Evacuating Schools on Fire

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ABSTRACT

Starting from the statement that time is the overruling factor in fire circumstances, this study dissects the egress operation in the
- physical domain : threats of untenable conditions and cut off exit ways.
- mathematical domain : users' velocity and egress flow rates as factors of the evacuation time; pre-calculation of the evacuation time in the building design stage; prediction of place and duration of traffic congestions : potential sources of panic; remedial measures in building outlay.
- psychological domain : importance of self-control and adaptation ability in the phases of discovering the fire, the shockmoment and decision-making reaction. There is a complaint about the nowadays poor character-building school education.
- practical domain : special school risks versus specific advantages expected to further smooth egress operations; evacuation strategy and tactics; the importance to inform and direct the evacuees (e.g. by megaphone) and to organize the evacuation in priority order according to local threats.

The paper considers the problems in special institutions attented by ambulatory and non-ambulatory impaired pupils. It motivates a drastic raise of night staff to pupils ratio and proposes a specific evacuation scheme, concentrated on the rescue of non-ambulatory users by accurate organization of thoroughly trained staff teams.

Key Words : ambulatory user; boarding school; congestion; design; discovery, escape routes, evacuation; fire drill; flow rate; human behaviour; layout; nervous stress; passage unit; personnel-pupils ratio; reaction; rescue; school; shock moment; special school; time; velocity.

1. INTRODUCTION

For a fire to break out and to extend, four accomplices need to agree : 1 - combustible matter; 2 - oxygen; 3 - an ignition source; 4 - time. But as soon as the fire has started, we have but a handful of seconds to act on the oxygen factor; we can try during a couple of minutes to quench the flames, and after the third minute we can only attempt to cope with the fourth factor : time. The overwhelming role of the time factor in a fire disaster appears from this formula, developed in Canada (ref. 1) :

$\frac{Tr + Ts}{Tc} \leq 1$, in which Tr = the time needed to discover a fire and to react; Ts = the time the occupants need to secure themselves; Tc = the time the fire needs to create untenable living conditions or to cut evacuation routes. If the result of this division is less than or equal to 1, safety conditions are fulfilled. Therefore the numerator value Tr + Ts should be kept as small as possible. There are no other controls over Tr than human advertence and detectors. Ts largely depends on the built environment, the characteristics of the escape routes, the users' presence of mind and capabilities. Tc is strongly influenced by the layout and construction of the building and by the oxygen supply.

In a school, apart from giving the alarm and calling the fire brigade, there is little that users, surprised by a fire, can do. But this little is of life importance. Hence, this trial to find the most appropriate egress conditions by identifying the factors that govern the extent of Ts and by analysing the evacuation episodes, with occasional hints to remedial design aspects.

2. THE FLIGHT TO SAFETY

The Ts action : flight to security, is a complicated mechanism ruled by the number of users, their physical conditions and moving velocity, the flow rate of exit ways, the horizontal and vertical distances to be covered.

2.1. Number of users : the connection is evident. But existing regulations, because their aim is to determine the stair width, neglect the number of ground floor users. Yet it is important that these should not obstruct the ground floor exits when the upper floors users already arrive. Direct ways out must be provided for the former, apart from a direct exit, at the bottom of each staircase, for the latter.

2.2. The physical condition, as a rule, does not cause any problem in schools, except for the kindergarten (which however is always ground floor located) and for the 0,3 % mentally normal but physically impaired, who should be helped by their fellow-pupils.

2.3. Velocity (V) varies according to horizontal (h) or vertical (v) traffic and, in the latter case, according to an upward (s) or downward (d) sense. The following normal average values resulted from measurings and checkings in schools (ref. 2) :
- horizontal velocity Vh : 90 m/min or 1,5 m/s
- vertical downward Vd : 132 stairs/min or 2,2 stairs/s
- vertical upward Vs : 108 stairs/min or 1,8 stairs/s.

2.4. Consequently, flow rates (D), expressed in number of persons (p) per passage unit (u) per second (s) also vary according to the same conditions.
- Horizontal rate Dh : Admitting the distance between two succeeding evacuees be 1 m, the flow rate is 1,5 p/u/s.
- Vertical downward rate Dd : The velocity is 2,2 stairs/s. Each moving evacuee occupies 2 stairs. Flow rate Dd attains 1,1 p/u/s.
- Vertical upward flow rate Ds : Likewise velocity Vs 1,8 stairs/s results in a flow rate Ds = 0,9 p/u/s.

