Component Additive Method (CAM) for Calculating and Demonstrating Assembly Fire Endurance

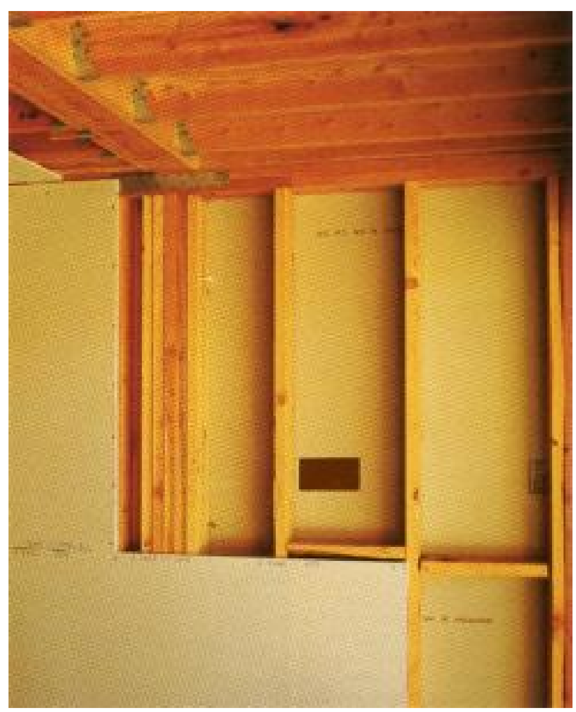
Wood-frame walls and floors offer designers a unique opportunity to provide structures with economy as well as proven energy performance. Where these assemblies are required by the building codes to achieve a minimum fire endurance rating, a wide range of options for design exists.

Building Code Requirements

For both new and existing construction, many building codes require structural elements such as exterior walls, load bearing partitions, floor/ceiling assemblies and roofs to achieve a minimum fire endurance rating. Historically, these "protected" assemblies have been tested in accordance with the standard fire test and assigned an hourly fire endurance rating based on time to failure. The ASTM Standard E119 "Standard Method of Fire Tests of Building Construction and Materials" is normally used.

Many sources are available for obtaining information on the fire endurance of assemblies. Generally, publications from recognized testing laboratories are the source for fire endurance ratings of assemblies that have been tested. Building codes and regulators accept assemblies included in these publications as having the identified fire endurance rating. Until recently, building officials did not recognize methods for determining the fire endurance rating other than through testing. This has resulted in non-acceptance of many assemblies for which an experimental fire endurance rating was not available.

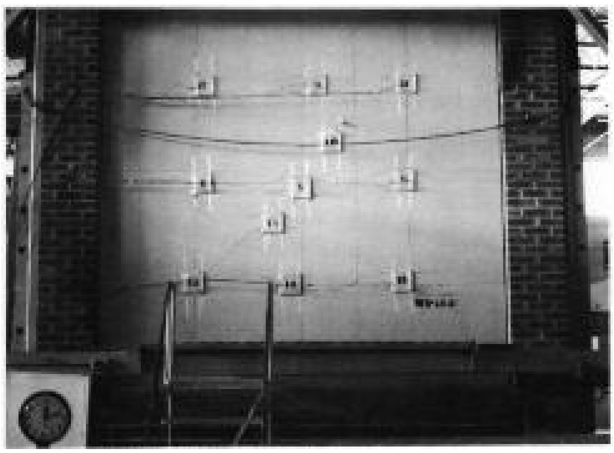
To permit use of "non-listed" assemblies, a methodology for calculating the fire endurance of load bearing and non-load bearing floor, wall, ceiling and roof assemblies has been adapted for use. A number of building codes now accept fire endurance ratings developed by this "Component Additive Method" (CAM) calculation methodology.



Component Additive Method (CAM)

History

The original methodology for calculating fire endurance ratings of assemblies by CAM was developed in the early Sixties by the Fire Test Board of the National Research Council of Canada. The methodology resulted from their detailed review of 135 standard fire test reports on wood stud walls and 73 test reports on wood-joist floor assemblies and the *Ten Rules of Fire Resistance Rating* by Tibor Harmathy, an eminent fire researcher from the National Research Council of Canada. Review of the fire tests provided assigned time values for contribution to fire endurance ratings for each separate component of an assembly. The "Ten Rules" provided a method for combining the individual contributions to obtain the fire endurance rating of the assembly.



Use and Application

Combining results of the fire tests and basis provided by the Ten Rules, a methodology for calculating fire endurance ratings was developed. The review of full-scale wood-framed assembly fire tests by the Fire Test Board validated the methodology. These tests included both load bearing and non-load bearing assemblies with wood, gypsum wallboard and other membranes. Fire endurance ratings ranged from 20 to 90 minutes.

