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FIRE PERFORMANCE OF NON-LOADBEARING LIGHT STEEL FRAMING WALLS - NUMERICAL SIMULATION

Paulo A.G. Piloto[1(*)], Mohamed S. Khetata[2], Ana B.R. Gavilán[3]
[1]LAETA-INEGI, Department of Applied Mechanics, Polytechnic Institute of Bragança (IPB), Portugal
[2] Science and Technology Park - Brigantia-EcoPark, Portugal
[3]Department of Mechanical Engineering, University of Salamanca (USAL), Spain
[(*)]*Email:* ppiloto@ipb.pt

ABSTRACT

Light steel frame (LSF) and prefabricated panels are widely used in non-load-bearing walls, with direct application to steel framed buildings. The fire resistance is usually provided by one or more layers of fire protection materials and the assembly is able to achieve a fire resistance in accordance to technical regulations. Different types of board material can be applied, including gypsum-based boards. This investigation evaluates the behaviour of the cavity, with and without insulation material. The finite volume method is applied to perform the thermal analysis of the wall taking into account the fluid effect in the cavity. The finite element method is applied to perform the thermal analysis of the wall with insulation material in the cavity. The fire resistance is compared for both models (with and without insulation) and a new simple formula is proposed for the temperature evolution in the cavity zone. Some insulant materials can reduce the fire resistance of the wall, when considering the insulation criterion.

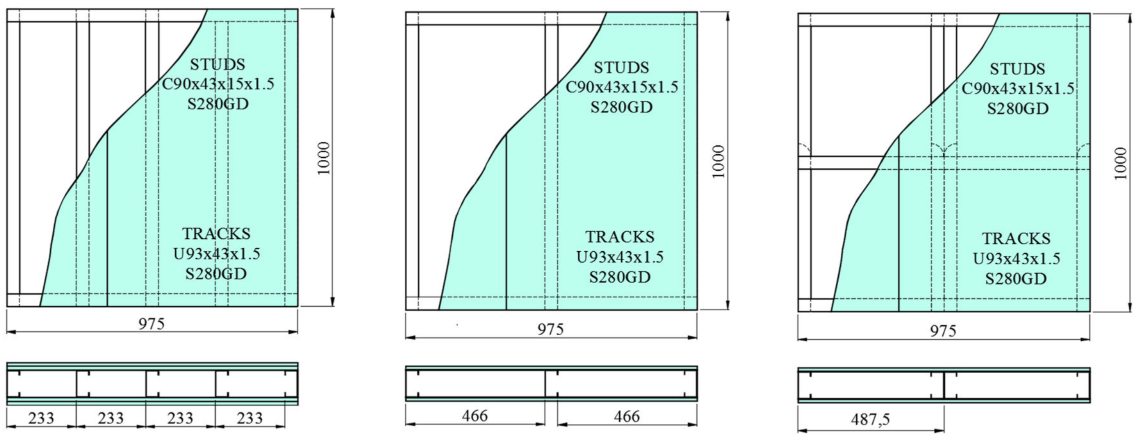
Keywords: LSF walls, fire resistance, ANSYS FLUENT, ANSYS MULTIPHYSICS.

INTRODUCTION

There is a wide range of application for non-loadbearing LSF walls in buildings, such as multi storey offices, educational buildings, health buildings, residential buildings and other type of public buildings. Non-loadbearing LSF walls prevent fire propagation into adjacent rooms, and must meet the requirements for fire resistance: prevent the propagation of fire; tightness against inflammable gas; and limitation of the temperature of the unexposed surface. The fire protection is usually provided by one or more layers of fire protection materials. Members which meet fire resistance standards are the result of the proper combination of certain materials and elements. The thin steel sections must be covered with a sheathing to prevent them from being damaged by fire. Self-drilling screws are commonly used in this assembly and should also be fire protected. Some incombustible insulation material can improve the fire resistance of the LSF wall, especially keeping the integrity of the wall (Arcelor, 2005). Gypsum plates and rockwool insulation have been approved as fire protection materials and can be combined with steel to build fire resistance walls, see Fig. 1.