2.5. Diagram 1 (ref. 3) compares the average horizontal and vertical flow rates D per u per s, visualized in points a, b, c, d (respectively 1 - 2 - 3 - 4 passage units). These differences in flow rates may cause congestions in the escape routes at each transition from a higher to a lower rate and this occurs to an extent of 1.5 - 1.1 = 0.4 p/u/s at transitions from Dh to Dd, and 1.5 - 0.9 = 0.6 p/u/s at transitions from Dh to Ds.

If we compare, in a horizontal vision, the positions of points Hc (horizontal flow rate in a 3-passage corridor) with Vdd (downward flow rate in a 4-passage staircase) and with Vse (upward flow rate in a 5-passage staircase), we notice

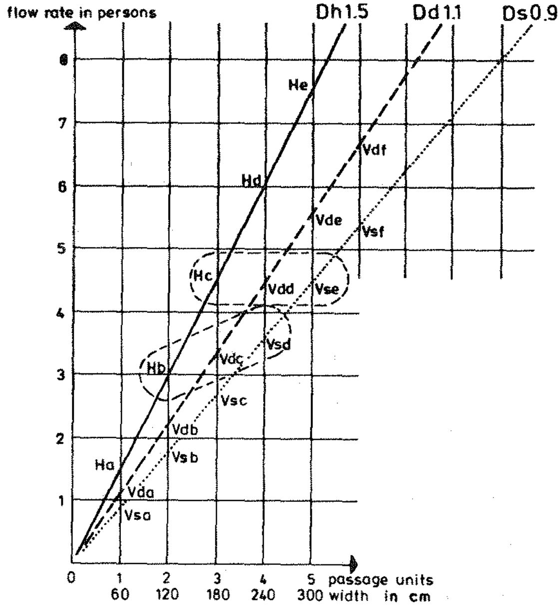


Diagram 1 : Normal evacuation flow rate D per passage unit per s

that these three segments attain an almost equal flow rate of 4.5 p/s. So, logically, to avoid <u>flow rate congestions</u>, we should build school staircases wider than corridors. This might shorten but not prevent another kind of traffic jam : the <u>cumulation congestion</u>, which occurs at the knot of a corridor with a staircase, when upstream users and those of the corridor level meet at the top of a downward stair-flight (fig. 2).

Obviously, cumulation congestions can only be neutralized by building staircases wider and wider as they draw near the exit level, imitating the river that extends as it absorbs its affluents. Starting from a different viewpoint, H.H. Kiehne (ref. 4) comes to a similar suggestion, logically unattackable, but, for economical reasons, not to be practised in schools. Still, it is during these inactive halts that panic is sneaking around among a crowd not familiar with the building (warehouses, hotels, restaurants..). But even in a school environment,

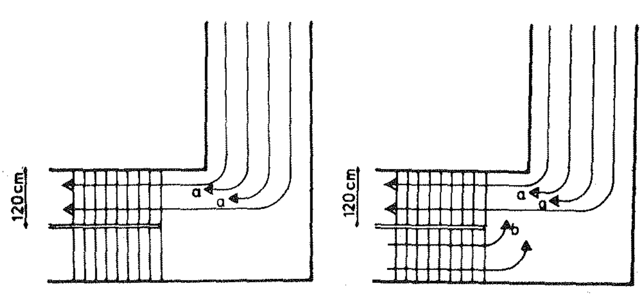


Fig. 2.1. : Flow rate congestion (a)
Fig. 2.2. : Cumulation congestion (b)

well known by its users, these stagnations might soon entail fear, degenerating into senseless behaviour.

Two positive actions can be taken :
- Since a relatively simple computing method (ref. 3) enables the architect not only to pre-calculate the evacuation time of the building under design, but also to predict place, time and duration of congestions, he can judge the need to add one, maybe two staircases to his project : precaution that will considerably shorten the traffic halts.
- During periodic fire-drills, pupils will experience and retain that congestions will occur where, when, for how long. The knowledge that these are inherent aspects of the lifesaving operation will lessen or even eliminate the psycho-physiological effects of these congestions.

