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Design model for the verification of the separating function of light timber frame assemblies

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ABSTRACT

In order to limit fire spread by providing adequate fire compartmentation, elements forming the boundaries of fire compartments are designed and constructed in such a way that they maintain their separating function during the required fire exposure (insulation and integrity criteria). While fire tests are still widely used for the verification of the separating function of light timber frame assemblies, design models are becoming increasingly common. A comprehensive research project on the separating function of light timber frame wall and floor assemblies with cladding made of gypsum plasterboards and wood-based panels was carried out at ETH Zurich in collaboration with the Swiss Laboratories for Materials Testing and Research (Empa). The objective of the research project was the development of an improved design model for the verification of the separating function of light timber frame wall and floor assemblies. A large number of small-scale fire tests permitted the analysis of different parameters on the thermal behaviour of protective cladding made of gypsum plasterboards and wood-based panels. The results of the fire tests allowed the verification and calibration of thermal properties used for thermal finite element (FE) analysis. Based on an extensive FE parametric study, the coefficients of the design model for the verification of the separating function of light timber frame wall and floor assemblies were calculated. The design model was verified by means of full-scale fire tests. The paper first describes the basic structure of the design model for the verification of the separating function of light timber frame wall and floor assemblies. Then, the main results of experimental and numerical analyses are presented. The results permitted the calculation of the coefficients of the design model for the verification of the separating function of light timber frame wall and floor assemblies.

1. Introduction

Light timber frame wall and floor assemblies are typical structural elements used in timber buildings. The assemblies consist of solid timber studs or beams with cladding made of gypsum plasterboards, wood-based panels or combinations of these layers. The cavities may be filled with insulation made of rock, glass or wood fibre or include voids. Unlike heavy timber structures in which the char layer of fire-exposed members performs as an effective protection of the remaining unburned residual cross-section, the fire performance of load-bearing and non-load-bearing light timber frame assemblies mainly depends on the protection provided by the cladding [1–3].

In order to limit fire spread by guaranteeing adequate fire compartmentation, elements forming the boundaries of fire compartments are designed and constructed in such a way that they maintain their separating function during the required fire exposure (requirement on integrity E and insulation I). The required period of time is normally expressed in terms of fire resistance using the standard fire exposure [4] and is specified by the building regulations. While fire tests are still widely used for the verification of the separating function of light timber frame assemblies, design models are becoming increasingly common. For ISO fire exposure criterion I (insulation) may be assumed to be satisfied if the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K, thus preventing ignition of objects in the neighbouring compartment. The criterion E (integrity) may be assumed to be satisfied if no flames or hot gases on the fire-unexposed side of the construction can be observed. Criterion I (insulation) is clearly defined and thus the verification can be made by heat transfer calculations instead of testing. On the other hand, criterion E (integrity) is mostly determined by observations, because calculations are still very complex (crack-formation, dynamics of hot gases, etc.). For example, premature integrity failure may occur due to sudden failure of claddings or opening of gaps, which often is dependent on the construction details such as fixings. However, extensive experience of full-scale testing of wall and floor assemblies

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permitted to define some rules about detailing of wall and floor assemblies that have been included for example in EN 1995-1-2 [5]. Thus, the criterion E (integrity) may be assumed to be satisfied if the criterion I (insulation) has been satisfied and panels remain fixed to the timber structure on the unexposed side.

In timber buildings, walls and floors are mostly built up by adding different layers to form an assembly. For the verification of the separating function of timber assemblies, component additive methods are common. These models are called component additive models, since the fire resistance of a layered construction is obtained by adding the contribution to the fire resistance of the different layers. In [6] calculation models for the verification of the separating function of light timber frame wall and floor assemblies used in the UK [7], Canada [8] and Sweden [9] as well as according to ENV 1995-1-2 [10] have been presented and reviewed. The current design method according to EN 1995-1-2 (Annex E) is based on the Swedish component additive method. As an enhancement of the method of ENV 1995-1-2 and the Canadian method, the Swedish component additive method takes into account the influence of adjacent materials on the fire performance of each layer and therefore describes the real fire performance more appropriately. However, the design method is based on input data that was deduced from a limited number of fire tests on wall assemblies and therefore only covers a limited range of timber structures.

