PRE-SCHOOL AND SCHOOL CHILDREN BUILDING EVACUATION

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ABSTRACT

The parameters of evacuation of adults in various purpose buildings in normal and emergency conditions have been profoundly studied[1-5] over the last decades; the same applies to physically handicapped people[6-10]. However, only little data were published about the evacuation of children and adolescents from the buildings of their mass stay.

Within the framework of this paper, the survey of fires with mass children loss was presented, as well as the results of non-announced evacuations, questionnaire survey of fire sufferers and results of research of educational staff actions in fire cases. It was established, that the school and kindergarten personnel, who determine the evacuation success, is not prepared for fire action procedure, thus causing loss of children.

An experimental research of parameters of children and adolescents movement as a part of flow has shown, that the travel speed of horizontal movement and motion via aperture qualitatively corresponds to the adult movement patterns.

The motion of children aged 3-5 up and down the stairs is equally slow due to the step size designed for adults.

1. PREAMBLE

Researchers in many countries focused on the evacuation of healthy adults; however in the last decades, their focus shifted to the evacuation of persons with functional abnormalities[1-3]. The issues of children and adolescent evacuation were left without due regard. Thirty years ago, a study was carried out devoted to buildings designed for mass stay of children and adolescents[11-13]. Within the last years, several papers were published concerning the studies of children evacuation in fire cases[14-15].

The assessment of safe children and adolescent evacuation requires understanding of principle distinctions between an adult and a child.

In his/her behavior, an adult is guided predominantly by conscious motives: he/she realizes why he/she is going or has to act in this way and not otherwise. The adult's behavior motives constitute a certain system, depending on things which are more or less important to him/her. A child's behavior motives are not purposeful as a rule, and do not constitute a system based on significance measure. A characteristic feature of children's behavior (especially of preschool children) is acting without thinking, under the influence of momentarily occurring feelings and wishes. These wishes and feelings are first of all caused by an intermediate environment, and things catching its eye. Therefore, their behavior depends on outer circumstances[16-17]. It is especially evident when the evacuation procedure starting point is assessed – without the adults' activity, children tend to ignore signals of the warning system. This predetermines special requirements for the arrangement of children evacuation procedure.

Walking physiology differs significantly as well. The children aged 2 - 5 years are forming the scheme (psychophysiological model) of their own bodies. In this period, principal motor skills and habits are formed,

and the motor experience is accumulated. The children aged 3-4 still feature irregular pace and inadequate accuracy of moves, inobservance of indicated direction, side swinging, opening arms to keep balance, feet shuffling, walking with half-bent legs.

The children of 5-6 are characterized by improved coordination of movements; associated moves of arms and legs are enhanced for more than 70% of children, pace is getting more regular. By the age of 7, 100% of children feature associated moves of arms and legs, an increased length of pace at a reduced tempo, an increased velocity of walking for a long distance. Thus, the moves of children aged 7 and older differ only in terms of quantity, whereas the moves of younger children are evidently having distinctive features as compared to the moves of an adult.

The elaboration of an optimal strategy of life protection at fire cases is connected with studies of peculiarities of their behavior in emergency situation. The necessity of behavioral studies in fire cases is also predetermined by the fact, that means and ways of their safety could only then be successfully applied, when they consider organizational, psychological and physiological aspects of human actions in fire cases.

2. ORGANIZATIONAL PROBLEMS OF EVACUATION OF BUILDINGS WITH MASS STAY OF CHILDREN AND ADOLESCENTS

Unannounced evacuation

In order to determine a qualitative pattern of children and adolescent evacuation from buildings of their mass stay in 2005, an auannounced evacuation of two children's amateur art centers in Moscow City was undertaken. The peculiarity of these buildings is the presence of children and adolescents of all age groups from 3 to 17. In the course of experiments the behavior of personnel (by means of questioning), the moment of the evacuation starting point, and the parameters of a human flow movement by video means were studied and measured.

Brief characteristics of buildings and the results of experiments are specified in table 1.

