Structural stability of rain screen cladding in fire

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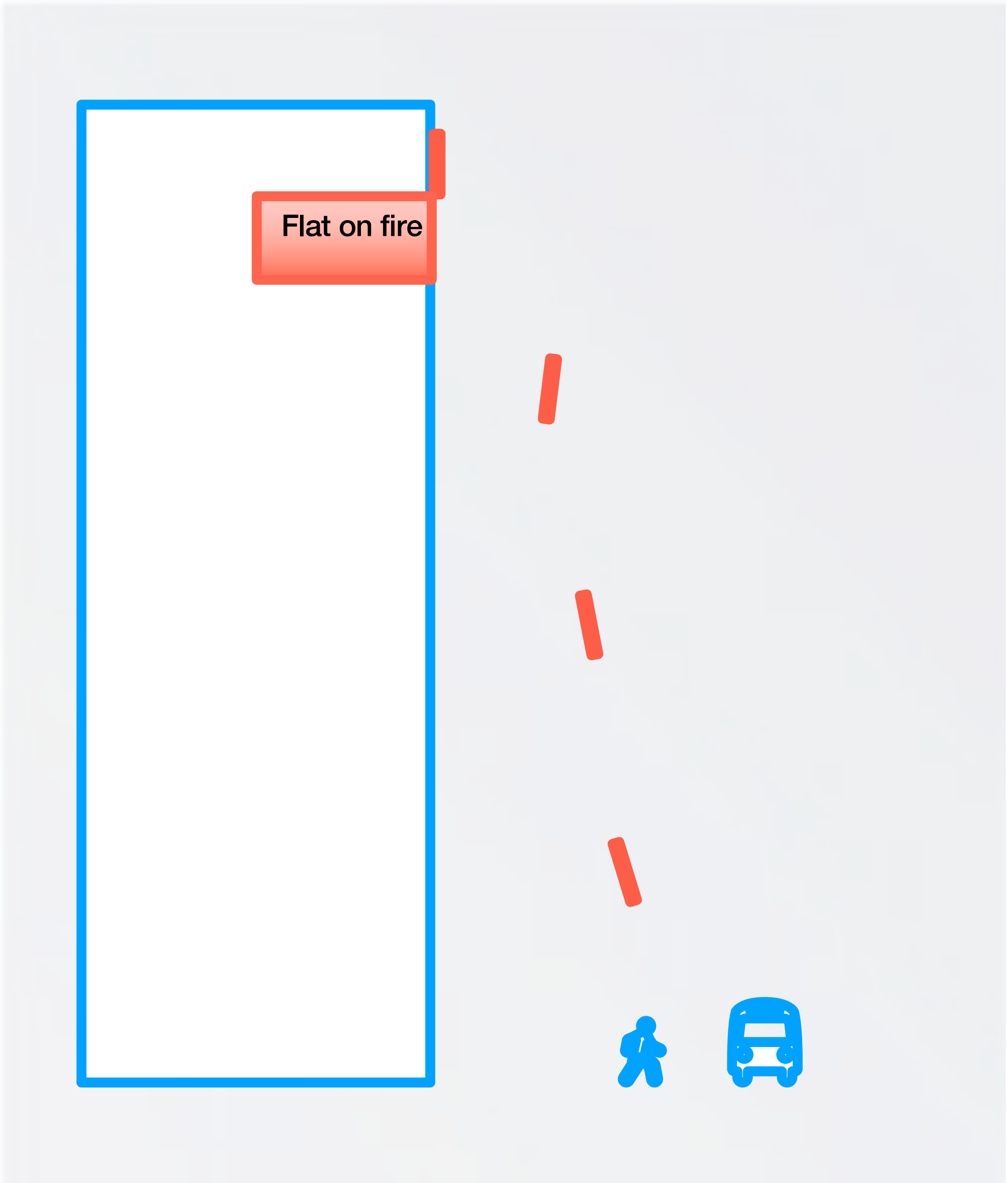
- This presentation is not challenging to the intellect or your knowledge of fire science.

- But the missile hazard of bits of cladding dropping off tall buildings in a fire is, nonetheless, important and, dare I say, easily and often overlooked as building design becomes more innovative and complex.

Cladding stability in fire is essential to eliminate the missile hazard

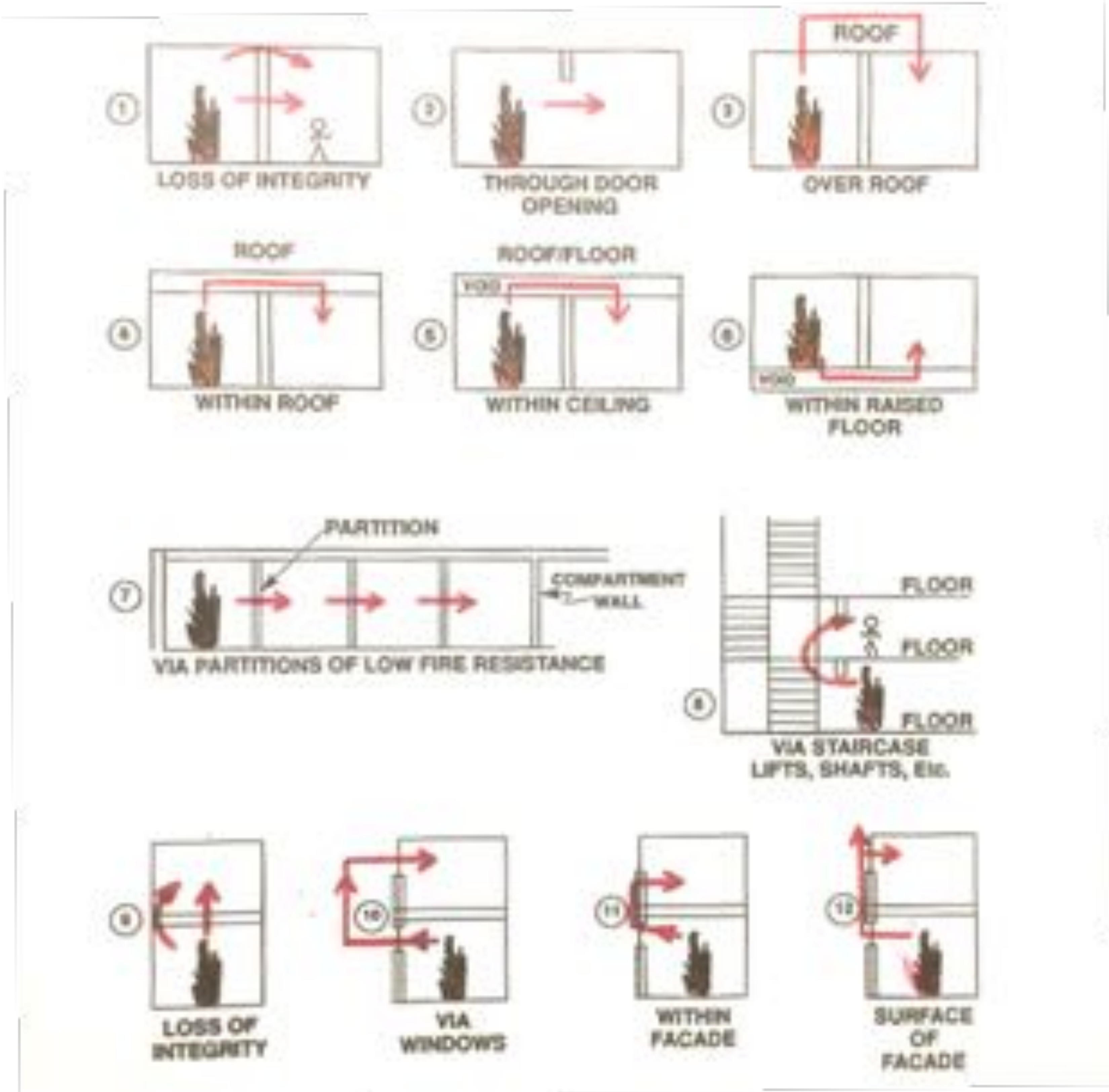
- Safety of fire fighters
- Safety of people outside building
- Third party property damage - buildings nearby, fire appliances, cars etc
- Cladding ‘boards’ can sail away from the building when falling from great height.
- Falling burning cladding can initiate secondary fires



Importance of retaining stability of cladding is height dependent

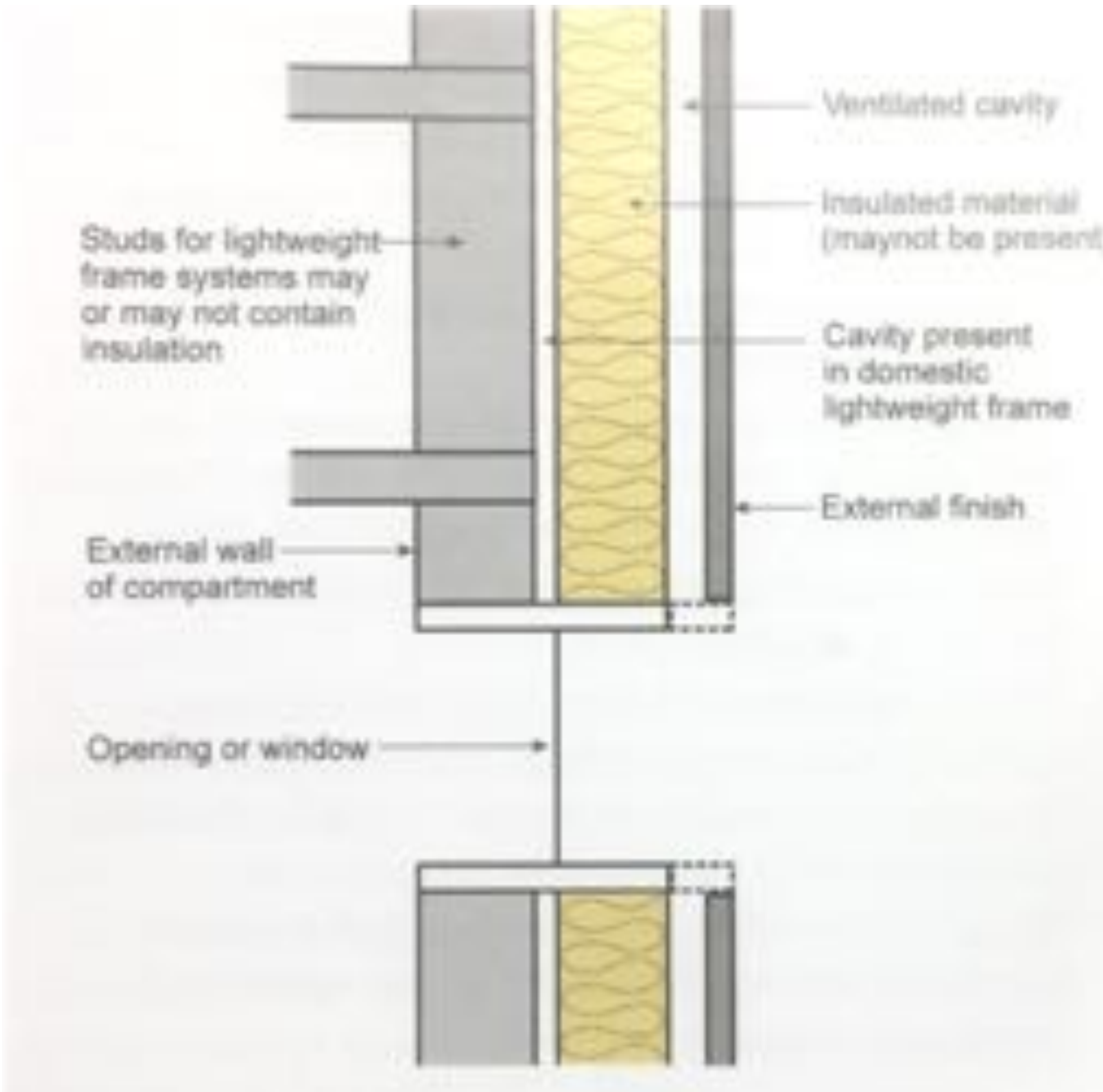
- Collapse of cladding in 2-storey building not important in terms of missile hazard
- Collapse of cladding on 20th storey of a building must be prevented because of the missile hazard. Do we agree?
- Building regulations and ADB don't explicitly require consideration of the missile hazard, except in the 'material fit for purpose' section. Not adequately covered in BRE report BR 135 either.
- I have covered the topic of stability of sandwich panels in my publications, but rain screen cladding is a relatively recent innovation.