The fire performance of the building product is regulated by the European standard EN13501-2 (CEN, 2009), using data from fire resistance tests. The performance characteristics must include the integrity capacity (E) (not evaluated in this investigation but with great importance during test) and the insulation capacity (I). The assessment of the insulation (I) shall be made by the calculation of the average temperature rise on the unexposed face limited to 140 °C above the initial average temperature, or, with the maximum temperature rise at any point limited to 180 °C above the initial average temperature, see Fig. 1.

Three light steel frames are to be analysed. The main difference is the number of steel studs, which are going to affect the temperature distribution in the unexposed surface. The simulation also includes different number of panels (one gypsum panel and two gypsum panels). The cavity is also simulated without solid insulation and with rockwool.



(a) Steel frame with 5 studs (b) Steel frame with 3 studs (c) Steel frame with 4 studs

Fig. 1 - Steel frame structure and panels.

A total of 12 simulations are presented, divided in two groups. One group was simulated with thermal and fluid analysis for both solid and fluid parts, while the other group considered only the thermal analysis for solids, assuming perfect contact between materials.

NON-LOAD BEARING WALLS UNDER FIRE

The non-loadbearing walls under analysis are made of a light steel frame structure (studs and tracks) separated by different distances. Two different layers of gypsum were considered, each with 12.5 mm thickness. The insulation of the cavity uses rockwool with 120 kg/m^3 density. Fig. 2 represents the cross sections that were analysed. The geometry of this wall is representative of the full-scale wall. The assembly uses vertical members (studs) made of steel GD280 using the profile C90x43x15x1.5 and horizontal members (tracks) made of steel GD280 using the profile U93x43x1.5.

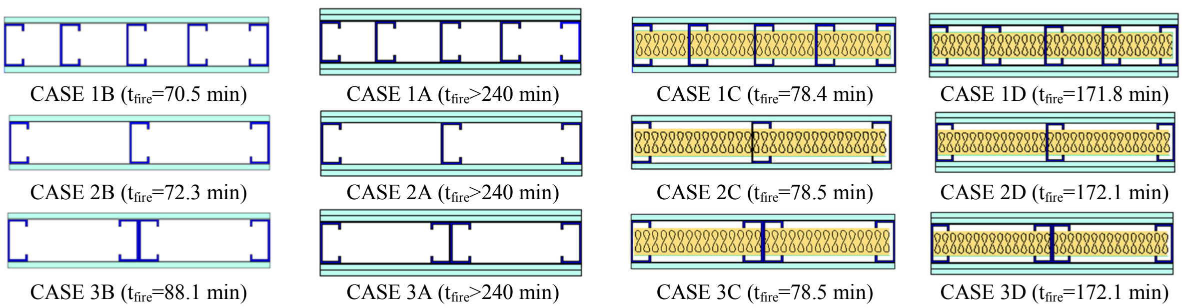


Fig. 2 - Cross sections of non-loadbearing walls.

One side of the wall is going to be submitted to fire and the other side is assumed to remain in contact with room temperature. The boundary conditions are defined in accordance to EN1991-1-2 (CEN, 2002), assuming heat transfer by radiation (emissivity of fire $\varepsilon_f = 1$) and convection (convection coefficient $\alpha_c = 25\left[W/m^2K\right]$) in the exposed side and heat transfer by convection (convection coefficient $\alpha_c = 9\left[W/m^2K\right]$ to include the radiation component) in the unexposed side. The temperature in the exposed side follows the standard ISO834 (ISO, 1999).

NUMERICAL MODEL

The numerical model considered fluid behaviour in the cavity of the wall (ANSYS FLUENT solver) and also solid behaviour (ANSYS MULTIPHYSICS solver). Only one half of the model was consider for each case (type of cross section).