Table 1. Characteristics of an educational building and the results of the experiment

Educational building	No. of floors	Dimensions in plan, m	No. of people	Availability of warning system	The maximum evacuation start delay, min	Total time of evacuation, min
Center of children's amateur arts 1 (CCAA 1)	2	30x60	70	available	4,20	4,75
Center of children's amateur arts 2 (CCAA 2)	3	30x70	220	unavailable	9,50	10,50

The results presented in table 1 show a higher total evacuation time for the CCAA 2 building. It is connected with the higher capacity of the building to a less extent, and to a larger extent – with the availability of the warning system. The fact is that the maximum distance from the remotest room with children does not exceed 150m, whereas the densities of human flows on evacuation paths nearly along the entire length never exceeded 1 person/m^2 (in separate cases these reached 2 persons/m^2), which enabled their motion with the minimum velocity of 1,25 -1,67 m/s. The reason is that the movement process itself did not contribute significantly to the total evacuation time.

At that, such a high rate of the evacuation starting point in CCAA is due to the following. According to the experiment scenario, a child having discovered the fire is running towards the exit, and notifies the security service officer at the exit of the building. After the receipt of the information about the fire, the officer evacuated the closest persons, and remained idle for 1.45 minutes, until the experiment organizers informed him about the fire and the necessity of warning people inside the building for the second time. Thereafter, the officer notified the director, who, in turn, started arranging the general evacuation of people

from the building. The delay of fire warning by the security service officer, as well as the necessity of notifying each room (due to the general warning system inoperability) played a significant role in the delay of the fire warning.

The data in table 1 demonstrate that 89.5% to 90.5% of this period make the evacuation start delay time. People spend this time to evaluate the situation, gather, and take decision of leaving the premises, and only about 10% of time is falling on proceeding from the place of people's stay to the exit.

The observed temporal characteristics of evacuation may cause the non-observance of the condition of a timely evacuation of people, which creates an obvious danger to life.

The data received in the course of non-announced studies are typical for the evacuation of buildings with children and adolescents. The table 2 specifies the data received by employees of State Fire Supervision in the course of an evacuation training at children's preschool institutions of various cities of the Russian Federation in 2007-2009.

Table 2. Time of kindergarten evacuation training

no.	no. of preschool children in educational institution	Place	Evacuation time, min
1	34	Balashikha City	8
2	90	Norilsk City	6
3	12	Alexeevka City	4
4	7	Kanash	5
5	"Alyonushka"	Shemursha village	5
6	"Teremok"	Town of Nazarovo	6
7	12	Yekaterinburg City	7
8	5	Town of Dolgoproodnyi	10
9	152	Penza City	3

Note 1. All buildings were equipped with an active warning system.
Note 2. Typical kindergarten constitutes a two-storied building with the maximum floor area 4000 m^2.

Questionnaire survey confirmed partially inadequate actions of the personnel. For example, it was established that 33.3% of pupils gathered without their instructor and 73.3% of pupils left the premises without the instructor's help. Thus, the conclusion was drawn that, in the course of evacuation, the pedagogical staff pays insufficient attention to arrangement of children evacuation, being unable to totally control the process.

The lack of the experience with the personnel in extreme situations (fire cases) is clearly confirmed by the remark of one of the instructors: *"If there were more children and if... not for the rumor that there will be evacuation training, as a matter of fact, I would stay idle."* We may conclude that the preparation level was not sufficient, as the same instructor declared in the questionnaire her repeated fire precautions training.

Pupil's pre-movement time

However, it could be assumed, that the time value at the evacuation starting point for a separate child would be small enough. To check the hypothesis, a series of additional tests was carried out. The analysis of video records of experimental evacuations and available operation information about the victims of fire, demonstrated that the children and adolescents evacuation procedure is determined by actions of personnel, that is why the time of the evacuation starting point was measured from the starting point of the evacuation arrangement by the instructor until the evacuation from the premises of the children's location. The measure of time till the evacuation from the premises contradicts the existing approach – until the movement starting point. However, within the premises with initial location of people, no distinct phase of children's movement

could be traced, since after the start of their motion heading for exit, children used to stop and wait for additional directions from the staff, and their movement itself started beyond the room.

