floor level. The code further permitted increased veneer height beyond the prescriptive limit, where engineering analysis was used to design the veneer system. The current prescriptive height limitations for masonry veneers over wood framing from ACI 530 are 9 m at plate, or up to 11.6 m (38 ft) at gables.

The commentary in the 1993 BOCA Code offered little explanation of the reasoning for the prescriptive height limit for veneers over wood framing:

Masonry veneers are non-structural assemblies with limited strength. Experience and test data indicate that masonry veneer panels should not have an average height above support greater than [7.6 m] 25 feet for [102-mm] 4-inch thick units and [5.5 m] 18 feet for [51-mm] 2-inch units.
This indicates the height limits were based primarily on the strength limitations of masonry veneers. Further investigation into the history of the development of these height limitations shows the height limits were originally developed to address strength concerns and to control differential movement between clay brick masonry veneers and wood framing.

While wood shrinks as it dries, brick masonry veneer’s characteristic long-term moisture expansion is non-reversible and conflicts with this shrinkage. The concept of limiting the height of veneer construction to control this differential movement may have been lost over the years, as engineers and code bodies seemed to concentrate more on strength and capacity issues related to code requirements. However, differential vertical movement becomes a significant design consideration as veneer heights increase over two stories.

The current maximum prescriptive height limit by ACI 530 (i.e. 11.6 m at the gable) is approximately 50 percent greater than the historic BOCA Code level of 7.6 m. As the prescriptive veneer height limit increased, tie spacing limits also became more restrictive, as shown in Table 1. The current edition of ACI 530 places no height limit on masonry veneers with compliant engineering design. It specifically requires veneers be designed and detailed to accommodate differential movement. As masonry veneer heights have increased through changes in prescriptive code requirements (and through the use of engineering design provisions), performance problems associated with differential movement have become more prevalent.

**Differential movement considerations**

Design and detailing for differential movement in brick masonry construction is continually reinforced through industry literature, technical articles, and detailing guides. However, these sources tend to focus on
structures with framing components of concrete and structural steel. Much emphasis is placed on detailing vertical expansion joints to accommodate horizontal movements in the brick wythe and detailing horizontal joints at shelf angles or other intermediate supports through the height of the veneer. Detailing to accommodate the vertical differential movement with brick veneer and wood frame construction has not enjoyed the same attention, but the basic concepts are the same as with other materials.

**Clay brick masonry**

In veneer construction, the primary movements affecting clay brick masonry are thermal and moisture. Veneers are non-load-bearing, supporting only their own weight so elastic deformations within the veneer are minimal. The average linear thermal expansion coefficient for clay brick masonry is $7.2 \times 10^{-6}$ mm/mm $\deg$C ($4 \times 10^{-6}$ in./in. $\deg$F), as specified in ACI 530. The magnitude of thermal expansion, or thermal contraction, is dependent on the temperature differential the veneer is subjected to in service. A thermal differential between 37.8 to 60 $\deg$C (100 to 140 $\deg$F) is often used for designing expansion joints in brick masonry.

Non-reversible moisture movements in clay brick masonry can exceed thermal movements. A large portion of this expansion occurs shortly after firing of the brick units as the units take on moisture from the atmosphere. However, expansion will slowly occur in the brick in service for many years.

ACI 530 specifies a moisture expansion coefficient for clay masonry of 0.0003 mm/mm (0.0003 in./in.). The Brick Industry Association (BIA) Technical Notes 18 Revised, *Volume Changes and Effects of Movement*, states the moisture expansion of clay brick masonry is estimated to range from 0.0002 to 0.0009 mm/mm (0.0002 to 0.0009 in./in.). While there is currently no accepted test standard to determine the moisture expansion of clay brick masonry, BIA suggests a
Table 1

