Fire hazards of facades with externally applied additional thermal insulation. Full scale experiments

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FULL SCALE EXPERIMENTS

by

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OUTLINE OF PROJECT

Different types of external additional insulation systems, applied on facades in multi-storey buildings, were tested on a full scale. The facades were exposed to flames and hot gases emerging from a window opening in a single fire compartment.

The increased risk of fire spread along the facade and through windows in storeys above the compartment in fire, were studied.

The results of the tests form the basis of deriving functionally well-defined requirements, differentiated with respect to the use and occupancy of the building and the conditions of fire fighting.

RENOVATION AND ADDITIONAL THERMAL INSULATION

Most houses constructed prior to 1960 require renovation or some functional upgrading. As the thermal resistance of the external walls of older houses, built by traditional methods, is low and the energy costs are now very high, there is a general need to apply additional insulation to the external walls to save energy and cut fuel costs.

The predominant technique hitherto used mineral wool insulation and a surface cladding of, for example, steel or aluminium sheets.

However, many of the buildings in need of this type of renovation are externally plastered. The desire to preserve the exterior of the old buildings led to the development of new external additional insulation systems which could be plastered. These systems often used a cellular plastic insulant.

INCREASED FIRE HAZARD

Old traditional walls of brick or lightweight concrete, externally plastered, would not normally contribute to the fire spread.

When insulating the walls, however, new materials and components are added, which may result in such an increased fire hazard.

A fire in a flat today generates a more intensive heat that it would have done 10-20 years ago due to the use of other types of materials in the furnishings. Experimental fires (fire tests) have shown that the increased use of synthetic materials (plastics), particularly in modern furnishings, can greatly increase the thermal exposure on the outside of the facades. This is attributable to a higher rate of mass release and the fact that plastics require more oxygen for complete combustion. The result is that the combustion of high energy fire gases will largely take place outside the fire compartment thus generating a severe heat exposure on the facade.

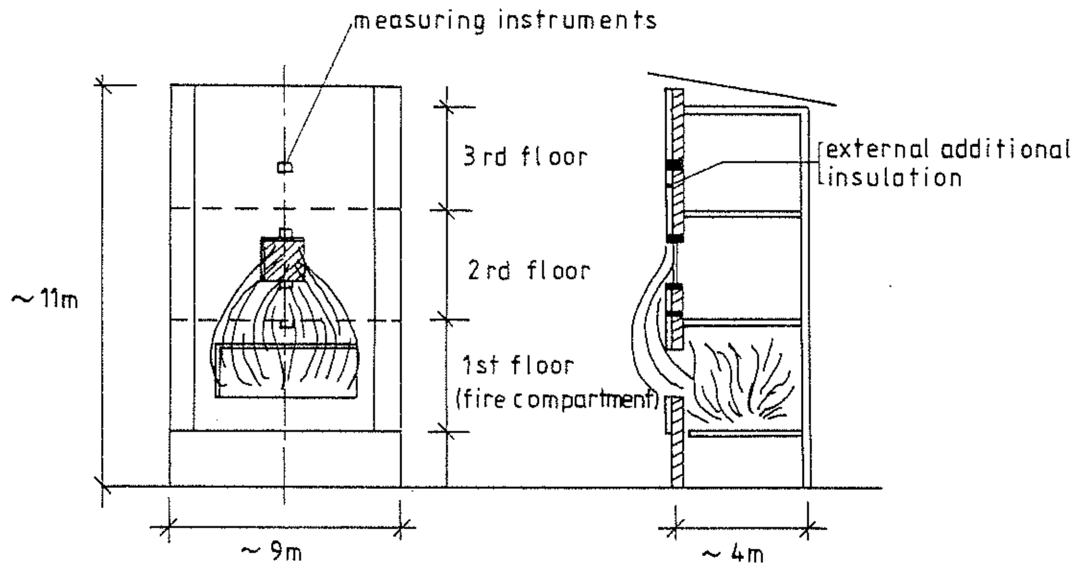

Figure 1 A real fire in a flat with furnishings of synthetic materials was simulated in the full scale tests at the Division of Building Fire Safety and Technology at Lund Institute of Technology

FIRE HAZARD COMPONENTS

The fire hazard of externally insulated walls may be split up into components as follows:

a) The surface spread of fire, i.e. the covering of the facade contributes to the fire.

b) Fire spread within the construction, e.g. combustion of insulation, wood studs, wind protection or through air space.

c) Fire spread from storey to storey through windows.

d) Large sections of the external additional insulation system falling down.