In developing the methodology, the Fire Test Board broke down the fire endurance of the assembly into the fire endurance contribution of the exposed membrane and the time to destruction of the framing members. As a result, the calculated fire endurance would equal the sum of 1) the contribution of the fire exposed membrane, 2) the time to failure of the framing members, and if applicable 3) any additional protection due to use of cavity insulation or reinforcement of the membrane.

The times assigned to protective wall and ceiling coverings are given in Table 1. These times are based on the ability of the membrane to remain in place during fire tests. This "assigned time" should not be confused with the "finish" rating of the membrane. The "finish rating" is the time it takes for the temperature to rise 250° F on the unexposed surface of a material when the material is exposed to a heat source following the ASTM E 119 Time-Temperature curve. As shown in Table 1, some pairs of membranes have been tested resulting in greater fire endurance times than the sum of the ratings of the individual membranes, in accordance with Harmathy's rule #1.

Ten Rules of Fire Endurance Rating

Rule 1. *The "thermal" fire endurance of a construction consisting of a number of parallel layers is greater than the sum of the "thermal" fire endurance characteristics of the individual layers when exposed separately to fire.*

Where two layers of panel materials, such as gypsum wallboard or plywood, are fastened to studs or joists separately, their combined effect is greater than the sum of their individual contributions to the fire endurance rating of the assembly. For example, the fire endurance time assigned to 1/2 inch gypsum wallboard is 15 minutes (see Table 1). Two layers of 1/2 inch gypsum wallboard have an endurance rating greater than 15+15=30 minutes.

Rule 2. *The fire endurance of a construction does not decrease with the addition of further layers.*

This is almost the converse of Rule 1. It says that any additional layers of wallboard or other panel materials will add to fire endurance no matter how many layers are added.

Rule 3. *The fire endurance of constructions containing continuous air gaps or cavities is greater than the fire endurance of similar constructions of the same weight, but containing no air gaps or cavities.*

Wall and ceiling cavities formed by studs and joists protected and encased by wall coverings adds to the fire endurance rating of these assemblies.

Rule 4. *The farther an air gap or cavity is located from the exposed surface, the more beneficial its effect on the fire endurance.*

In cases where cavities are formed by joists or studs and protected by 2 inch thick panel materials against fire exposure, the beneficial effect of such air cavities is greater than if the protection is only 1/2 inch thick.

Rule 5. *The fire endurance of an assembly cannot be increased by increasing the thickness of a completely enclosed air layer.*

Increasing stud or joist depths from 4 inches to 6 inches, or even to 12 inches, does not increase the level of fire endurance.

Rule 6. *Layers of materials of low thermal conductivity are better utilized on the side of the construction on which fire is more likely to happen.*

A building material made of wood fiber is more effective against thermal transfer than is a material having relatively high thermal conductivity, such as metal. Wood will be more effective in protecting against excessive rise in temperature on the opposite face of assemblies. This temperature rise can lead to failure under test acceptance criteria.

Rule 7. *The fire endurance of asymmetrical constructions depends on the direction of heat flow.*

Walls which do not have the same panel materials on both faces will demonstrate different fire endurance ratings depending upon which side is exposed to fire. This rule results as a consequence of Rules 4 and 6, which point out the importance of location of air gaps or cavities and of the sequence of different layers of solids.

Rule 8. *The presence of moisture, if it does not result in explosive spalling, increases fire resistance.*

Materials having a 15 percent moisture content will have greater fire endurance than those having 4 percent moisture content at the time of fire exposure.

Rule 9. *Load-supported elements, such as beams, girders and joists, yield higher fire endurance when subject to fire endurance tests as parts of floor, roof, or ceiling assemblies than they would when tested separately.*

A wood joist performs better when it is incorporated in a floor/ceiling assembly, than tested by itself under the same load.

Rule 10. *The load-supporting elements (beams, girders, joists, etc.) of a floor, roof, or ceiling assembly can be replaced by such other load-supporting elements which, when tested separately, yielded fire endurance not less than that of the assembly.*

A joist in a floor assembly may be replaced by another type of joist having a fire endurance rating not less than that of the assembly.

The times assigned to wood studs and joists were determined based upon the time it takes for the framing members to fail after failure of the protective membrane. The fire endurance time assigned to framing members is given in Table 2. These times are based on the ability of framing members to provide structural support when subjected to the ASTM E 119 fire endurance test without the benefit of a protective membrane.

