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AN ANALYSIS OF HUMAN FLOW COMPOSITION IN VARIOUS TYPES OF BUILDINGS

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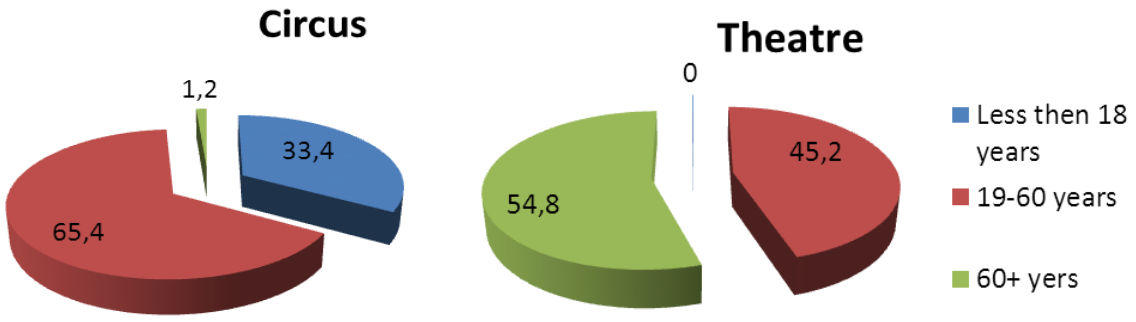
Abstract
Currently, many countries are using the just one relation between the travel speed and density of a human flow for various buildings (except special, i.e. hospitals etc). Application of average curve leads to the underestimation of the fire danger, as the speed of the most vulnerable people – children and elderly people, as a rule, slower. Examination of the composition of flows in the various buildings allowed to identify the typical types of flows in different buildings. 10 distinctive groups were identified based on observation data. For each of the groups the parameters of their movement were defined.

Keywords
Human flow composition, fundamental diagram, movement parameters, fire evacuation

INTRODUCTION

In the various buildings the composition of the human flow by sex and age is obviously different. It is established, that the movement speed of men and women is slightly different; however, the greatest impact on the speed and movement kinetics provides an age. Analysis of the flow composition by age showed, that even in similar urban objects, e.g. in a public performance buildings, the composition of human flow will be, according to field observations as follows: for a circus - 33.4 % of children and adolescents, 65.4% of people of working age and 1.2 % of older people (over 60 years). For a theatre - 0,0/45,2/54,8 % respectively, Figure 1. The composition of human flows in other buildings even more different. However, currently the building codes of many countries apply just one “fundamental diagram” considering density impact on travel speed for particular route type for all types of buildings. There may be only the exception for buildings, designed for disabled people. This approach tends to underestimate the time of evacuation and consequently the fire hazard.

Figure 1. The composition of the flow of people by their age in the same class of buildings