A reasonably substantial level of fire damage to the facades is acceptable, but not a fire spread from flat to flat during a prescribed, critical time, derived from the time for the fire brigade to respond and start fire fighting.

The contribution to the fire spread by combustible materials used in the external additional thermal insulation depends on the following material characteristics:

* Ignitability
* spread of flame
* rate of heat release.

These characteristics vary with the level and duration of the thermal exposure.

For certain plastic materials, the rate of vertical flame spread depends on "preheating". As an example, it has been proved theoretically and experimentally that the rate of flame spread after preheating to 13 kW/m^2 (a moderate exposure on a facade from a compartment fire) was 17 times higher than without the exposure of an external radiation.

THE SERIES OF TESTS

The test fire

During the full scale tests the externally insulated facade of the test building was exposed on the outside to a severe thermal influence, representative of a real fire in flats with furnishings of synthetic materials (Figure 1). The fire load, chosen for the fire tests, corresponds to a probability in excess of 20% in the Swedish statistics for living-rooms. This means a fire load density of 110 MJ per m^2 total surface area of enclosure. The test fire simulates a real fully developed fire in a flat during approximately 10 minutes.

The geometry of the window opening determines the shape and size of the flame emerging from the window (Figure 2).

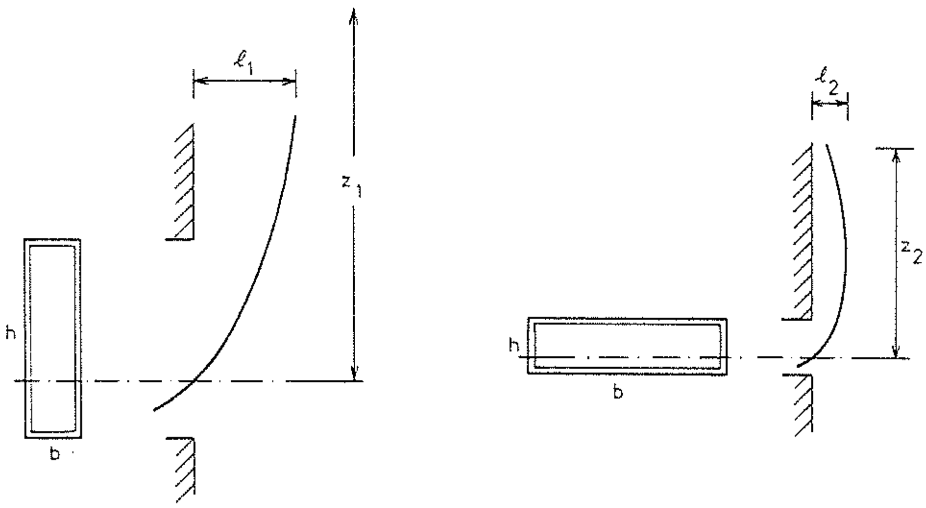

Figure 2 A high and narrow window opening produces a larger flame (z_1) having a greater distance from the surface of the wall (ℓ_1) whereas, a wide and low window opening creates a shorter flame (z_2) which is closer to the surface of the wall (ℓ_2). The latter type of flame will give the wall surface, immediately above the window, a more severe exposure

In the full scale tests, the fire compartment had an opening factor $A\sqrt{h}/A_t$ - characterizing the ventilation of the compartment - which varied from 0.06 $m^{\frac{1}{2}}$ at the beginning of the test, when window-sash and window-frame were intact, to 0.08 $m^{\frac{1}{2}}$ at the end of the test, when sash and frame were completely burnt. A is the area and h the height of the window opening, A_t is the total interior surface of the structures, enclosing the compartment, window opening included. The enclosing structures are made of aerated concrete with a density of 700 kg per m^3.

