Timber frame houses
Fire resistance

STEP lecture E12
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Objective

To provide information on the fire behaviour of timber frame houses.

Summary

A survey upon design and calculation procedures to determine the fire resistance of timber frame houses is given. The fire behaviour of single components made of wood and/or wood-based materials as well as non-combustible panels and insulating layers is discussed in detail.

Introduction

The fire resistance of a timber frame house depends on two specific functions. Single components such as beams, columns, walls, floors, stairs and roofs have to fulfill a loadbearing function and (especially walls and floors) are necessary for compartementation. Fire compartementation should prevent fire expansion and keep rooms or escape routes free from flames and hot gases.

According to these functions the design procedure for the single component is the following:

EC5: Part 1-2: 2.1.

Criterion R

Mechanical resistance in the event of fire is required. Structures shall be designed and constructed in such a way that they maintain their load-carrying function during fire exposure.

Members shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure, i.e.

Criterion E

No integrity failure due to cracks, holes or other openings large enough to permit fire penetration by hot gases or flame.

Criterion I

No insulation failure leading to temperatures of the non-exposed surface exceeding admissible limits.

The members shall comply with criteria *R*, *E*, and *I* as follows:

-	*R* (load carrying):	beams, columns, walls.
-	*RE* (*I*) (load carrying and seperating):	floors and walls.
-	*EI* (separating):	partition walls.

The criteria are time dependent and vary with the use of the strucure. The time period is defined in minutes as 15, 20, 30, 45, 60, 90, 120, 180, 240 or 360 minutes.

Behaviour of the entire structure

The classification of a single components requires that each connected element fulfills the same criterion as the component. This means that for example a beam only fulfills it's load-carrying function for a certain time if all the appropriate single components (stiffening, bracket, bracing...) do not fail within the required time period. The interplay of the abilities of each element forms the fire resitance of the entire structure.

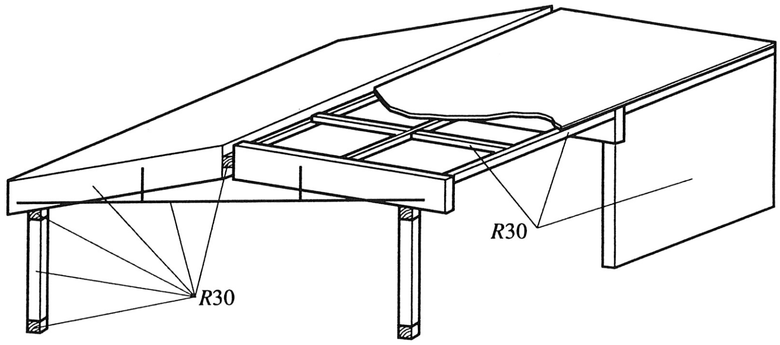


Figure 1 Example entire structure R30 (Kordina, Meyer-Ottens, 1994).

In the following some calcualtion methods will be presented for single components. In most cases classification according to the rules given will prove conservative and testing of the element is indispensable.

Behaviour of the single component

Members

The fire resistance of unprotected timber members is discussed in lecture B17. In some cases a protection by claddings might be necessary. But from the aesthatical point of view and from a designers point of view it is better to reach a fire resitance time by an unprotected member. For calculating the fire resitance of a protected timber member the kind of protection gives information about the fact from how many sides charring has to be considered (1-4 sided).

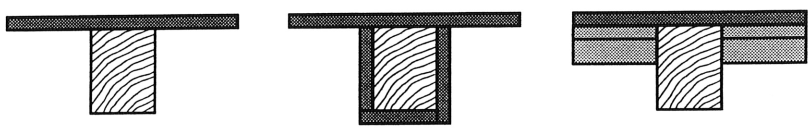


Figure 2 Member unprotected, totally covered and partly covered.

Charring need not to be considered for surfaces of members covered by fire protective claddings when

EC5: Part 1-2: 3.6

$$t_{pr} \geq t_{f,req}$$

where

t_{pr} is the failure time of protective board or other protective material, i.e. the duration of effective protection against direct fire exposure.

$t_{f,req}$ is the required fire resistance time under standard fire exposure.

When surfaces of members are covered by fire protective claddings or are aligned with other structural members having a failure time smaller than the required fire resistance time $t_{f,req}$ charring of the member starts at the failure time t_{pr} of the cladding.

Panels, insulating layers

Panels are produced from wood and/or wood-based materials with binders. Panels are non combustible under the following conditions:

- use of binders such as gypsum, cement, etc.
- use of fire retardants.

