An Experimental Data-Set on Pre-school Children Evacuation

Article *in* Fire Technology · January 2017

DOI: 10.1007/s10694-016-0643-x

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This paper has been published as: Najmanova H, Ronchi E (2017). An experimental data-set on pre-school children evacuation. Fire Technology. Doi: 10.1007/s10694-016-0643-x

AN EXPERIMENTAL DATA-SET ON PRE-SCHOOL CHILDREN EVACUATION

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Abstract

This study presents an experimental data-set describing movement and behaviours of pre-school children. Data is presented together with detailed information about the evacuation procedure and the data collection methods, in order to enable a comprehensive interpretation of the results and to enhance the understanding of pre-school children evacuation. Data was collected during two semi-announced evacuation drills conducted in the same pre-school institution in Prague, Czech Republic, in 2013. The experiments involved a total of 188 children aged from 3 to 6 years; two age groups of children are distinguished: Junior children (aged 3-4 years) and Senior children (aged 5-6 years). The presented data-set consists of travel speeds on horizontal and vertical escape routes (stairs), pre-evacuation times, and total evacuation times. The travel speeds of Junior children on a horizontal plane ranged from 0.69 m/s to 1.33 m/s. Higher speeds of Junior children were observed on an internal straight staircase (mean 0.57 m/s) than on an external straight staircase (mean 0.34 m/s). For Senior children, a mean travel speed equal to 0.56 m/s was found on external spiral staircases. Good agreement is observed between the observed travel speeds and the results reported in the literature. This corroborates that the main variables impacting the movement and the self-rescue abilities of children are age and the configuration of the escape route. The observed pre-evacuation times were longer in classrooms with Junior children (mean value 46 s) than in classrooms with Senior children (mean value 20 s). The total evacuation times ranged from 81 s to 186 s, depending on the location of the classroom and the evacuation route.

Keywords: Fire Safety; Evacuation; Children; Pre-school; Drill; Data-set

Highlights

- Empirical data from two evacuation drills involving children from 3 to 6 years is presented
- Travel speeds, pre-evacuation time, and total evacuation time are presented
- The data-set is compared with existing comparable literature
- Considerations affecting the self-rescue abilities of pre-school children are discussed

1. INTRODUCTION

In the context of fire safety engineering, particular attention has been paid to potential "at-risk" populations, e.g. to people with physical and mental impairments, elderly people and other vulnerable groups, who might not be able to perform self-rescue activities and who will need assistance in evacuating [1]–[4]. In the last decade, there has been increasing scientific interest in describing the movement abilities and the evacuation performance of children [5]–[14]. However, to date, the level of understanding of children evacuation dynamics is still relatively limited [6].

When discussing children's evacuation, there is a fundamental need to make a clear distinction across different age groups of children, as the walking patterns of young children may differ not only from those of adults, but also from those of older children. The growing and developing processes of children change significantly during various stages from birth to adulthood. In general, childhood extends from the end of infancy to the start of adolescence; there are two stages in childhood - early childhood (including pre-school years) and middle childhood (including the elementary school years) [15]. In early childhood, the basic locomotor, stability, manipulative, and cognitive skills are still developing, and are conditional on physical and psychological changes based on central processes of growth, maturation, and behavioural development [16], [17]. Until approximately 4 years of age, walking parameters such as cadence, speed, and step length are controlled by the maturation process, while the continuing changes after 5 years of age are more attributed to body height and limb length [18]. Generally, the movement patterns underlying the basic motor skills are reasonably well developed in most children by 6 or 7 years of age [15]. These findings indicate that the movement abilities of children of pre-school age differ considerably from their movement abilities in later phases of their lives, and must be taken into consideration when children's safety evacuation is evaluated.

This paper presents an experimental data-set derived from two evacuation drills involving children ranging in age from 3 to 6 years conducted in a pre-school educational institution in Prague, Czech Republic, in 2013. The purpose of this study is to introduce new detailed data that takes into account specific movement parameters of pre-school children. The data thereby helps to extend and expand our limited knowledge and understanding with a view to protecting this vulnerable part of the population. The main contribution of this work is to provide an empirical data-set with the full context of the evacuation procedures that were performed together with a data collection and evaluation method that enables a comprehensive interpretation of the results. The presented results can therefore serve as inputs for fire safety design and egress modelling [19]. Since the physical abilities and the evacuation behaviour of children may be impacted by variations in human growth and by differences in social background across countries and cultures [20]–[22], the context of the data-set can be extended to take into account a particular cultural environment.

Adopting this approach, the presented data-set is accompanied by a detailed description of the population, the evacuation procedure and strategies, the geometry of the escape routes, exit selection, and other assumptions made in the subsequent data analysis. The main variables of interest in this study are the total evacuation times (also called arrival times [13]), the pre-evacuation times, and the travel speeds on horizontal and vertical escape routes. These are the most widely used variables for evacuation prediction in fire safety design. In order to reflect specific evacuation procedures in pre-school facilities, special attention is paid to describing and evaluating children's travel speed, where a distinction is made between the speed of continuous movement (also known as the movement speed) and the speed on particular parts of escape routes, including various stops (also known as the modelling speed [23]). The data-set presented here can be used as an input in fire safety design, e.g. hand calculation methods and egress modelling, which is increasingly becoming a tool for performance-based evacuation analyses. A comprehensive description of the results will therefore help to prevent misuse of the results in subsequent engineering applications. In addition, this paper provides an enhanced insight into the evacuation of pre-school children, outlines the main parameters influencing the evacuation process for pre-school children, and compares the data-set that has been obtained with a summary of corresponding data available in the literature.

The aims of this work can be summarised as (a) present a new detailed data-set describing the performance of pre-school children during evacuation drills, which is needed as crucial input into fire safety design, (b) provide a detailed description of the data collection methods, in order to make the presented results easier to interpret and contribute to the relevant use of the data-set, (c) compare the data-set with the results of previous studies, (d) determine the conditions that most significantly affect the process of evacuating pre-school children, and enhance understanding of children's evacuation process, taking into consideration specific evacuation procedures in pre-school facilities.

The remainder of this paper is organised in the following way. In Section 2, a review of available research studies dealing with evacuation of pre-school children is presented, and an overview of data-sets focusing on the travel speeds of pre-school children is summarized. Section 3 provides a detailed description of data collection methods, including the enclosure, a description of the population and the evacuation procedure. Section 4 presents the data-set describing the movement of pre-school children during evacuation drills (pre-evacuation times, total evacuation times, and travel speeds on horizontal and vertical escape routes). Section 5 offers a qualitative discussion of the results, and compares them with available results from previous research studies. The conclusions of the study are presented in Section 6.

