Fire Research Note No. 878

FIRE AT WULFRUN SHOPPING CENTRE, WOLVERHAMPTON, 24. 12. 70

by

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July 1971

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SUMMARY

This note gives details of a fire which occurred in a shop facing on to a covered shopping arcade in a modern shopping centre. A number of features are of interest.

Calculations show that a layer of gases at a high temperature extended beneath the ceiling of the covered arcade for its entire length and that this condition and smoke logging of the arcade must have become established in about a minute from the time when the fire in the shops flashed over. It appears that the fire brigade were called just in time to prevent extensive fire spread.

KEY WORDS: Fire account, shopping mall, fire spread, smoke, spread

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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1. INTRODUCTION

1.1. The shopping complex

The complete complex consists of two elements - the Wulfrun Centre and the Mander Centre - separated from each other by Bell Street. A covered arcade which bridges over the street forms the connecting link between the two centres: shops line either side of the arcade except for the bridge section which has large openable windows on one side. (Fig.1).

1.2. The covered arcade

The covered arcade is 85 m long and approximately 7.5 m wide. There is a close boarded false ceiling 3.6 m above floor level over the bridge and Mander Centre end; at the Wulfrun Centre end the height to the roof slab is 4.2 m and 0.60 m below this level, a series of 0.15 x 0.05 m joists supported by the roof and spaced approximately 0.60 m apart give the impression of a false ceiling. A number of structural beams 0.50 m deep project down from the roof slab across the arcade at intervals.

1.3. The extremities of the covered arcade

At the Mander Centre end the covered arcade opens into a piazza or open court; the Wulfrun Centre end is continued as an open mall with canopies above the shops on either side.

Note: In this report we have referred to an open pedestrian way as a 'mall' and a covered pedestrian way as an 'arcade'.

1.4. Number of storeys

The area affected by fire has shops at the arcade level with shop tenants' storage and car parking facilities below and with customers' car parking at roof level above. Above part of the carpet shop where the fire started is a store belonging to the adjoining food super market.

1.5. Construction of the Wulfrun Centre

The construction consists of reinforced concrete slabs and columns with brick or concrete block separating walls between tenancies. Approval for the scheme was given before the Building Regulations were in force and building work commenced about 1965.

1.6. Fire protection for the Centre

Full sprinkler protection for all shops in the Centre had not been adopted and only one shop involved (the department store) had a sprinkler system.

The Centre's security office was not manned at night and there was no automatic fire alarm or detector system in the area involved other than the automatic fire alarm to the fire brigade from the department store sprinkler system.

1.7. Fire origin and cause

The fire originated in a carpet store and was discovered at 06.08 by a butcher in a nearby shop who saw smoke. The cause is not known but the fire brigade suggest that the fire may be due to 'carpets stored in contact with lighting spotlamps or electric storage heaters'.

1.8. Summary of incident

(i) At 05.30 the smell of smoke was noticed by an employee passing through the arcade but since no further evidence was found he took no action.

(ii) At 06.08 a passerby saw smoke above the department store. He dialled 999.

(iii) At 06.12 the department store sprinkler system (AFA) connected to brigade headquarters operated. (Five heads opened in the arcade and three more inside the shop protecting a window display).

(iv) At 06.12 the fire brigade arrived to find the arcade smoke logged. At the Mander Centre end visibility was nil. At the Wulfrun Centre end firemen reported a 'tunnel of flame' in the arcade and at this stage no entry was possible.

(v) Firemen fought the fire in the carpet store from the junction of the mall with the arcade and when it had been sufficiently reduced an approach was made through the arcade from the Mander Centre using breathing apparatus. The bridge windows (the glass of which had not even cracked) were opened for smoke clearance.

(vi) At 07.08 the fire was reported 'out'.

1.9. Summary of damage (for fuller details see Appendix 1)

(i) The carpet stores was burnt out and all stock virtually destroyed.

(ii) The shop fronts of three shops opposite were damaged by fire.

(iii) The three shops in (ii) above and four others were smoke logged with considerable damage to stock and decorations.

(iv) The timber open 'false ceiling' in the arcade was burnt in the area in front of the carpet store and for 16 m beyond (Figs 1, 2, and 3).

(v) The reinforced concrete roof slab over the carpet stores and the adjacent part of the arcade was badly damaged by spalling of concrete and the consequent exposure of reinforcing bars.

(vi) A crack due to thermal expansion appeared in the separating wall between the bakers' shop and the book shop. (See Fig.1).

(vii) Three sprinkler heads inside the department store shop window display operated causing some damage to stock although there was no sign of damage to the outside of the showcase.

(viii) A large crack appeared in the roof surface covering above the fire area. (This crack disappeared upon the cooling of the slab).

(ix) The close boarded ceiling to the arcade received extensive superficial damage from heat and smoke and plastic diffusers to ceiling light fittings were distorted throughout.

2. DISCUSSION

2.1. Temperature attained in the Arcade

It has been estimated by making some broad assumptions (Appendix II) that the heat output of the fire in the carpet store was of the order of 30 MW*.