In the cold season, the evacuation of children is practiced with blankets thrown upon and even full dressing to avoid the exposure to cold, at least in case of the evacuation training. Considering the foregoing, to quantitatively assess the time consumption, 3 evacuation scenarios were evaluated: In indoor clothing (Fig. 1a), with a blanket thrown upon the shoulders (Fig. 1b), and full dressing of warm clothing (Fig. 1c).

Figure 1. Options of evacuation of children in the cold season:
a) without winter clothing; b) with a blanket thrown upon; c) in winter clothing.

Results of the pre-movement time for various fire scenario are presented in the table 3

Table 3. Statistic values of the evacuation starting point depending on the evacuation method

Statistics		**Evacuation procedure starting point depending on the evacuation method, sec**		
		without winter clothing	**with blankets thrown upon**	**with winter clothing**
Mean		7,96	22,66	196,37
95% confidence interval for mean	lower limit	6,43	17,27	174,46
	upper limit	9,48	28,05	218,28
standard deviation		3,26	11,52	46,82
minimum		4,20	8,20	125,60
Maximum		18,20	48,20	269,70

As a result of the experiments, it was established that the starting point of the evacuation from the kindergarten premises in the optimum case (without clothing) makes 4.2 to 18.2 sec with the mean value of ca. 8 sec. A significant time consumption for evacuation preparation is based on the following. After the "Fire" vocal signal, children did not move from their places with no attempts of self-reliant evacuation from their room till the intervention of their educators (who took the children by the hand and helped them out). There are several explanations hereto. The principal reason lies in psychological peculiarities of children: a

specific brain area responsible for behavior, including taking reasonable decisions, develops in the age of 12 to 24 years. Besides, the fire safety training of children in such kind of buildings is not sufficient.

It bears mentioning, in case of erroneous decision of dressing children the time of evacuation start increases significantly – up to 4.5 minutes, which, in turn, depends on the number of educators in a group (there were two in the experiment).

In exceptional cases, the children evacuation scenario with blankets flung on is possible, since it enables avoiding exposure of children to cold with possibility of getting sick, requiring relatively insignificant time losses.

Questionnaire survey of the fire sufferers

The experiments were carried out in a pseudo-emergency situation, which is connected with objective difficulties of the arrangement of the forced evacuation of children and adolescents. Moreover, even the use of a smoke generator available for experimenters was prohibited by the management of education administration to exclude a stressful impact on children. However, we managed to carry out a questionnaire survey of children and staff as sufferers of fire in a secondary school.

The purposes of the said experiment were determined by the fact that the development of the best evacuation and rescue strategy is connected with the study of motives and human behaviour under fire conditions[18]. The survey was carried out one month later by interviewing 446 students of 4-10 grades and teachers in accordance with a specifically designed questionnaire, who were present in the school during the fire. The main attention was focused on detecting the awareness level regarding the school's fire protection system, fire warning method, similarities and differences in the evaluation of the situation and actions taken, the level of confidence in the decisions made independently. It should be noted that 15% of the respondents got their open skin areas burned, 4% got mechanical injuries, 2,7 % were slightly intoxicated.

The results of the questionnaire survey are provided in Table 4.

Table 4. Comparative results of teachers' and students' survey

Question	Students		Teachers	
	+	-	+	-
Awareness level of the school's fire protection system ("+" ware, "-" not aware,)	71	29	-	100
Fire warning method ("+" detected independently, "-" learned from the others)	38	62	46	54
Evaluation of situation and actions taken ("+" coincidence of decision and action, "-" divergence of decisions and actions)	33	67	100	-
Level of confidence in decisions made independently ("+" counted on support, "-" did not count on support)	18	82	23	77
Opinion of the level of building fire protection ("+" confident in fire security, "-" not confident in fire security)	42	58	7	93

A comparative assessment of the teachers' and students' replies to the question about the degree of awareness of the school's fire protection system proves that number of negative replies increases with the age of respondents. E.g. 28% of students of 4th and 5th grades gave negative answers (i.e. not aware of the

building's fire safety systems) while 100% of teachers had no idea of the fire safety system!