Some fire spread routes affecting life safety



Some of these scenarios were present in the Grenfell tower block conflagration.

Principle of rain-screen cladding



Courtesy BRE (report 135)

May be used on new buildings or existing buildings.

Can give modern appearance while improving thermal comfort and weather resistance.

Can also be a fire hazard as shown by the Grenfell Tower fire in June 2017.

Ideally the external cladding/finish should protect combustible insulation from direct fire impingement.

Holistic fire risk assessment

This is one of the Chalcots estate tower blocks in Camden where residents were evacuated following the Grenfell fire and there were concerns over the use of ACM cladding.

Not easy to say if this cladding is a threat to life.

Need to consider all parts of the fire safety strategy:
construction of cladding,
fire compartmentation,
smoke control,
escape route design,
evacuation strategy (stay in place?),
fire detection and alarm,
emergency lighting,
fire suppression,
fire fighting facilities,
fire safety management
Consultation procedures
etc.

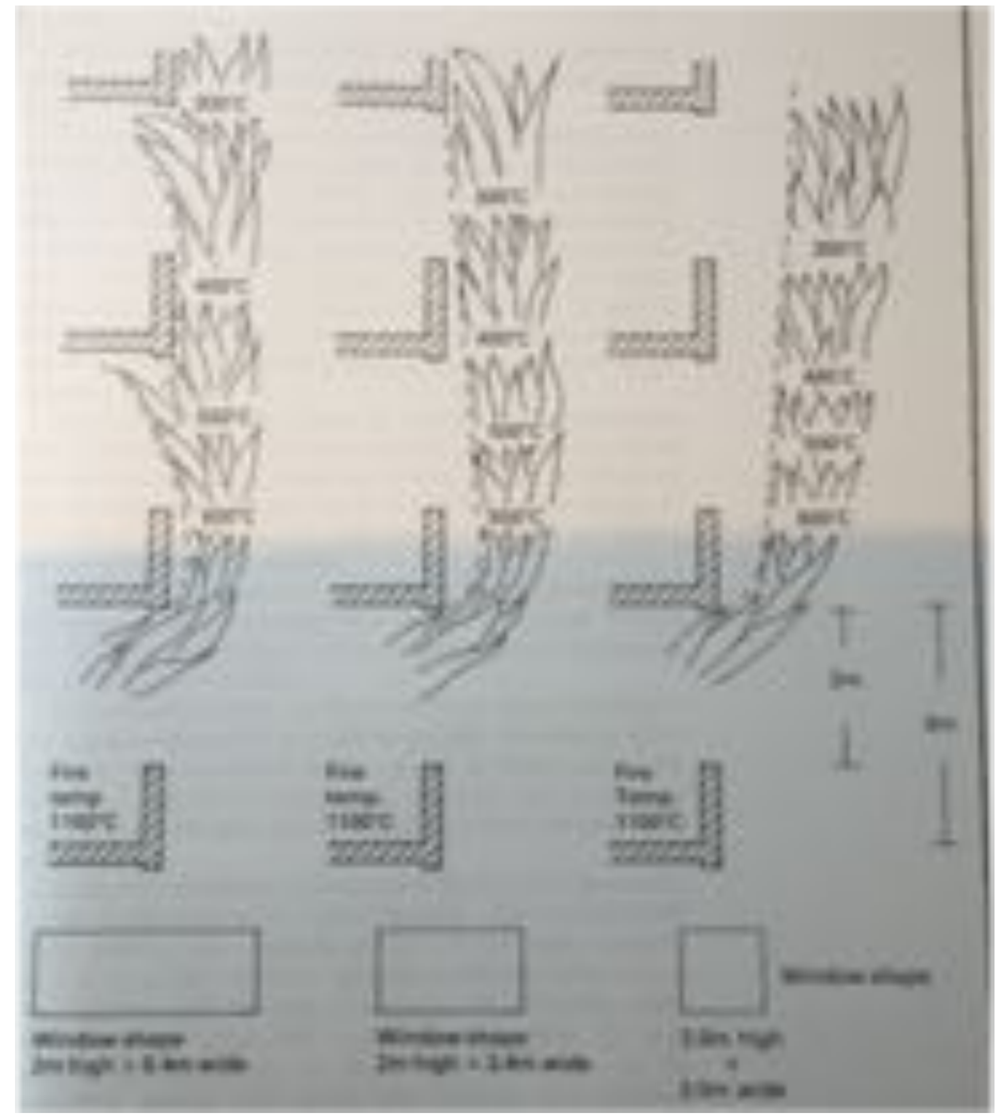
See BS 9999 and BS 9991 for guidance on new buildings and LACORs for existing buildings.

The external fire scenario

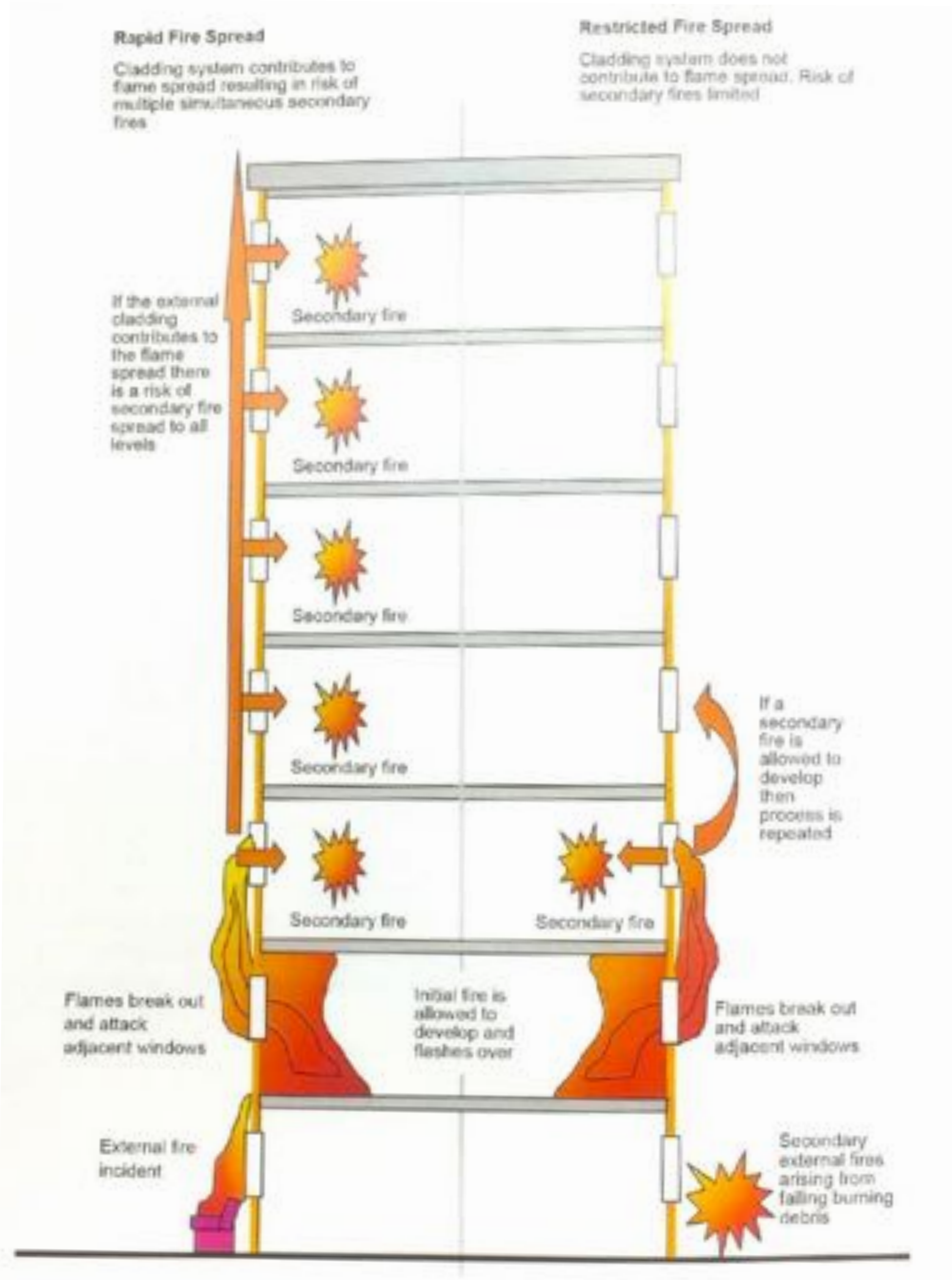
Flames jetting out of the top of a window below the cladding could be 800 - 1200 degC.

Entrainment of air in flame plume can then lead to much lower temperatures experienced by the cladding away from the jetting flame where combustion is stoichiometric.

Cladding temperature depends on fire load density in compartment, thermal properties of compartment boundaries (linings), window size and shape, through draft (if any), flame thickness and emissivity and duration of flaming and location of cladding in relation to flames. PD 7974-3 may help quantification here.



Data from Butcher/Parnell book showing effect of window shape on flame trajectory



External fire scenarios.

Figure taken from BRE Report 135

The Regulation on external fire spread

Extract of Approved Document B 'Fire safety'

Requirement	*Limits on application*
External fire spread **B4.** (1) The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building. (2) The roof of the building shall adequately resist the spread of fire over the roof and from one building to another, having regard to the use and position of the building.	