2. LITERATURE REVIEW

Only a small number of studies have addressed the evacuation of pre-school children. The self-preservation capacity in pre-school children was studied by Tatuic and Dederichs [24], who carried out an international questionnaire survey among teachers in day-care centres and experts in child development. The lower age-limit for pre-school children to be capable of understanding and following simple instructions was stated to be between 2.5 – 3 years of age. Another study at the Technical University in Denmark investigated variables concerning the walking abilities of children aged from 3 to 6 years during evacuation drills in day-care centres [5], [6]. The research studies were focused on measuring the travel speed on stairs and on horizontal planes, the flow through doors, and the densities, and monitoring behavioural considerations, such as the need for assistance from the staff. The data-set that was obtained was also used for a comparative study employing egress modelling of children movement using the software Nomad [7].

Kholshevnikov and Samoshin [8] discussed some issues in the evacuation of children. Their study presented the results of an unannounced evacuation drill for two children's amateur art centres involving children aged from 3 to 17 years, and pre-evacuation times in pre-school buildings according to different dressing scenarios in a cold season (children left the buildings without winter clothing, with a blanket thrown round them, or in winter clothing). The pre-evacuation times and the movement parameters of children ranging from 3 to 7 years of age were studied on the basis of observations in pre-school educational institutions under the conditions of routine building use and during evacuation experiments [9]. The research results include the basic relationship between travel speed (walking or running) and the density of flow of children of different ages moving upstairs, downstairs, on a horizontal plane, and passing through doors.

Another investigation of the evacuation behaviour of children of pre-school age formed a part of a study conducted in Japan [10]. This study dealt with the evacuation procedure in two nursery facilities attended by children aged from 0 to 5 years during regular, announced evacuation drills. The results consisted of flow rates through exits of classrooms and travel speeds on certain parts of horizontal and vertical escape routes.

The evacuation process during school egress trials conducted in an educational institution attended by children aged from 3 to 16 years was analysed by the GIDAI research group in Spain. Capote et al. [11] and Cuesta et al. [12] presented data-sets from three evacuation trials performed in the selected school building. The measured parameters, specifically pre-evacuation times, stair travel speeds, and flow rates through the exit doors, were used as input data for simulations in the STEPS, GridFlow, and Pathfinder egress models in order to assess the capability of these models to represent the movement of children. The methods for collecting and evaluating evacuation data obtained in five evacuation trials in a school facility were discussed in detail in [12], [13]. However, the results for pre-schoolers are mentioned only marginally in these studies.

An overview of data-set focusing on the travel speeds of pre-school children that are available in the literature mentioned above is provided in Table 1 and Table 2. The data is summarised with regard to the age of the children, the environment where the observations were conducted (exterior or interior), the geometry of the staircases, and the method for calculating the travel distance.

Table 1 Literature review of the travel speed of pre-school children on stairs (downstairs)

No.	Age of children [years]	Staircase (location/geometry /familiarity to children)	Stair geometry (rise/tread/slope) [mm; mm;°]	Mean/Min/Max/SD [m/s]	Travel distance calculation method	Reference
1	3-6	INT / Spiral / DU	190/290/33.0	0.58 / 0.25 / 1.40 / 0.31	STD, F, [3)]	Larusdottir and Dederichs [5]
2		EXT / Spiral / ESC	170/290/30.0	0.13 / 0.08 / 0.33 / 0.06		
3	3-4	INT / Straight / DU	Different stair geometry	0.50 / 0.39 [1)] / 0.62 [1)] / 0.29	[2)], F, LD	Kholshevnikov and Samoshin [9]
4	4-5	INT / Straight / DU		0.67 / 0.53 [1)] / 0.81 [1)] / 0.17		
5	5-7	INT / Straight / DU		1.16 / 1.09 [1)] / 1.23 [1)] / 0.23		
6	3-4	INT / Straight / DU	165/300/28.8	0.32 / 0.25 / 0.35 / 0.03	STD, F (one flight observed only), [3)]	Takizawa et al. [10]
7		INT / Straight / ESC	170/275/31.7 175/290/31.1	0.15 / 0.09 / 0.27 / 0.04		
8	4-5	INT / Straight / DU	165/300/28.8	0.58 / 0.36 / 0.77 / 0.10		
9		INT / Straight / ESC	170/275/31.7 175/290/31.1	0.42 / 0.34 / 0.52 / 0.05		
10	5-6	INT / Straight / DU	165/300/28.8	0.67 / 0.47 / 1.01 / 0.13		
11		INT / Straight / ESC	170/275/31.7 175/290/31.1	0.50 / 0.36 / 0.71 / 0.09		
12	4-6	INT / Straight / DU	185/275/33.9	0.48 / 0.28 / 0.77 / 0.14	STD, F, [3)]	Cuesta et al. [12]
13				0.61 / 0.14 / 1.12 / 0.21		
14				0.47 / 0.23 / 0.69 / 0.11		

[1)] 95% confidence interval
[2)] Information on the travel distance calculation method is not available, STD can be assumed
[3)] Information on density is not available
INT = Internal staircase, EXT = External staircase
DU = Daily-used staircase, ESC = Metal escape staircase (unfamiliar to the children)
STD = Slope travel distance on staircase, F = Flights considered only (landings excluded)
LD = Low density < 1.0 persons/m^2

The following findings emerge from the review of the literature on pre-school children evacuation: the performance of children during an evacuation differs from that of adults, and the movement abilities and skills of children are highly age-dependent. Two major research gaps can be found, namely (a) predictions of children evacuation using egress models is limited by the scarcity of relevant input data and by the ability of models to simulate some behavioural and movement patterns that are typical for children, (b) more data is needed for an appropriate understanding of the evacuation process involving young children.

Table 2 Literature review of children travel speed on the horizontal plane

No.	Age of children [years]	Location	Mean/Min/Max/SD [m/s]	Collection method	Reference
1	3-6	INT	0.84 / 0.42 / 1.36 / 0.25	Walking speed, LD	Larusdottir and Dederichs [5]
2		INT	2.23 / 0.83 / 3.24 / 0.64	Running speed, LD	
3	3-4	INT	1.05 / 1.00 [1)] / 1.10 [1)] / 0.22	Walking speed, LD	Kholshevnikov and Samoshin [9]
4		INT	1.78 / 1.70 [1)] / 1.86 [1)] / 0.29	Running speed, LD	
5	4-5	INT	1.12 / 1.06 [1)] / 1.19 [1)] / 0.17	Walking speed, LD	
6		INT	1.87 / 1.77 [1)] / 1.97 [1)] / 0.34	Running speed, LD	
7	5-7	INT	1.61 / 1.54 [1)] / 1.68 [1)] / 0.22	Walking speed, LD	
8		INT	2.30 / 2.14 [1)] / 2.47 [1)] / 0.46	Running speed, LD	
9	3-4	INT	1.07 / 0.65 / 1.94 / 0.30	Walking and running speed (not distinguished) [2)], LD	Takizawa et al. [10]
10		INT	1.59 / 0.93 / 2.36 / 0.41		
11	4-5	INT	1.47 / 0.60 / 2.47 / 0.52		
12		INT	1.43 / 0.68 / 2.70 / 0.50		
13	5-6	INT	1.68 / 0.85 / 2.78 / 0.50		
14		INT	1.33 / 0.85 / 1.73 / 0.20		

[1)] 95% confidence interval
[2)] Results obtained in two buildings presented separately for each age group
LD = Low density < 1.0 persons/m^2
INT = Interior environment

3. DATA COLLECTION METHODS

In the present study, the data was collected during two evacuation drills carried out in a pre-school in Vinoř municipality located in uptown Prague in May 2013 (Evacuation Drill I) and in June 2013 (Evacuation Drill II). The evacuation drills were conducted with prior agreement of the pre-school headmistress. All parents were informed in advance, and they were asked for permission to make video recordings of the children during the evacuation process.