The flow analysis was considered laminar and based on density variation. The fluid motion is induced by heat transfer and the solution is transient and non linear. ANSYS FLUENT Density-based solver solves the governing equations of continuity, momentum and energy simultaneously. Pressure is obtained through the equation of state. Governing equations for additional scalars are solved afterward and sequentially (radiation).

The integration time for each time step was 60 s, with the possibility to be reduced to 5 s. The convergence criterion was based on the residuals for each equation. The numerical model divided the cross section in finite cells. The domain variables (pressure, velocity, temperature) were calculated in each cell, at the same time. Fig. 3 represents the finite division of all the domains (solid and fluid) for CASE 1A, using the size of the cell equal to 0.0005 m.

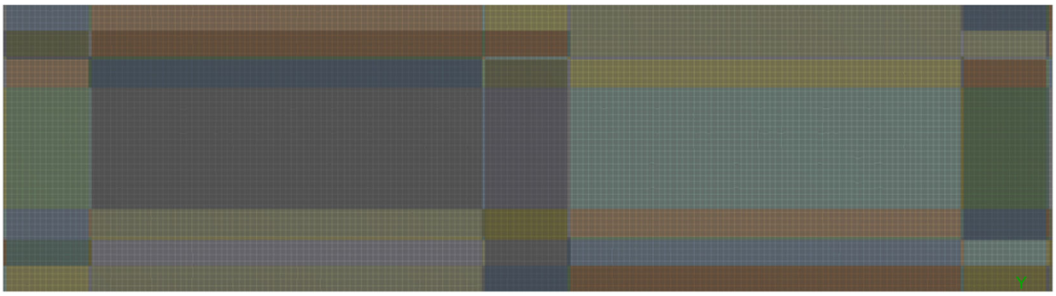


Fig. 3 - Finite cells used for CASE 1A model.

The solid model used ANSYS MULTIPHYSICS to solve transient and nonlinear thermal analysis, using full option solution method. The same time step was used with similar convergence criterion for the heat flow. Fig. 4 represents the mesh of CASE 1D. The density of the mesh used for ANSYS MULTIPHISICS is smaller in comparison with the cells used in ANSYS FLUENT, nevertheless the thickness of the studs was divided into three finite elements. The mesh was defined based on a convergence test.

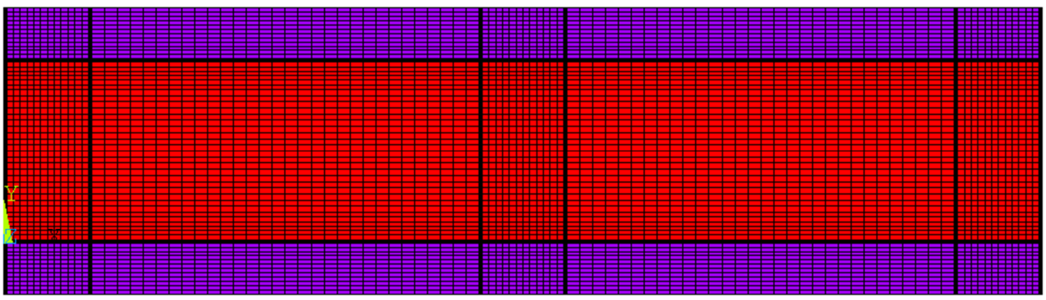


Fig. 4 - Finite element mesh used for CASE 1D model.