The regulatory guidance

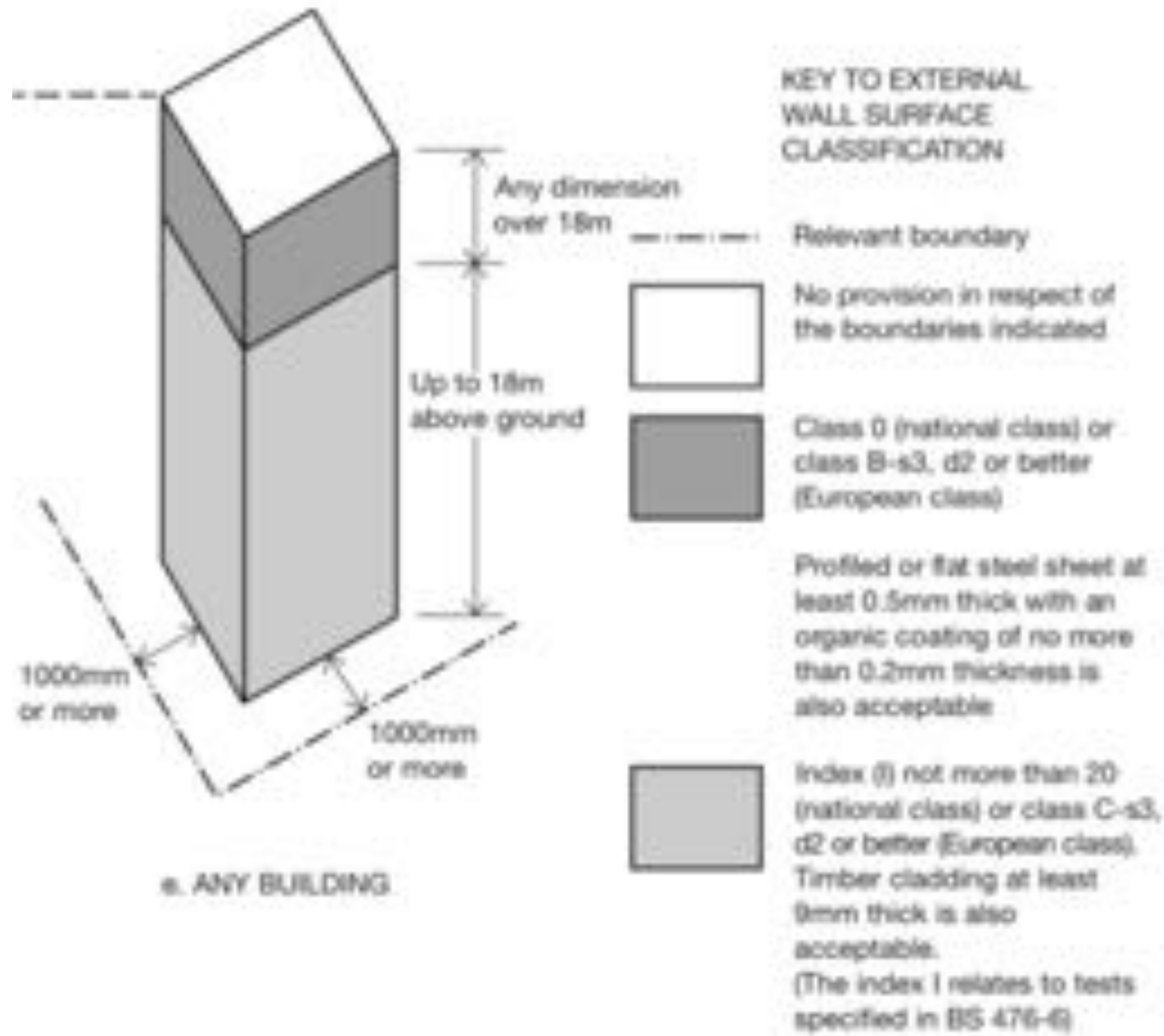


Diagram 40 of ADB2 relating to external walls of buildings > 18m high

Materials of limited combustibility and the external wall

Table A7 of ADB2 states insulation material in external wall construction can be:

- Non-combustible material, or
- Any material with a density > 300kg/m3 etc
- Any material with a non-combustible core at least 8mm thick having combustible facings not more than 0.5mm thick etc
- Any material with a density < 300kg/m3 which when tested to BS 476-11:1982 does not flame for more than 10 sec and temp rise in centre is <35degC and temp rise in furnace is <25degC

Clearly, no plastic foam can be a material of limited combustibility as its density is too low or it cannot satisfy the BS test criteria.

This means that external cladding >18m high must be assessed using the BS 8414 test

Plastic foam insulations used in buildings

- PU Polyurethane
- PIR Polyisocyanurate
- Ph Phenolic

- EPS Expanded polystyrene
- XPS Extruded polystyrene
- PE Polyethylene (recent use in buildings)

All are combustible and can have their RTF performance improved by adding facings of aluminium foil. However when the fire insult is large, as in thick highly emissive flames jetting out of a window, foil facings are inadequate (aluminium melts at 650degC) and active 'runaway' combustion of the foam can then occur.

Building regulations for buildings: floor > 18m high

According to the Building Regulations 2013 Approved Document B2, Part B3, Clauses12.5 to 12.7, external cladding of a building more than 18m high is required to be of

- limited combustibility or
- satisfy a full-scale test according to BS 8414-2.
- The BCA (Building Control Alliance) states, in its 2015 technical guidance, 'The BR135 / BS8414 tests deal solely with the spread of fire once it has entered the cavity. Hence, the requirements for cavity barriers in accordance with Section 9 of AD B2 are required in all cases including around openings in the façade' I do not agree.

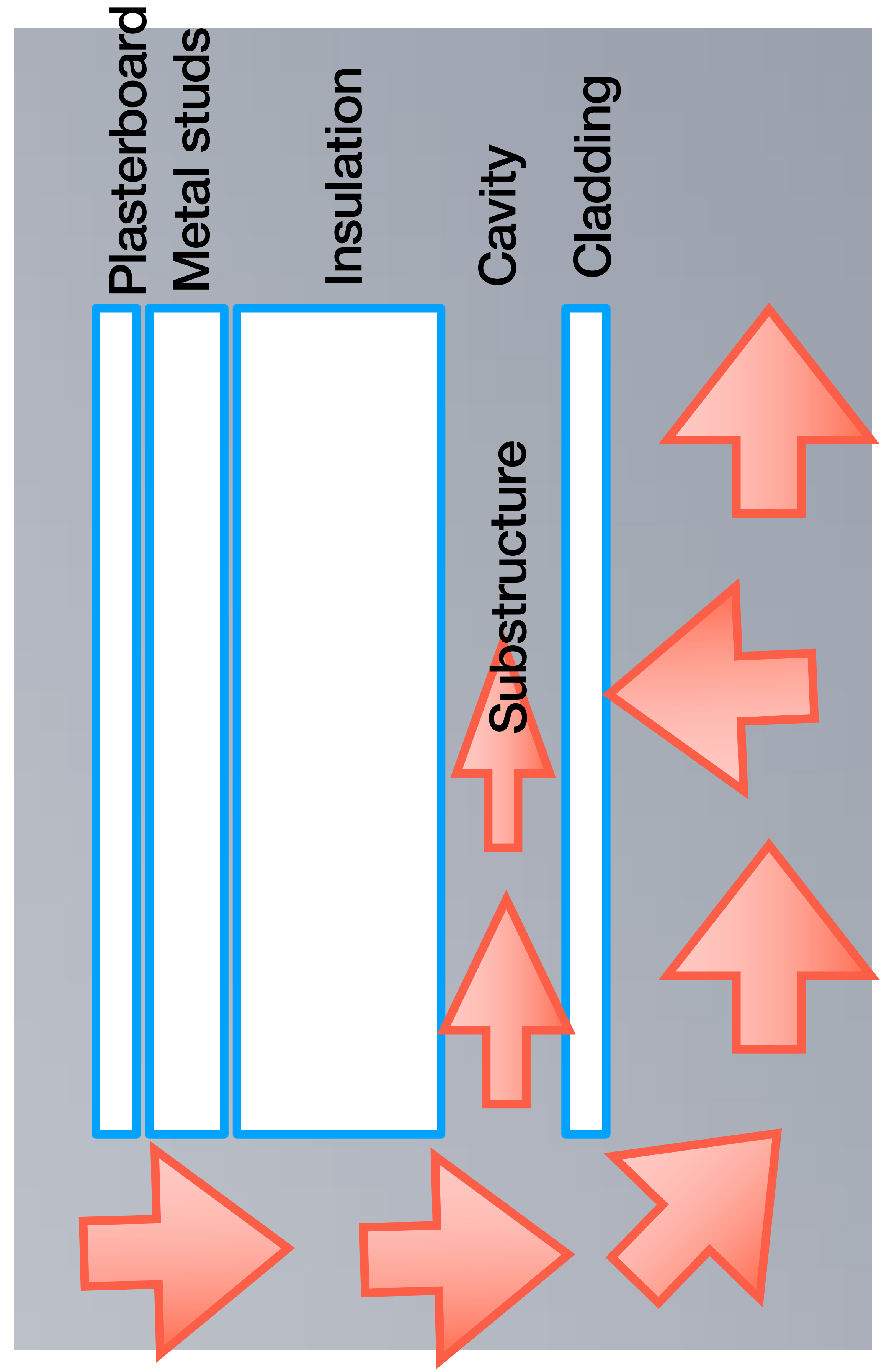
Annex A of BRE report BR135 contains acceptance criteria for the BS 8414-2 test.

The hidden substructure

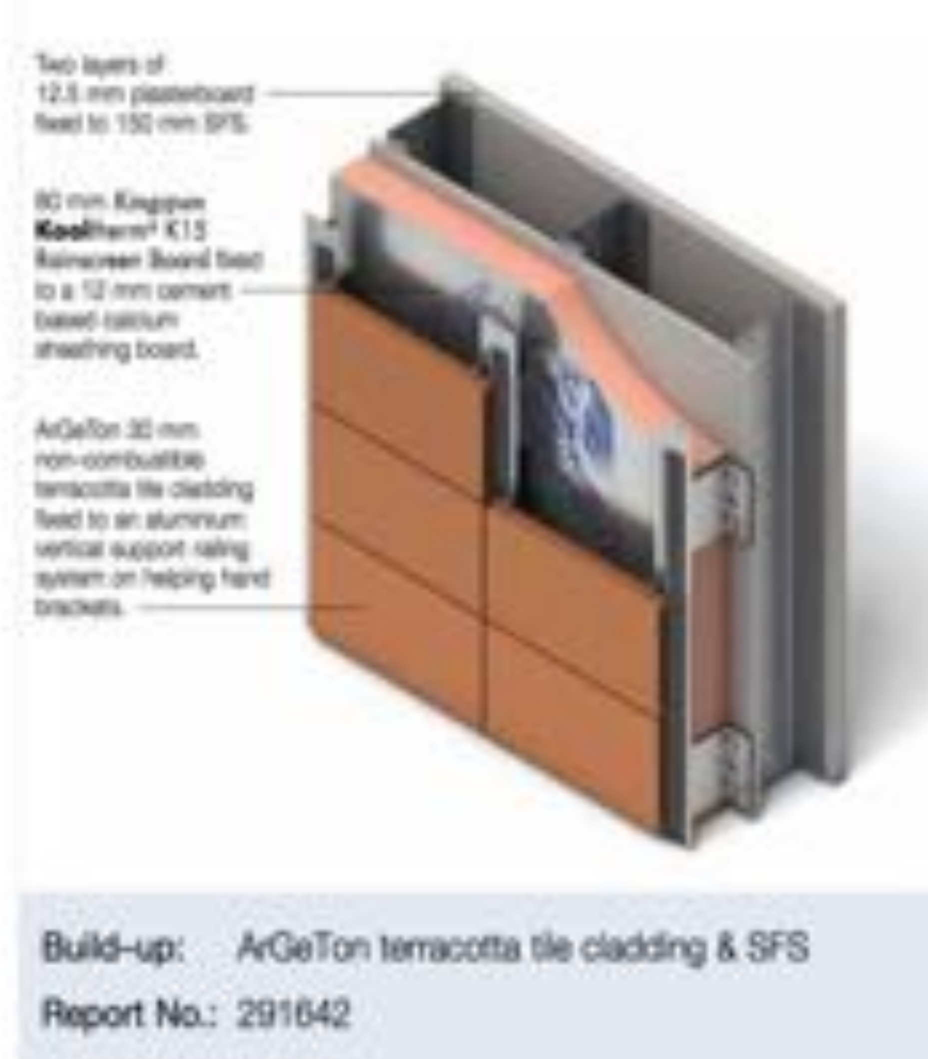
The lightweight substructure supporting the rain screen cladding may be cold formed aluminium alloy (melting point 650 degC) or steel (1550 degC)

Substructure can be heated and weakened by conduction through cladding or directly by convection of fire gases through air cavity

Vertical fire spread in cavity will be more severe and extensive if insulation is combustible. Effective cavity barriers at each floor level may eliminate cavity fire spread - but will fire cause massive distortions in cladding substructure defeating the cavity barrier?