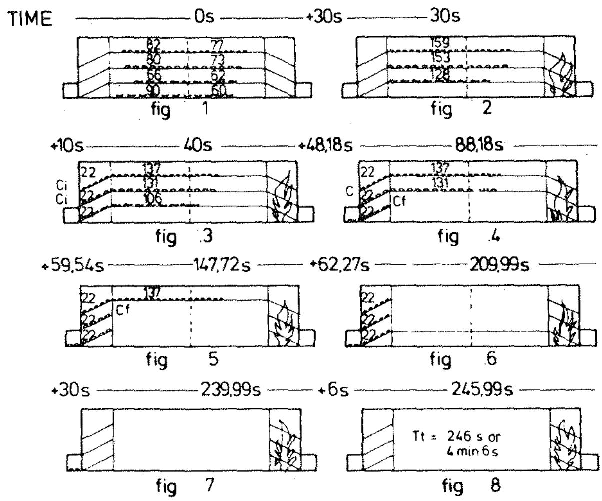
2.6. Design interferences : Some hints to designers emerge from §§ 2.1 to 2.5: - The every-day traffic routes are also the escape routes. - Avoid the need to build emergency stairs. - Divide the building, and even each compartment, into evacuation sectors, i.e. the areas to be discharged by each staircase and each outdoor exit. - Throughout the building, these sectors should be balanced in importance according to the prognosticated number of their users. - Avoid mixing stairway exits with those that discharge the groundfloor. This means that wherever possible, the staircase-bottom should have a doorway direct to open air. - All stairways are completely encaged and closed by walls and doors of 1 or 2 h fire resistance, according to the height. - The wider you plan the stairs, the fewer you have to provide, but the more you further cumbersome concentrations of evacuees, the fewer are the chances to spread the alernative exit ways. - So, whenever possible, use a stairwidth of 2 passage units with railings on both sides. Stairs of 3 passage units are dangerous, the central user having no rail protection. In case of 4 passage units, the stairs have two side and one central railings.

2.7. Evacuation Time : Figure 3 shows the evacuation scheme of a 4 levels school, divided into 2 fire compartments and occupied by 590 users (90 + 60; 66 + 62; 80 + 73; 82 + 77). There is a 1.20 m wide staircase (2 u) at each extremity. The ground floor has 4 issues, 1.80 m wide (3 x 4 = 12 u). One staircase is under untenable conditions. Basing on distances, on the respective V and D values, and proceeding by phases, the prediction computings result in the partial and complete evacuation times of
- 30 s for the ground floor - 88 s for the 1st floor - 148 s for the 2nd floor - 210 s for the 3rd floor - 246 s for the whole building. From the 40th second, the 2nd and 3rd floor students will be caught in a congestion that will last 48 s for the former and 108 s for the latter (respectively 40th s = Ci to 88th s = Cf; and 40th s to 148th s = Cf).

It should be noted that the same number of users, otherwise spread over the three upper floors, will experience congestion times that differ from the above scheme, for the duration always depends on the number of predecessors. But in spite of different congestion delays (and of their different total) the entire evacuation time being the sum of moves and stops, will be constant. The same phenomenon evidently occurs when the upper floors evacuation is operated in a different order. Anyway, a school should be evacuated within 5, a boarding school within 7 minutes.

3. HUMAN FACTOR

Yet, a school is not an hour glass, the grains of which obey to gravity. The matter that flies from a fire is made of muscles and nerves. The precedent schemes, impersonal and mathematic, should be confronted with a graph showing



Ci : start
Cf : end
of congestion

Figure 3 : Chrono-analytic evacuation scheme

the nervous tension evolution of people caught by a fire (ref. 5). This evolution covers 3 phases : a. discovery of the fire - b. shock moment - c. reaction.

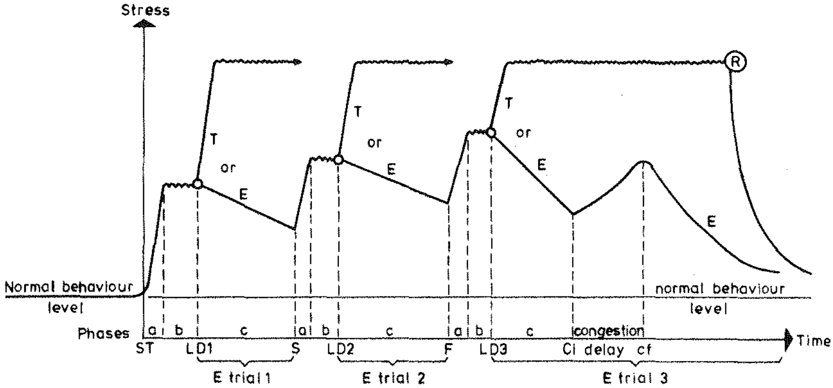
3.1. Discovery conditions (a) may widely vary, from effective presence on the spot, and consciousness, to sleep and being at some distance, recognizing physical signals or perceiving the alarm. But the common denominator of these conditions is : surprise. Quick adaptation abilities will be of utmost importance in the next moments.