3.1. Building description

The participating pre-school institution forms a part of a public school campus. The classrooms in which the pre-school children evacuation drills took place are situated in two buildings: a free-standing three-storey building (named Building A in this paper), and a part of a three-storey elementary school building (named Building B in this paper), see Figure 1.

In accordance with the Czech Fire Safety Code [25], two emergency routes are provided in each of the buildings: an escape route through a daily used internal staircase and an alternative escape route using a spiral staircase or a straight staircase outside the buildings. In Building A, Staircase A-I is the main, internal, straight staircase used daily by the children. Staircase A-II is an external, metal, straight escape staircase with a see-through grating landings and stair treads. In Building B, Staircase B-I is a straight flight (containing 6 steps only), situated in Classroom D, which leads to the escape route outside the building; when leaving the building, upstair movement is required only on this staircase. Staircase B-II and Staircase B-III are external, metal, spiral escape staircases with solid stair treads. Staircase B-II connects the 2nd floor with the 1st floor only; at point B7 the evacuation routes from the 2nd floor and 1st floor merge. The external horizontal parts of the escape routes (landings) outside Building B are made of steel grating stock panels. Details of the geometry of the staircases are listed in Table 3. The handrails are placed at a height of 1.25 m above the floor, additional handrails at a height 0.55 m are available in Building A only.

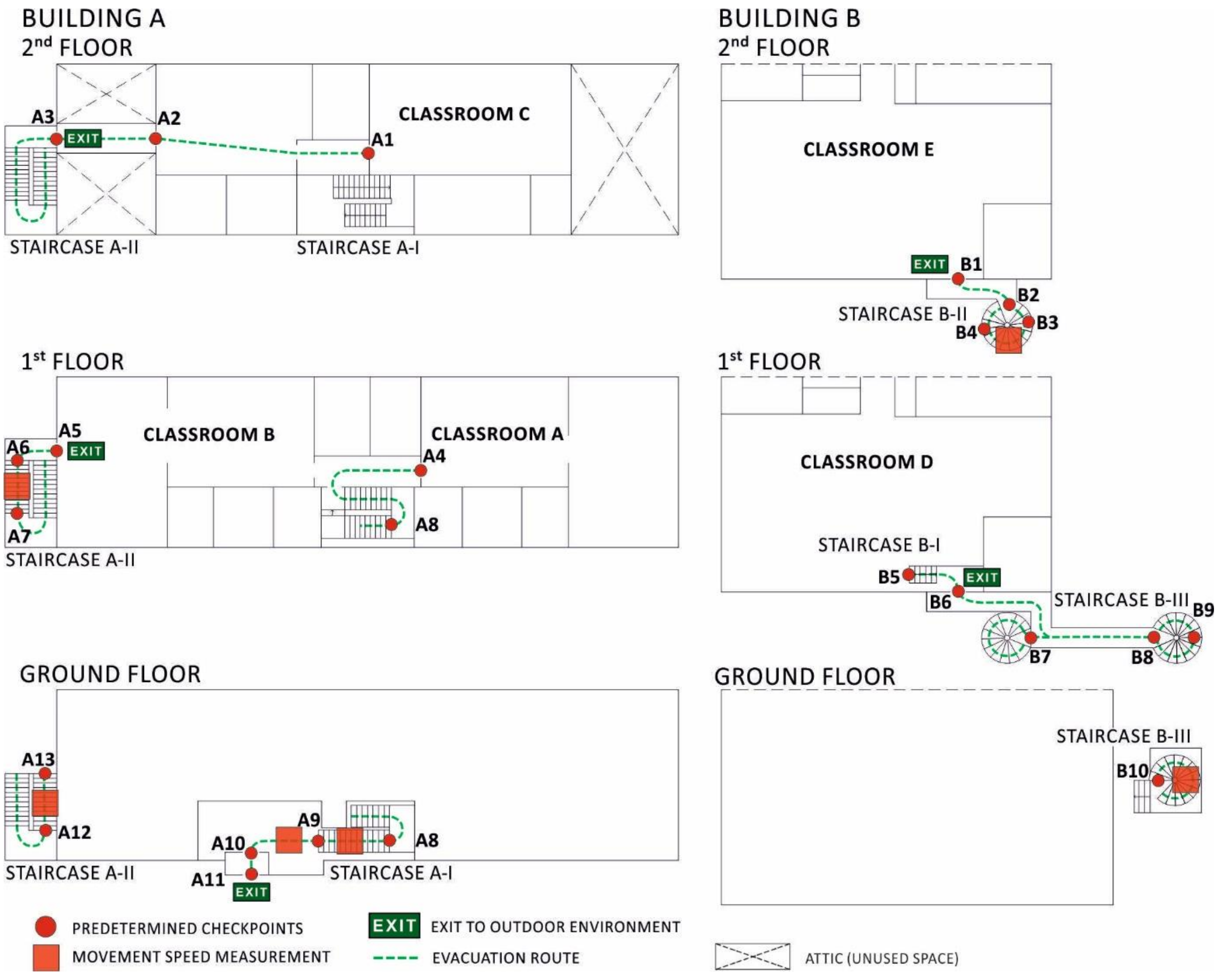

Figure 1 Layout of the pre-school buildings with a description of the escape routes and checkpoints

Table 3 Staircase geometry

Staircase		Location	Rise height [mm]	Tread depth [mm]	Slope of stair [°]	Flight width [mm]	Height of handrail [mm]
Building A (Junior children)	Staircase A-I	Interior	150	300	26.6	1200	550
	Staircase A-II	Exterior	160	260	31.6	1200	550
Building B (Senior children)	Staircase B-I [1)]	Interior	155	300	27.4	915	1250
	Staircase B-II	Exterior	165	420 [2)]	21.0	1200	1250
	Staircase B-III	Exterior	165	420 [2)]	21.0	1200	1250

[1)] Movement upstairs
[2)] Measured 0.3 m from the wide edge of the tread

3.2. Population description

The pre-school is attended by children in the age range between 3 to 6 years. Children are divided according to different age groups into "Junior" classes (aged 3-4 years) and "Senior" classes (aged 5-6 years) classes: 3 Junior classes are located in Building A (Classrooms A, B, and C), and 2 Senior classes are located in Building B (Classrooms D and E); see Figure 1. In each class, there were approximately 20 children who were in most cases supervised by two staff members. The distribution of the children and the staff members involved in the evacuation drills is shown in Table 4. The pre-school population generally does not include children with mental or physical disabilities, but children with temporary physical injuries may occasionally be part of the pre-school population. During the drills, the observed population did not include any children with physical disabilities which would have to be taken into consideration when evaluating the evacuation process.