The thermal exposure on the facade, caused by the compartment fire, is illustrated in Figure 3 which shows the distribution along the vertical symmetric line of the facade of the maximum values of the temperature (10 cm outside the facade) and the radiation and total heat flow towards the facade, obtained in a calibration test with no external additional thermal insulation. The corresponding gas temperature-time curves of the fire compartment are given in Figure 4.

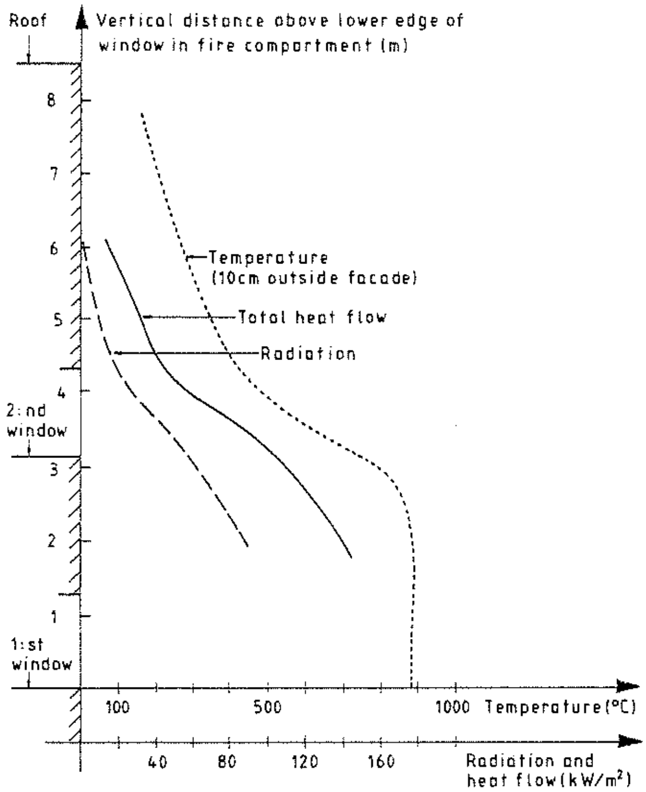

Figure 3 Distribution along vertical symmetry line of the facade of maximum values of temperature (10 cm outside facade) and radiation and total heat flow towards the facade. Calibration test with no external additional thermal insulation

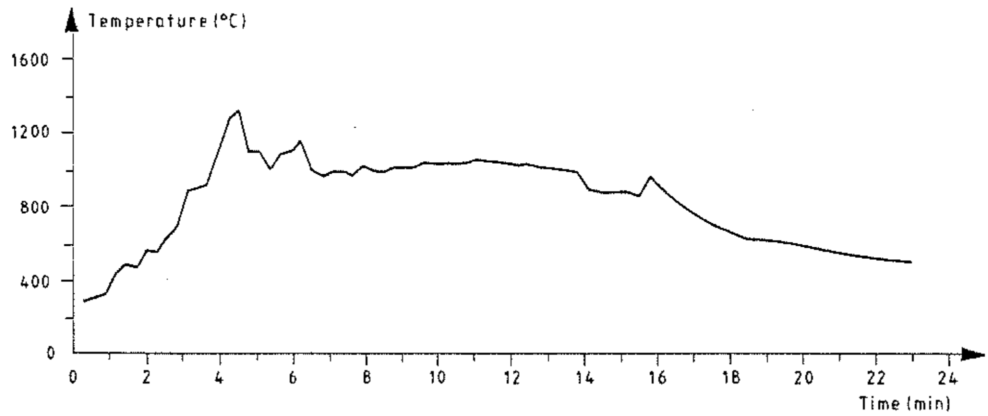

Figure 4 Gas temperature-time curve of fire compartment. The curve refers to measuring point located 10 cm below ceiling on vertical centre line in compartment

The test house

The test house has a load bearing structure of steel and walls, ceilings and floors of aerated concrete. The building is three storeys high with one room in each storey. The compartment fire was arranged in the room on the first floor (see Figure 1). The additional insulation system was applied to the front facade, made of aerated concrete with a density of 700 kg per m^3.