3.2. Discovering a fire causes a psychological shock (b), rushing up a sudden stress to suspense that may preclude people from thinking logically. Physical perturbations and psychological troubles may occur and produce a gap of impotence wide enough to lose precious time.

3.3. Reaction conditions (c) are in reliance to one's preparedness for fire circumstances, to the degree of familiarity with the premises, to other people's presence, to physical smoke and heat conditions. Life danger may lame any initiative, but can also push people to extraordinary actions to save either themselves or others and to take outstanding risks.

3.4. Conditions may change as time proceeds or as occupants travel to the exit : they may be caught in poisonous gases (escape trial 1 in diagram 4) or stopped by flames or heat (trial 2) or be upheld in a congestion (trial 3). Such incidents entail new developments in the evolution, re-passing through stages a - b - c. If there seems to be no outcome any more, nervous stress rises to untenable suspense, capable of pushing individuals or groups to desperate acts. Selfpossessed characters will decide to wait for fire brigade rescue.

3.5. This analysis implies that behaviour in fire is determined by a large variety of diverging factors. As one fire differs from another, as different persons have opposite reactions to similar stimuli or similar reactions to different circumstances, the margin of overall correct action principles is narrow. No doubt correct reactions can only spring from a constructive attitude gained and trained by education. What really matters, is to persevere in such



Ci Congestion delay (start)
Cf Congestion delay (end)
E Escape
F Escape cut off by flames
LD Life danger
R Rescue by fire brigade
S Escape cut off by smoke
St Start of fire conditions
T Occupants trapped

Note : Much more complex situations may occur, but they will nevertheless be composed by the essential elements shown above.

Diagram 4 : Nervous stress on human behaviour in fires.

attitude throughout the three phases, keeping up self-control and command of mental forces in all circumstances : this is part of the character-building program of school education that should start at an early age but which nowadays seems to suffer from neglection.

4. PRACTICE

4.1. The above wanderings through physical, mathematic and psychological domains indicate that life in schools is not more dangerous than elsewhere. Still, some specific risks are permanent defiances, such as

- the dense occupancy (the densiest after theatres, movies and churches);
- the duration of occupancy (possibly up to 60 h/week, owing to evening use);
- the presence of a boiler house, collective kitchen, laboratories, workshops, extended energy-nets;
- the age and the behaviour of the young users.

However, the school population disposes of some trumps that could not concur elsewhere : the users know the premises; they are attended by educators who in case of need take initiatives to react (cf. phase c); knowing each other, the users shape a solid community; they are young and alert.

4.2. This offers a reliable safety base, on condition that positive attitude and efficient actions in case of calamity be carefully prepared according to the 3 phases : discovery, shock moment, reaction.

Phase a : discovery

1. Fire is signalled to the schoolhead. He calls the fire brigade and gives the alarm.

Phase b : shock moment

2. From the alarm signal onwards, the teacher's attitude is of utmost importance to the pupils' composure and reassurance.

Phase c : reaction

3. Stop all avocations. 4. Shut windows and doors. 5. Check corridor conditions on opaque smoke and excessive heat; if so, remain in room, keep door shut and fill gaps with moist paper or cloth. Wait for rescue by fire brigade. 6. If corridor conditions are tenable, leave room, shut doors, 7. Teacher and/or fellow pupils assist impaired pupil. 8. Each teacher takes the lead of his group but stays at the rear to command and control. 9. Get to the usual staircase. 10. If not practicable, turn to an other staircase. 11. Proceed crawling in smoky atmosphere. 12. Don't use lifts. 13. Do not overtake other fugitives. The group should stay homogeneous, as it left the room. 14. In case of congestion, close up as to shorten queues. 15. If no staircase is practicable, take refuge in the next fire compartment. 16. Teacher checks completeness of group.