Table 4 Distribution of children and supervising staff enrolled in the observed evacuation drills

Building	Classroom	Exit	Evacuation Drill I (May 2013)		Evacuation Drill II (June 2013)	
			Children	Staff	Children	Staff
Building A (Junior children)	Classroom A	Main building exit (A11)	22	2	22	2
	Classroom B	External staircase A-II	18	1	14	2
	Classroom C	External staircase A-II	18	2	14	2
Building B (Senior children)	Classroom D	External staircase B-III	19	2	22	2
	Classroom E	External staircase B-II, B-III	20	2	19	2
Total			**97**	**9**	**91**	**10**

3.3. Evacuation procedure

Both evacuation drills were semi-announced. The date of the event was known to the staff in the case of Evacuation Drill I, while Evacuation Drill II was officially planned on an unspecified day within June 2013. The staff was not directly informed of the specific time of the drills; however, it is to be assumed that staff members may have noticed signs of preparatory work in the building (e.g. the presence of strangers in the corridors) in the morning hours of the evacuation day.

To ensure that all classes were present inside the buildings, the evacuation drills were conducted in the morning hours. The specific time was chosen taking into account the pre-school daily routine schedule, in order to avoid particular time periods in which the same activities, e.g. eating or resting time, occur in each class. Therefore, children were participating in various small-group or large-group activities when the signal to start the evacuation was given. Since there was no automatic fire alarm installed in the buildings (i.e. in accordance with the Czech Fire Safety Code [25] only an autonomous smoke detection system is required in pre-school facilities), both evacuation drills were started with a verbal warning made personally by the drill organisers (researchers) in each building. The vocal message (in Czech) "Building evacuation. Please leave the building immediately" was given at the same time on each floor where the observed classrooms were located. Since the doors of Classrooms A, B, and C were open, the persons making the call for the evacuation stood in the corridors outside the classrooms in Building A; in the case of Building B, the doors of Classrooms D and E were opened and the message was given in each classroom. To obtain data-sets on the movement of the children both on the internal staircases and on the external staircases, selected classes were asked to leave the building using the escape routes outside the buildings. The initial position and the evacuation route of each class are shown in Figure 1. According to the usual practice executed during normal operation in the pre-school (typical for most pre-school institutions in the Czech Republic), the following principles were complied with when leaving the building: the children in each class moved as a compact group, the movement of a group was controlled by responsible staff members, and merging of two different groups was avoided. After the evacuation process was completed, all evacuees gathered at the assembly point in the garden situated in front of Building A, and they later returned into the buildings when instructed.

3.4. Data collection

In order to make a continuous observation of the movement of the people along the evacuation routes, the evacuation drills were recorded using 13 video cameras located inside and outside the buildings (digital handheld video cameras and digital cameras, minimum resolution 640x480, minimum frame rate 25 fps). The video cameras were placed so that they captured predetermined checkpoints for subsequent data processing (marked points A1-A11 and B1-B10 in Figure 1) namely the exits from the classrooms, the main exits from the buildings, and the staircase areas. It should be noted that since one camera was able to record multiple checkpoints, the markers in Figure 1 do specify not the position of the cameras but the areas where movement was evaluated (checkpoints). Due to limited mounting equipment, the video cameras were horizontally positioned and were visible to the children, but were out of their reach and had no impact on their movement behaviour. The camera density parameter was not evaluated due to the limited number of cameras in the buildings. A manual analysis of the recordings was executed using the GAMSplayer1.1 video analysis tool. This tool was developed for the purposes of evacuation research at CTU in Prague, and allows an analysis to be made of each frame. The time when a person passed through a checkpoint was recorded to one decimal place for each camera location. However, during Evacuation Drill II, there was a complication with a camera placed in Classroom C in Building A. In this case, therefore, the time when the children were passing through the door from Classroom C was estimated using the recordings of other cameras on the second floor. Apart from that, due to the inaccurate recording angle of the video cameras and resulting uncertainty about the exact location of children in some positions, the accuracy of the presented values for pre-evacuation and for the total evacuation times is conservatively limited to seconds. During the evacuation drills, the following variables were observed and collected:

- Total evacuation times (Arrival times)
- Pre-evacuation times
- Travel speed on horizontal and vertical escape sections

The travel speeds were calculated for each child separately as a ratio of travelled distance over corresponding time of travel on each specific part of an escape route. The distances on the straight staircases located in Building A were determined as the inclined length of the flights (AB), and the travel paths on landings were considered as arcs (BC) [26]. The distances on the spiral stairs outside Building B were calculated as the length of a circular helix (AC) determined at a point 0.3 mm from the wide edge of the tread; the external landings were accounted as horizontal sections. The method used for calculating the travel distances on the stairs is illustrated in Figure 2.

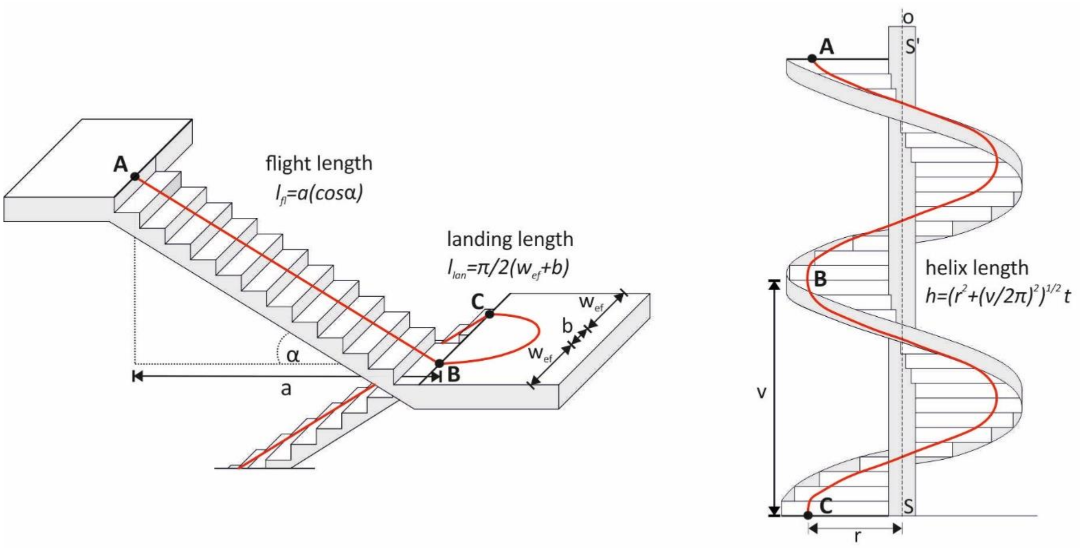

Figure 2 Distances on stairs and landings

The same hypothetical travel path was considered for all persons who were using a particular escape route (the assumed trajectories for each escape route are indicated in Figure 1). The walking speed of staff members was to a large extent adapted to the movement of the children (since they were assisting the children or giving instructions to them). The movement of the staff was therefore not assessed.