Systems of external additional thermal insulation tested

A series of full scale tests was carried out on external additional thermal insulation systems of the following principal types:

Alternative 1. Insulation of mineral wool + wood studs + steel or aluminium sheet cladding

Alternative 2. Insulation of mineral wool + relatively thick layer of plaster

Alternative 3. Insulation of cellular plastic + relatively thin layer of plaster.

The external additional thermal insulation systems included in the series of tests are specified in the appendix.

Measurements and test criteria

Evaluation of the tests was made by visual observations and photography, by measuring the temperatures within the flame, near the surface of the wall and within the insulation, and by measuring the radiation and heat flow towards the facade. Observations and measurements are given in special reports for each insulation system tested.

The preliminary test criteria applied are the following:

1. No collapse of major sections of the external additional thermal insulation system.

2. The surface spread of flame (a) and the fire spread within the insulation (b) should be limited to the bottom part of the window on the 3rd floor. External flame which can ignite eaves is not permissible.

3. There must be no spread of fire to the 2nd floor through the windows - deemed to be verified if the total heat flow towards centre of windows was $\leq$ 80 kW per m^2, which roughly corresponds to an unacceptable risk that the panes of glass will crack.

Criteria 1 and 2 will generally be applied to buildings of up to 4 storeys. They also apply to buildings of up to 8 storeys provided that the fire can be extinguished from the outside. For buildings of between 5 and 8 storeys which do not allow fire extinguishment from the outside and for buildings higher than 8 storeys criterion 3 will be applied in addition. All three demands will also be in force for public buildings as nursing homes, hospitals, etc.

Results

Table 1 shows the results of all full scale tests.

Risk of fire spread by external flames or from within the insulation system (including the wood studs) occurred for alternative 1, and alternative 3 (in three of the systems tested). There are, however, systems embraced by alternative 3 where the risk of fire spread by these means is negligible.

Table 1

System No.*	Test results				Notes
	Criterion 1	Criterion 2(a)	Criterion 2(b)	Criterion 3	
1.1	failed	failed	passed	failed	fire spread in the studs
1.2	passed	passed	passed	passed	
2.1	passed	passed	passed	passed	
2.2	passed	passed	passed	passed	
2.3	passed	passed	passed	passed	estimated results
3.1	passed	passed	passed	failed	
3.2	passed	passed	passed	failed	
3.3	failed	failed	failed	failed	
3.4	failed	failed	failed	failed	
3.5	passed	passed	passed	failed	
3.6	passed	passed	passed	passed	
3.7	passed	passed	passed	failed	
3.8	failed	passed	failed	failed	
Wood panel facing	failed	failed	failed	failed	

*See Appendix

Fire spread to flats above the primary fire, through windows, can occur if all the panes of glass crack in the flat above. The additional heat from combustible components accelerates this process. This is independent of the rate of heat flow towards the windows and all systems which showed local heat flow towards the window ≥ 80 kW per m^2 failed on criterion 3.

Two systems of alternative 2 (mineral wool to relatively thick layer of plaster) were tested with a satisfactory result - complying with all three criteria.

Further tests on systems of alternative 2 were therefore abandoned in favour of more systems which primarily belonged to alternative 3. The system No. 2.3* was not tested, for this reason, despite the fact that it was included in the original plan. System No. 2.3* was considered to be safe from a fire point of view.

CONCLUSIONS

Generally, it was noted that, in assessing fire hazard, the combination and order of materials as well as constructional detailing used in an additional insulation system are more important than the ignitability of the individual materials involved.

The fire hazard must be determined by testing the complete system as used in practice.

*See Appendix

Appendix. External, thermal insulation systems tested

Alternative 1

1.1 (Ahlsell)
- 95 mm glass wool, density 22 kg/m^3, between horizontal and vertical wood studs 95 x 50 mm^2
- asphalt felting AC 150/200, fastened to the wood studs
- trapezoidally profiled steel sheet TH 30, 0.6 mm thick, PVF_2 lacquer 50 μ; (airspace cut off immediately under the windows in first and second floor).

1.2 (Korrugal)
- 95 mm mineral wool, density 40 kg/m^3, between horizontal wood studs 95 x 50 mm^2
- windprotective paper glued to the mineral wool on fabric; fire class "heavy ignitable"
- vertically profiled aluminium sheet TRP 20, 0.5 mm thick; metal lacquer 16 μ.