Rain screen cladding systems are sometimes complex and may contain a large amount of combustible plastic foam. These examples have passed the BS 8414-2 external cladding test.
The substructure supporting the external cladding may be aluminium alloy (melting point 650 degC) or steel.



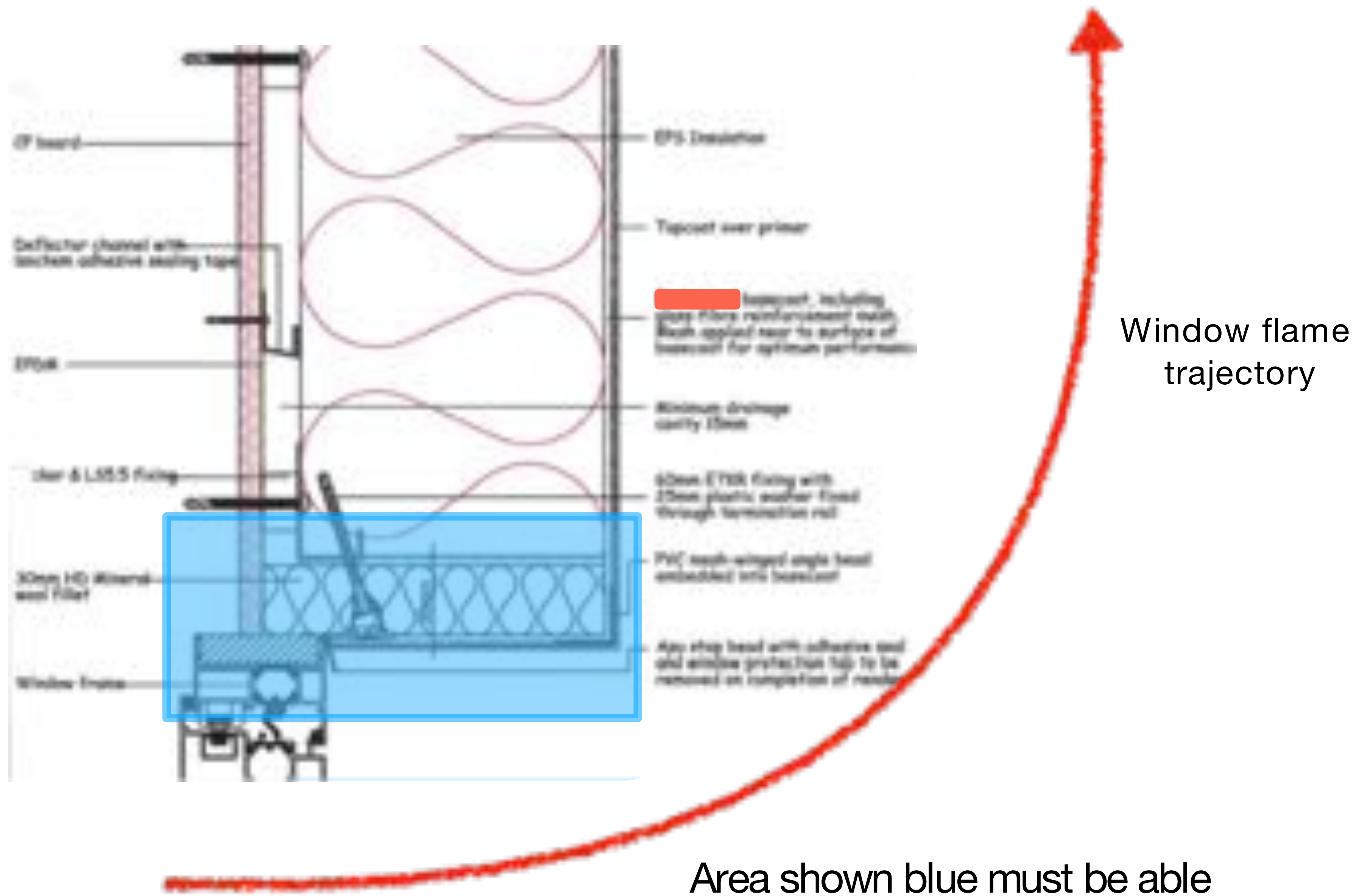
Kingspan Karrier panel facade system used on retail buildings.

This rain screen cladding system uses interlocking steel-faced sandwich panels as the insulation which is a good feature as the combustible plastic foam cannot easily become involved in fire.

The thicker and more insulating the ‘encasement’ of the plastic foam, the longer it takes for the foam to become involved in fire.

This has a ventilated cavity but is it an example of rain screen cladding?

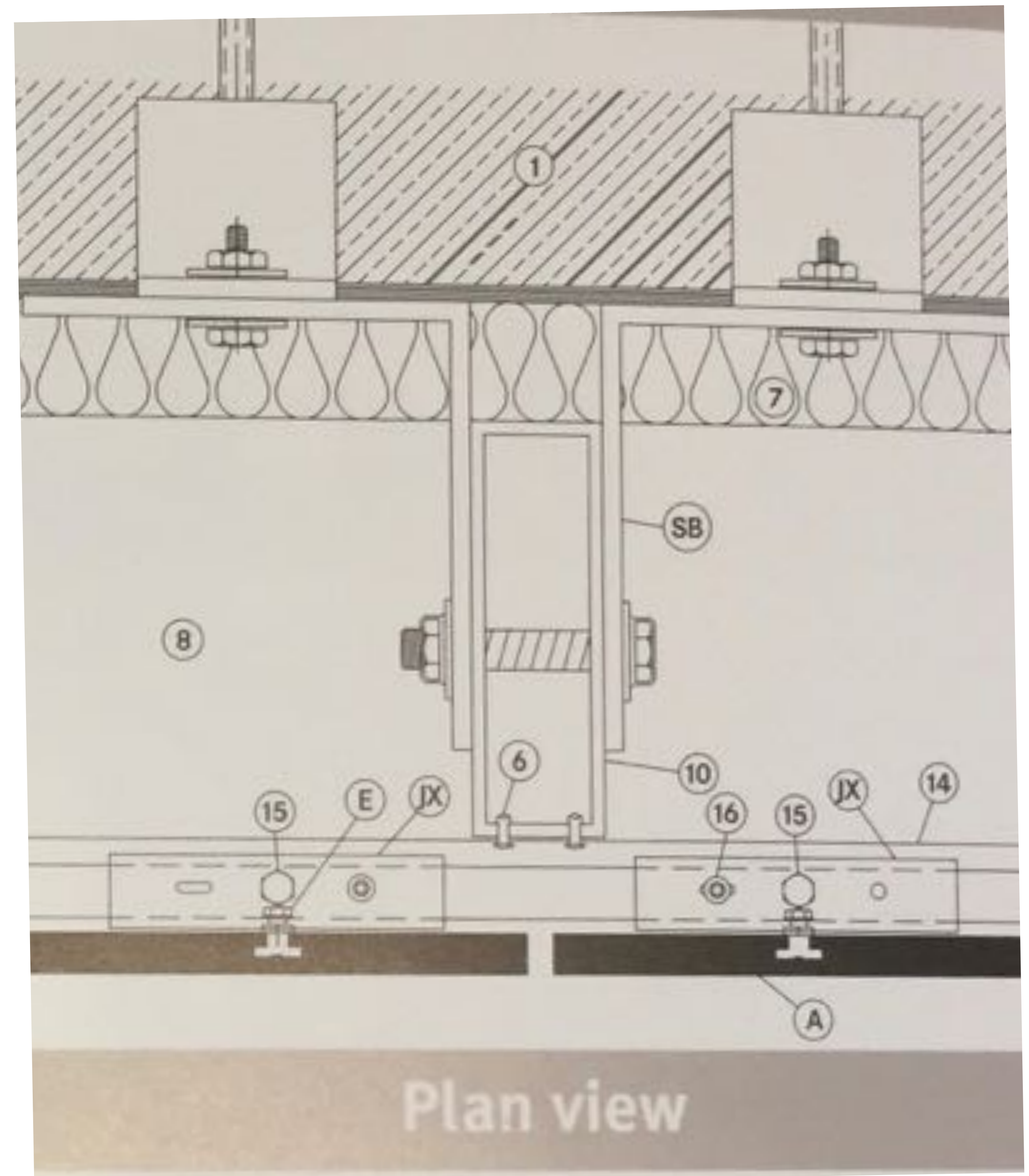
It contains a lot of EPS plastic foam covered on the outside with a glass fibre mesh embedded in a resin matrix. Internal room lining not shown.



Area shown blue must be able to prevent failure as this is area of greatest fire insult from jetting flames

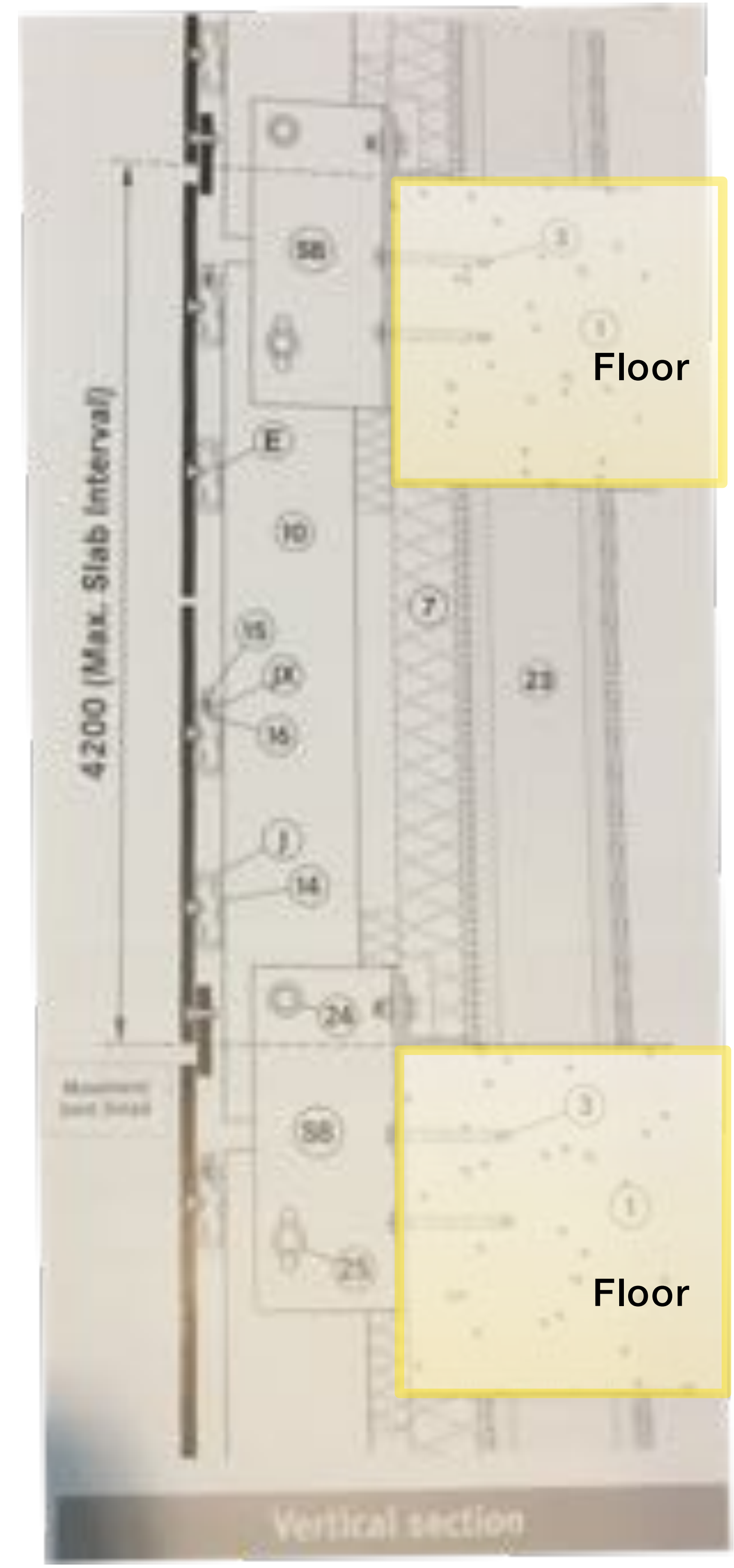
Extract of proprietary system using granite panels

- Granite panels are held in place with ‘dovetailed’ headed studs mounted on substructure with expansion/contraction details.
- Example of good design.
- BS 5835-2 states that all ceramic panels with a surface area > 0.1m2 must be mechanically fixed when used above 1st floor level.