Given the specific evacuation procedures adopted in pre-school facilities, assumptions have to be stated when evaluating the travel speeds of children. As in most cases each class moves through a building as a compact group (with a fixed internal order of the children), the individual travel speed is limited by the movement of the other children and by the staff members' instructions (e.g. to stop and wait for slower children in the group). In order to provide relevant results for use in egress modelling and fire safety design, the difference between movement speed and modelling speed has to be taken into account. The concept of modelling speed was introduced by Fridolf et al. [23], as a response to methods used for people movement representation adopted by current evacuation models, which in most cases simulate the movement of people simplified as non-stop straight flow. In contrast to movement speed, which is calculated by dividing the actual distance by the time employed (excluding all stops), modelling speed (intended for modelling purposes) is determined as the ratio of the theoretical (straight) travel distance to the time of travel, including the duration of all stops that are made.

In this paper, the movement speeds were measured on specified parts of the escape routes where the movement of the children was not influenced by acceleration and deceleration phases, waiting, or queuing. To obtain the actual movement speeds, the movement of the children was observed on selected flights (excluding landings) on the straight stairs and on selected sections of the helix in the case of the spiral stairs. The movement speed on the horizontal plane was measured only on parts of the escape routes where the children were moving continuously. The sections of the escape routes where the movement speeds were calculated are shown in Figure 1 and are specified in the Results section (see Table 7, 8, 9 and 10). It is appropriate to mention that although movement speed describes continuous movement, it does not correspond to unimpeded speed, because the pace of children may be influenced by other children (e.g. by the pace of slower children on stairs).

In order to describe the movement ability of children to cover a particular distance on a staircase or on a horizontal plane, the modelling speeds were evaluated, including the acceleration and deceleration phases of the movement, the stops made by the children, queuing times, and other pauses and delays related to group movement typical for pre-school children. In several cases, stops had to be made when the exit doors were being unlocked, or when one group yielded to another group on a staircase. These pauses in walking were included in the considered movement time on each travel section, and they were assessed as part of the modelling speeds; a description of the stops and their impact on particular modelling speeds is presented in the Results section.

4. RESULTS

The results presented in this section include total evacuation time, pre-evacuation time, and horizontal and vertical travel speeds.

4.1. Total evacuation time

The evacuation time is defined as the time needed by each child to reach the exit of the building (see point A11 in Figure 1) or the end of the external staircase (see points A13 and B10 in Figure 1). The arrival times for the first and last child in each class are summarised in Table 5. The interval when an exit/end of the staircase was being used is defined as the difference between the times when the last and first child passed through ("Exit in use" in Table 5). In addition, to provide detailed information on the time spent on the external escape routes, the time interval in which the external staircases (including the external horizontal landings in the case of Building B) were in use was estimated ("Exterior" column in Table 5). A graphical comparison of the results obtained in both drills and the probability distributions of the total evacuation times is shown in Figure 3.

This paper has been published as: Najmanova H, Ronchi E (2017). An experimental data-set on pre-school children evacuation. Fire Technology. Doi: 10.1007/s10694-016-0643-x

Table 5 Total evacuation time of each class during both evacuation drills and exit use

Building	Classroom	Exit	Evacuation Drill I				Evacuation Drill II			
			First	Last	Exit in use	Exterior	First	Last	Exit in use	Exterior
			[s]	[s]	[s]	[s]	[s]	[s]	[s]	[s]
Building A (Junior children)	Classroom A	Main building exit (A11)	83	99	16	-	93	104	11	-
	Classroom B	Staircase A-II	98	142	44	74	71	106	35	67
	Classroom C	Staircase A-II	164	186	22	114	129	151	22	96
Building B (Senior children)	Classroom D	Staircase B-III	57	81	24	59	102	131	29	94
	Classroom E	Staircase B-II, B-III	88	118	30	100	69	103	34	86