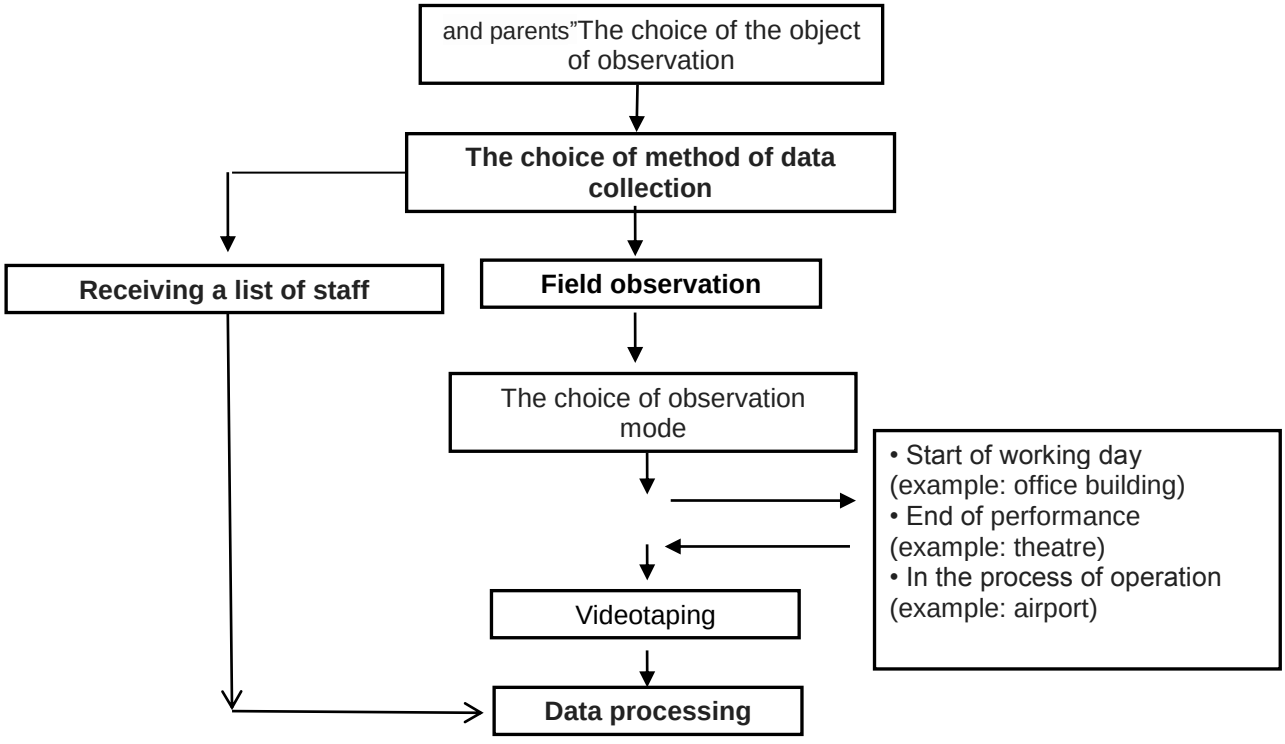
The obtained results (Fig. 1) show that the composition of the flow in the considered buildings is significantly different by age: the circus it is noted the prevalence of children and adolescents (over 30 %), and in the theater – older people (over 50 %) that has a significant impact on the values of the parameters of the flow of people [1-5], and as a result, the evacuation time and the magnitude of fire risk. Calculation showed that depending on the composition of the flux and speed of the movement of people of different groups an evacuation time can vary in the range of up to 20 %. In a study [6] was obtained dependence the average flow speed from the number of older pedestrians (going low speed): with the increase in the number of average flow velocity is significantly reduced.

Thus, to date, there is an urgent need to identify the characteristic groups of the composition of the flow of people in buildings for various purposes and to study the parameters that characterize the features of their movement [7].

THE METHODOLOGY OF THE EXPERIMENT

To assess the composition of the flow a set of studies have been conducted to identify an age distribution of people attending these or other objects of urban development activities. The empirical data collection consisted of a fixed data of human flows in various buildings were collect by the following technique, Figure 2. An example of processing of video with the aim of analyzing the composition of human flow is shown in Fig. 3.