4.3. These principles shape the essence of evacuation strategy. But in action, tactics must constantly adapt to circumstances in rapid evolution, near by or at a distance. Ignorance of somewhat remote developments may put people on the wrong way. Therefore, whenever possible, the evacuating users should receive information. Concentrated terms, in a calm voice (from a megaphone or a telecom system fed by an autonomous energy source) can save lives. Moreover the same procedure allows, from the start, to organize the evacuation in a priority order according to the urgence of threat : 1. the compartment and the floor where the fire started; 2. the floors above and 3. the floors beneath the fire.

5. SPECIAL SCHOOLS AND SPECIAL BOARDING SCHOOLS

Here, the problem must be reconsidered entirely. The deficiencies of the handicapped fall into the areas of perception, response and mobility and call for special precautions as to the design and construction of the building, the number and the qualification of educators, the rescue in case of fire.

These deficiencies take different forms which moreover may combine into complexes of mental or physical or both mental and physical impairment. A fire in such institutions threatens heterogeneous groups of pupils - with slow and confused perception, - some of whom do not understand what is going on, - who react in unpredictable ways, - who are subject to strong emotions, - and a number of whom are immobilized by handicaps.

This latter aspect takes a primordial importance, as in all deficiency categories (mental, emotional, functional, physical, sensorial) occur a number of children with mobility problems that prevent them from leaving, without help, a building on fire. Investigations revealed that this percentage may vary from 10 to 80 % (ref. 6) : the regular school evacuation procedure is out of the question.

5.1. Considering the variety of individual capacities, the specific egress pattern covers three phases (figure 5) :

- The ambulatory pupils (A) can be evacuated (E1) in a group by the educator to a safe place where they are guarded (G1).
- To comfort, to guard (G2) and to prepare the waiting non-ambulatory (N-A) pupils are combined actions that require one or several more staff members.
- Evacuation (E2) of the non-ambulatory (N-A) pupils must be done individually and successively. Once brought outdoors, these pupils must also be guarded (G3) and comforted. This may be combined with G1. Figure 5 represents the egress scheme for a group of 20 pupils (8A + 12 N-A); in phase E2 two staff members are operating : they each evacuate one N-A, in six repetitions.

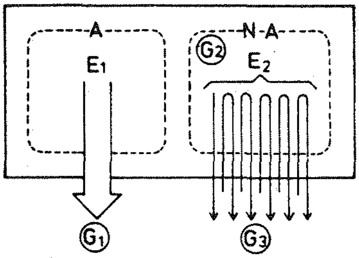


Figure 5 : Evacuation pattern for impaired pupils.

If only one educator were available, he should travel twelve times, during twice as much time, - assuming that there are no corpulent adolescents who need double help.

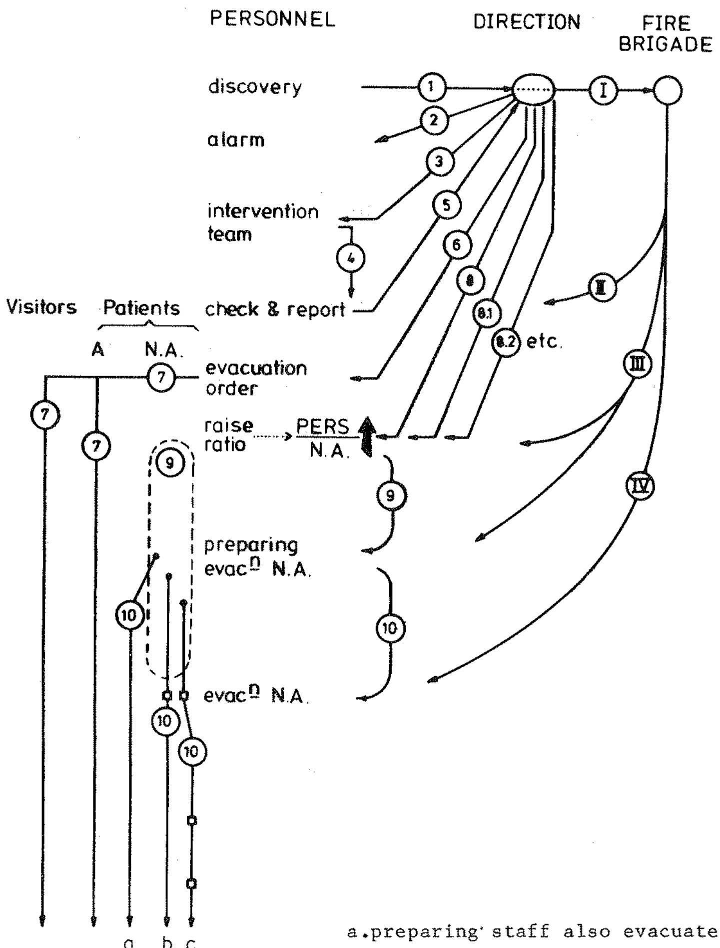
5.2. It is obvious that the egress time of N-A pupils is inversely proportional to the number of operating staff. In daytime, teachers, tutors, administrative, medical and social and service personnel (all having to take part in egress operations) compose an average personnel/pupils ratio of 1 to 4, which offers reasonable chances to perform an evacuation in due time. At night, conditions are substantially worse, as only the administrator and the night tutors are present, the latter in an average ratio of 1 to 17 pupils. In case of calamity, mutual assistance among tutors (cf. figure 5) is virtually excluded, since they should not leave the pupils entrusted to them. If outside assistance does not show up almost immediately, there will be victims. The tutors/pupils ratio should be raised to 1 to 10, plus an infant nurse (not group bound as the tutors are) per 30 pupils. This arrangement would result in a 1 to 7.5 ratio.