Hot gases would have travelled away from the fire in both directions as a layer beneath the ceiling[2] which has been calculated to have extended down to roughly 2 m from the floor (Appendix II). Beneath this layer air would have been flowing in towards the fire (Fig.3); smoke would have mixed into this return flow of air particularly at the ends of the arcade and it would have been heavily smoke logged.

The Wulfrun Centre end of the arcade was partly closed by a screen extending downwards from the bottom of the roof slabs to 3 m from the ground (Fig.3); this very largely acted as a barrier to the passage of flames in that direction since there was only evidence of flames having impinged on the soffit of the canopies for a short distance beyond the covered section of the arcade. The screen would also act as a partial barrier to the travel of hot gases so that, if wind effects were small, more hot gases would travel towards the Mander Centre than in the opposite direction.

On the evidence of the charring of the decorative wood joists (Fig.3) simulating a false ceiling of the arcade, flames had extended beneath the roof slabs of the arcade for a distance of 16 m beyond the carpet store in the direction of the Mander Centre. At this point the hot gas layer would have had a mean temperature of roughly 400°C (Appendix II) which would probably have fallen to roughly 200°C at the Manders Centre end of the arcade. Other temperatures are indicated in Fig.1. The lack of damage to the surface finish of the close boarded ceiling of the bridge indicates that the boards were probably exposed to the 300°C hot gases for only a short time - with this exposure the surface of the ceiling was calculated to have attained a temperature of 100°C in about $\frac{1}{2}$ min and after 5 min it would have reached 180°C.

In spite of being subjected to gases at probably 300°C the external glass windows in the bridge did not even crack although windows in showcases on the opposite side did crack, this underlines the futility of relying on the breaking of glass windows by heat to provide smoke venting.

A temperature of 220°C beneath the ceiling outside the department store would be more than adequate to open the sprinkler heads even if the fire were short lived. The estimated depth of the layer of hot gases was greater

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*The heat output of each of the $2\frac{1}{2}$ m square kerosine fires in the Glasgow tunnel tests[1] was about $2\frac{1}{2}$ MW

than the distance beneath the ceiling of the top of the showcases outside the department store so that it is not surprising that gases penetrating through leaks in the top of the showcase opened sprinkler heads.

Although the bottom of the layer of the outward flowing hot gases was probably just above the firemen's heads a relatively stagnant layer of cooler (but still hot) smoky gases would probably have formed beneath this layer with relatively cool air only near the floor. Bearing in mind the likelihood of high levels of radiation it would have been virtually impossible for firemen to approach the fire from the Mander Centre end of the arcade. It was fortunate that the brigade were able to approach the fire from the other side through an open section of the mall; all the evidence points to their having quickly reduced the rate of burning. Soon afterwards firemen were able to penetrate the arcade from the Mander Centre in spite of thick smoke. It is apparent that heat can be a major obstacle to fighting a fire in an arcade of relatively small cross section.

2.2. Exposure hazard to shops along the mall

Some calculations have been made (based on rather approximate data) of the rates of heat transfer to the shops opposite the burning carpet store and also to those adjoining it (Appendix II). These are compared with rates of heat transfer necessary to cause ignition of cellulosic materials[4,5], (Fig.5).

Because the arcade and its shops are in effect one building the space separation requirements of the Building Regulations do not apply and the separations of the shops across the arcade are less than those which would have been required had the shops been on opposite sides of an open street. Even so had the mall been open (with no projecting canopies) the heat radiated to the shops opposite the carpet store would probably not have been sufficient to cause spontaneous ignition of cellulosic materials, although pilot ignition would have been possible. However, because the arcade was roofed over, flames impinged on the top of the shop front and most combustible materials could be ignited. The heat transfer to the top of the front of the book and toy shop was probably less than that to the shops opposite but was still sufficient to ignite cellulosic materials.

The worst exposure in both instances was to the upper part of the fascia which was apparently constructed of a non-combustible material. Calculations, ignoring the absorbtion of radiation by smoke, suggest that the shops opposite the carpet store should have been subjected to considerable radiant heat because the radiation from the store itself would be augmented by radiation from the ceiling flames. Even at the bottom of the shop front the radiation heat could have been sufficient for the spontaneous ignition of cellulosic materials. The window would have reduced this radiation to below that necessary for the pilot ignition of cellulosic materials until the glass itself became hot enough to radiate heat. However the calculated heat generation should have been sufficient to cause at least browning of paper behind the window, whereas some tissue paper behind the window of the greengrocer's shop was not damaged by heat; it is possible that smoke within the mall was screening the shop fronts from some of the radiation. It would not however lessen the effect of flame impingement.

The relatively small amount of damage to the shops in spite of the high rates of heat transfer to them indicated that the times for which they were exposed to these high rates of heat transfer must have been short, a few minutes at the most.

Most of the shop fronts remained intact although the glass was cracked and this must have delayed ignition of the interiors.