These time values are in part the result of full-scale tests of unprotected wood studs and floor joists where the structural elements were loaded to design capacity. They apply to all framing members and do not increase if, for example, 2 by 6 inch studs are used rather than 2 by 4 inch studs as implied by Harmathy's rule #5.

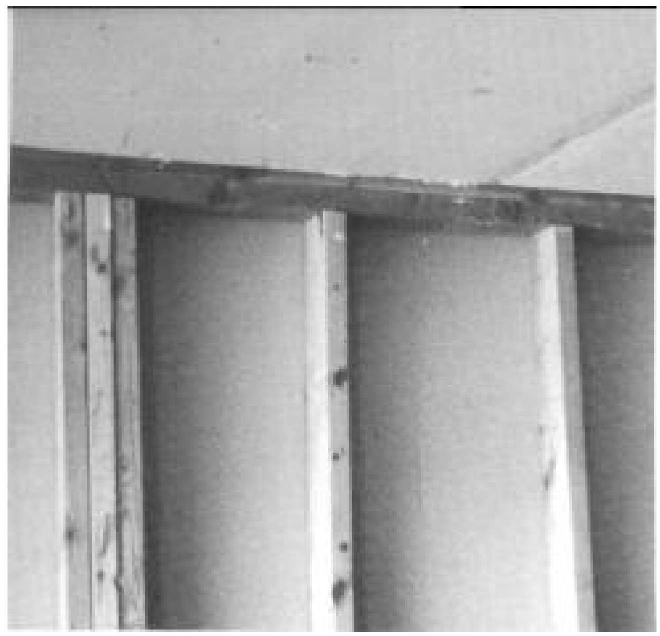
Walls

Additional fire endurance can be provided to wall assemblies by the use of high density rockwool or paper or foil-faced glass fiber insulation batts. The time assigned to each type of insulation as contributing additional fire endurance to the assembly is presented in Table 3. For a wall or partition where only plywood is used as the membrane on the side assumed to be exposed to the fire, insulation shall be used within the assembly.

In developing this methodology it was also determined that the primary function of the membrane on the unexposed side of an exterior wall is to keep the insulation in place and prevent the transmission of heat. Fire endurance of wall assemblies is consistently dependent upon the fire exposed-side membrane. As a result, it is considered very reasonable to substitute various exterior cladding materials as the membrane on the unexposed side or exterior wall assemblies[1]. Therefore, where a fire endurance rating for an exterior wall is to be determined using CAM, any combination of sheathing, paper, and exterior finish listed in Table 4 may be used, or the outer membrane may consist of any membrane combination that is assigned a time for contribution to fire endurance of at least 15 minutes in Table 1

Roofs and Floor/Ceiling Assemblies

In the case of a roof or floor/ceiling assembly, fire testing is normally done with exposure from below the assembly. To comply with this calculation methodology, floor and roof assemblies must have a protective membrane in conformance with Table 1. The upper membrane must consist of a subfloor or roof deck and finish in conformance with Table 5. Alternatively, any combination of membranes listed in Table 1, with a fire endurance rating of at least 15 minutes, may be used on the unexposed (upper) side. If the proposed assembly is a ceiling with an attic above, most building codes allow elimination of the upper membrane.



[1] For examples of fire rated exterior walls see "Design for Code Acceptance No. 3: One-Hour Fire Rated Wood-Frame Wall and Floor/Ceiling Assemblies" American Wood Council, 2010.

Table 1 Time Assigned to Protective Membranes

Description of Finish	Time, min.
3/8 inch Douglas fir plywood, phenolic bonded	5
1/2 inch Douglas fir plywood. phenolic bonded	10
5/8 inch Douglas fir plywood. phenolic bonded	15
3/8 inch gypsum board	10
1/2 inch gypsum board	15
5/8 inch gypsum board	20
1/2 inch Type X gypsum board	25
5/8 inch Type X gypsum board	40
Double 3/8 inch gypsum board	25
1/2 + 3/8 inch gypsum board,	35
Double 1/2 inch gypsum board	40

Notes:

1. On walls, gypsum board shall be installed with the long dimension parallel to framing members with all joints finished. However, 5/8 inch Type X gypsum wallboard may be installed horizontally with the horizontal joints unsupported.

2. On floor/ceiling or roof/ceiling assemblies, gypsum board shall be installed with the long dimension perpendicular to framing members and shall have all joints finished.

3. Recommended fastener schedule:
wall assemblies = Type S or W screws with a minimum 1.5 inch penetration into the wood member at 7 inches o.c.
floor assemblies = Type S or W screws with a minimum 1 inch penetration into the wood member at 7 inches o.c.