<table>
<thead>
<tr>
<th>Building Officials and Code Administrators (BOCA) Code</th>
<th>Section</th>
<th>Backing</th>
<th>Veneer height limitation</th>
<th>Tie spacing</th>
<th>Tie size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maximum horizontal</td>
<td>Maximum vertical</td>
</tr>
<tr>
<td>1975</td>
<td>854.4.3</td>
<td>Wood frame</td>
<td>102-mm (4-in.) brick veneer shall not be more than 7.6 m (25 ft) above its supports on foundation wall or on corbels of masonry or steel; not more than 5.5 m (18 ft) for 51-mm (2-in.) veneers.</td>
<td>813 mm (32 in.)</td>
<td>406 mm (16 in.)</td>
</tr>
<tr>
<td>1981</td>
<td>1225.4.3</td>
<td>Wood frame</td>
<td>The average height of 102-mm brick veneer shall be not more than 7.6 m above its supports on foundation wall or on corbels of masonry or steel; not more than 5.5 m for 51-mm veneers.</td>
<td>813 mm</td>
<td>406 mm</td>
</tr>
<tr>
<td>1984</td>
<td>1225.4.3</td>
<td>Wood frame</td>
<td>The average height of 102-mm brick veneer shall be not more than 7.6 m above its supports on foundation wall or on corbels of masonry or steel; not more than 5.5 m for 51-mm veneers.</td>
<td>813 mm</td>
<td>406 mm</td>
</tr>
<tr>
<td>1987</td>
<td>2107.3</td>
<td>Wood frame</td>
<td>The average height of 102-mm brick veneer shall be not more than 7.6 m above its supports on foundation wall or on corbels of masonry or steel; not more than 5.5 m for 51-mm veneers.</td>
<td>813 mm</td>
<td>406 mm</td>
</tr>
<tr>
<td>1990</td>
<td>2103.5.2</td>
<td>Wood frame</td>
<td>The average height of 102-mm brick veneer shall be not more than 7.6 m above its supports on foundation wall or on corbels of masonry or steel; not more than 5.5 m for 51-mm veneers.</td>
<td>813 mm</td>
<td>406 mm</td>
</tr>
<tr>
<td>1993</td>
<td>1405.1</td>
<td>Approved backing</td>
<td>The construction shall have horizontal supports located at each story height above the initial 9 m (30 ft). Exception: height increases are permitted where an engineering analysis is prepared by a registered design professional and approved.</td>
<td>813 mm</td>
<td>406 mm</td>
</tr>
<tr>
<td>1996</td>
<td>1405.5</td>
<td>Wood frame</td>
<td>American Concrete Institute (ACI) 530-95, Building Code Requirements for Masonry Structures, Chapter 12: 9 m at the plate; 11.6 m (38 ft) at the gable.</td>
<td>813 mm</td>
<td>457 mm (18 in.)</td>
</tr>
<tr>
<td>1999</td>
<td>1406.5</td>
<td>Wood frame</td>
<td>ACI 530-95, Chapter 12: 9 m at the plate; 11.6 m at the gable.</td>
<td>813 mm</td>
<td>457 mm</td>
</tr>
</tbody>
</table>
value of 0.0005 mm/mm (0.0005 in./in.) for designing veneer construction where an upper bound of potential moisture expansion is desired for detailing purposes. This author also suggests the more conservative value of 0.0005 mm/mm moisture expansion coefficient for detailing purposes in veneer construction. For the maximum veneer height permitted by ACI 530 at a gable, the corresponding vertical, non-reversible brick moisture expansion is approximately 6 mm (0.25 in.).

Wood frame
As with clay masonry, thermal and moisture movements are the primary influences on wood framing materials. The average linear thermal expansion coefficient for pine lumber is approximately 3.6 x 10^-6 mm/mm °C (2 x 10^-6 in./in. °F). Typically, wood framing in conditioned spaces is not subjected to significant temperature variations as is the case with the exterior masonry veneer wythe. Therefore, it is often reasonable to neglect thermal movements in the wood framing.

Shrinkage in wood components begins as the material dries below the fiber saturation moisture content, approximately 27 to 30 percent for most species. Wood continues to shrink as the moisture content decreases until it stabilizes at an in-service equilibrium moisture content. For interior wood framing in conditioned spaces, the equilibrium moisture content typically ranges from approximately eight to 12 percent.

Wood is anisotropic, experiencing different amounts of shrinkage relative to the direction of the wood grain. Radial shrinkage (i.e. across growth rings) is approximately four percent, while tangential shrinkage (i.e. parallel to growth rings) is about eight percent for most softwoods. (Longitudinal shrinkage [i.e. parallel to the grain] is small and often neglected in design detailing.)

Common framing lumber is manufactured and sold in mixed species and mixed grain patterns, making exact
prediction of wood shrinkage difficult. The Department of Commerce’s (DoC’s) voluntary product standard (PS) 20-99, American Softwood Lumber Standard, suggests a shrinkage value of one percent for each four-percent point drop in moisture content. (The American Forest & Paper Association [AF&PA] concurs with this recommendation.) This translates to a shrinkage coefficient of 0.0025 mm/mm (0.0025 in./in.) per percent change in moisture content for typical softwood lumber. The Western Wood Products Association (WWPA) advises a shrinkage coefficient of 0.0020 mm/mm (0.0020 in./in.) per percent change in moisture content for Western softwood species. In its Technical Note Report No. 10, Shrinkage Calculation for Multi-story Wood Frame Construction, WWPA also suggests a shrinkage coefficient of 0.00005 mm/mm (0.00005 in./in.) per percent change in moisture content for longitudinal shrinkage (where it is desirable to include this component in an analysis).