Had the calling of the brigade been further delayed for even a short time it is likely that further shops - particularly the book and toy shop would have been involved. The heat output of the resulting fire would have been greater than that of the burning carpet store and the resulting flames beneath the ceiling of the arcade could well have extended across the bridge so that the possibility of fire spreading to the Mander Centre cannot be ruled out.

2.3. The effect of the open timber joists

All the observed damage has been explained on the basis of a fire in the carpet store which, although large, was smaller than the maximum which could have occurred in a shop of that size. It is unlikely that the timber joists would have ignited until the fire in the carpet store had reached such a size that flames were travelling horizontally beneath the roof slabs.

The joists are spaced so far apart that one could not be ignited directly from the next so that damage to the joists could only be caused by flames beneath the roof slab (except in front of the carpet shop where there was a high intensity of radiation).

The fuel gases produced by pyrolysis of the joists would be expected to contribute to the horizontal flames. Had the roof slabs been lined with timber (instead of the joists being fitted) the exposed surface area of wood would have been roughly the same and small scale experiments have shown that of the order of half the horizontal flame length could have been attributed to the wooden lining[6]. However there is no data to show whether this would apply to the joisted ceiling.

Had the close-boarded suspended ceiling in the Mander Centre been carried over into the Wulfrun Centre, flames would have been confined beneath the suspended ceiling instead of beneath the roof slabs at a higher level. Even ignoring the contribution of the flammable products of pyrolysis of the ceiling, the horizontal flames would have been longer and at a lower level so that the exposure hazard would have been much greater.

3. CONCLUSIONS

3.1. There is no evidence to show how long the fire in the carpet store took to build-up to the state when the windows broke, although it must have been fairly small half an hour previously. It is likely that the breaking of the windows was followed by a rapid increase in the rate of burning of the fire. The fire could only have been burning at its maximum rate for a few minutes; had it been burning longer other shops would have become involved.

3.2. Once the shop windows had broken the rush of hot gases would probably have reached the end of the arcade in the Mander Centre in about one minute and conditions would then have been untenable for any occupants of the arcade and escape through the arcade from shops would have been impossible.

3.3. The open joisted wooden ceiling undoubtedly contributed fuel to the fire but even if the ceiling had been completely non-combustible the conditions in the mall would have been little if any less severe and the chance of fire spread would not have been much less.

3.4. The deep non-combustible fascia above the shop fronts (Fig.2) remained in position preventing the flames beneath the ceiling from entering the shop; the glass windows remained in position for sufficiently long to delay the ignition of materials in the shop by radiation. These two factors undoubtedly restricted fire spread before the arrival of the brigade.

3.5. The shop fronts were not smoke tight and considerable financial loss was sustained by a number of shops due to smoke damage.

3.6. Firemen were able to fight the seat of the fire from the open mall. Had the fire occurred in a shop further into the arcade (for example the toy and bookshop) fire fighting from the arcade would have been virtually impossible and consequently the fire spread is likely to have been more extensive.

3.7. The damage to the concrete roof slab appeared to be excessive in view of the short time for which the fire was burning at its maximum rate. (The slab which supports a car park might well be rated at 2 hours in the B.S.476 Fire Resistance tests).

4. ACKNOWLEDGMENT

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APPENDIX I

DAMAGE TO INDIVIDUAL SHOP UNITS AND TO THE ARCADE

Carpet stores

(i) Almost complete burn out of contents.

(ii) All plaster off walls.

(iii) Shop front destroyed.

(iv) Spalling of concrete off 50 per cent area of soffit of roof slab giving complete or partial exposure of main slab reinforcement (some rods hanging down). Such spalling mainly confined to central area of shop.

(v) All concrete cover to columns intact but with some hair cracks observed.

(vi) Some spalling to reinforced concrete main beams but to much lesser extent than to roof slab.

(vii) Shop closed for reinstatement at time of visit.

Food supermarket

(i) Some smoke damage to goods near front of shop.

(ii) Glass to shop front cracked by heat.

(iii) Some cracking to brick walls to staircase enclosure due to thermal expansion. Plaster key with brickwork destroyed in places. (Brickwork said to be 'very hot' after the fire).

(iv) Paintwork to rain water pipe in storeroom immediately above Eastern Carpet Store badly blistered and charred by heat.

Book and Toy shop

(i) Glass to shop front remained intact during fire but cracked in places. Timber members to shop front partly burnt.

(ii) Shop smoke logged due to smoke entry through ventilation louvres above glass in shop front.

(iii) Damage to all stock by smoke.

(iv) Shop closed for reinstatement at time of visit.

Bakers shop

(i) Shop front glass cracked but remained in position.

(ii) Shop smoke logged due to smoke entry through non-smoke tight construction of shop front.

(iii) Large crack in separating wall at rear of shop due to expansion of roof slab.

(iv) All stock spoilt.

(v) Shop reinstated and open for business at time of visit.

Tobacconist

(i) Glass to shop front remained intact. No apparent damage to steel shop front framing.

(ii) Shop smoke logged due to entry of smoke through gaps in fascia panel above glass to shop front.

(iii) Approximately 30 per cent of total stock spoilt.

(iv) Shop closed for reinstatement at time of visit.