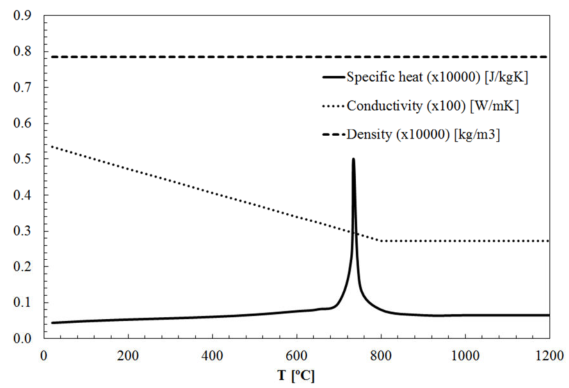
MATERIAL PROPERTIES

The thermal properties are decisive to simulate the performance of the non-loadbearing wall. The thermal properties are temperature dependent for all the materials involved.

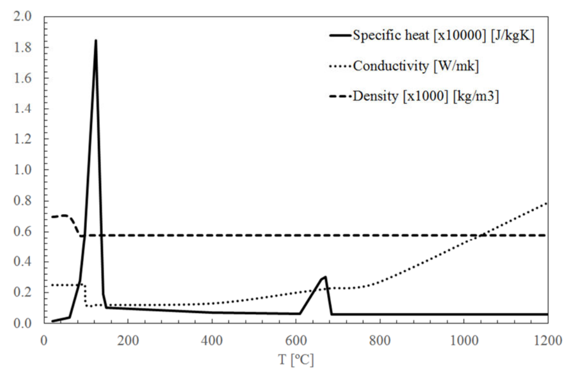
Steel presents typical evolution for the specific heat (c_{ps}) with a maximum value that account to the allotropic transformation. The thermal conductivity depends on temperature (λ_s) and specific mass (ρ_s) is considered constant, see Fig. 5, (CEN, 2005).

The thermal properties of Gypsum X considered in this investigation were determined by experiments (Sultan, 1996), using Differential Scanning Calorimeter (DSC) for the specific heat (c_{pg}), Thermal Conductivity Meter for conductivity (λ_g) and a vacuum conditioning chamber for the specific mass (ρ_g), see Fig. 5.

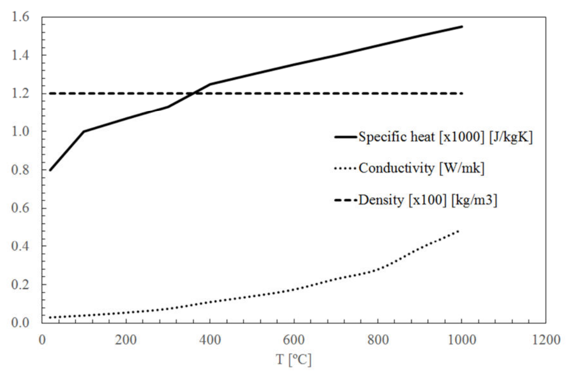
The thermal properties of the Rockwool depends on the fabrication process. During the production process, the fibres are pressed to achieve different densities, being the heaviest ones produced as boards and the lightest as mats. The specific mass of this material (ρ_i) was considered equal to 120 kg/m³, being the specific heat (c_{pi}) and thermal conductivity (λ_i) temperature dependent, see Fig. 5. The fibre itself starts melting around 1000 ºC (Steinar Lundberg, 1997).