Alternative 2

2.1 (G+R method)
- 100 mm glass wool, density 60 kg/m^3
- metal mesh 50 x 50 x 2 mm^3, fastened with nails to the areated concrete facade through the glass wool
- 30 mm layer of insulating plaster (expanded polystyrene grains + cement), density 350 kg/m^3
- 8 mm surface coating of cement mortar, density 1800 kg/m^3

2.2 (tm-method)
- 20 mm wooden wool, density 350 kg/m^3
- 80 mm mineral wool, density 80 kg/m^3
- metal reinforcing mesh 25 x 25 x 1.0 mm^3 (also in the window splays) fastened to the wall by expander, angle and pin
- 10 mm ground coating of cement mortar
- 10 mm rude plaster + 8 mm surface coating of plaster

2.3 (Serporock)

- 50-120 mm mineral wool, density 90 kg/m^3
- special mobile expander for fastening of mineral wool and metal reinforcing mesh (4 expanders/m^2)
- metal reinforcing mesh 19 x 19 x 1.1 mm^3
- 10 mm ground coating of cement mortar KC 35/65/550
- surface coating of 15 mm cement mortar + 7 mm light plaster.

Alternative 3

3.1 (Cementa)

- 60 mm polyurethane foam, density 35 kg/m^3, fastened to the wall with cut nails and washers
- glass fibre fabric 3.5 x 3.5 mm^2
- 8 mm ground coating of plastic modified cement mortar (30% cement)
- 2 mm surface coating of synthetic resin with binding medium of vinyl.

A gusset of steel at the upper edge of the windows.

3.2 (ISO-FIN)

- 100 mm expanded polystyrene, density 20 kg/m^3, fastened to the wall by bolts
- 19 x 19 x 1.05 mm^3 metal reinforcing mesh fastened to the polystyrene (also in the window splays)
- 6 mm glass fibre reinforced cement mortar
- coloured plaster.

3.3 (ISPO-1)

- adhesive mortar with organic agents
- 100 mm expanded polystyrene, density 20 kg/m^3
- glass fibre fabric 4 x 4 mm^2
- 4 mm ground coating of adhesive mortar
- 3-4 mm acrylic co-polymer surface coating.

3.4 (ISPO-2)

- adhesive mortar with organic agents
- 60 mm expanded polystyrene (German product), density 20 kg/m^3, classified as B1 according to DIN 4102

- glass fibre fabric 4 x 4 mm^2
- 4 mm ground coating of adhesive mortar
- 3-4 mm acrylic co-polymer surface coating.

3.5 (ISPO-3)
- adhesive mortar with organic agents
- 60 mm expanded polystyrene (German product), density 15 kg/m^3, classified as B1 according to DIN 4102
- thick glass fibre fabric 4 x 4 mm^2
- 13 mm mineral light plaster with filling of Perlit (expanded volcanic material).

3.6 (Termofasad)
- 60 mm polyurethane foam, density 35 kg/m^3, fastened to the wall with plug nails and washers
- 2 mm ground coating of cement mortar with 5% acrylic co-polymer
- glass fibre fabric 4 x 4 mm^2
- 3 + 3 mm layers of mortar
- 2 mm surface coating (of same material as ground coating).

A gusset of steel at the upper edge of the windows.

3.7 (Varmotex)
- 80 mm extruded polystyrene, density 32 kg/m^3
- anchor pins of metal and plastic
- 19 x 19 x 1.05 mm^3 metal reinforcing mesh, fastened to the polystyrene by angle nails
- 7 mm glass fibre reinforced cement mortar
- coloured plaster.

200 mm thick strips of mineral wool were applied on framing of joists.

3.8 (Yxhult)
- 55 mm polyurethane foam, density 30-35 kg/m^3, fastened to the wall by combination of adhesive and plastic plugs
- 6 mm ground coating of vinyl co-polymer with 30% cement

- glass fibre fabric 4 x 4 mm^2, coated with 45% PVC
- 2 mm decorating synthetic resin of vinyl (no cement).

A gusset of steel at the upper edge of the window.