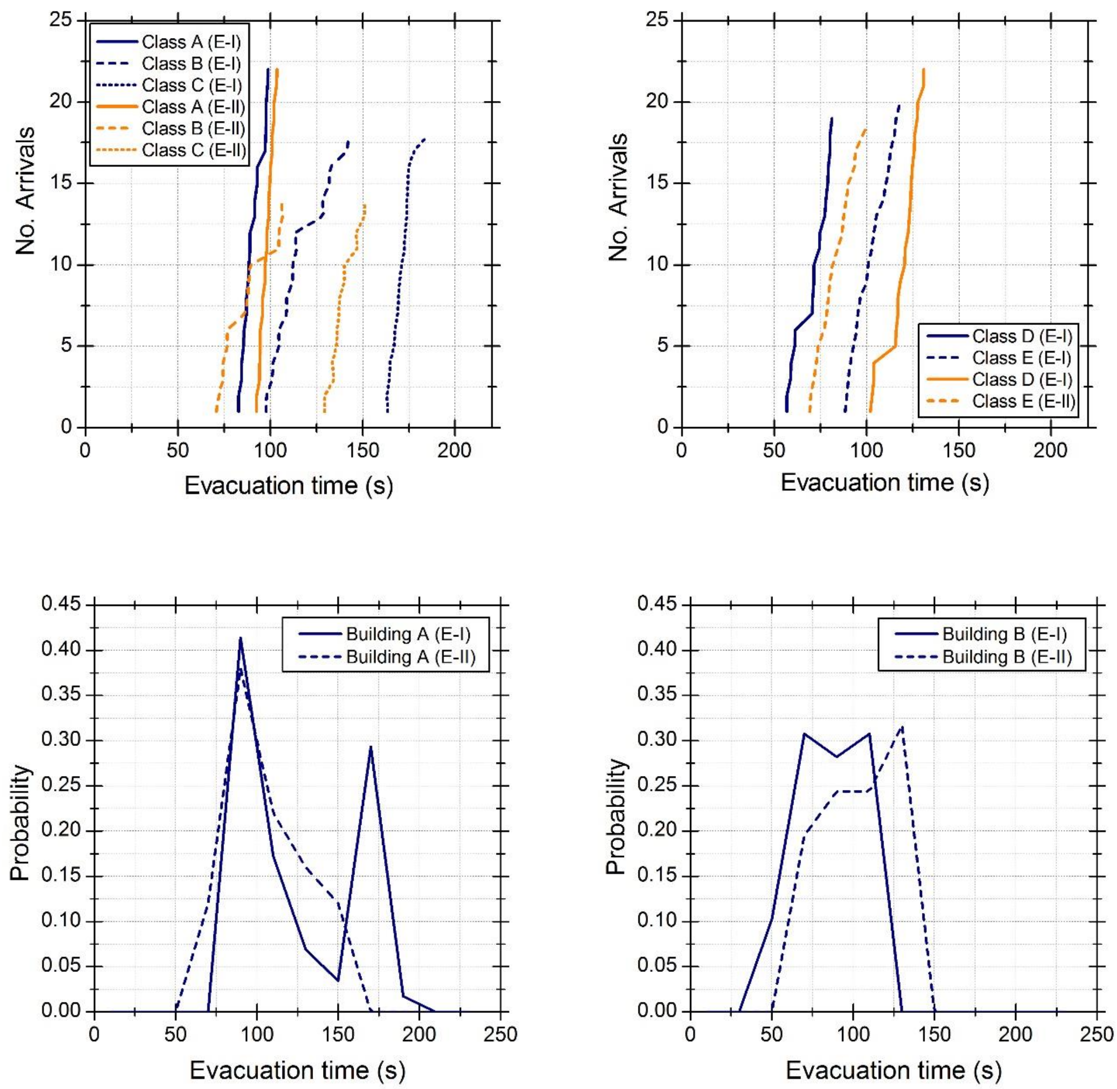

Figure 3 Upper left: Evacuation times for Building A; Upper right: Evacuation times for Building B; Bottom left: Probability distributions of the evacuation time for Building A for both evacuation drills; Bottom right: probability distributions of the evacuation time for Building B for both evacuation drills

4.2. Pre-evacuation time

Since pre-school children move through the building in organised groups, the pre-evacuation time was determined for each classroom as the time between the delivery of the verbal warning (starting from the first word of the warning) and the time for the group to be ready to start its movement. This corresponds to the time when the first child started the evacuation by approaching the classroom door moving towards to the exit of the building. The pre-evacuation times for each class measured in both evacuation drills are given in Table 6.

Table 6 Pre-evacuation times of each classroom during both evacuation drills

Building	Classroom	Evacuation Drill I [s]	Evacuation Drill II [s]
Building A (Junior children)	Classroom A	55	58
	Classroom B	68	39
	Classroom C	37	21
Building B (Senior children)	Classroom D	16	32
	Classroom E	18	13

The results show that the pre-evacuation times were shorter in the classrooms with Senior children (mean value 20 s) than in the classrooms with Junior children (mean value 46 s). The pre-evacuation time is highly dependent on the individual reaction and the approach of responsible staff members. The activities performed during the pre-evacuation periods which were decided and organised by staff were dependent mainly on the age group of the children. Before leaving a classroom, Junior children are asked to form pairs, holding another child's hand, and to stay in a compact group, while the number of children and the empty classroom were checked (even several times) simultaneously. The instruction had to be repeated many times to the children, and some of them needed physical contact to start moving to the door from the classroom. By contrast, the Senior children behaved more independently and more quickly when following the instructions given by staff members. In addition, no check was made that the classroom was empty, and, in the case of Class E, the children were even not asked to form pairs before leaving the building.

4.3. Travel speed on stairs

The stair travel speed was evaluated separately according to the age group of the children and the location of the staircase (external or internal). In order to provide a robust representation of the speed values, the travel speed results obtained in both evacuation drills were combined when a consistent evacuation process occurred during the evacuation drills. For junior children (aged 3-4 years), the movement speed was calculated on the last flight on Staircase A-I and was calculated separately on two flights on Staircase A-II. The movement speed of the Senior children was assessed in the middle part of Staircase B-II and on Staircase B-III. Due to the short length of Staircase B-I (one flight with 6 steps only) the continuous movement speed was not evaluated and only the modelling speed was evaluated there (as described below). The observed movement speeds on each staircase (mean, minimum, maximum, and standard deviation values) are shown in Table 7.

Table 7 Movement travel speed on stairs (data from both evacuation drills is included)

Speed	Staircase		Location	Geometry	No.	Mean / Min / Max / Standard deviation [m/s]
Movement speed	Building A (Junior children)	Staircase A-I (A8-A9)	Interior	Straight	44	0.57 / 0.40 / 0.87 / 0.12
		Staircase A-II (A6-A7, A12-A13)	Exterior	Straight	128	0.34 / 0.16 / 0.47 / 0.07
	Building B (Senior children)	Staircase B-I	Interior	Straight	N/A	N/A
		Staircase B-II (B3-B4)	Exterior	Spiral	39	0.53 / 0.40 / 0.71 / 0.09
		Staircase B-III (B9-B10)	Exterior	Spiral	80	0.59 / 0.38 / 0.87 / 0.09
No. = Number of collected data points						

The measured stair travel speed values indicate the different mean values according to the age of the children and the configuration of the stairs. The travel movement speed of Junior children on the daily used internal stairs (0.57 m/s) is almost twice as high (68 % higher) as their speed on the external grating (see-through) stairs (0.34 m/s). That is, approximately the same speed value as for the Senior children moving on the spiral stairs in the outdoor environment (0.56 m/s). A more careful downstair movement, leading with one foot, was observed in many cases for Junior children who also, in accordance with the staff member's instructions, walked in pairs holding each other's hand or using handrails. By contrast, the Senior children moved more individually (not in pairs), in most cases. The modelling travel speed was calculated along the entire travel path on the staircases (the sum of the length of the flights and the length of the travel paths on the landings on straight stairs), with the exception of Staircase A-I, where the movement speed was observed on only one flight. The observed modelling stair travel speeds of the children are shown in Table 8. In the case of spiral Staircase B-II, the modelling speeds are described separately for each evacuation drill. The difference in results observed in each drill lies in the time delay caused by a stop that had to be made when yielding to another class during Evacuation Drill I. The time delay was approximately 10 s for the first child in the group.

Table 8 Modelling travel speed on stairs (data from both evacuation drills is included)

Speed	Staircase		Location	Geometry	No.	Mean / Min / Max / Standard deviation [m/s]
Modelling speed	Building A (Junior children)	Staircase A-I	Interior	Straight	N/A	N/A
		Staircase A-II (A3-A13)	Exterior	Straight	64	0.30 / 0.21 / 0.41 / 0.06
	Building B (Senior children)	Staircase B-I (B5-B6) 1)	Interior	Straight	41	0.50 / 0.37 / 0.67 / 0.08
		Staircase B-II (B2-B7)	Exterior	Spiral	20 2)	0.41 / 0.36 / 0.49 / 0.04 2)
					19 3)	0.51 / 0.42 / 0.64 / 0.05 3)
		Staircase B-III (B8-B10)	Exterior	Spiral	80	0.56 / 0.39 / 0.86 / 0.09

1) Movement upstairs
2) Evacuation Drill I only
3) Evacuation Drill II only
No. = Number of collected data points

Differences can be observed between movement speeds and modelling speeds. As suspected, the modelling speeds are lower, since they include all stops and delays along the escape routes. Apart from stops that were made in accordance with staff members' instructions, the children's travel speed was mainly influenced by the speed of the children moving in front or on the side. This resulted from the supervised movement in groups, with a given internal order of pairs of children that permitted neither overtaking nor walking downstairs independently, which might otherwise have occurred due to variations in the children's performance. It should be noted that the results obtained on internal Staircase B-I were considerably influenced by the short length of the observed flight. The results are mentioned here for illustrative purposes only. The probability distributions of the observed travel speeds on different staircases are shown separately in Figure 4. In the majority of cases, a normal distribution of travel speeds can be observed, which is in line with literature data describing both adult travel speed [27], [28] and children travel speed [2].