The main panels are: all veneers only board (AVO board), particle board, fibreboard, gypsum plasterboard.

Due to the fact that some panels have a charring rate lower than solid wood they increase the time of fire resistance of the component. In most cases they are used in combination with walls and floors to satisfy separating functions inside the house (e.g. escape routes, stairways). For panels used as fire protective cladding (Figure 3) a failure time has to be determined. Failure time in this case means that the increase of temperature on the opposite side of the fire exposure has not yet reached the maximum of 180 *K* for combustible panels and 500 *K* for non combustible panels (during fire tests at this time black areas could be seen on the opposite side). According to the different behaviour of the materials in the event of fire it is necessary initially to assess the failure times on the basis of tests.

EC5: Part 1-2: Figure 3.1

Figure 3 Example for panels used as fire protective cladding.

The failure time for fire protective claddings of wood and wood-based panels may be found from the equation

EC5: Part 1-2: 3.7

$$t_{pr} = \frac{t_p}{\beta_0} - t_r \qquad mm$$

where

β_0 is the charring rate according to EC5: Table 3.1.

t_p is the thickness of wood or wood-based panel cladding. In the case of two or more layers of board t_p is the sum of thickness of each layer.

t_r = 4 *min* has been introduced to prevent falling-off of panels and/or premature penetration of fire into empty spaces (holes in the panel).

If the cladding consists also of more than one material, the time of fire resistance for the panel is in general the sum of each layer's fire resistance. A fire protective cladding should always be fixed to the member itself and in case of multiple layer claddings not one to the other. Load-carrying panels need not to be analysed, if their residual thickness is at least 60% of the thickness required for normal temperature design.

According to EC5 Part 1-2 insulating layers have a melting point > 1000 °C and are non-combustible. The most common products are wood-wool panels and mineral fibre board. Especially for wall- and floor construction insulating layers are of great importance to reach the separating criterion. It is indispensable that the insulating layer are fixed carefully and tight (compressed).

For non-combustible insulating material with a thickness of more than 20 *mm* and a density of more than 30 kg/m^3 which remain coherent up to 1000 °C failure time may be taken as

EC5: Part 1-2: C5

$$t_{pr} = 0{,}07\ (t_{ins} - 20)\ \sqrt{\rho_{ins}} \quad min$$

where

t_{ins} is the thickness of insulation material in *mm* and ρ_{ins} is the density of the insulting material in kg/m^3.

Bracings

Bracings should not fail within the required fire resistance period of the member. Bracings should have a residual cross section of at least 60% of the cross sectional area required for normal temperature design, otherwise the frame must be analysed as an unbraced frame. This rule should also be applied for walls and floors (panels).

Walls

For the sake of classification in case of fire, wall constructions are divided into the following groups:

- *Non-load-bearing* walls are flat components that are, also in case of fire, stressed only by their dead load. In structural design they do not perform any stiffening function.
- *Load-bearing* walls are stressed by compression. If walls are required to maintain the buckling stiffness of load bearing walls upright the afore - mentioned rules (bracings) should be applied.
- *Separating* walls are located between apartments, used for stairways, escape routes or fire walls. Their main function is to avoid fire transfer from one room to another. For separating constructions fire exposure from only one side has to be considered.
- *Non-seperating* (non - loadbearing) walls. They do not need any fire resistance.

A wall only performs the seperating function if openings (especially doors and windows) have the same fire resistance (e.g. seperating function). In practice only outer and not inner walls meet this requirement. Experience has shown that outer walls with a length of > 1 *m* perform the seperating function.

The construction of a wall follows the principles shown in Figure 4.

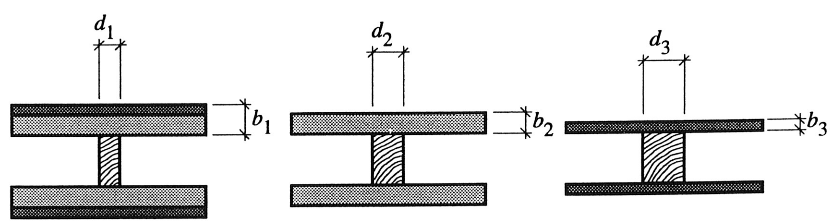


Figure 4 Increasing stud cross section acc. to thinner panels (Kordina, Meyer-Ottens, 1994).

Figure 4 shows that the thickness of a wall is in general depending on the thickness of the panels (loadbearing wall) or insulating layers (seperating wall). Using no insulating layer or reduction of the panel thickness implies a larger cross section of the studs to reach the same fire resistance.