Lumber for wood frame structures is typically specified to be supplied at moisture contents of 15 or 19 percent. When the lumber is not protected while stored on-site, the moisture at the time of installation can exceed this level, leading to a greater amount of shrinkage for the lumber components as they dry to their in-service equilibrium moisture content.

Calculation of differential movement magnitude
Calculation of thermal and moisture movements can be relatively simple for brick veneer/wood frame construction. Figure 1 shows a typical four-story wood frame wall section with dimension lumber framing, dimension lumber floor joists, and an exterior clay brick veneer façade. This figure is used as an example to demonstrate calculation of differential movements. In the example presented, the potential differential movement is calculated at the fourth floor window head. (Similar calculations can be performed at any height along the wall.)

Brick veneer movements
For the purposes of the demonstration calculation, a temperature differential of 37.8 C (100 F) is assumed at the brick veneer wythe. This represents the temperature differential that could be expected in summer conditions. (The brick wythe movement calculation is presented in Figure 2.) The temperature differential is considered to be positive, representing thermal expansion of the brick wythe. It is representative of the total upper bound brick

\[
\text{Total brick wythe movement (in.)} = H \times [(T \times k_t) + k_e]
\]

Where:
- \( H \) = veneer height (in.)
- \( T \) = temperature differential (F)
- \( k_t \) = thermal expansion coefficient (in./in. F)
- \( k_e \) = Moisture expansion coefficient (in./in.)

For example, when

- \( H \) (Brick height to fourth-floor window head) = 38.5 ft x 1 ft/ft = 462 in.
- \( T = 100 \) F
- \( k_t = 4 \times 10^{-4} \)
- \( k_e = 0.0005 \)

then

\[
\text{total brick wythe movement (in.)} = 462 \times [(100 \times 4 \times 10^{-4}) + 0.0005] = 0.41 \text{ in.}
\]
The total predicted differential movement between the brick veneer and wood frame at the fourth floor window head is simply the addition of the calculated clay brick expansion and the wood frame shrinkage. In the example, this summation equals approximately 43 mm (1.7 in.)—a surprisingly sizable magnitude of differential movement to accommodate at a window opening, particularly for designers who have not previously performed the calculations.

The types of failures shown in Photo 1 (page 45) and Photos 2 and 3 (page 46) occur because the window systems tend to be structurally attached to the wood framing, traveling with it as it shrinks. Above the windows are typically loose steel lintels set in the veneer wythe, which travel with the veneer wythe as it expands. Failures can materialize as simple tearing of sealant joints at window perimeters or as crushing and bowing of window frame components when the window system is in contact with the brick wythe at the time of construction as shown in Photo 3. Similar failures can occur at doors, louvered, or other components set in openings through the brick wythe.

The differential movement can also affect the brick wythe's structural stability when the veneer ties fail (or two-piece adjustable ties become disengaged) due to the magnitude of the differential vertical movement. Photo 4 (page 50) illustrates vertical movement at a two-piece adjustable veneer tie in an existing wall; the tie shown had sufficient engagement to remain functional. However, Photo 5 (page 50) depicts near disengagement of a two-piece

<table>
<thead>
<tr>
<th>Total Wood Frame Movement (in.)</th>
<th>( = MC \times [(S_h \times D_h) + (S_v \times D_v)] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where:</td>
<td></td>
</tr>
<tr>
<td>( MC )</td>
<td>Change in Moisture Content (%)</td>
</tr>
<tr>
<td>( S_h )</td>
<td>Shrinkage coefficient horizontal members (in./in. % change in moisture content)</td>
</tr>
<tr>
<td>( D_h )</td>
<td>Sum of horizontal member thicknesses (in.)</td>
</tr>
<tr>
<td>( S_v )</td>
<td>Shrinkage coefficient vertical members (in./in. % change in moisture content)</td>
</tr>
<tr>
<td>( D_v )</td>
<td>Sum of vertical member lengths (in.)</td>
</tr>
</tbody>
</table>

For example, when calculating shrinkage based on wall section framing adjacent to window opening, continuous wall framing elements (See the ‘a’ component of Figure 1):

- Total plate thickness = 10 plates x 1.5 in. = 15 in.
- Total joist thickness = 3 joists x 11.25 in. = 33.75 in.
- Total horizontal member thickness = 48.75 in.