Department store

(i) Three sprinkler heads in shop window operated causing damage to stock by water.

(ii) Some penetration of smoke into part of shop.

Radio shop

(i) Glass to shop front cracked near top only.

(ii) Shop smoke logged due to smoke entry through ventilation louvres above entrance door from arcade.

(iii) Probably little serious damage to stock.

(iv) Shop closed for reinstatement at time of visit.

Fishmonger and Greengrocer

(i) Shop front damaged by fire. Glass broken.

(ii) Some plaster of wall near front of shop.

(iii) All decorations and stock spoilt by smoke logging and heat.

(iv) Little apparent burning of stock even that near glass shop front.

Wine Merchant

Butchers shop

Note: Both these shops had temporary hoardings replacing the shop fronts and were closed at time of visit. Inspection could not be made but the fire brigade reported fire damage to be similar to that in the Fishmonger and Greengrocer's shop.

Unoccupied shop Unit No.19

(i) Slight damage by fire to top of wooden hoarding in front of shop.

Arcade

(i) Some spalling to soffit of roof slab exposing reinforcement immediately adjacent to Carpet Stores.

(ii) 0.15 x 0.05 m timber joists at approximately 0.50 m centres forming open false 'ceiling' destroyed by fire in the area indicated in Fig.1.
Remainder of joists blackened by smoke.
Close boarded ceiling to bridge and remainder of arcade slightly affected by heat and smoke.

(iii) Close boarded timber soffits to underside of canopies on either side of open arcade blackened by smoke for first 10 m. Some slight charring to ends nearest fire.

Roof car park

(i) Large cracks appeared in the finished roof surface above the Carpet Stores. On coooling the cracks disappeared and the damage to the structural slab is not yet known.

APPENDIX II

CALCULATIONS OF CONDITIONS IN THE WULFRUN CENTRE FIRE

Estimates of heat output etc

The carpet shop was completely involved in flames and horizontal flames extended for 16 m beyond the shop in the direction of the Manders Centre. In the other direction there was only slight damage from flames beneath the roof screen (Fig.3) although the layer of hot gases extended to about 1 m below the level of the screen. This suggests that flaming occurred within the layer of hot gases (rather than at its base) and that the flames beneath the ceiling were not starved of air.

The rate of flow of air to the fire was calculated as follows:

(a) The air flow would be greater than the rate of entrainment by a flame front equal in width to the shop front (W) and of height equal to the height of the bottom of the layer of hot gases (h_b)[8].

$$M = 0.195 W h_b^{3/2} \text{ kg/s}$$

$$\simeq 10 \text{ kg/s}$$

(b) The air flow would be less than the buoyancy flow along the arcade into a very large chamber completely full of hot gases produced by a fire.

$$M = 0.5 \ A_e h_e^{\frac{1}{2}} \text{ kg/s}$$[9]

where A_e is the total area of entrances to the arcade (c.43m^2)

h_e is the height of the entrances (a mean height of 3.3 m was taken)

$M \simeq 40$ kg/s

Since the area of the shop was only about $2\frac{1}{2}$ times the window area it is likely that the actual ventilation rate was nearer (a) than (b). A value of 20 kg/s was taken.

The depth of the layer of hot gases was calculated by applying the 'weir' formula to the flow of gases out of both ends of the arcade.

$$M_w = 2/3 \ w \ C \ \rho_o \ d^{3/2} \ (2 \ g \ \theta \ T_o)^{\frac{1}{2}}/T$$

where M_w is mass rate of flow of gases over the weir

w is the width

C is the coefficient of discharge

d is the depth of the layer of hot gases beneath the roof screen

θ is the temperature of the gases

T is the absolute temperature of the gases

The hot gas layer extended to 2 m from the floor, the rate of flow out of the Mander Centre end was 12 kg/s and out of the Wulfrun centre end was 8 kg/s.

The heat output of the fire was estimated as follows:

(a) A maximum value of the heat output was obtained by assuming that all the oxygen was burnt in an air flow of 20 kg/s. The heat output per kg of air burnt for many fuels[10] is 3 MJ, this gives a maximum heat output of 60 MW.

(b) From the length of the horizontal flames[6]

$$l = 220 \, (m'/\rho_o)^{\frac{2}{5}} \, g^{\frac{1}{5}}$$

m' was the mass rate of burning per unit width of arcade

l was the flame length measured from an 'effective source', a distance of approximately 2h behind the source where h was the ceiling height.

Because of the geometry of the shop and arcade it was difficult to define a meaningful flame length. This was taken to be the mean distance of travel of the hot gases from the rear of the shop to the tips of the flames.

Adding 2h gave $l \simeq 40$ m

and $m \simeq 2$ kg/s

Where m was the total burning rate. Assuming the fuel was cellulosic with a calorific value of about 15 kJ/g the heat output was about 30 MW. This is likely to be an underestimate because the geometry of the arcade and the presence of the open joists simulating a false ceiling would be likely to increase mixing and shorten the flames for a given rate of burning. Against this the joists would have provided some additional fuel for the ceiling flames so that 30 MW was considered to be a reasonable value for the heat output of the fire in the shop itself.