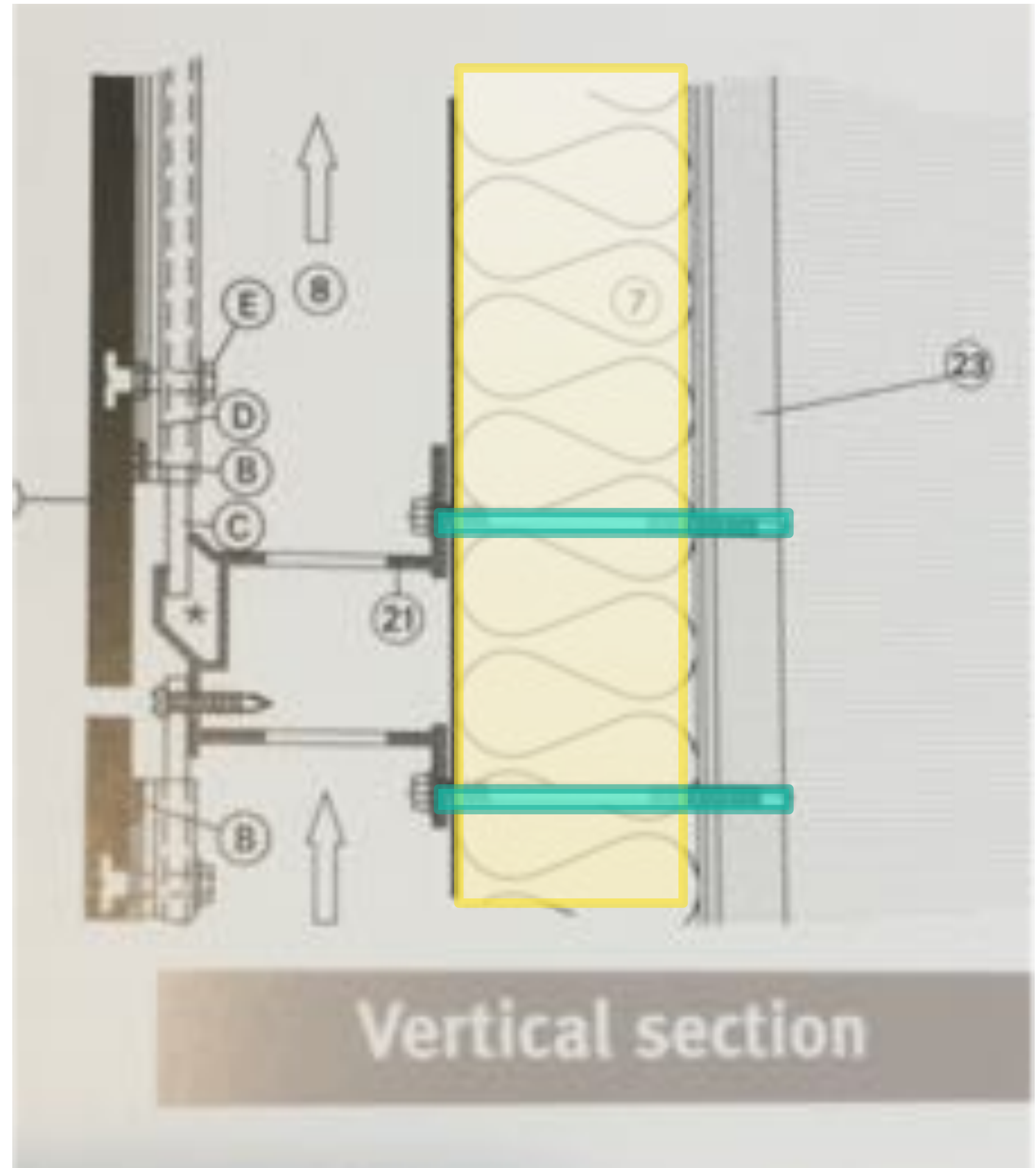
Vertical section though two floors showing attachment of substructure and stone panels

Again, there is attention to detail to allow for unrestrained thermal movement, but how is it all assembled?

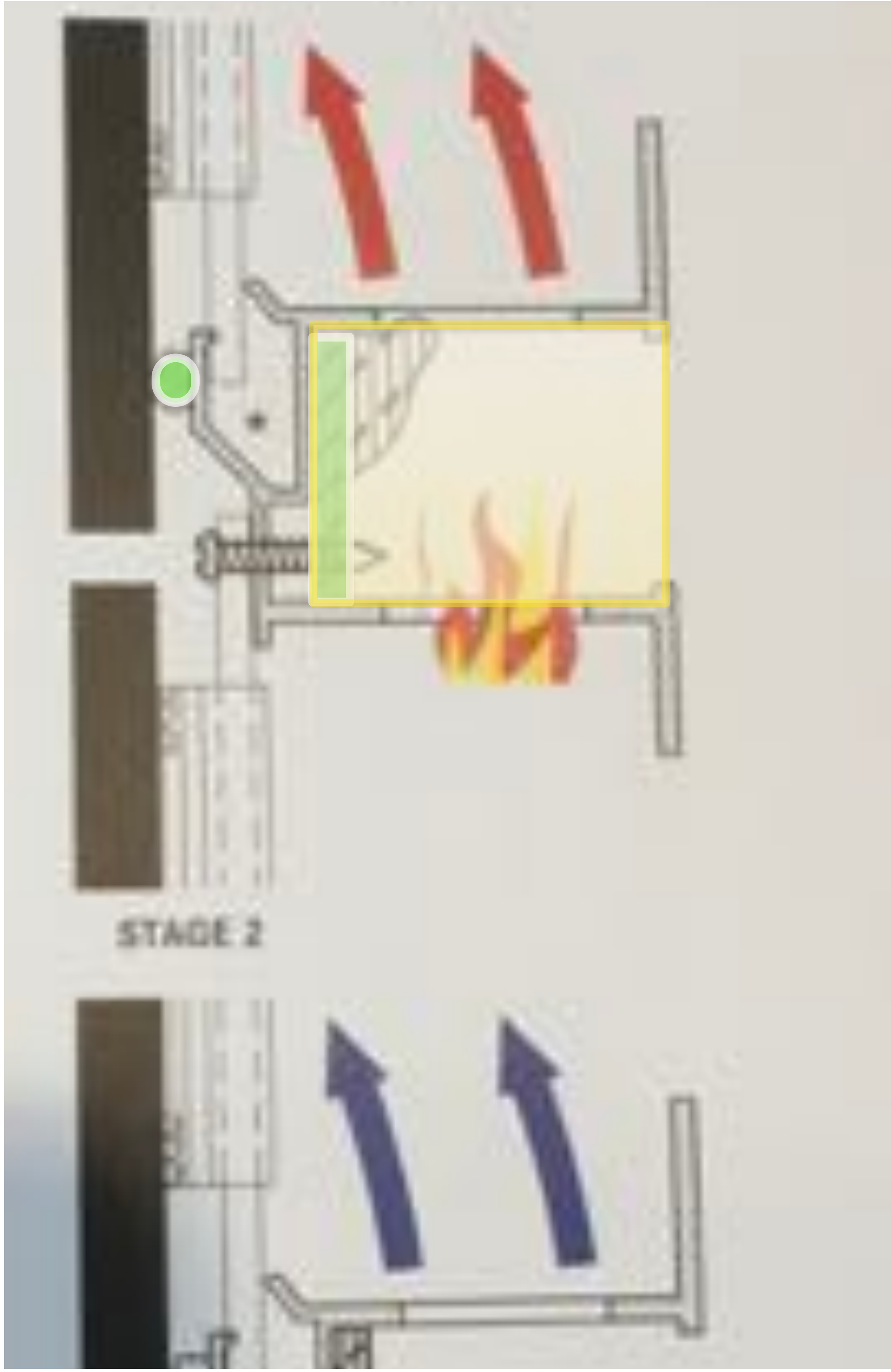


Cantilevered fixings

Soft insulation does not support mechanical fixings penetrating background support structure. Care needed as self-tapping screws coloured green are acting as long cantilevers



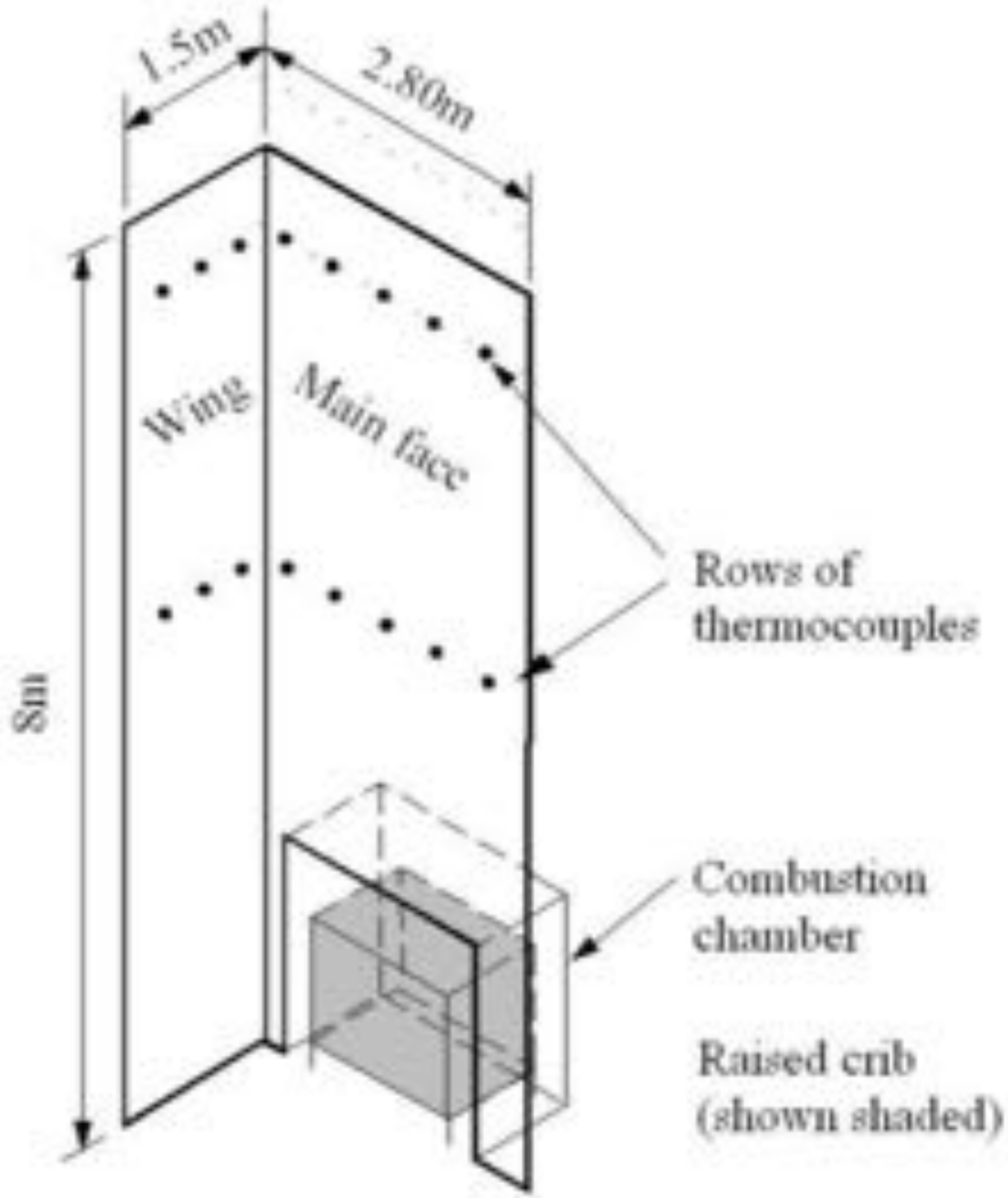
Fire stopping using intumescent strip inside aluminium extrusion