5.3. The correct evacuation proceeding is founded on four basic actions : 1) Next to the alarm issue and the fire-brigade warning, the maximum of available personnel is directed toward the rooms that hold the pupils most threatened by smoke or fire. 2) One or more teams of staff members bring groups of ambulatory users to a safe place, preferably outside, whilst 3) other teams prepare the non-ambulatory to be evacuated individually. 4) The actual N-A egress phase is operated by a third range of teams, either chainwise or in shuttle travels (users in wheelchairs, borne, transported on stretchers, dragged along on blankets, even rolled off in their mobile beds).

This model for handicapped children's evacuation corresponds, mutatis mutandis, to the egress scheme advised for hospitals and homes in a study done at the request of the LEUVEN University (ref. 7). Diagram 6 clearly shows that all action weight is concentrated on the supply of manpower capable of participating in the N-A pupils'rescue (Actions 8 - 8.1 - 8.2 - II - III - IV).

5.4. Where to start and which impaired pupils should be helped first are crucial questions. No doubt the immediate concern goes to the most threatened user, i.e. the one being in the most critical position owing to the proximity of fire, smoke, toxic gases. Once this pupil is ready for evacuation, there is a second most threatened, a third..., - priority being always determined by the most endangered spot (ref. 8).

5.5. Where to evacuate impaired users ? In any case : to a place of safety. The radical answer is : the outdoors. A. Tait's relevant statement on this matter is : "The ideal arrangement is the provision of escape routes so arranged that



a.preparing staff also evacuate N-A, or
b.egress teams evacuate N-A in shuttle travels, or
c.egress teams evacuate N-A chainwise.

Diagram 6 : Hospitals and Homes evacuation scheme (ref. 7)

any occupant in a building can turn his of her back on a fire and proceed to make their way without hindrance, in the direction of open air until safety is reached" (ref. 9). This radical evacuation model can only be performed by N-A occupants if they are located on the ground- or an other egress level and do not have to tackle steps and stair problems on their way out.

In the limited evacuation scheme, egress from endangered rooms provisionally does not go farther than the next compartment which is not (yet) threatened by flames of smoke, owing to the fire-resistive capacities of its walls, ceilings, floors and doors. Thus such a compartment is a provisional shelter for the occupants of a nearby endangered compartment.

One cannot make a preliminary choice between radical and limited egress.

Fire conditions, even in the same building, may well impose either of the schemes.

5.6. Limitation of risks in cases of extended smoke and flame spread, which require total evacuation, undoubtedly call for arrangements in time and space whereby the NA handicapped should be located, by day : on the egress level or on the floor immediately above; by night : on the egress level only (ref. 6 and 10).

5.7. Drills : Owing to the pupils' manifold shortcomings, fire-drills in special schools and boarding schools should more than anything else aim at preparing the personnel members to coordinate their exiting tasks and behaviour and to efficiently manage the egress.

6. CONCLUSION

As a conclusion, let architects, educational building officers, school directors and staff remember that in regular and even more in special schools, the succes of evacuating a building on fire is never measured after the number of rescued, but after the number of victims. And each time one is one too many.

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