The represents 400 m^2 of exposed surface of carpet (equivalent to the area of the walls, ceiling and floor of the shop) burning at a rate of 5 g/s per m^2 (rather less if an appreciable amount of acrylic carpeting was involved as this has a higher heat of combustion than wool).

The rate of burning would be equivalent to the complete combustion of roughly 1 m^2 of carpet per second.

Temperature of layer of hot gases beyond the flame tips

Experiment[6] has shown that the mean temperature of the layer of hot gases at the tips of horizontal flames is of the order of 400°C. This means that the heat flowing along the arcade in the layer of hot gases at the flame tips was about 8 MW compared with the 6 MW calculated from the results of experiments on ceiling flames[6].

Temperatures at points beyond the flame tips were obtained from the formula[2]

$$\theta_x = \theta_o \exp(-Hwx/MS)$$

where θ_x was the temperature at a distance

x beyond the flame tips

S was the specific heat of the gases (taken to be 1 J/g)

H was an effective heat transfer coefficient of the layer to the ceiling (assumed to be cold) and downwards. This was taken to be 30 $Wm^{-2}degC^{-1}$

The calculated temperatures are given in Fig.1.

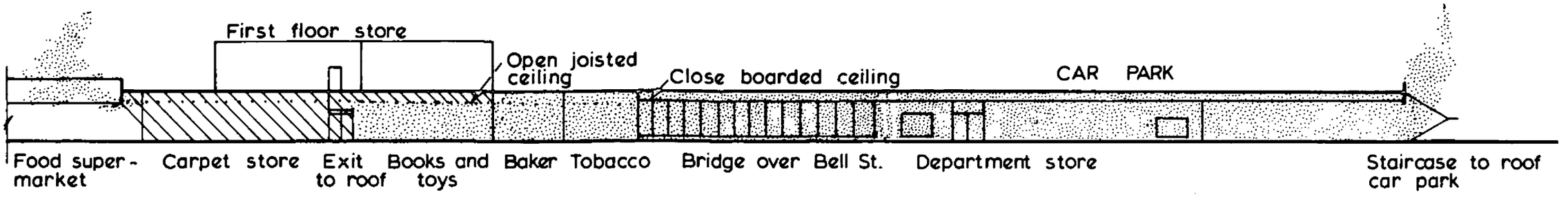
Heat transfer to shops across the mall

The maximum configuration factor of the shop windows across the mall with respect to the carpet shop window was 0.13 exceeds that recommended for space separation between buildings (0.075). If the fire in the shop was radiating at an intensity of 150 kW/m^2 this would result in a maximum radiant flux of about 20 kW/m^2 falling on the shop window - this represents conditions in an open mall.

The brigade spoke of a 'tunnel of flame' implying that flames were impinging on the top of the shop front and curling down. Under these conditions the heat transfer rate to the top of the shop fronts might have been as high as 160 kW/m^2 (radiation and convection from fully emissive flames at 1000°C) although data on the heat transfer from horizontal flames at a point half-way between the effective source and the tips indicate a more likely value of 70 kW/m^2.

Near the bottom of the windows the configuration factor with respect to the carpet shop front was 0.12 and with respect to flames beneath the ceiling it was 0.32. Radiation downwards from horizontal flames at a point about half-way between the effective source and the tips would be roughly 60 kW/m^2 so that the total radiation received by the bottom of the window would be about 40 kW/m^2 i.e. about twice the amount that it could have received if the mall had been open. This assumes that the atmosphere in the mall was clear, smoke would have absorbed at least part of this radiation.

The radiation received by goods immediately behind an intact window would be about 20 per cent of that falling on the window while it was cold, increasing to about 50 per cent when the glass became hot.