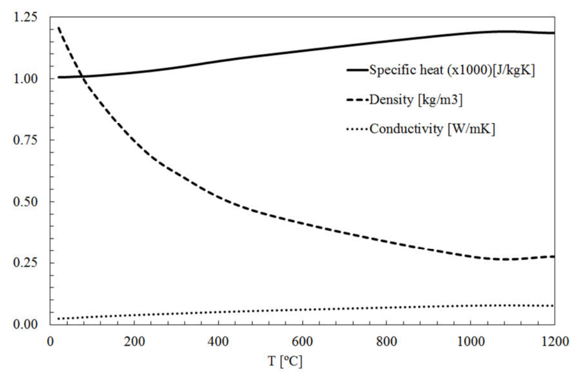
(a) Steel



(b) Gypsum X



(c) Rockwool



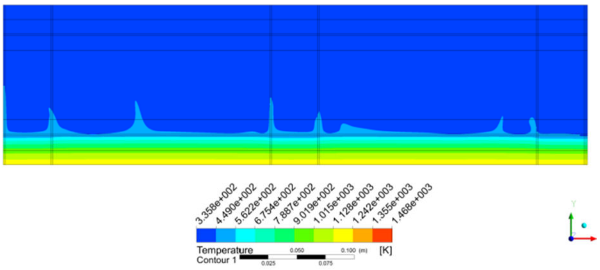
(d) Air

Fig. 5 - Thermal properties of steel, gypsum, rockwool and air.

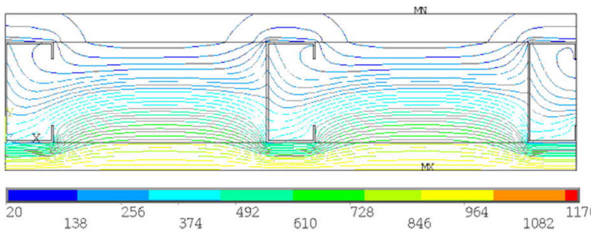
RESULTS

The fire resistance of the non-loadbearing wall depends on the calculation of the unexposed surface temperature. This temperature is not uniform and depends on the quantity of steel included in each type of non-loadbearing wall. The performance criteria used for this construction element accounts for the calculation of the average temperature T_{AVE} and maximum temperature T_{MAX}.

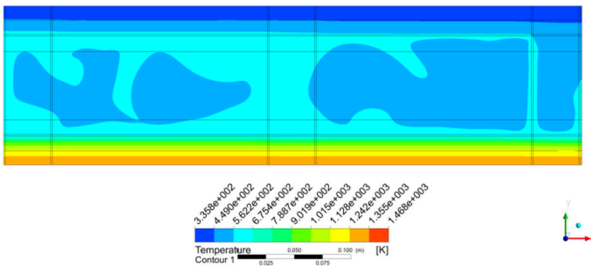
The calculation of the maximum temperature and average temperature depends on the 17 nodal results, distributed over the length of the unexposed surface. Fig. 6 represents the temperature field for CASE 1A and CASE 1D, for two time steps.



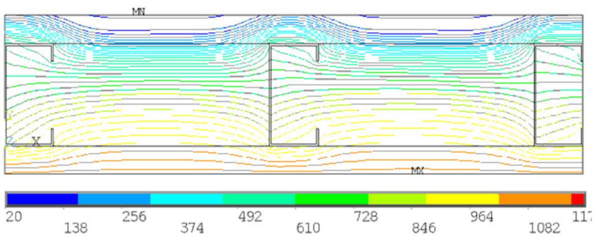
CASE 1A - temperature [K] for time 60 min.



CASE 1D - temperature [ºC] for time 60 min.



CASE 1A - temperature [K] for time 170 min.

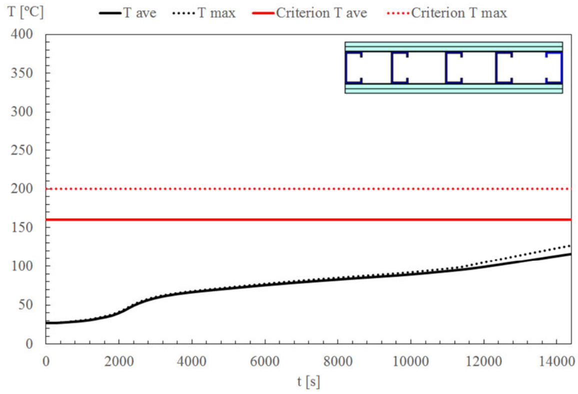


CASE 1D - temperature [ºC] for time 171.8 min.