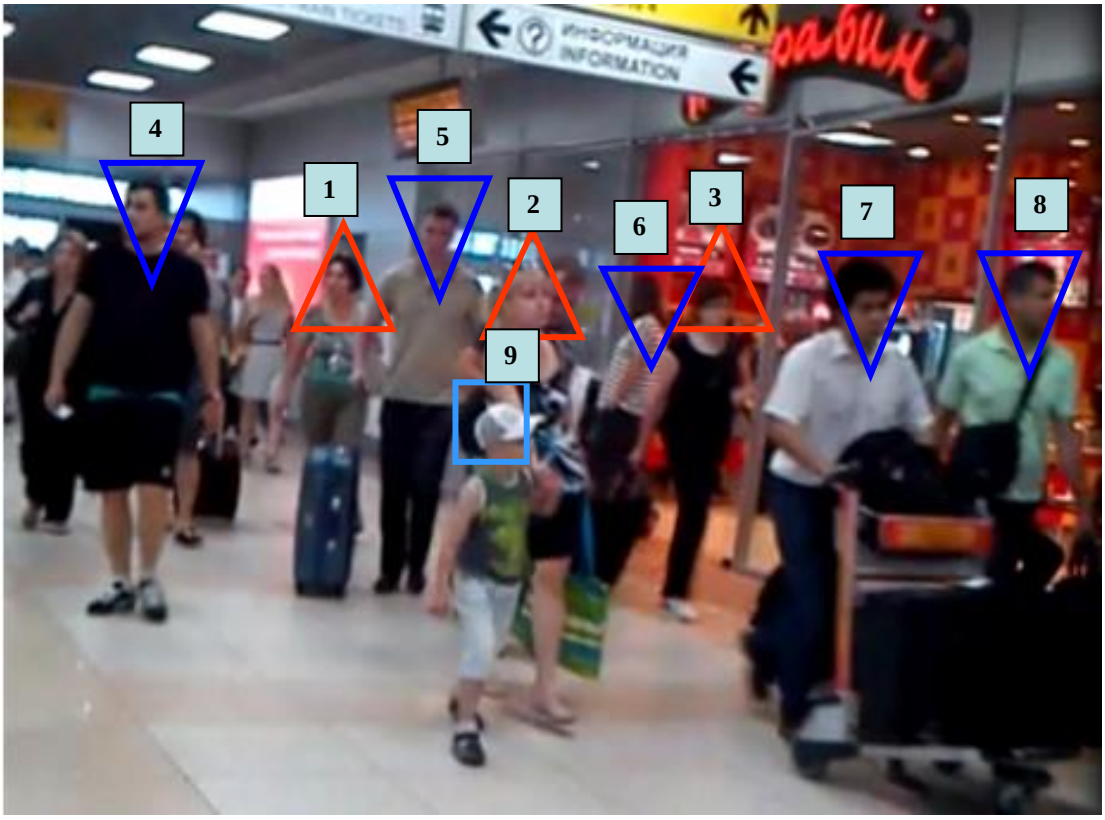
Figure 2. The block diagram of the data collection methodology



It should be emphasized that, of course, almost in any type of buildings, the composition of the flow might significantly vary. For example, in the summer, secondary school could be accommodated by seasonal workers, at the morning session of the cinema on weekends and vacation days will increase substantially the number of children and adolescents, in working hours of weekdays at the retail stores will increase the number of elderly people and so on. Therefore, in the framework of

this work the most typical people were considered as the target group. Usually the adjustment of observational data were obtained based on 3 similar buildings. Observations covered 28930 people in buildings of all classes of functional fire hazard.

Fig. 3. An example of a study of the composition of the flow of people in an airport:
△ – females; ▽ – males; □ – children;
1-9 – identification numbers of people involved in the surveillance area



AN IDENTIFICATION OF THE TYPICAL GROUPS OF THE FLOW OF HETEROGENEOUS COMPOSITION

The criterion for sampling was homogeneity test. A standard technique to check the homogeneity of two (or more) independent random samples is the goodness-of-fit-test. The most common in this case are the Kolmogorov – Smirnov and χ2-Pearson criterion. The first applies only for continuous random variables, whereas the second applies in the discrete case and continuous (by sampling continuous random variables). Data on the composition of the flow of people by age are discrete: for example, age group of person "under 2 years", "with 2 to 6 years", etc. Important feature of the χ2-Pearson criterion is the ability to analyze any number of samples, therefore, for the considered problem it is more preferable [8]. Based on the analysis it has been allocated 4 typical group of flow of heterogeneous composition.

Group 1 is characterized by the presence in its composition people of all age groups, except very young and very old people; code name "Active family" (example: airport, shopping mall);

Group 2 – is characterized by the presence in its composition a large number (over 30 %) of children, adolescents and their parents, most are of working age; the code name "Children and parents" (example: circus, theatre for children);
Group 3 is characterized by the absence of children in its composition, and consists of people of working age and retirees; the code name "Employees and retirees" (example: evening performances in the theatres, public service i.e. bank);
Group 4 is characterized by the composed of people of all age groups; the code name "All age groups" (example: apartment dwellings);