LONGITUDINAL SECTION THROUGH ARCADE

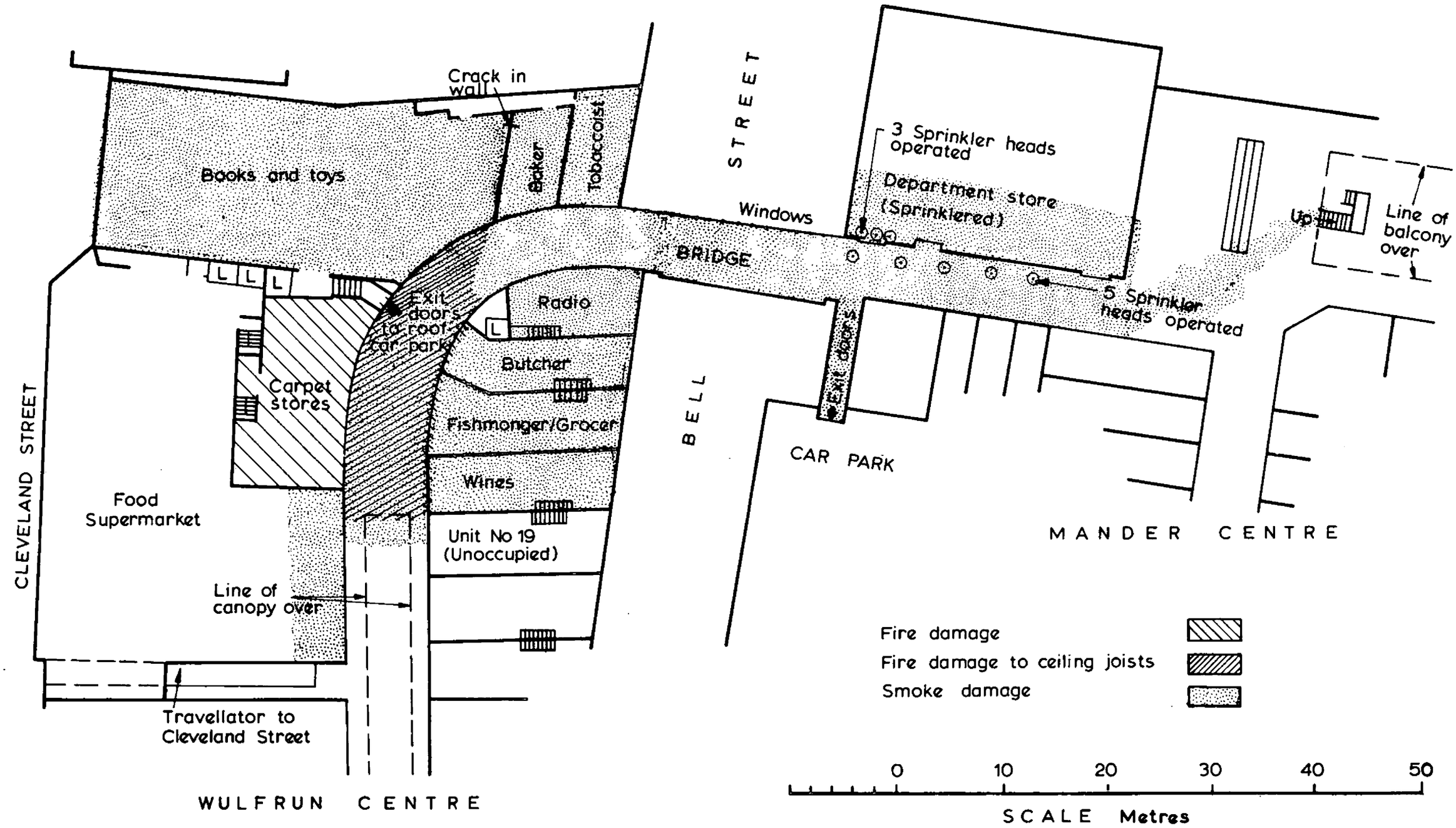


FIG. 1. PLAN OF WULFRUN CENTRE WOLVERHAMPTON

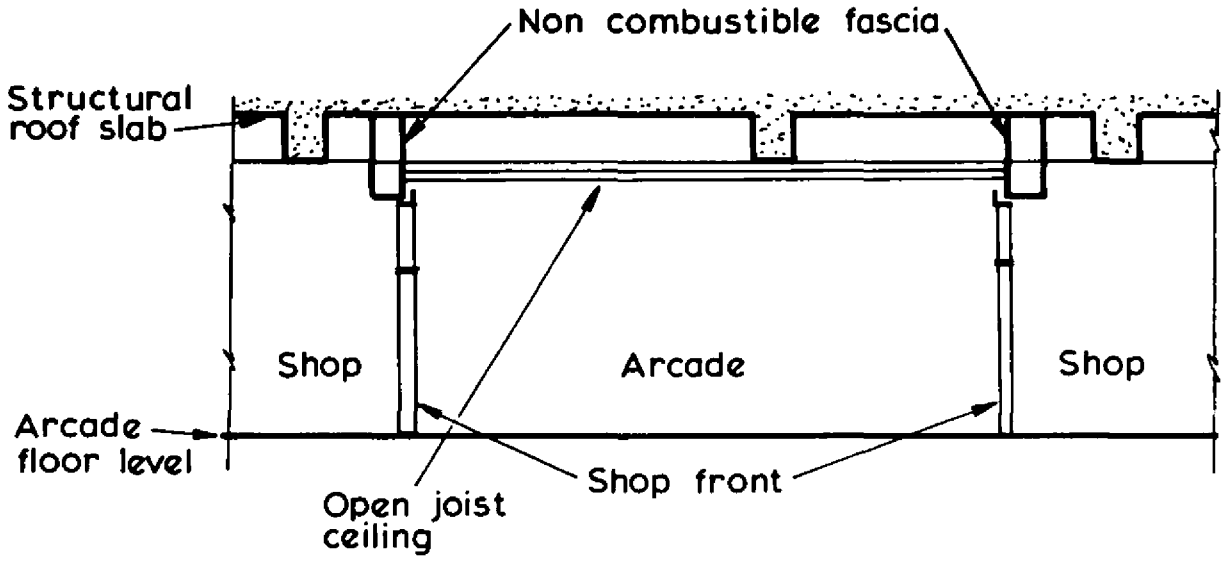