The replies of victims concerning a fire warning method allowed to establish whether the typical signs of fire were detected independently. In average more than half of students and teachers learned about the fire from others which proves inefficient work of the school's warning system.

The change of human response under extreme conditions of fire was evaluated on the basis of concurrence and divergence of the situation assessment and actions taken. The concurrence of decisions made with actions was regarded as a positive answer and divergence as a negative one. The majority of the respondent students (67%) showed divergence between decisions and actions which can be regarded as 'unadapted behaviour' and which proves the absence of fixated fire evacuation training skills. Interestingly, the decisions made by the teachers did not differ from the actions.

To identify the level of respondents' confidence in independently made decisions, the survey attempted to find out if respondents thought of or sought any external assistance (positive reply) or just relied on themselves (negative reply). It was established that a vast majority of the respondents relied upon themselves which may testify of insufficient training of the students' fire behaviour. The established fact is a solid argument testifying of inefficient fire behaviour training of the respondents.

As seen from the Table 5 in average 42% of students and just 7% of the staff were sure the building fully complies with fire security requirements and gave a positive answer to this question.

The work conducted helped to formulate the following conclusions.

1. Based on the survey findings and taking into account the reliability of answers it can be stated that the student training in fire behaviour wasn't satisfactorily organized. This is proved by the circumstance that 82% of respondents did not expect any external assistance and took self-rescuing actions.
2. The school fire warning system is not totally perfect: as a result, 42% of students learned about the fire from other persons and 38% noticed the attributes of fire themselves.
3. In average, 67% of students exhibited divergence of decisions with actions actually taken, which may signify the elements of panic in human response and absence of certain fire evacuation skills.

Thus, the issues of fire safety training appear to be very important. In order to improve the respective training one should assess what typical mistakes are made by teachers while organizing a fire evacuation. The answer to this question obtained by means of a dedicated fire behaviour data collection technique.

Researching staff action – computer video presentation

So, evacuation time of buildings with children and teenagers is rather long (up to 10 minutes), at the same time, almost 90% of the time is used to arrange the evacuation of children. It was decided experimentally evaluate the actions of staff members at the fire detection stage. For this purpose a computer-aided video-presentation (CVP)[19] was arranged. The reasons for its development, design principles and application algorithm are described e.g. in the work[20]. CVP still pictures are given in Figure 2.

The application of the said method allowed to establish that at the fire detection stage (fire outbreak or smoke) the first and the most common action is a fire warning. However, the people who discovered the fire tended to inform the management of the incident instead of activating the fire warning system and call the fire department, although it is a well-known fact that a 1-minute delay of fire notification leads to a ten-fold increase of the fire area. The intention to notify the management of the emergency is connected with behaviour patterns exercised under normal circumstances – all problems need to be reported to the management, thus, shifting the decision-making responsibility to other people.

Another widespread action will be the collection of additional information about the fire (this is more typical for smoke detection situations), request for help by security service and gathering of personal belongings. Nonetheless for 48.6% of staff the first step will be the evacuation of children.

Figure 2.
Computer-aided video presentation to evaluate the behaviour of the teaching staff during the fire.

1) A teacher conducts the lesson in drawing

2) The teacher with children comes out into the corridor

3) Teacher with children discover smoke or fire in the adjacent room

The staff activity analysis allowed to conclude that 66.9% of the staff have failed to perform the actions prescribed by the effective instructions. It was plainly seen that many respondents didn't have a clear viewpoint as is indicated by their behaviour and confound answers. Moreover, in some cases the respondents suggested rather unclear and inadequate actions. For instance, the participant #27 suggested in the event of fire detection 'that the children be brought down using the curtains'. The participant #21 suggested that children be used for warning purposes: send one to inform a doorkeeper, another from room to room which is a rather dangerous decision. Participant #31 proposed after having evacuated children into the open air 'to wet oneself with water, close the open parts of the body and attempt to get to the classroom' in order to save the valuables.