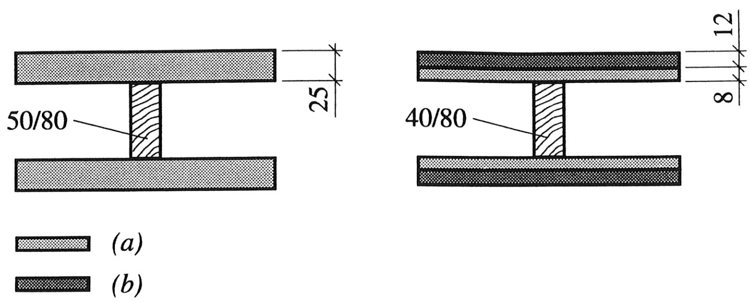


Figure 5 *Examples for load-bearing walls R30. (a) Wood-based panel, (b) gypsum plaster board.*

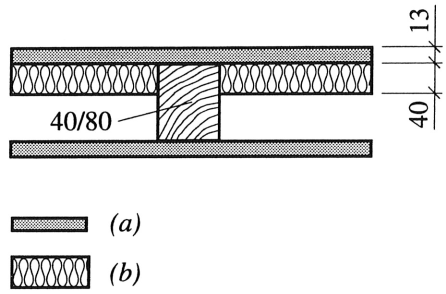


Figure 6 *Example for separating wall REI 30. (a) Wood-based panel, (b) insulating layer.*

Another problem for wall constructions are installation. Especially sockets reduce the necessary wall thickness and therefore it is not allowed that they face each other. This smaller wall thickness might diminish the fire resistance and has to be made up for by insulating layers.

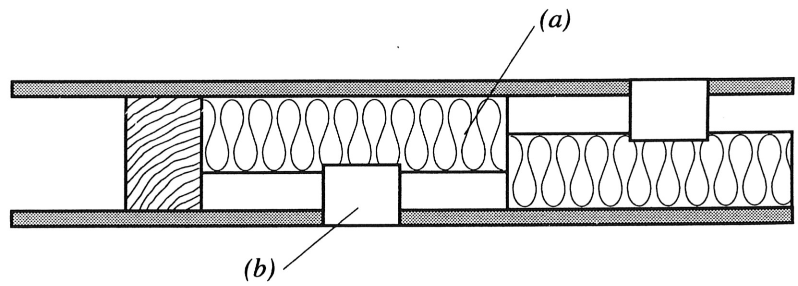


Figure 7 *Socket protected by insulating layer. (a) Insulating layer, (b) socket.*

For separating constructions the main verifications are as follows:

EC5: Part 1-2: 2.3

I The increase of temperature on the unexposed side is limited to 140 *K*. This criterion is satisfied if the residual layers have a remaining failure time of 15 *min* beyond the required fire resistance time (see Figure 2, 3).

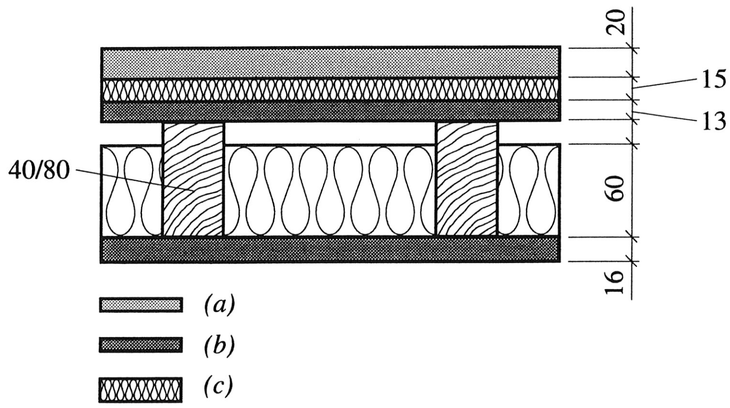
II The maximum temperature rise at any point is limited to 180 *K*, and no fire penetration through panel joints occurs. This criterion is satisfied if the panel joints in the outer layer of the non-exposed side are not directly exposed to fire, with a safety margin of 5 *min* (see Figure 2, 3).

III To allow for building services in walls it should be verified that - after removing 45 *mm* of the layer on one side at a time - the reduced construction has a residual failure time of 5 *min* beyond the require fire resistance time.

It should also be ensured, that the panels remain fixed to the timber frame on the unexposed side. This requirement is fulfilled when criterion II is observed.

Floors

In general the same principles (claddings and insulating layers) as for wall design could be applied. Composition flooring (or floor covering) on the upper side represents an effective protection against fire. Charring and breaking through (of loads) can be prevented by composition flooring. The under side is in most cases the unfavourable side of the floor construction (concerning fire resistance) and must be protected (insulating layer). According to this charring has to be considered from the under side.