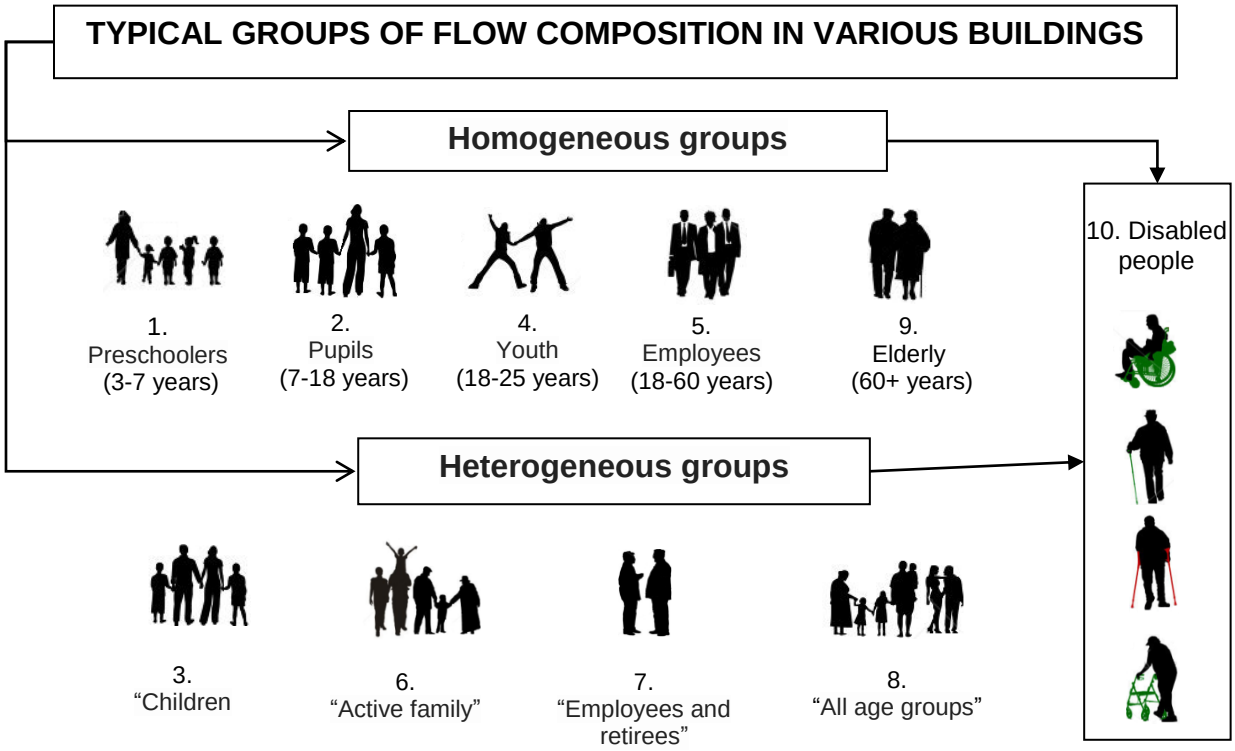
The estimated composition of the flow of these groups are presented in Table 1 and in Figure 4.

Table 1. The estimated composition of the groups of the flow of heterogeneous composition

Name of the group	The percentage in a human flow					
	Children		People of working age		Retirees	
	6 yeas and less	7–17 years	18–25 years	26–59 years	60–74 years	Over 75 years
Children and parents	7,61	26,76	11,55	54,08	0	0
Active family	3,89	4,48	7,30	71,65	9,74	2,95
Employees and retirees	0	0	1,08	44,09	52,31	2,53
All age groups	9,25	11,66	12,35	48,37	10,20	8,17

Taking into account the group of the flow of homogeneous composition ("Preschoolers", "Pupils", "Youth", "Employees", "Elderly" and "Handicapped"), and additionally revealed during this analysis four groups of heterogeneous flows (table 1), in total we've got of 10 different groups of composition of the flow in total, Figure 4. The analysis allows to solve the important problem of differentiation of buildings depending on the flow of evacuees composition. The next issue is to define parameters of movement of groups of heterogeneous flows.