FIG. 2. CROSS SECTION THROUGH ARCADE

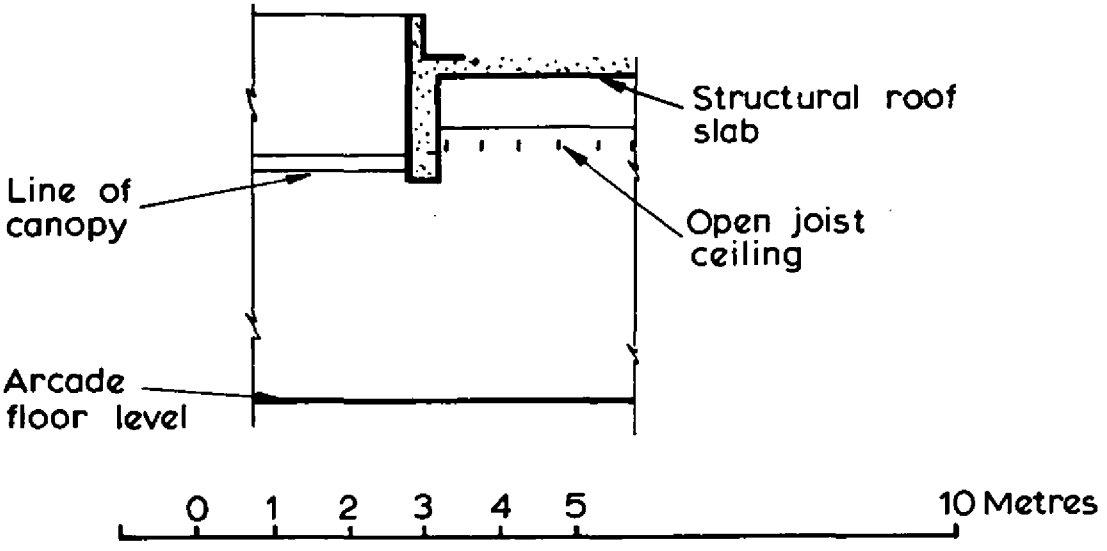


FIG. 3. SECTION THROUGH END OF COVERED ARCADE (WULFRUN CENTRE)