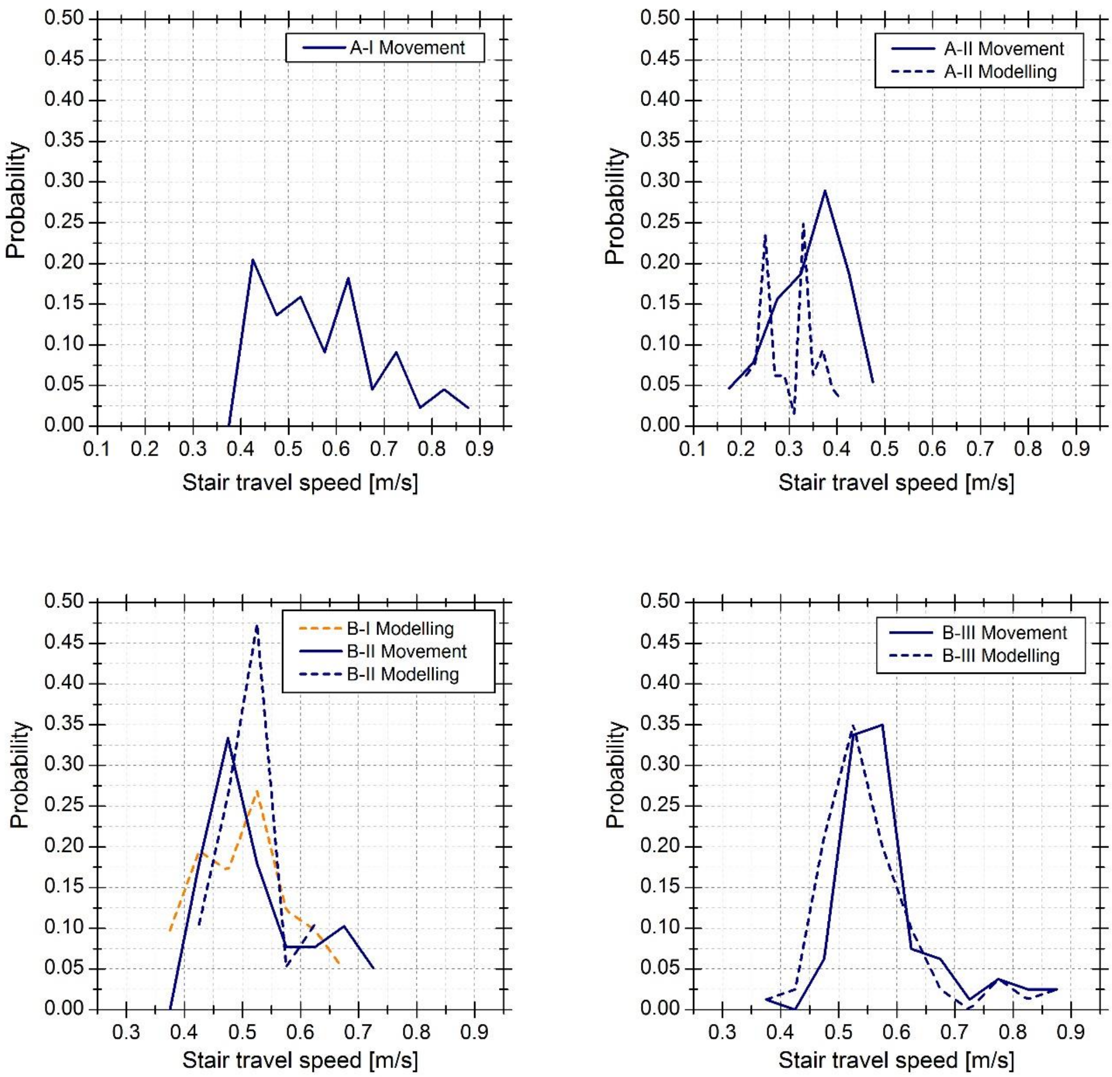

Figure 4 Probability distributions of travel speeds on stairs; Upper left: Staircase A-I; Upper right: Staircase A-II; Bottom left Staircase B-I and Staircase B-II (The B-II modelling curve shows the result for Evacuation Drill I without the waiting delay); Bottom right: Staircase B-III

4.4. Horizontal travel speed

Since there were few parts of the escape routes where the movement of the children was not influenced by queuing or by waiting, the movement speed on horizontal planes was calculated for Junior children in Building A only (see Table 9). It should be mentioned that in this case, although it describes continuous movement, the movement speed also does not correspond to unimpeded speed, because the pace of the children may have been influenced by other children. To provide consistent data, the presented results describe walking movement only (two cases when children were running for a short time were excluded). Because of consistent conditions in both evacuation drills the observed results were combined. The probability distribution of the observed movement speeds is shown in Figure 5. Similarly to the travel speeds on stairs, the diagram shows a normal distribution of the results.

Table 9 Movement travel speed on the horizontal plane (data from both evacuation drills is included)

Speed	Travel path		Location	No.	Mean / Min / Max / Standard deviation [m/s]
Movement speed	Building A (Junior children)	Classroom A (A9-A10; 2.0 m)	Interior	42	1.02 / 0.69 / 1.33 / 0.17
No. = Number of collected data points					

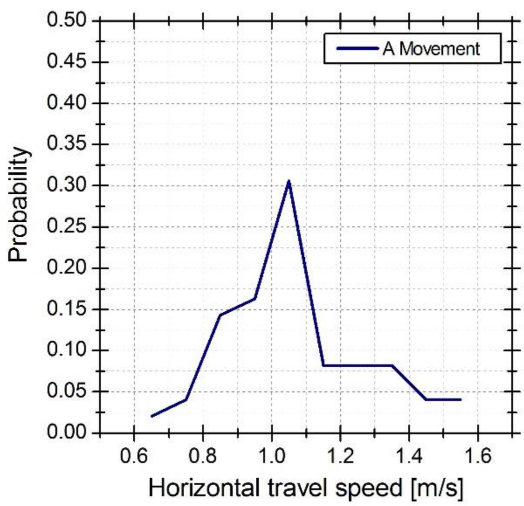

Figure 5 Probability distribution of the horizontal movement speeds of Junior children in Building A

In order to describe the ability to cover a particular horizontal distance, modelling speeds were assessed on internal escape routes for Junior children and on external escape routes for Senior children, i.e. on the landings connecting building exits with spiral staircases and connecting spiral staircases to each other. Since the conditions differed in each evacuation drill, the modelling speeds were calculated for each evacuation drill separately (see Table 10). To show how the stops influenced the results, an additional description is given below.