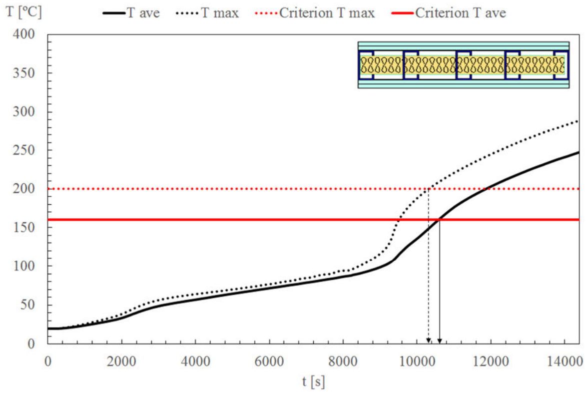
Fig. 6 - Temperature results for CASE 1A and CASE 1D.

The lip-flange corner of the stud (CASE 1D) presents higher temperature when compared to the flange-web corner of the same profile, in the exposed side. The temperature of the lip-flange corner is smaller than the temperature of the flange-web corner, in the unexposed side of the wall. This behaviour may be justified by the higher heat flux expected on the web of the stud, due to smaller heat conduction resistance.

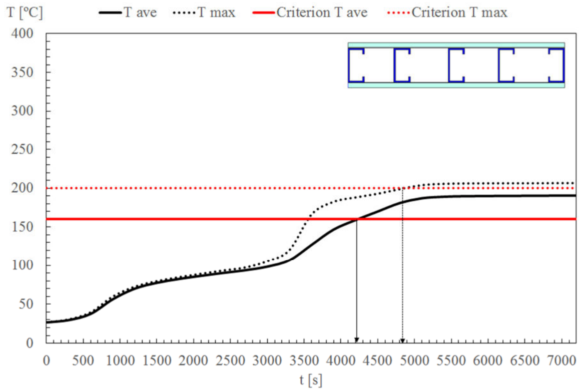
The temperature field of the fluid region (CASE 1A) is not uniform and depends on the velocity field. The maximum velocity during simulation was 0.35 m/s. This value is responsible for a small convection coefficient inside the cavity. This fact justifies the modification of the temperature on the unexposed gypsum plates (ANSYS FLUENT) and the increase of fire resistance in comparison to the second group of simulations (ANSYS MULTIPHYSICS), see Fig. 7.