EC5: Part 1-2: Figure C4

Figure 8 *Example for floor construction REI30. (a) Flooring, (b) panels, (c) insulating layer.*

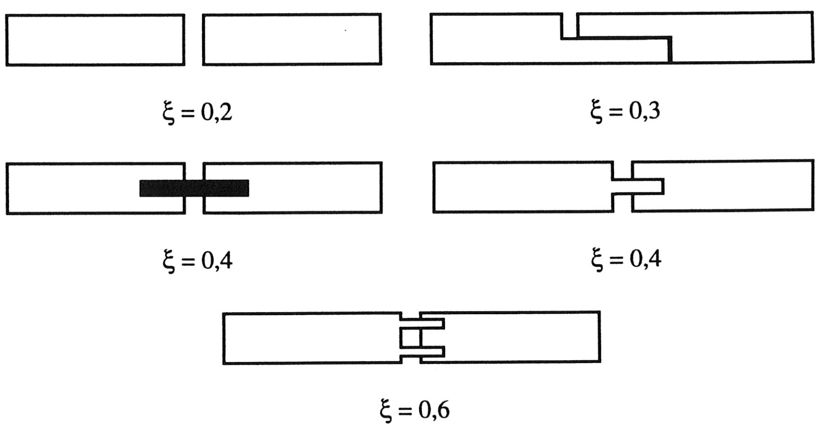
In addition to the above-mentioned facts (fire protective cladding), failure times for floors exposed to fire from below should, in the vicinity of panel joints, be taken as

EC5: Part 1-2: C1

$$t_{pr} = \xi \frac{h_p}{\beta_0}$$

where

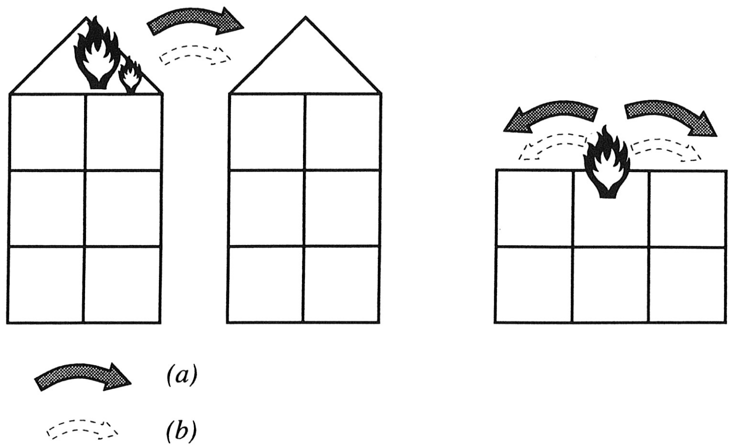
ξ is a reduction coefficient accounting for increased charring at joints (see Figure 4) and h_p is the height of the panel.



EC5: Part 1-2: Figure C4

Figure 9 *Reduction coefficient accounting for failure time at joints for floors exposed to fire from below.*

Roofs
The function of the roof structure is to be resistant against fire spread or heat radiation as shown in Figure 9. Only in some special cases roof structures take over stiffening or seperating functions (e.g. attic flats).

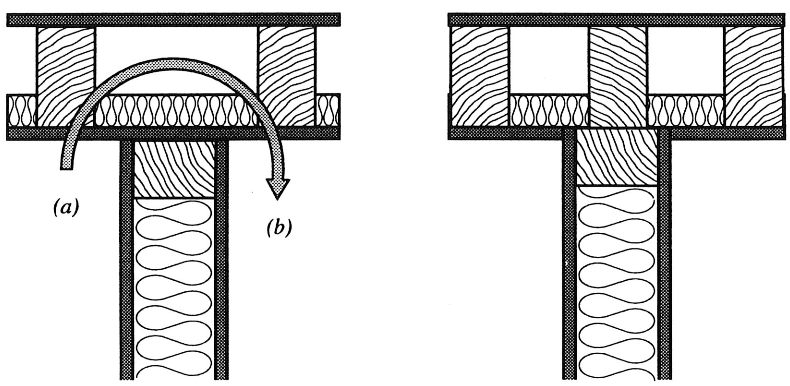


EC5: Part 1-2: Figure C.4

Figure 10 Possibilities of fire load on roofs. (a) fire spread through sparks, (b) heat radiation.