The research findings are supported by the analysis of the real fires, Table 5.

Table 5. Description of some fires with a mass life losses of children and teenagers.

№	Date. Fire location	Number of casualties	Number of injured
1	22.03.1998 School, Mombasa, Kenya	22	80
2	01.06.1999. Camp, Seoul, South Korea	23	3
3	26.03.2001 Boarding school, Machakos, Kenya	58	28
4	01.06.2001 Boarding school, Salemal, the Yamalo-Nenets Autonomous District, Russian Federation	7	-
5	05.06.2001 Boarding school, Nachan, China	13	-
6	12.03.2002 Boarding school, Mecca, Saudi Arabia	15	50
7	25.10.2002 Psychoneurologic boarding-school, Moscow, Russian Federation	6	6
8	07.04.2003 Secondary school, Sydybal, Russia	22	31
9	21.04.2003 School, Makhachkala, Republic of Dagestan, Russian Federation	30	Over 100
10	13.01.2005 School, Iran	16	-
11	18.12.2006 Day care facility, Moscow, Russian Federation	-	8
12	22.06.2007 Day care facility, Rostov-on-Don, Russian Federation	2	-

The cause of a children's fire-related mortality, mentioned in Table 5 was a complete or insufficient staff preparedness for actions in fire situation. For instance, during the fire in the Moscow Psychoneurologic Boarding-school (№7 Table 5) the children themselves fired the fire. During the fire in a boarding school of Mecca (№6 Table 5) the staff failed to timely open the doors of emergency fire escapes; during the fire in a boarding-school of Sydybal (№8 Table 5) unqualified actions of the staff caused the panic among the children, and that eventually led to the failure to organize people.

The official fire statistics in the Russian Federation shows that as many as 200386 fires took place in 2008 with 15165 persons reported dead including 584 children…

Nonetheless, fires in day care facilities and schools in exceptional cases lead to human fatalities. Usually, in emergency it is possible to organize the evacuation of people. The regularities of travel speed along the portions of evacuation routes are described in the following chapter.

3. TRAVEL PARAMETERS OF CHILDREN AND TEENAGERS

The research of rules of human flow travel in school buildings with regard to the age composition to establish an impact of travel regularities on the spatial arrangement of school buildings under normal conditions and development of recommendations for standardization of communication routes was made in the Russian Federation at the end of 1970s. Altogether 1618 measurements of human flow travel parameters were made in school buildings of 7 cities of the USSR[11-12].

The research data of human flow travel consisting of children and teenagers under normal conditions are given in Figs. 3, 4.

Figure.3.
Travel speed – density relation for pre-school and school children on horizontal plane

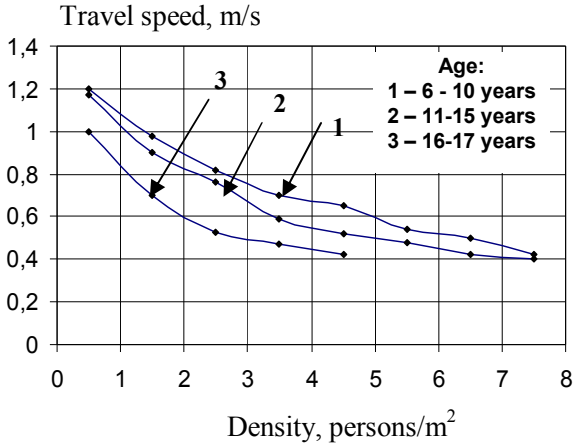
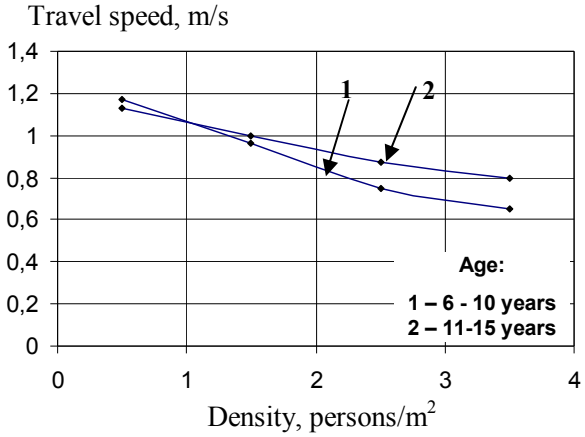