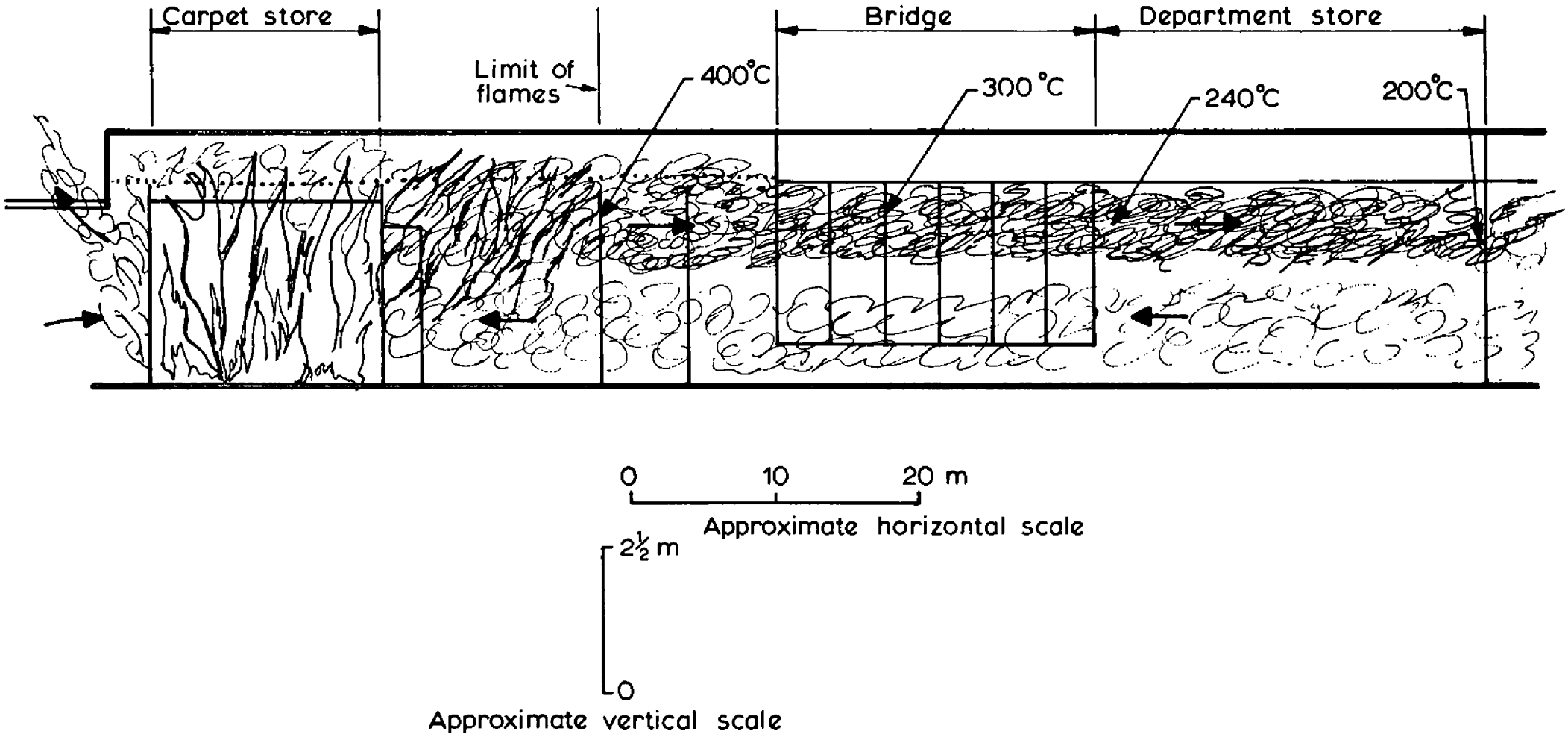


FIG. 4. TEMPERATURES AND FLOW PATTERNS IN ARCADE

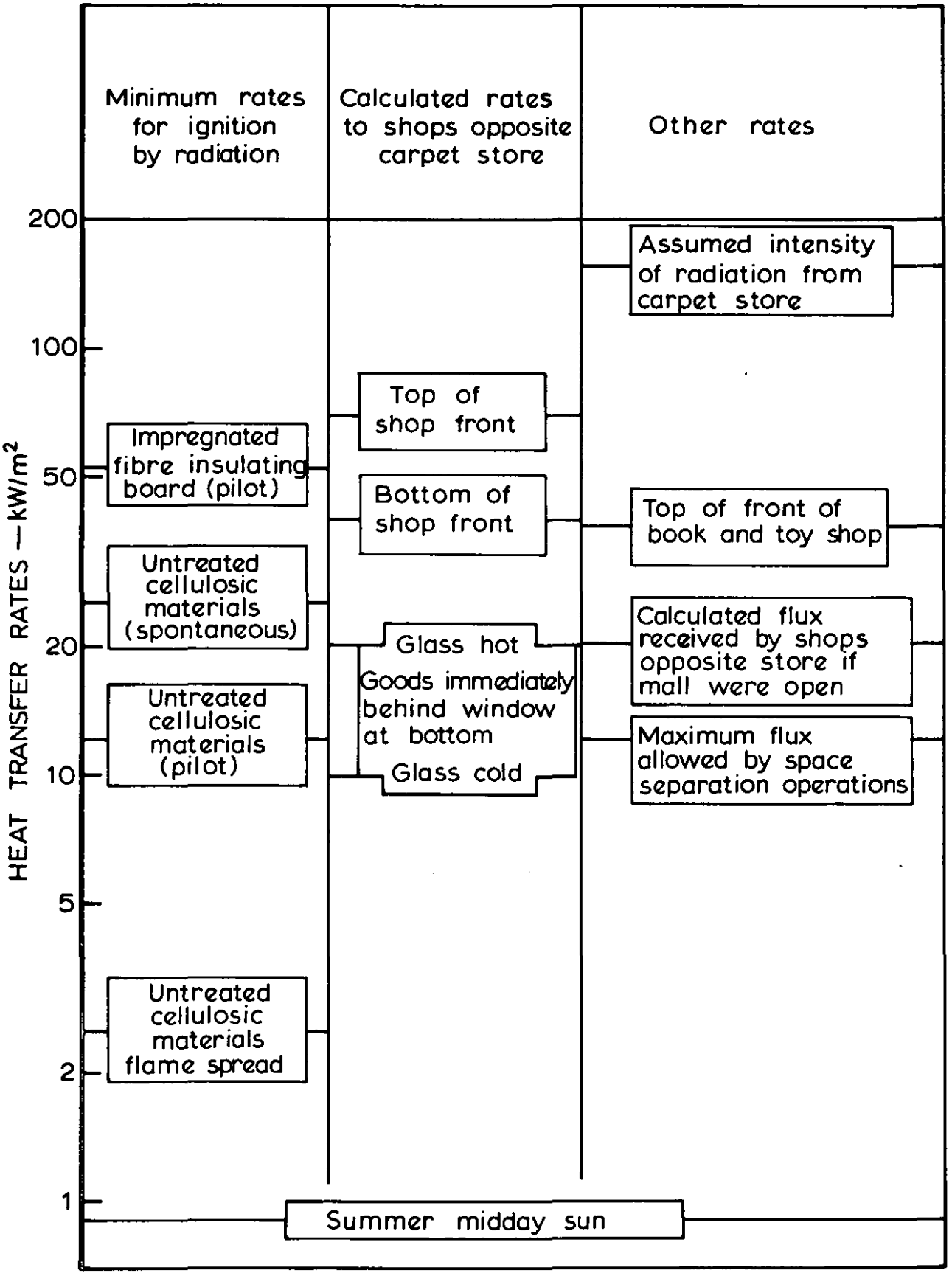


FIG. 5. COMPARISON OF HEAT TRANSFER RATES