Stairs
Calculation of fire resistance follows the principles discussed for member design. In the event of fire stairs can be necessary (escape routes) or not. As concerning timber structures stairs used as escape routes have to keep their loadbearing function upright during the fire period time. Stairs used for seperating functions are carried out very seldom.

Joints, grooves
Joints are dealt with in lecture C19. Especially connenctions between walls and floors for rooms with seperating function must be carried out in a way that makes them resistant against premature fire (or hot gases) penetration. Otherweise the whole construction fails before the required time. Also grooves between claddings have to be smoothed with a filler.



EC5: Part 1-2: Figure C4

Figure 11 Example wall - floor connection. (a) Side of fire exposure, (b) fire penetration.

The connection on the left side would (after a certain fire period) not be as resistant against fire penetration as the connection on the right side.

Connections to adjoining floors and walls should be detailed such that

EC5: Part:1-2: Chap.C4.3

- the fixing is not affected by failure of panels.
- gaps at interfaces will not give way to fire penetration into the void between panels and frame.
- failure of panels of one construction will not give way to fire penetration into the void of an adjoining construction.

If floors or walls are connected to massive constructions different deformations and expansions may occur. In this case the interface should be sealed with non-combustible material.

Minimum dimensions
In most countries minimum dimensions are given to guarantee (without verification) a certain time of fire resistance. Unprotected timber frame members should have minimum dimensions of 38 *mm*. For walls individual panels and sheets a minimum thickness $t_{p,min}$ related to the span l_p in *mm* of the panel is given by:

EC5: Part 1-2: C6,7

$$t_{p,\min} = \frac{l_p}{62,5}$$

$$t_{p,\min} \geq 8mm$$

Wood based panels in single-layer constructions should have a characteristic density of at least 350 kg/m^3.

Example

Non load-bearing construction for inner or outer walls. The test result showed failure on the opposite surface after 65 minutes, with fire exposure from the inside.

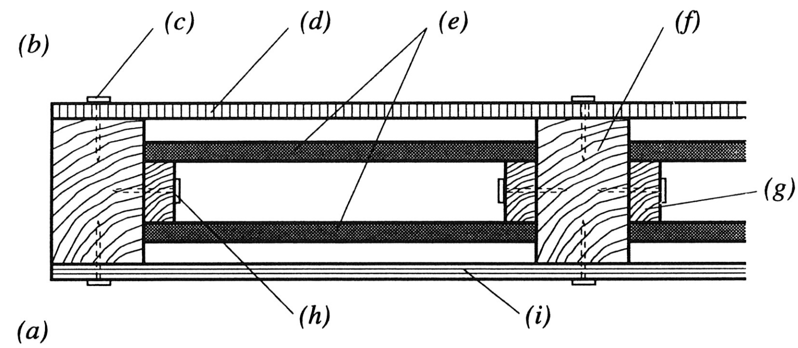


Figure 12 *Non-load-bearing wall. (a) outside, (b) inside, (c) nails 2,1 x 40, (d) wood-based panel, (e) mineral fibre board, (f) sawn timber 60 by 97 mm, (g) sawn timber 25 by 46 mm, (h) nails 3,4 x 80, (i) wood panels with groove and tongue joints.*

According to EC5 Part 1-2 the main verification for seperating constructions (*EI*) are as follows:

a) Fire exposure from one side.

b) Residual layers should have a remaining failure time of 15 minutes beyond required fire resistance time (increase of temperature limited to 140 *K*).

c) Safety margin in the outer layer of 5 minutes (maximum temperature rise at any point limited to 180 *K*).

d) Residual cross section of the timber frame member are at least 60% of the cross section necessary for normal temperature design is required.

Verification for *EI* 40:

a) Fire exposure is only from one side (see above).
b) Failure times.

Wood based panel	8,4 minutes.
Mineral fibre board	20,4 minutes.
Wood panel	20,8 minutes.

Sum of all layers = 8,4 + 20,4 · 2 + 20,8 = 70,0 min > 40 + 15 = 65 minutes.

c) Safetey margin in the outer layer of 5 minutes.

Sum of all layers except outer layer = 8,4 + 20,4 · 2 = 49,2 min > 40 + 5 = 45 minutes.

d) Residual cross section 60%.

Charring for the timber frame member	31,6 minutes.
Charring rate for solid timber	0,8 *mm*/minutes.
Charring depth	25,3 *mm*.
Remaining cross section (height)	71,7 *mm* = 74% > 60%.

Conclusion:
This wall meets all the requirements (a) to (d) necessary for seperating function *EI* 40. Although the construction reached separating function for 65 minutes in the fire test it would not perform *EI* 60 in calculation.

References

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