Figure 4.
Travel speed – density relation for pre-school and school children on stairs down



The described field observations were made under normal conditions of school building operation. The analysis of statistic sampling uniformity of primary and middle school-aged children travel has shown that they detect no influence of age composition and significant difference in travel speed in horizontal pathways and downstairs. It is natural to suggest that these features of school-aged children travel are connected with an age-specific physiology. However, it remains unclear how and what age-specific physiology rules are present and should be manifested in developing the travel speed relationship of school-aged children and determine their distinction from a similar relationship of adults' travel speed. To fully solve this issue the participation of psychologists and physiologists in the research of human flow travel relationships is needed. It appears, that a priori decision connected with a human flow travel, and for them it will be impossible; in any case, the special literature provides no specific answers to the emerging issues. The analysis of the experimental data has shown that human flow travel speed at schools follows the generally established psychophysiological rules[21] and described by the function:

$$\overline{V}^{E}_{Dj} = \overline{V}^{E}_{0j}\left(1 - a_j \ln\frac{D_j}{D_{0j}}\right) \qquad [1]$$

$\overline{V}^{E}_{D,j}$ - is the average travel speed of pedestrians in a flow, m/s;

$\overline{V}^{E}_{0,j}$ - is the average travel speed of pedestrians on a route without the influence of density, m/s;

a_J - is an empirical constant for each type of pathway;

Di - is the prevailing density of the flow, persons/m2 (or m2/m2);

Doj - is a threshold value of flow density on the j-the pathway, persons/m2 (or m2/m2 if pedestrians are measured based on their horizontal projection).

E - is an indicator of the emotional state of the pedestrian (the category of movement);

J - is an indicator of the type of route traversed;

So, according to the data of the statistical population of all the series of the conducted natural observations and experiments in the school buildings there was obtained an opportunity to define the concrete values of all the formula terms which describe the regularity of the connection between the parameters of a flow of children of primary and secondary school age during their motion moving under normal conditions for different types of the way according to the formula [1]. You can see them in the table 6.

Table 6. Values of coefficients a_j and $D_{0,j}$ according to the type of the way. Normal conditions. Primary (6-10 years) and secondary (11-15 years) age groups.

Type of the way	V_0, m/s	a_j	D_0, people/m^2
Horizontal in the buildings	1.08	0,295	0,465
Upwards staircase	1.08	0,295	0,465
Downwards staircase	0,85	0,305	0,534

It is unlikely to obtain similar data at the evacuation from the school buildings in case of emergency. It is possible to approximate them to a reliable ascertainment with specially organized experiments which are dangerous and difficult to implement with children. A more suitable way to conduct such experiments could be the involvement of a senior-aged group of schoolchildren. The world practice research study has not witnessed such experiments in school buildings. Nevertheless, it is known that unique experimental investigations of movement of the human flows were held under the conditions which simulate the emergency[22]. The primary group taking part in these experiments were the students of the fire high school aged 18 to 20, i.e. recent schoolchildren of the senior age group and even their peers. The movement rate of the human traffic of this composition will be described with the formula [1]. The values of the coefficients are indicated in the table 7. The results of the experiments are indicated in the diagrams at the Figure 5.

Table 7. The values of the coefficients a_j and $D_{0,j}$ depending on the type of the way. Emergency conditions. Senior age group (18-20 years).