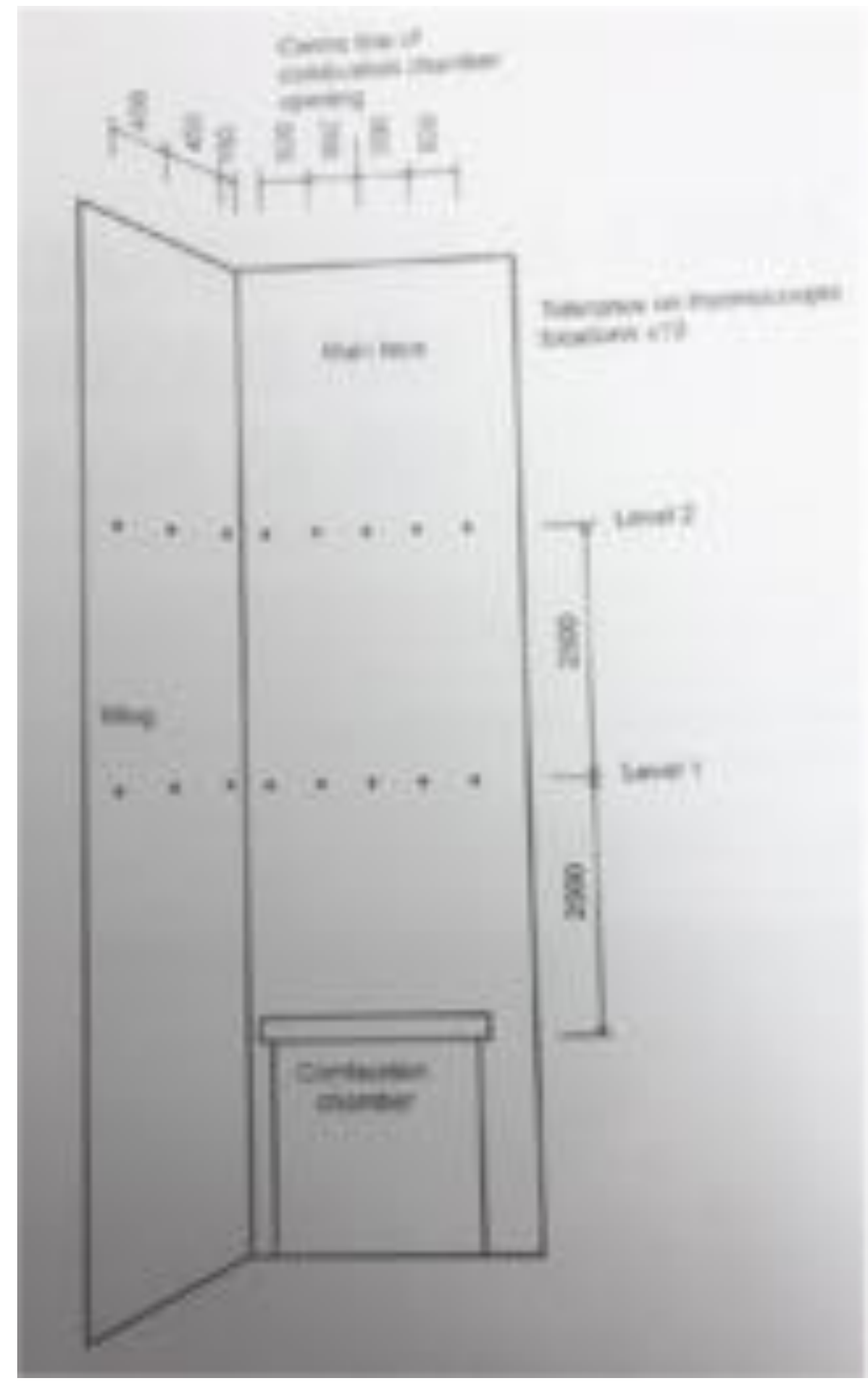


Intumescent strip shown green swells in fire to fill void coloured yellow

Recall that aluminium melts at 660degC

BS 8414 external cladding test rig





Examples of test specimens after test (taken from BRE Report 135)

Figure 9: System with insulation comprising a material of limited combustibility, after test

Figure 10: Thermosetting core without adequate fixings or fire breaks

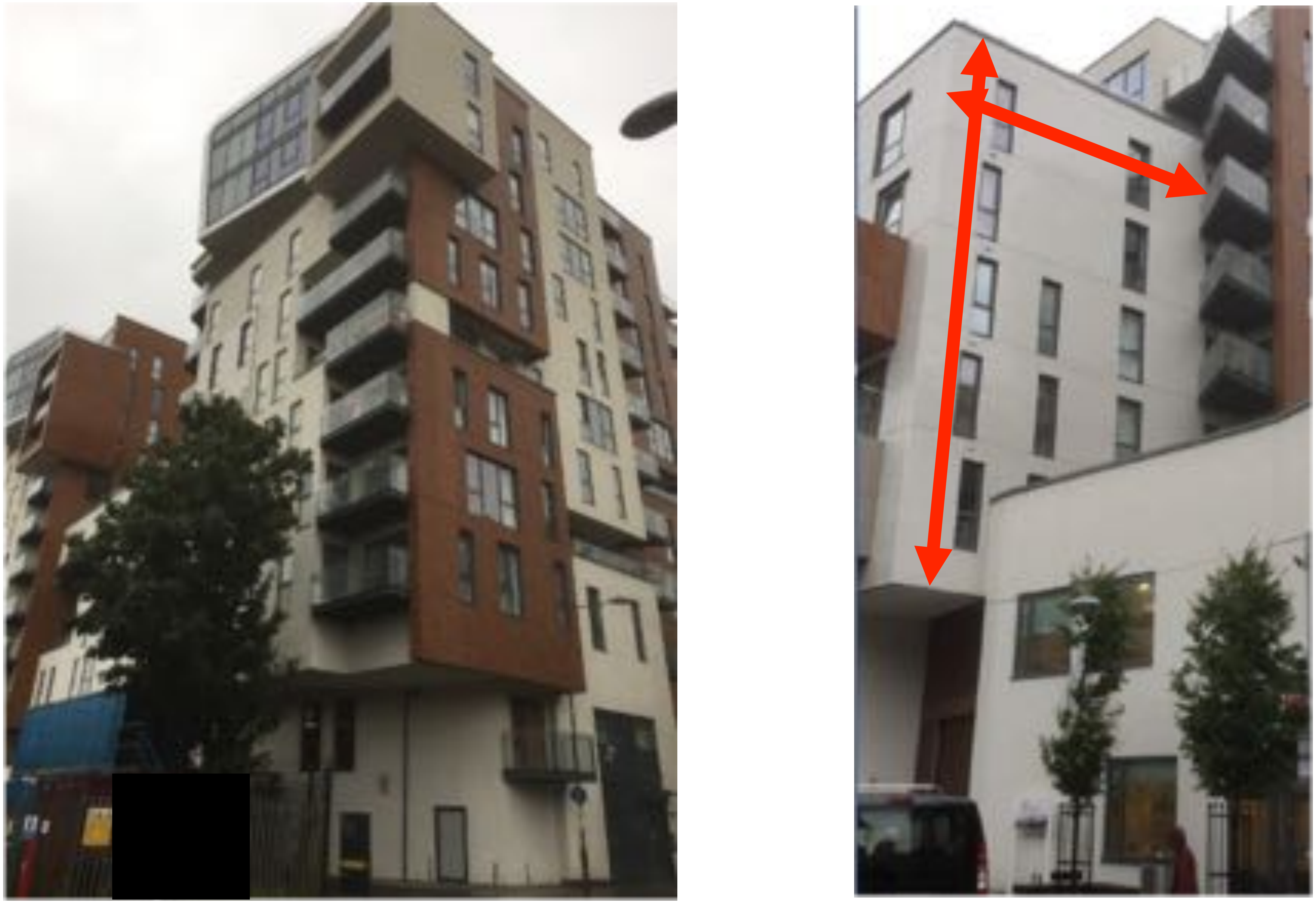
Summary of failure criteria for BS 8414-2 external cladding fire test

External spread: Temp>600degC at 5m above top of fire chamber for 30 sec within 15min of start time

Internal spread (eg in ventilation cavity): Temp > 600degC at 5m for 30sec within 15min of start time

Mechanical performance: None.
However Annex A2.4 states that" ongoing system combustion following extinguishing of the ignition source shall be included in the test and classification reports, together with details of any system collapse, spalling, delamination, flaming debris or pool. The nature of the mechanical performance should be considered and be part of the overall risk assessment when specifying the system".

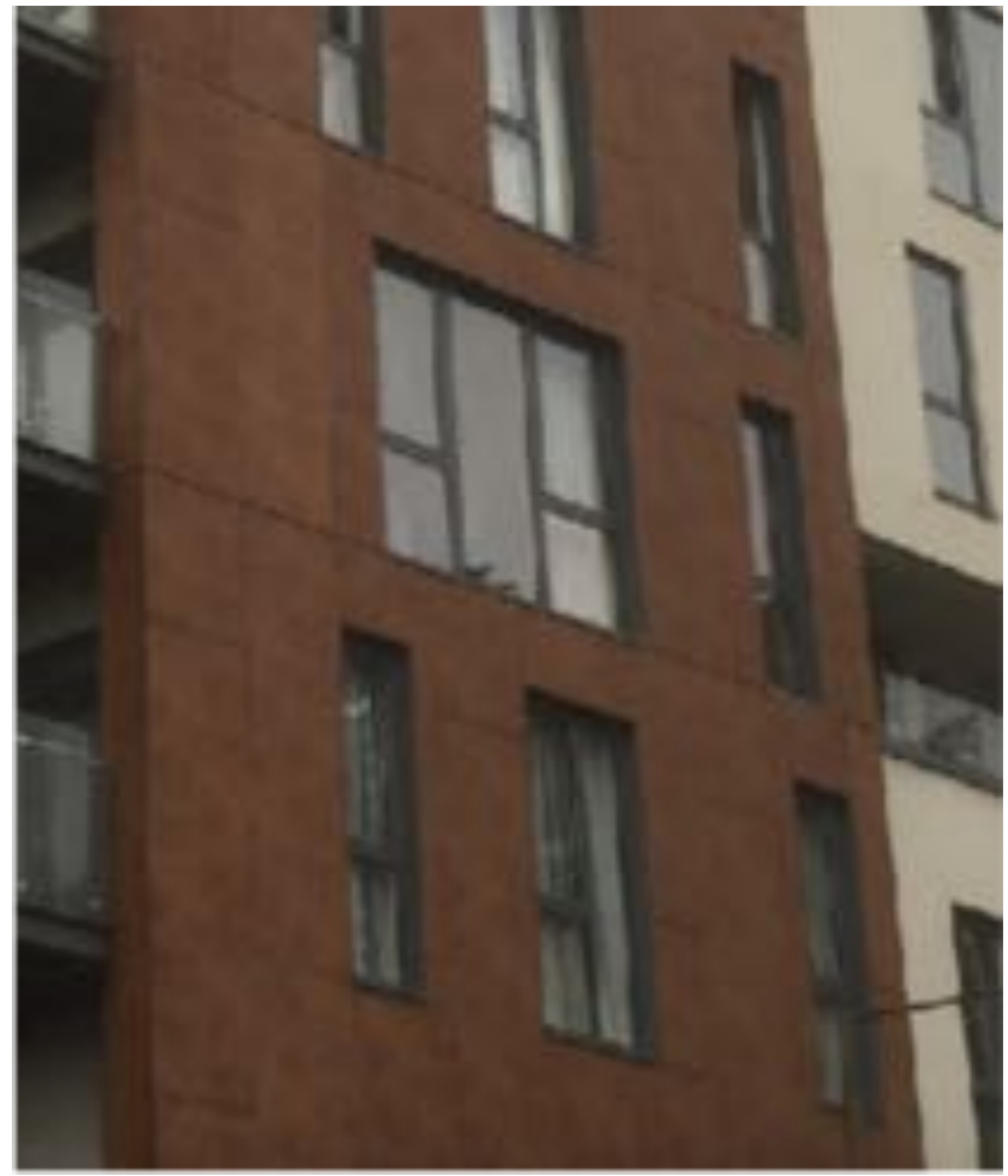
Start time is when external thermocouple at level 1 reaches 200degC.
Test duration 30 minutes