Table 2 Time Assigned To Wood-Frame Components

Description of Frames	Time, min.
Wood studs. 16 inches on center	20
Wood joists. 16 inches on center	10
Wood roof and floor truss assemblies, 24 inches on center	5

Table 3 Time Assigned for Additional Protection

Description of additional Protection	Time, min.
Add to the fire endurance rating of wood stud walls if the spaces between the studs are filled with rockwool or slag mineral wool batts weighing not less than 1/4 lb./sq. ft. of wall surface.	15
Add to the fire endurance rating of non-load bearing wood stud walls if the spaces between the studs are filled with glass fiber batts weighing not less than 1/4 lb./sq. ft. of wall surface.	5

Table 4 Membrane on Exterior Face of Walls

Any combination of sheathing, paper (if required), and exterior finish listed below may be used.

Sheathing	Paper	Exterior Finish
5/8 inch T & G lumber 5/16 inch exterior grade plywood 1/2 inch gypsum board	Sheathing paper	Lumber siding Wood shingles and shakes 1/4 inch ext. grade plywood 1/4 inch hardboard Metal siding Stucco on metal lath Masonry veneer
None	None	3/8 inch ext. grade plywood

Table 5 Flooring or Roofing Membrane

Assembly	Structural members	Subfloor or roof deck	Finish flooring or roofing
Floor	Wood	1/2 inch plywood or 11/16 inch T&G softwood lumber	Hardwood or softwood flooring on building paper; or Resilient flooring, parquet floor, felted-synthetic-fiber floor coverings, carpeting, or ceramic tile on 3/8 inch thick panel-type underlay; or Ceramic tile on 1-1/4 inch mortar bed.
Roof	Wood	1/2 inch plywood or 11/16 inch T&G softwood lumber	Finish roofing material with or without insulation.

Example Calculations

Example 1: *Determine the fire endurance rating of a wall assembly having one layer of 5/8 inch Type X gypsum wallboard attached to wood studs on the fire exposed side (interior, see Figure 1).*

Table 1 shows that 5/8 inch Type X gypsum wallboard has a fire endurance time of 40 minutes. Table 2 shows that wood studs spaced 16 inches on center have a fire endurance time of 20 minutes. (Adding additional membranes to the framing would also be permitted according to Harmathy's rule #2.)

If the wall is assumed to be exposed to fire from both sides (e.g., for interior fire rated partitions), each surface of the framing member would be required to be fire protected with at least 40 minutes of membrane coverings in Table 1. If the proposed wall is assumed to be exposed to fire from one side only, as is required of an exterior wall, the fire exposure is assumed to be from the interior, which would require a total contribution of 40 minutes from the membrane coatings from Table 1. It should be noted that to achieve the assigned fire endurance rating, the exterior side must be protected in accordance with Table 4 or any membrane that is assigned a time of at least 15 minutes as listed in Table 1.

If wall cavities between studs had been filled with rockwool insulation adding 15 minutes of fire endurance, as noted in Table 3, the 5/8 inch Type X gypsum wallboard could be replaced by 1/2 inch Type X gypsum wallboard. Thus, adding the fire endurance contribution times for the 1/2 inch gypsum wallboard, wood studs, and insulation (25 minutes + 20 minutes + 15 minutes) the resultant fire endurance rating for the wall would also equal 60 minutes.

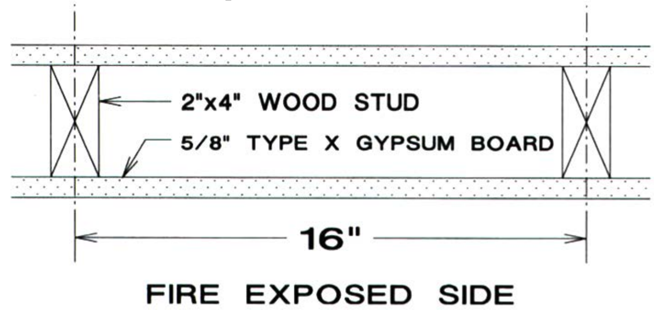


Figure 1 Interior Wall

5/8 inch Type X gypsum board	=	40 minutes
Wood studs	=	20 minutes
Combined Assembly Fire Endurance Rating	=	60 minutes

Example 2: *Determine the fire endurance rating of a floor/ceiling assembly having wood joists spaced 16 inches on center and protected on the bottom side (ceiling side) with two layers of 1/2 inch Type X gypsum wallboard and having a 1/2 inch plywood subfloor on the upper side (floor side).*

Table 1 shows that the fire endurance time for each layer of 1/2 inch Type X gypsum wallboard is 25 minutes. The fire endurance time assigned for wood joists, as shown in Table 2, is 10 minutes.