Figure 4. Main design groups of flow composition in various types of buildings



THE RELATIONS BETWEEN PARAMETERS OF FLOWS OF DIFFERENT COMPOSITION

Since 1983 in Russia has been applied the following relation between the speed and density of a human flow [9,10]:

$$V = V_0\left(1 - a\ln\frac{D}{D_0}\right) \quad (1)$$

where V is the speed of human flow movement depending of flow density; V_0 is the speed of free movement (in the absence of the influence of other people: $D < D_0$), depending also on the level of the emotional state of people; D – is the flow density; D_0 is the threshold density beyond which the density becomes a factor influencing the speed of the people flow; **a** – coefficient.

Then, to describe the parameters of traffic flows of different composition is necessary to define the average velocity of their free movement V_0, the coefficient **a** and the threshold density D_0. An average free movement speed is determined depending on a speed of movement of people of a particular age considering their number in a general flow.

In terms of psycho-physical science of the coefficient **a** determines the intensity of perception of stimulus (crowd density) on the sensor system of the person. Indeed, the higher values of **a**, the sharper the density affects the speed, the faster it decreases. In this regard, for groups of mixed composition ratio was taken as the relevant to age group most widely represented in the flow considered here, because high values of **a** lead to more "acute" reactions to density and slower travel speed.

A very important issue in psychophysics is the study of thresholds of sensitivity. A sensitivity is the magnitude of the stimulus, in which appears barely perceptible (minimal) sense. In the theory of human flows this threshold is the value of density D_0, which causes a moving pedestrian the need to

reduce speed. Thus, the value of the threshold density D_0 was taken to be the minimum of the values for the age groups, forming a human flow, as in this case, the speed of the movement would be lower.

The joint influence of increase **a** and decreased D_0 will result in speed reduction. This allows to achieve the most "tough" characterizing the process of evacuation for the calculation of fire risks.

To build computational relations for the heterogeneous flows the movement parameters of the appropriate age groups was selected according to [1-5, 9-14] for the category of movement "Of increased activity" [10].

The results of the build dependencies that characterize the mass movement of different groups of the flow are given in Table 2, and their graphical interpretation are given on Figures 5-7. It should be emphasized that, despite the proximity of the calculated values for groups of 2-7 and 5-6, the kinematics of their movement, determined by the values of flow density, presence of children and the elderly, movement in the composition of the family and social groups, they have its own characteristics.

Table 2. The calculated relationships between the parameters of the flow

Group number	Parameters values	Route type			
		Horizontal	Door	Stairs down	Stairs up
1	$V_0/a/D_0$	60,0/0,275/0,78	60,0/0,350/1,20	47,0/0,190/0,64	47,0/0,275/0,76
2	$V_0/a/D_0$	92,6/0,284/0,75	92,6/0,350/1,20	92,4/0,338/0,94	65,9/0,289/0,84
3	$V_0/a/D_0$	97,3/0,428/0,51	97,3/0,456/0,533	97,4/0,433/0,64	62,5/0,338/0,56
4	$V_0/a/D_0$	120/0,308/0,723	120/0,308/0,533	129/0,353/0,583	76,8/0,305/0,67
5	$V_0/a/D_0$	100,0/0,295/0,51	100,0/0,295/0,65	100,0/0,40/0,89	60,0/0,305/0,67
6	$V_0/a/D_0$	92,0/0,425/0,51	92,35/0,253/0,533	90,6/0,367/0,64	58,8/0,414/0,56
7	$V_0/a/D_0$	69,6/0,428/0,51	69,6/0,456/0,533	61,7/0,5033/0,64	53,9/0,414/0,56
8	$V_0/a/D_0$	86,2/0,428/0,51	86,3/0,456/0,533	81,4/0,503/0,64	57,3/0,414/0,56
9	$V_0/a/D_0$	35,0/0,428/0,96	30,0/0,456/1,02	25,0/0,433/0,93	25,0/0,338/0,56

Note. People with limited mobility (group No. 10) are divided into additional groups depending on their age and kind of body dysfunction and are discussed in this paper.

The proposed model has such required properties as universality, that is, it can be applicable for the flow of any composition. The input parameters are only the distribution of people by age. This is especially true today with the increase in life duration and different distribution of people by age in different countries.