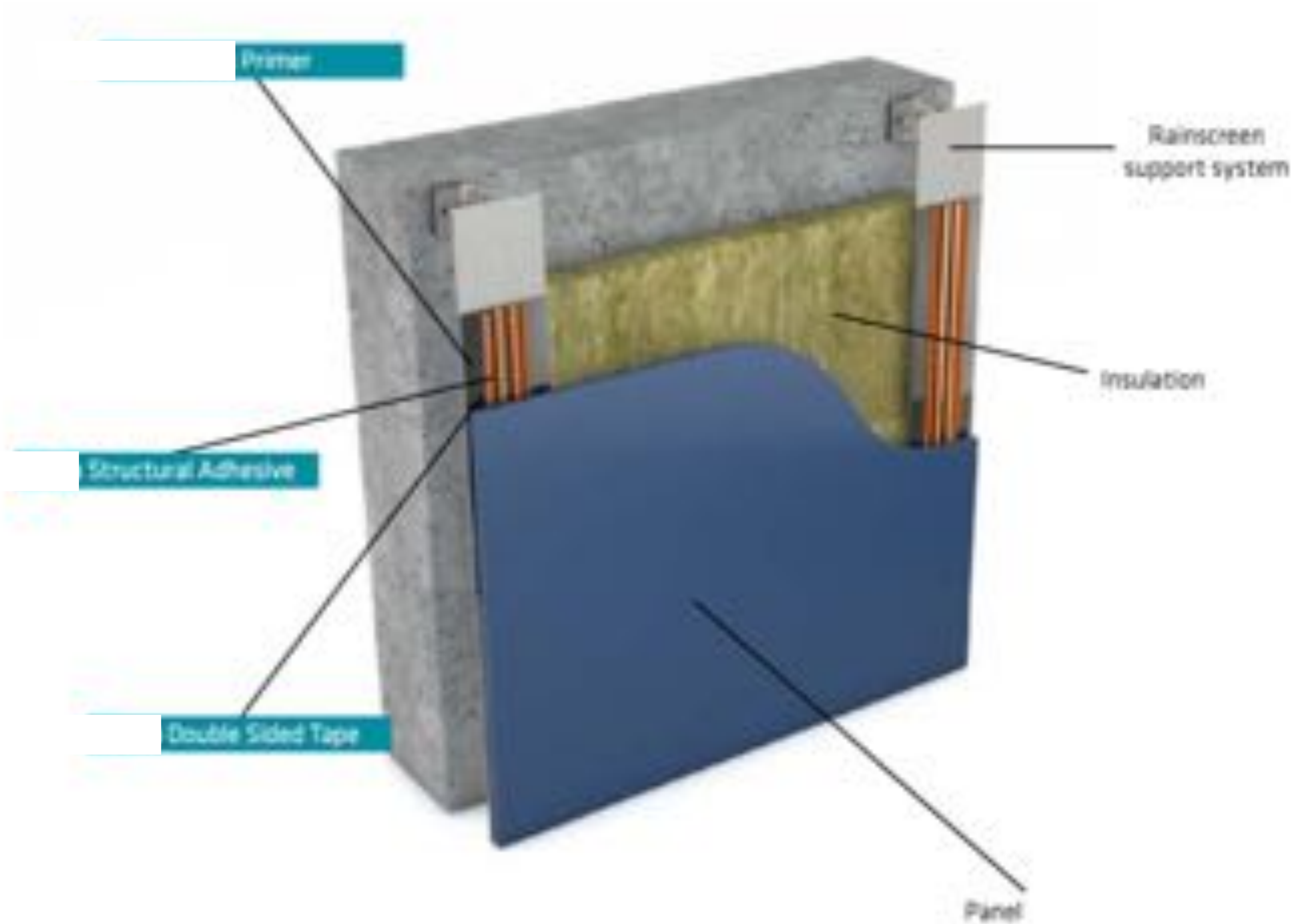
Three different cladding systems on one building complex I assessed

A glued panel system of external cladding

- Glued panels above window and around window reveals could fall down in a jetting fire?
- Is this any worse than areas of window glass falling down in a fire - we don't legislate against this?



In this ventilated facade the external panel is held on with 3 strips (shown orange) of thermosetting polyurethane adhesive. How long will the panel remain in place if exposed to radiation from jetting flames?



Adhesive service life l hr at 150degC.   Failure temp of 200degC often used for PU

Part of a proprietary brick slip cladding system during construction. This system has passed the BS 8414-2 cladding fire test.

However it is noted that the brick slips began falling off the specimen from 12minutes after starting the test. 5 minutes after end of test (test ends at 30 minutes when crib extinguished) roughly 4m height of brick slips had fallen off and a large area of the charred plastic foam was visible.

It is reported by BRE that a ‘large pool fire had developed on the floor’ and at 60 minutes (30 minutes after the incipient fire (crib) had been extinguished) there was continued burning of the insulation where the brick slips had fallen.

Timber crib fire used in BS 8414-2 test

Timber crib is nominally 1m deep by 1m high by 1.5m wide.
This crib gives nominal total heat out put of 4500MJ over 30 minutes at a peak rate of 3MW.

Does this adequately represent the fire severity of flames jetting through a window opening in a real fire?

Digression on severity of timber crib fire.

Cooke test at BRE in 1994 using domestic fire load and 50% ventilation in front wall.

Note large flames which would severely punish external cladding above opening.

These flames are radiatively more severe than in BS 8414 cladding test

Radiation is proportional to absolute temperature to 4th power

$$\varepsilon\sigma(T_f^4 - T_a^4)$$

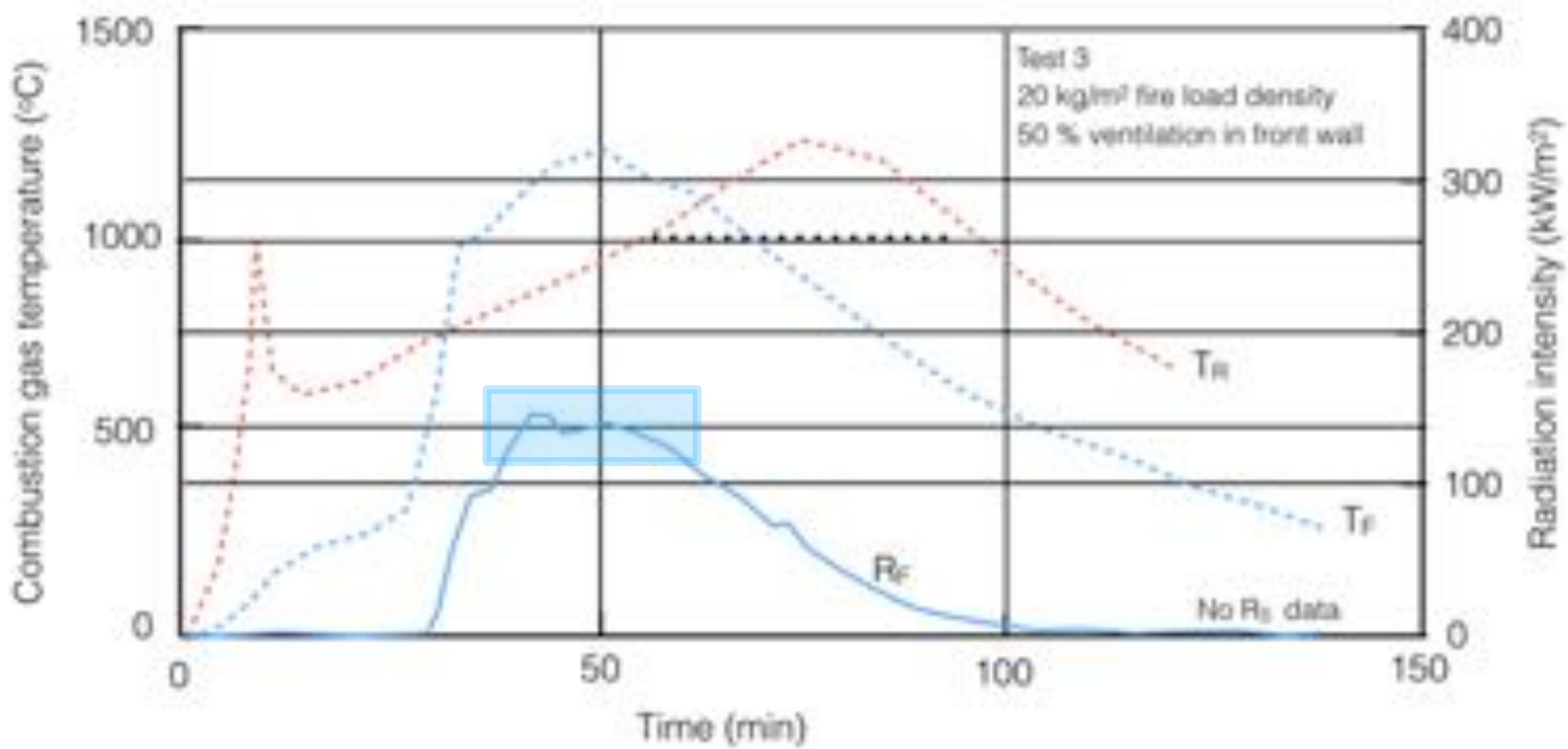
where

ε = emissivity

σ = Stefan-Boltzmann constant (5.67×10^{-11} kW·m^{-2}·K^{-4})

T_f = flame temperature (K)