Type of the way	V_0, m/s	a_j	D_0, people/m^2
Horizontal in the buildings	2,37	0,295	0,57
Opening	2,42	0,295	0,52

According to the results of the investigations some recommendations were elaborated to ensure a unimpeded human flow traffic as well as suggestions as to the regulation of parameters for communication routes in the school buildings with children aged from 6 to 17 years.

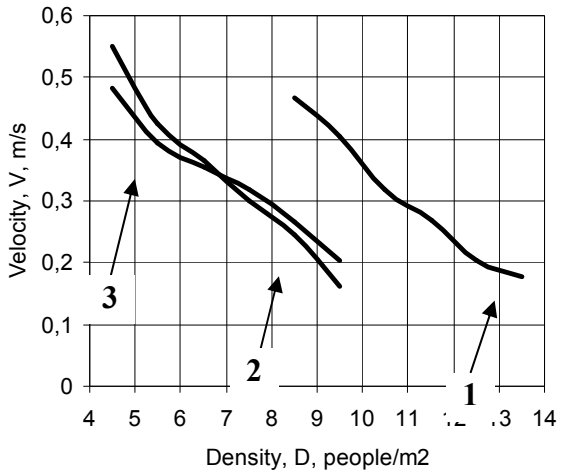
In 2008 – 2009 there were conducted some experiments aimed to study the movement of pre-school children 3 to 6 years old. The assessment of motion parameters of the human traffic was carried out using video recordings of human traffic flow with a pre-shot analysis grid sized 1m x 1m placed at a child's head height. Up to date there are 356 completed measurements of traffic flow parameters. It was established that the movement along the horizontal path in general is subject to previously identified consistent pattern[21] of motion for an "increased activity" category of movement.

Nevertheless, the experiments identified one specific characteristic of motion: travel speed on the staircase is almost twice as low as compared to a horizontal movement. Moreover, in the range of densities under consideration the travel speed up and down the stairs is similar.

There should also be mentioned the fact that the motion of children walking hand in hand up the stairs is 1.5 times higher than the velocity at the individual motion along the same type of the track. It is related to the small length of the footstep which extends gradually at walk as the child grows and depends on the height of children. The pace of a 2-year-old child equals to 32 cm, that of a 4-year-old – 40 cm, 5-year – 47 cm, 6-year – 49 cm, 7-year – 53 cm, while the length of an adult's footstep equals approximately to 65-75 cm. According to the national norms the width of the staircase tread run generally should not be less than 25 cm, and the stair height – not more than 22 cm, i.e. it corresponds to the average length of adult footstep.

Figure 5.

The results of the investigation of movement of young people aged 18-20 during the evacuation



1 – horizontal way; 2 – downward staircase; 3 – upward staircase

It is easy to define the length of the inclined trip between two stairs' steps (it equals approximately to the length of the footstep). Short footsteps make a child's body swing; a child tries to make careful footsteps on every stair's step which significantly slows down its velocity of motion. But if the child feels auxiliary support nearby (a hand of another participant of motion or a handrail), the motion becomes more confident and it increases the speed.

CONCLUSIONS

It could be considered proven: the reason of deaths of children and teenagers fire fatalities in the buildings with their mass stay is a poor staff fire training. It is confirmed by the analysis of the actual fires with massive losses of people, long (up to 10 min) general evacuation of children from the building, during which up to 90% of the time is lost on the evacuation organization with a relatively pre-movement time (7.96 sec. on average) of the students from the premises. At that, the majority of children are evacuated without the teacher's assistance. The reason for that is the non-fulfilment of the measures to be taken at fire as required by the legislation (up to 66.9% from the total number of the respondents).

With the purpose of regulating and calculating the process, the motion of children and teenagers that are the part of a flow and the results of the conducted investigations were analyzed. It was established that the motion of children aged 3 to 5 years, as well as, most obviously, of the primary age group, possesses an important characteristic feature which is a low speed of motion on the staircase and the growth of speed when it is possible to use the handrails or walk hand in hand. The established consistent patterns of motion of children and teenagers require that the construction solutions applied for the erection of staircase flights should be revised.

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