- Total length of studs = \((3\;\text{studs} \times 103.25\;\text{in.}) + (1\;\text{stud} \times 90.375\;\text{in.})\)
  \( \times 12\;\text{in.} / \text{ft} = 400\;\text{in.} \)
- Lumber supplied moisture content = 19 percent
- Lumber equilibrium moisture content = 10 percent
- \( MC = \) nine percent
- \( S_h = 0.0025 \)
- \( S_v = 0.00005 \)

Therefore:

- Total wood frame movement = \( 9 \times [(0.0025 \times 48.75) \)
  \( + (0.00005 \times 400)] = 1.28\;\text{in.} \)

wythe expansion when the thermal expansion component of movement is combined with the moisture component. As thermal movements are reversible under cold weather conditions, the thermal movement would result in seasonal contraction of the veneer reducing the effect of the non-reversible moisture expansion. The predicted total expansion of the brick wythe under the conditions assumed is approximately 10 mm (0.4 in.) at the fourth floor window head.

Wood framing movements
The wood framing in this example is assumed to be in a conditioned space, meaning there is no significant thermal movement of the wood framing. In this example, the wood framing was specified to be supplied at a moisture content of 19 percent and is anticipated to reach an equilibrium moisture content of 10 percent in service. The wood movement calculation assumes an average shrinkage coefficient of 0.0025 mm/mm (0.0025 in./in.) per percent change in moisture content for horizontal framing members, plates, and joists, which are influenced more by radial and tangential shrinkage. For vertical wall studs predominately affected by shrinkage parallel to the grain, the calculation assumes 0.00005 mm/mm (0.00005 in./in.) per percent change in moisture content.

The calculation is performed by simply summing the dimensions of horizontal framing members (plates and joists) and the total length of wall studs, applying the appropriate shrinkage coefficient multiplied by the moisture content change from installation to in-service equilibrium conditions (Figure 3). The predicted total wood frame shrinkage under the conditions assumed is approximately 33 mm (1.3 in.) at the fourth floor window head.
adjustable veneer tie due to differential movement between the wythe and wood frame wall.

Accommodating differential movement
Detailing to accommodate differential movement at windows and other openings can become difficult at the upper floors of multi-story wood frame construction. The following general design procedures can be employed to reduce the total differential movement potential between the brick wythe and wood frame:
• Framing lumber should be specified to have a maximum delivered moisture content of 15 percent;
• Engineered wood floor joist systems should be selected, as these systems shrink less than dimension lumber;
• Lumber must be protected from the weather while kept on-site;
• Lumber should be stored on supports above the ground;
• Building frames should be dried-in as soon as possible; and
• Installation of windows and other components in openings should be specified as late in the construction process as possible to permit some drying of wood frame components prior to window installation.

The following details should be incorporated in the design documents to accommodate differential movement between the brick veneer and wood frame components:
• Soft joints should be provided at perimeters of exterior window and door openings and brick veneer;
• Adjustable veneer ties should be specified with sufficient adjustment capacity to accommodate the predicted differential movement;
• Vertical veneer tie spacing should be coordinated with vertical brick coursing to help maintain vertical movement capacity in adjustable tie systems; and
• In cases where predicted vertical differential movement cannot be readily accommodated by detailing at windows and other penetrations through the veneer, shelf angles should be installed to support the veneer, and horizontal expansion joints should be installed at the shelf angles. (Alternately, installing a different siding material in combination with the veneer could reduce the latter’s continuous vertical height.)

Prescriptive building code provisions have evolved and provide more liberal height limits for veneer construction over wood frame, especially when engineering analysis is used during the design process. The use of brick veneer over wood frame construction on buildings of three to four stories is now commonplace, with veneer heights often exceeding 12.2 m (40 ft). Still, specifiers should keep in mind these types of structures require special attention and detailing to avoid problems due to vertical differential movement between the clay brick wythe and wood frame.

Additional Information

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Additional Information

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American Concrete Institute
Brick veneer
Building Officials and Code Administrators Code
Differential movement
Wood framing

Abstract
In low-rise, multi-story construction, wood framing can offer an economical alternative to concrete and steel. Unfortunately, its increased use with the application of brick veneer as the façade finish (or as a component of the façade) has resulted in increased problems. Specifiers must understand—and deal with—the potential vertical differential movement between the masonry and the supporting framing.