Adding the assigned times of two layers of gypsum wallboard and wood joists, a fire endurance rating of 60 minutes or one hour is calculated.

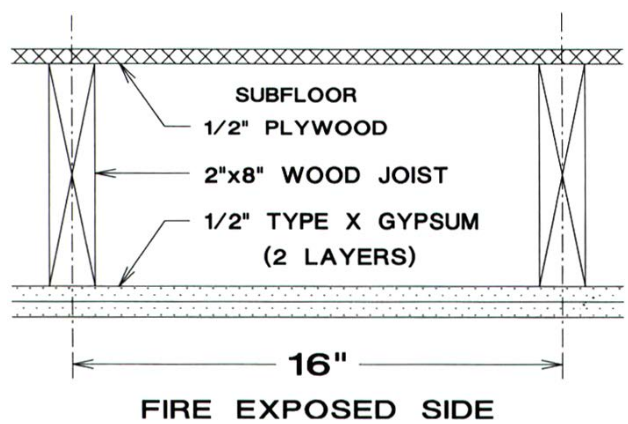


Figure 2 Floor/Ceiling Assembly

1/2 inch Type X Gypsum board	=	25 minutes
1/2 inch Type X Gypsum board	=	25 minutes
Wood joists	=	10 minutes
Combined Assembly Fire Endurance Rating	=	60 minutes

Example 3: *A private residence is being changed to an office. The load bearing exterior walls of the residence consist of 2 by 4 inch studs spaced 16 inches on center, 1/2 inch gypsum wallboard on the inside, and 5/16 inch exterior grade plywood, sheathing paper and 1/4 inch hardboard siding on the outside. The cavities between the wood studs are filled with 1/4 lb/sq.ft. glass fiber batts. The code requires the exterior wall of the structure to be upgraded to one hour fire endurance with fire exposure from the inside only. What modifications can be made to comply with the code requirement?*

Table 1 shows the 1/2 inch gypsum wallboard has a contribution to the assembly fire rating of 15 minutes. According to Table 2, the studs have an assigned time of 20 minutes. According to Table 3, the glass fiber does not contribute to the fire endurance of a load bearing wall. Thus, the fire endurance rating of the exterior wall of the residence equals 35 minutes.

In order to upgrade the wall to one hour, a protective membrane should be added on the inside, contributing 25 minutes or more to the assembly rating. For example, a 1/2 inch Type X gypsum wallboard adds 25 minutes according to Table 1, leading to a total of 60 minutes.

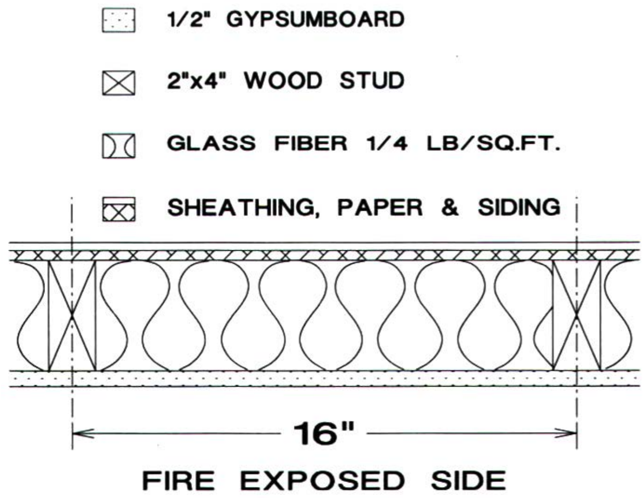


Figure 3 Exterior Wall

1/2 inch Gypsum board	=	15 minutes
Wood studs	=	20 minutes
Combined Assembly Fire Endurance Rating	=	35 minutes

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Conclusion

Assemblies of wood construction are used increasingly in architectural designs because of their adaptability to a variety of style preferences, economies of construction, and the energy saving performance of such systems. These assemblies can now be evaluated to determine their fire endurance rating by a Component Additive Method, avoiding expensive fire testing.

Designers are also encouraged to review AWC's online Heights and Areas Calculator[2] for additional information.

The procedure described in this publication is intended to assist the designer of wood-frame structures in meeting specified fire endurance requirements. Special effort has been made to insure the accuracy of the information presented. However, AWC does not assume responsibility for particular designs or calculations prepared from this publication.

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[2] Online Heights and Areas Calculator available free of charge on the American Wood Council website: www.awc.org.