A comprehensive research project on the separating function of light timber frame wall and floor assemblies with cladding made of gypsum plasterboards and wood-based panels has been carried out at ETH Zurich in collaboration with the Swiss Laboratories for Materials Testing and Research (Empa). The objective of the research project was the development of an improved design model for the verification of the separating function (insulation and integrity criteria) of light timber frame wall and floor assemblies. A large number of small-scale fire tests permitted the analysis of different parameters (material, thickness, position and number of the layers) on the thermal behaviour of protective cladding made of gypsum plasterboards and wood-based panels [11,12]. The results of the fire tests allowed the verification and calibration of thermal properties used for thermal finite element (FE) analysis. Based on an extensive FE parametric study, the coefficients of the design model for the verification of the separating function of light timber frame wall and floor assemblies were calculated [13]. The design model was verified by means of full-scale fire tests.

The paper first describes the basic structure of the design model for the verification of the separating function of light timber frame wall and floor assemblies. Then, the main results of experimental and numerical analyses are presented. Their results permitted the calculation of the coefficients of the design model for the verification of the separating function of light timber frame wall and floor assemblies.

2. Design method for separating function of timber constructions

A comprehensive design method for the verification of the separating function of timber constructions has been developed based on an extensive experimental as well as finite element thermal analysis [13]. The design method is capable of considering timber assemblies with an unlimited number of layers made of gypsum plasterboards, wood panels or combinations thereof. The cavity may be void or filled with insulation made of rock or glass fibre. The design method is valid for following materials:

- Solid timber panels (density ≥ 400 kg/m^3).
- Oriented Strand Board (OSB) (density ≥ 550 kg/m^3).
- Particleboards (density ≥ 500 kg/m^3).
- Plywood (density ≥ 400 kg/m^3).

Table 1
Thickness and mean density of the gypsum boards tested under ISO fire exposure.

Manufacturer	Type	Thickness tested (mm)	Density (kg/m^3)
Manufacturer 1	Gypsum fibreboard (GF)	10, 12.5, 15, 18	1186
Manufacturer 2	Gypsum plasterboard (GP) of type A	15	908
	Gypsum plasterboard (GP) of type F	15	853
	Gypsum fibreboard (GF)	12.5	1504
Manufacturer 3	Gypsum plasterboard (GP) of type A	10, 12.5, 15, 25	810
	Gypsum plasterboard (GP) of type F	15	889
	Gypsum fibreboard (GF)	12.5	1313

- Gypsum plasterboards:
  Type A, H and F according to EN 520 [14].
  Type X according to ASTM C1396 [15] or CAN/CSA-82.27-M91 [16].
- Gypsum fibreboards according to EN 15283-2 [17].
- Rock fibre insulation (density ≥ 26 kg/m^3).
- Glass fibre insulation (density ≥ 15 kg/m^3).

The developed design method is based on the additive component method given in EN 1995-1-2. Thus, the fire resistance t_{ins} of the timber assembly is taken as the sum of the contributions from the different layers (claddings, void or insulated cavities) according to their function and interaction as follows (Fig. 1):

$$t_{ins} = \sum_{i=1}^{i=n-1} t_{prot,i} + t_{ins,n} \quad (1)$$

with

$\sum_{i=1}^{i=n-1} t_{prot,i}$ Sum of the protection values $t_{prot,i}$ of the layers (in direction of the heat flux) preceding the last layer of the assembly on the fire-unexposed side (min).

$t_{ins,n}$ Insulation value $t_{ins,n}$ of the last layer of the assembly on the fire-unexposed side (min).

Protection and insulation values of the layers can be calculated according to the following general equations taking into account the basic values of the layers, the coefficients for the position of the layers in the assembly and the coefficients for the joint configurations:

$$t_{prot,i} = (t_{prot,0,i} \cdot k_{pos,exp,i} \cdot k_{pos,unexp,i} + \Delta t_i) \cdot k_{j,i} \quad (2)$$

$$t_{ins,n} = (t_{ins,0,n} \cdot k_{pos,exp,n} + \Delta t_n) \cdot k_{j,n} \quad (3)$$

with

$t_{prot,0,i}$	Basic protection value (min) of layer i (Fig. 1 and Table 3).
$t_{ins,0,n}$	Basic insulation value (min) of the last layer n of the assembly on the fire-unexposed side (Fig. 1 and Table 3).
Δt_i, Δt_n	Correction time (min) for layers protected by gypsum plasterboards of type F or type X as well as gypsum fibreboards (Table 5).
$k_{pos,exp,i}$, $k_{pos,exp,n}$	Position coefficient that takes into account the influence of layers preceding the layer considered (Table 4).
$k_{pos,unexp,i}$	Position coefficient that takes into account the influence of layers backing the layer considered (Table 6).
$k_{j,i}$, $k_{j,n}$	Joint coefficient (Table 7).

3. Fire tests

A series of 17 small-scale fire tests (in the following mentioned as V1 to V17) was performed with non-loaded specimens consist-