Fig. 5. The calculated relationships between travel speed and flow density for different groups of flow composition when moving along the horizontal path

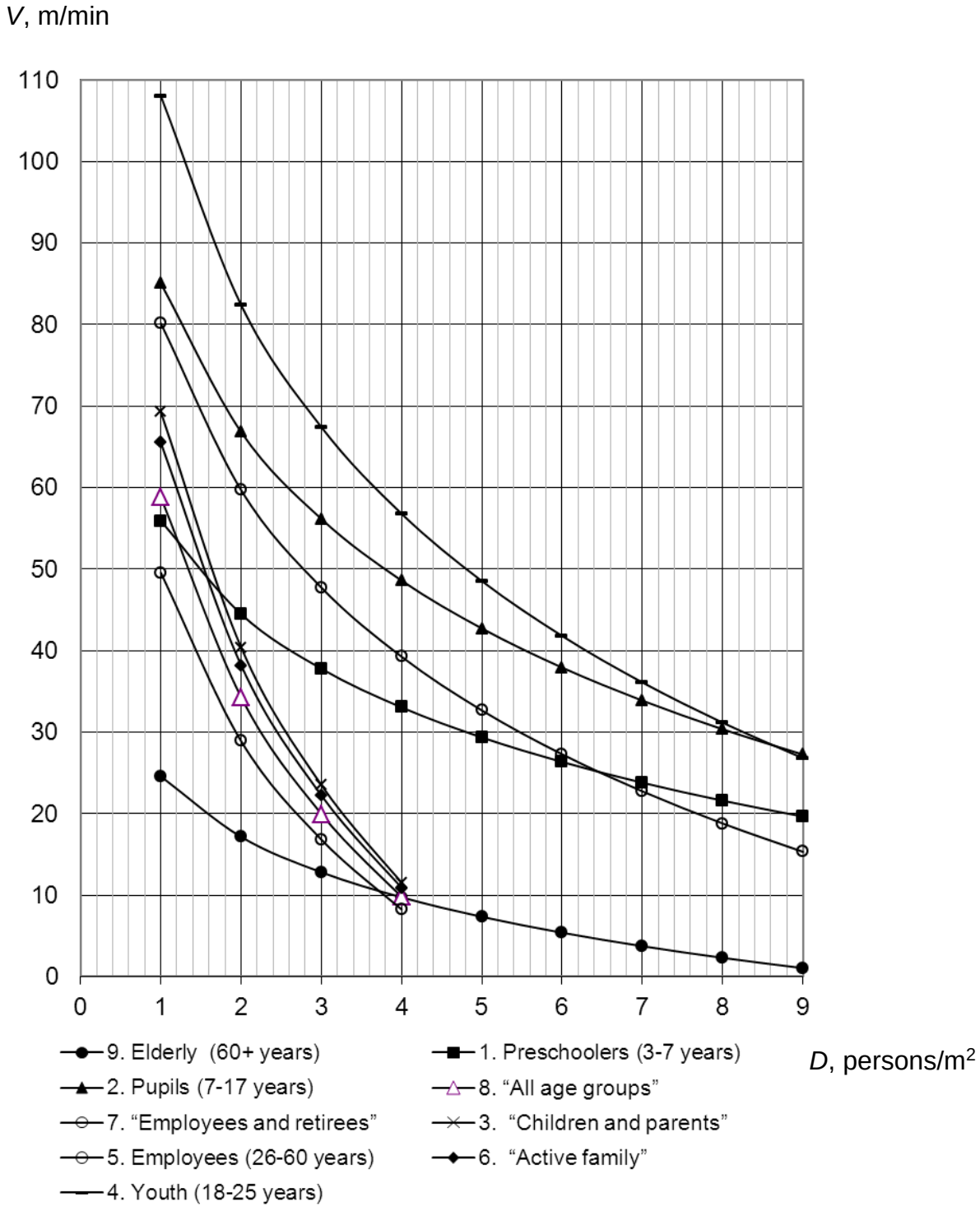


Fig. 6. The calculated relationships between travel speed and flow density for different groups of flow composition when moving down the stairs