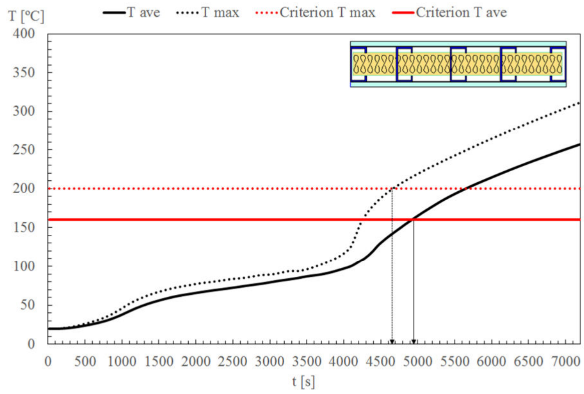
CASE 1A -



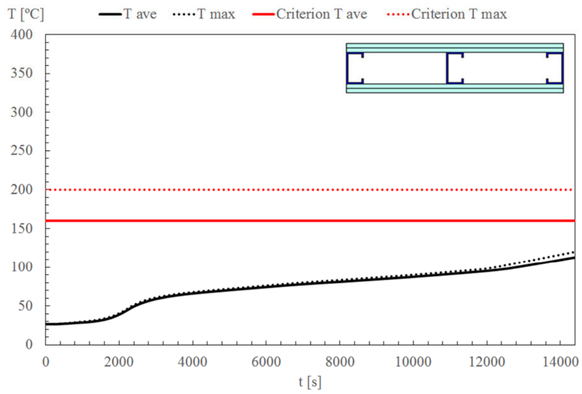
CASE 1D -



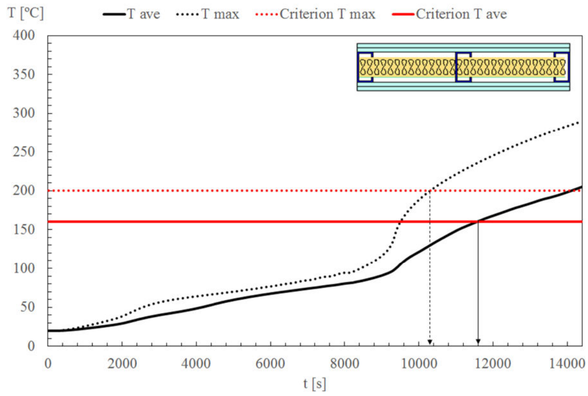
CASE 1B -



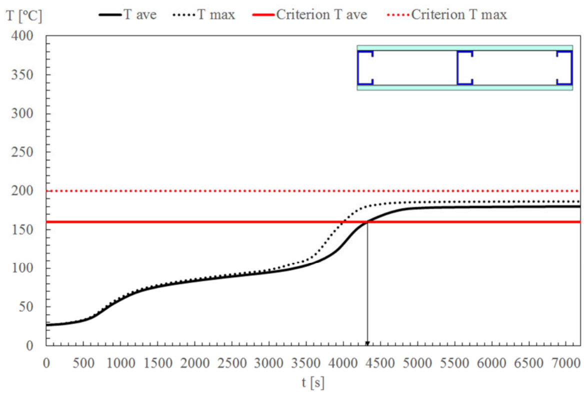
CASE 1C -



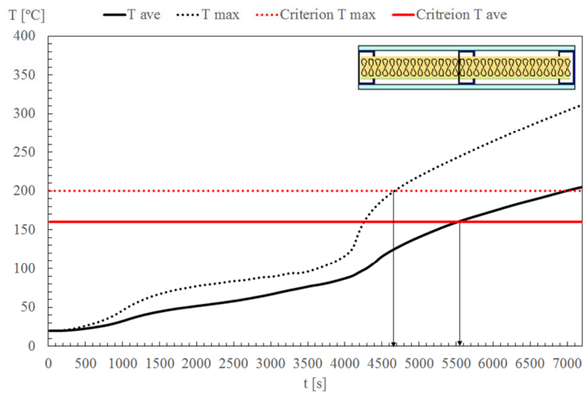
CASE 2A -



CASE 2D -

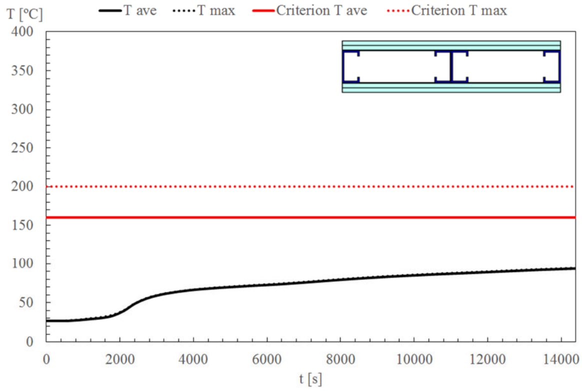


CASE 2B -

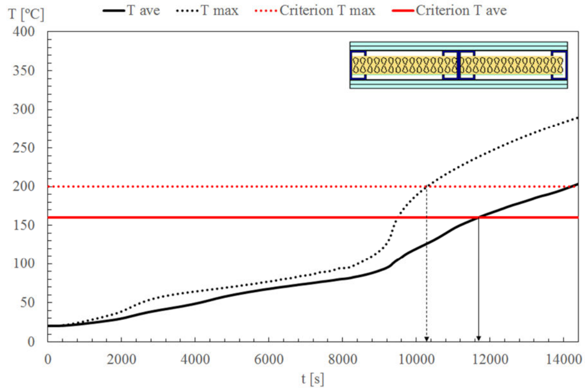


CASE 2C -

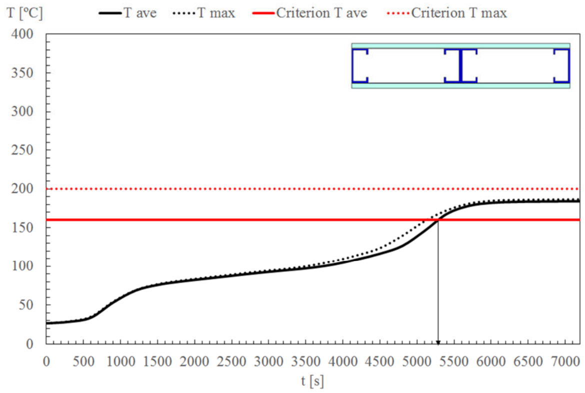
Fig. 7 - Time history for Temperature in the unexposed surface (all cases)



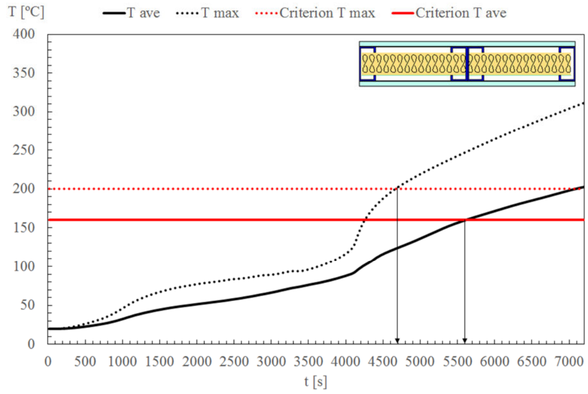
CASE 3A -



CASE 3D -



CASE 3B -



CASE 3C -

Fig. 7 (*continued*) - Time history for Temperature in the unexposed surface (all cases).

The solid material used for insulation of the cavity region (rockwool) has a conductivity smaller than the one considered to simulate the fluid (air) in the cavity. This justifies the higher conductivity resistance of the air in comparison to rockwool. The conductivity is the only mean of heat transfer in the solid cavity, while radiation and convection are also consider in the simulation of the fluid cavity.

CONCLUSIONS

This study shows the fire resistance of non-loadbearing LSF wall when considering the cavity simulated with fluid and the cavity simulated with solid. The fire resistance was evaluated only for the insulation criterion, therefor by the calculation of the maximum temperature and average temperature of the unexposed surface of the wall.

The fire resistance of the wall depends on the number of plates used in the assembly. When only one plate is consider, the walls were fire rated with I 60. The insulation capacity (I) is the ability of the element of construction to withstand fire exposure on one side only, without the transmission of significant heat transfer from the exposed side to the unexposed side. Transmission shall be limited so that neither the unexposed surface nor any material in close proximity to that surface is ignited. The element shall also provide a barrier to heat, sufficient to protect people nearby. The (I) classification of an element of construction shall be given on the basis of the shortest time for which either the maximum or mean temperature rise criteria are satisfied on any discrete area. Failure of the integrity criterion (E) shall also mean failure of insulation (I), whether or not the specific insulation temperature limits have been exceeded. For this reason, special attention should be consider to the integrity criterion and in particular to the fire protection of the connection elements (self-drilling screws).

The used of two gypsum plates with 12.5 mm thickness each, increase the fire resistance of non-loadbearig walls for more than 2 hours. The fire resistance depends on the material used for the simulation of the cavity.

More simulations are being developed with ANSYS FLUENT, considering different simulation models, especially trying turbulence models.

Experimental results should be developed to validate both numerical models used for simulation of the assembly, in particular the fire resistance tests and thermal properties characterization.

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