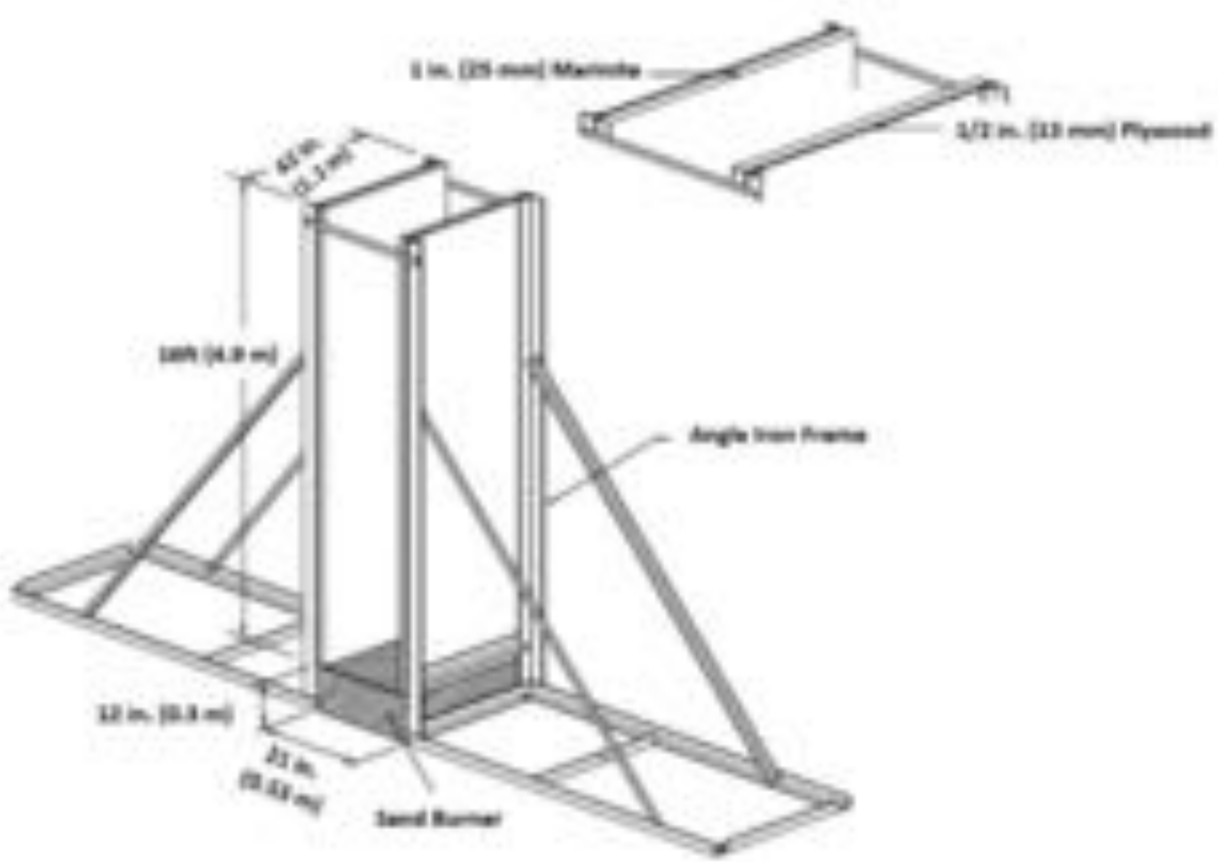
T_a = ambient temperature (K)



Emitted radiation intensity from front of compartment reached 140 kW/m2 in Cooke tests at BRE

The ANSI/FM 4880 16ft high parallel panel test

A cheaper and quicker test method for external cladding adopted in the US.



The ANSI/FM 4880 16ft high parallel panel test and the BS 8414 test.

The 16-ft PPT method simulates a realistic fire scenario and imparts heat fluxes of the order of 100 kW/m^2 to the wall panels. This fire scenario is representative of both exterior fires in corner situations and post-flashover fires from the building interior.

The peak heat flux in the tests studied ranged from ~20 kW/m^2 to up to 200 kW/m^2 in certain cases; the peak heat flux to the façade increased with an increase in the HRR and with decrease in the aspect ratio of the window (i.e., wider windows provide higher heat flux flashover fires). Many similar studies in the literature [27, 33-36], including both experiments and simulations, have shown that a heat flux of the order of 40 kW/m^2 is not representative of a realistic fire hazard, and instead heat fluxes of the order of 70-80 kW/m^2 to be more realistic representations of post-flashover fire scenarios.

The wood crib source in BS 8414 produces approximately 75 kW/m^2 peak heat flux at 3.3 ft (1 m) height above the window opening on the external wall. The wood crib can be substituted with an alternate fuel source that can provide heat fluxes that vary in the range of 45 to 95 kW/m^2 over the first 20 minutes of the test with a steady-rate mean heat flux of 75 kW/m^2 within this period.

Failure criteria: ANSI/FM 4880 V BS 8414

Large-scale Fire Test	Burner and HRR	Peak Heat Flux to Panels	Wall Specimen Height Above Window/Burner	Primary Criteria for Failure
16-ft PPT	Propane burner: HRR = 360 kW	~100 kW/m^2	16 ft (4.9 m)	Peak HRR > 1100 kW
BS-8414	Wood crib: HRR = 3 ± 0.5 MW	~75 kW/m^2	20 ft (6.0 m)	Temperature at 16.4 ft (5 m) height rises 1110 °F (600 °C) above ambient

The fire hazard of plastic foam insulation

- The next two slides are views taken from a video of French fire tests based on the BS 8414 test scenario except that the tests were made in the open air. It can be seen that the plastic foam insulation supports very severe fire spread.

French tests similar to BS 8414 in concept - 7 minutes into test

PIR foam in flames over whole height, about to have timber crib extinguished

French tests similar to BS 8414 in concept - later in test after PIR extinguished

Extreme left, XPS foam flaming over entire height

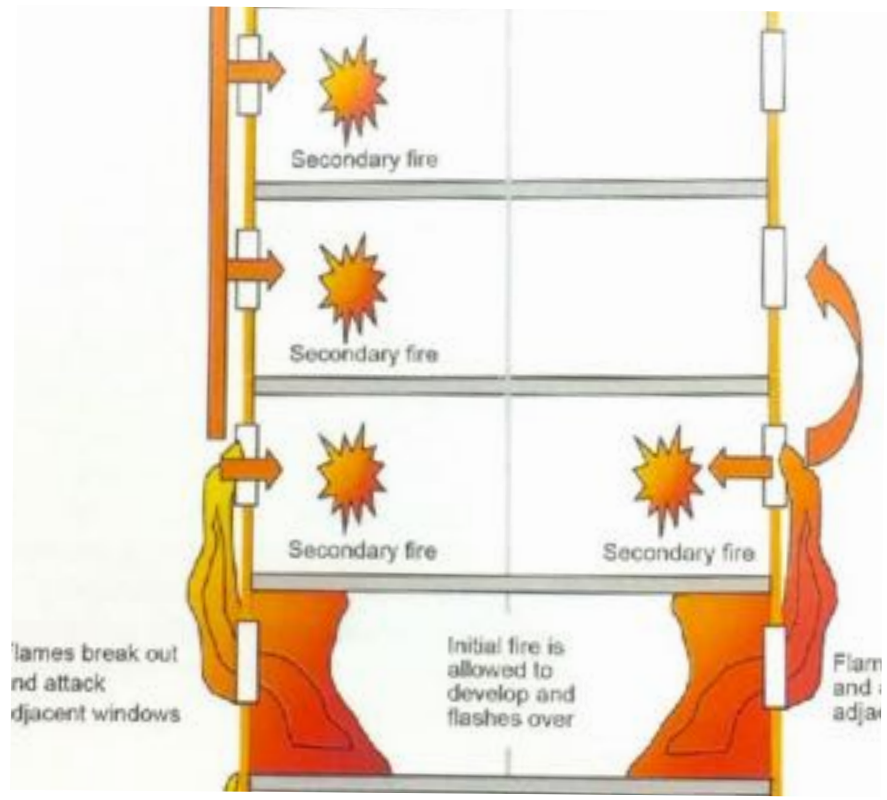
Built 1974.
24 storeys.
Upgraded approx 2016.
No sprinklers.

71 ? dead.

Suspected many inadequacies in fire precautions and poor building management.

The Grenfell tower block fire in the heart of London, 14 June 2017

The missing window.



No window opening in BS 8414 test specimen.

Does not deal with secondary fires e.g. ignition of curtains behind glazing in storey above.

Ignition radiation intensity can be calculated (BS 7974) from gas temperature data but what emissivity value should be assumed? Radiometer data preferred.

If specifiers dont read the BRE report they be unaware of the window anomaly.

Some practical solutions.

- Keep cladding system if construction exactly reproduces test specimen that has passed BS 8414-2 test. But note author's reservation on severity of timber crib fire exposure.
- Install automatic sprinklers throughout building and remove external fire hazards, or
- Remove cladding and replace with limited combustible cladding e.g. replace all plastic foam with stone wool insulation, or
- Instal insulating fire curtains to all windows around perimeter to stop secondary fires starting with fire jumping from window to window, or
- Make very careful qualitative/probabilistic and holistic fire risk assessment using parts of BS 7974 to extend the results of the BS 8414-2 test. Very difficult and risky in my view.

Conclusions and personal opinions on rain-screen cladding

- All plastics are combustible according to BS combustibility test and common sense. Don't waste time testing EPS, PU, PIR PE or Phenolic foam for combustibility as was reportedly done in the Grenfell fire aftermath.
- Possession of Class 0 is sometimes used to justify use of plastic foam in claddings. Facing a plastic foam with aluminium foil to get Class 0 is not relevant to the cladding fire scenario.
- BS 8414 test should include radiometers in test spec at 'window' position so that *radiation* onto facade is measured. Fire plume temperatures not sufficient.
- Assessment of risk of vertical fire spread in high rise buildings from results of BS 8414 test needs to be done by fire safety engineer/scientist.
- Crib used in BS 8414 test should be bigger to more closely represent real flashover fires. Test should last longer than 30 minutes. Government should fund testing of plastic-containing systems to assess effect of larger crib sizes.
- ADB and other code guidance is difficult to interpret.
- Too many variables in modern rain-screen cladding systems (eg different types and thicknesses of foam , different cavity thickness, different facing attachment methods, different perimeter sealing methods around windows). Problem: cant test every 8m high design as too expensive and time consuming.
- The missile hazard of falling bits of cladding needs to be covered clearly in regulatory fire guidance. It is known that some rain-screen panels are glued onto alum support rails using a PU adhesive, but there is a lack of data on high temperature resistance of adhesive. This cannot be right.
- Observations on missile behaviour of cladding made in BS 8414 fire test should be stated on summary of test report, not tucked away at end of report - few specifiers may be aware of this data. Can it be right that 4m height of brick slips can fall off in BS 8414 test and yet be considered a pass? Should the initiating fire (the timber crib) be extinguished after 30 minutes?
- There is tendency to say that sprinklers or fire curtains should be fitted if data on cladding dubious.
- The more complex the cladding system the greater the possibility of poor performance and the greater the difficulty in predicting fire performance.
- As in many other disasters it has been shown again in the Grenfell disaster that there is a need for education of specifiers and checking authorities on the behaviour of plastic foams in critical fire safety scenarios. Stay in place strategy should be used with great care.

Missile hazard of cladding

It seems that inadequately fixed external panels are being specified which in a fire can drop off presenting a missile hazard.

Some external cladding panels are being simply glued to lightweight aluminium sections. In fire these adhesive joints can fail due to conducted heat weakening the adhesive.

No UK regulation or code seems to address the missile danger to fire fighters and others near the building. Author has highlighted this problem with sandwich panels.

Difficulties establishing what cladding system has been installed?

- Getting as-installed drawings.
- Making non-destructive inspections.
- Gaining access at high storey levels.
- Getting product information post completion.
- Establishing existence and quality of hidden work.

Thank you for your attention