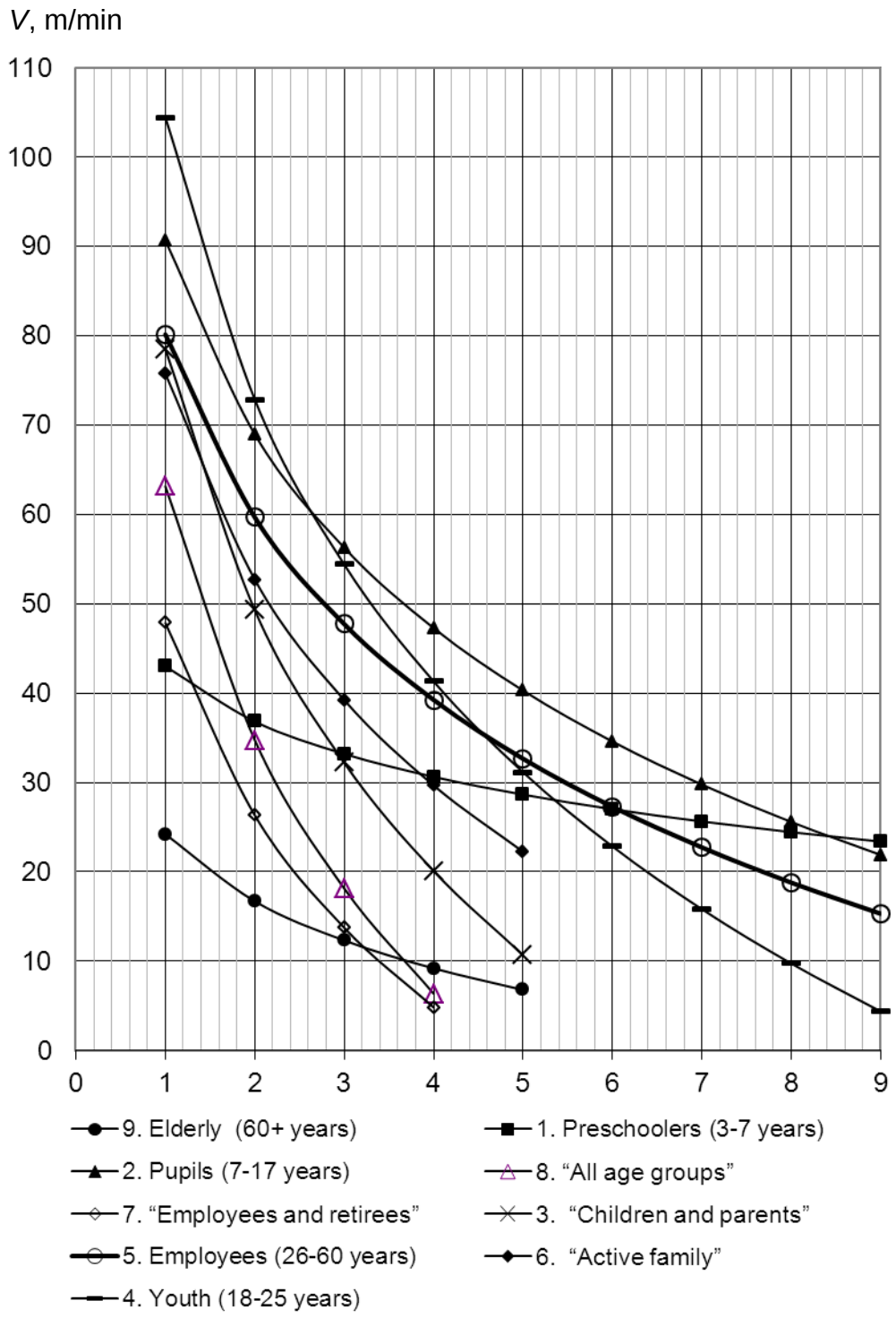
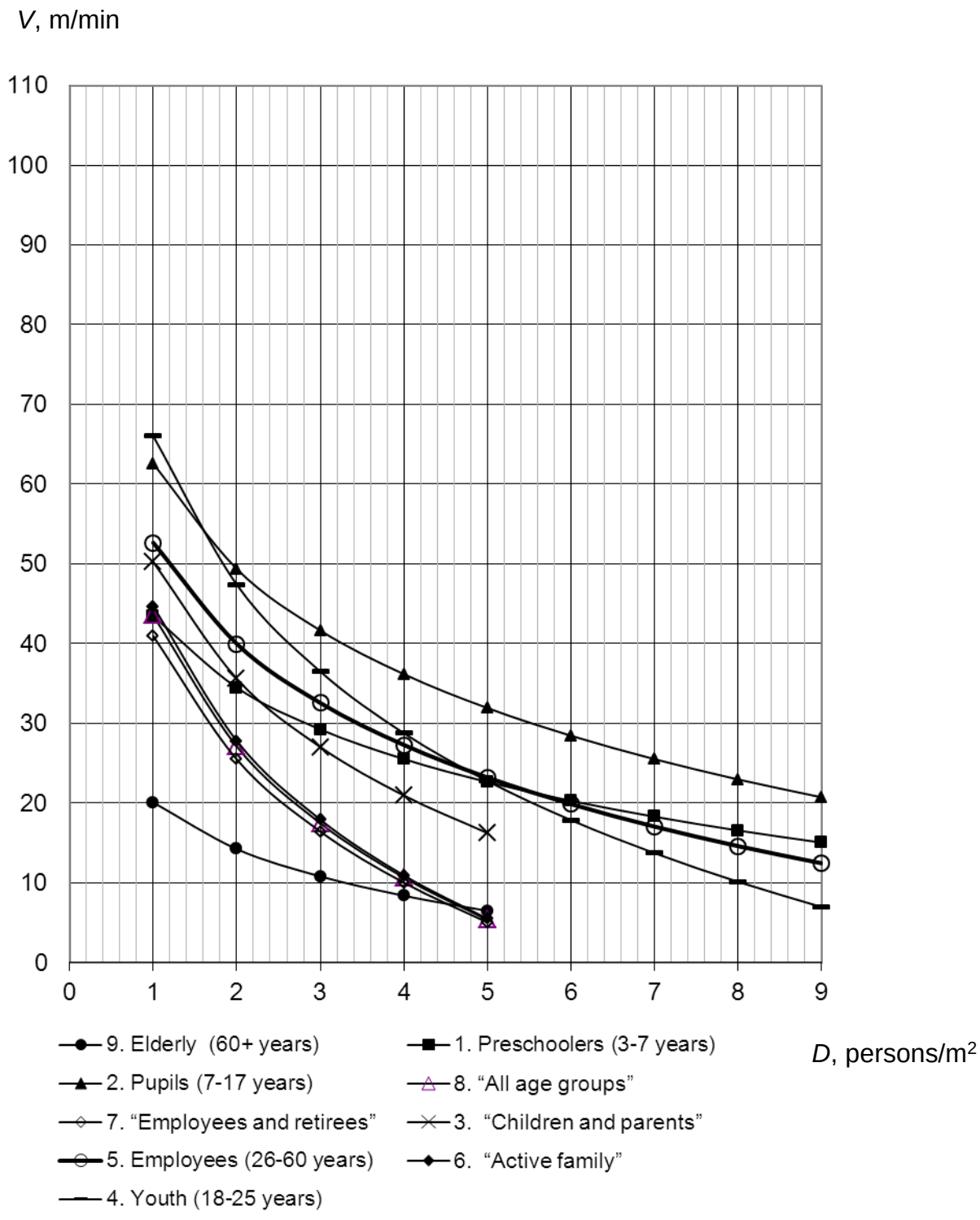


Fig. 7. The calculated relationships between travel speed and flow density for different groups of flow composition when moving up the stairs



CONCLUSIONS

Based on the data of field observations and its further mathematical analysis the typical groups of homogeneous ("Preschoolers", "Pupils", "Youth", "Employees", "Elderly" and "Handicapped") and heterogeneous ("Children and parents", the "Active family", "Employees and retirees", "All age groups") types of flows were revealed. Based on the theory of human flows the parameters of flows movement of designated groups were determined. Correlation of building type and corresponding group of flow allows to improve the accuracy of calculations [15] of the process of evacuation of people from buildings in case of fire.

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