The modelling speeds of the Junior children include time delays caused by the need to unlock exit doors in Building A (points A2, A3, and A11). The results show that the evacuation procedure was quite similar for the children in Classroom C during both evacuation drills. The difference in the modelling speeds of the children in Classroom A resulted from different waiting times needed for unlocking the exit door: the waiting time was 4 s in Evacuation Drill I, whereas the waiting time was twice as long (8 s) in Evacuation Drill II, because a staff member had left a key in the classroom and had to go to retrieve it. The modelling speed for the Senior children was affected by the stops made when yielding to another group of children and waiting for a free escape route. In Evacuation Drill I, Class E had to wait for 10 s until the landing could be entered by the first child, because it was occupied by Class D. Conversely, in Evacuation Drill II, Class D had to stop its movement for 26 s to avoid merging the flows of children from Class E, who had been the first group to arrive at the marching point (B7). Thus the presented results cover both situations for each class.

Table 10 Modelling travel speed on the horizontal plane (data from both evacuation drills is included)

Speed	Travel path		Location	No.	Mean / Min / Max / Standard deviation [m/s]
Modelling speed	Building A (Junior children)	Classroom A (A9-A11; 5.25 m)	Interior	22 [1]	0.76 / 0.55 / 1.35 / 0.22 [1]
				22 [2]	0.58 / 0.35 / 0.78 / 0.16 [2]
		Classroom C (A1-A3; 17.1 m)	Interior	18 [1]	0.46 / 0.42 / 0.50/ 0.03 [1]
				14 [2]	0.41 / 0.35 / 0.46 / 0.03 [2]
	Building B (Senior children)	Landing 2nd floor Classroom E (B1-B2; 3.65 m)	Exterior	19 [1]	0.75 / 0.46 / 1.18 / 0.20 [1]
				22 [2]	0.70 / 0.44 / 1.02 / 0.24 [2]
		Landing 1st floor Classroom D (B6-B8; 11.5 m)	Exterior	19 [1]	0.62 / 0.57 / 0.68 / 0.03 [1]
				22 [2]	0.27 / 0.24 / 0.31 / 0.02 [2]
		Landing 1st floor Classroom E (B7-B8; 6.65 m)	Exterior	20 [1]	0.35 / 0.29 / 0.46 / 0.05 [1]
				19 [2]	0.77 / 0.48 / 0.93 / 0.13 [2]

[1] Evacuation Drill I only
[2] Evacuation Drill II only
No. = Number of collected data points

5. DISCUSSION

The data-set describing the specific evacuation process and the performance of pre-school children was presented in the previous section. Supporting the findings in previous studies reviewed in the literature [5]–[18], the observed results show that the conditions having the main impact on the movement abilities of children are (a) the age of the children and (b) the configuration of the escape route. Another factor which may be related to children movement patterns is their familiarity with the escape routes and with the environment. These factors are discussed in this section, and the observed movement speed of the children is used as the criterion for comparison. To provide a deeper insight into this issue, the data-set presented in this paper is compared with the available results published in research studies (summarised in Table 1 and Table 2 in the literature review section of this paper (Section 2).

First of all, because of possibly different initial conditions or data collection methods, it must be pointed out that the data in the presented overview should not be compared directly. Although factors influencing children movement, such as the age of the children or the configuration of the escape route (e.g. the shape and the slope of the staircase, the stair configuration, etc.) are available in the literature, travel speed data result from a combination of these individual initial conditions which are typically unique in each experimental study. In addition, there are other factors that are usually not accessible, such as the instructions given to the children by adults, or the grouping of the children during the evacuation (i.e. individual movement or in groups). These inaccessible factors have a major impact on the evacuation process. Despite this limitation, a comparison of relevant data-sets with the results of the present experiment focused on particular conditions (the age of the children, the geometry of the staircases, and the type of environment) can be assumed to indicate trends that might be taken into consideration in fire safety design.

In order to account for the different movement abilities of children across the various phases in childhood, age is a commonly used criterion. In general, this implicit criterion should be seen as a simplification to address both the physical and the psychological aspects of the development of young children. The influence of physical dimensions was observed especially when the children were moving on stairs. Shorter children walked downstairs leading with one foot, which slowed down their travel speed considerably. The behavioural development of the children also had an effect on their movement abilities - less independent and less sure children searched for support, using handrails or holding another child's hand. Age also impacted the movement of the children indirectly, as different instructions were given by staff members to children in different age groups. In general, the staff members looked to be more careful and more cautious when looking after younger children: the Junior children were asked to keep walking in pairs, holding another child's hand and handrails, whereas Senior children had more independence and, in most cases, they moved individually (not in pairs).

In this study, the movement travel speeds on stairs of the Junior children (3-4 years old) were measured on straight staircases in both indoor and outdoor environments. The observed staircases differed in their geometry and construction. The slope of the internal staircase was 26.6° (the rise height was 150 mm and the tread depth was 300 mm), whereas the external staircase was steeper by 5° (the rise height was 160 mm and the tread depth was 260 mm). In addition, the treads of the external staircase were made as see-through grating panels. The observed mean speed on the internal staircase was 0.57 m/s, while on the external staircase it was 0.34 m/s, which means a decrease of 40%. When interpreting this value, we can assume that the difference in the speeds indicates the influence of the different configuration of the escape routes, and also the impact of the environment on the movement abilities of the children, where the non-familiar outdoor environment decreased the stair speed of the children. This trend confirms the observations made by Larusdottir and Dederichs [5], where the speed on a non-familiar external staircase with see-through treads was significantly lower, despite the lower slope of the staircase (Table 1; lines 1-2). The assumed impact of children's familiarity with the environment is also seen in the results published by Takizawa et al. [10], where the speed on a daily used staircase (Table 1; line 6) was twice as high as the speed on an escape staircase that was not familiar to the children (Table 1; line 7).

The measured mean movement speed of Senior children (5-6 years old) on the external spiral staircase was 0.56 m/s. Although a spiral staircase might be expected to be more challenging for children, this value is almost the twice the measured speed for the Junior children on the straight external staircase. It may be assumed that the difference in the results derives from the different configurations of the external staircases, where the slope of the spiral staircase was lower by 10.6° owing to wider treads (420 mm), and the treads were solid (not see-through). Apart from the impact of the different configurations of the staircases, children's age can be identified as a key factor for different speeds. In general, it is observed that older children move at higher speeds, this trend is also shown in the results published by Kholshevnikov and Samoshin [8] (see Table 1; lines 3-5) and by Takizawa et al. [10] (compare Table 1; line 6 with lines 8 and 10, and line 7 with lines 9 and 11).

The horizontal movement speed was observed only for Junior children on the internal evacuation routes; so far this information does not help to describe the impact of the children's age or of the configuration of the escape route on the movement abilities of the children. However, the results can be compared with data in the literature (see Table 2). If we compare the observed horizontal movement speed (mean value 1.02 m/s) with line 3 (1.05 m/s) and with line 9 (1.07 m/s), we can observe that it corresponds with the speeds of children in the same age group.

Moreover, a comparison between the movement speed on stairs (the mean speed on the internal staircase 0.57 m/s and on the external staircase 0.34 m/s) and the movement speed on the horizontal plane of Junior children shows that the children moved very much more slowly on the stairs; the horizontal-stair travel speed ratio was equal to 0.56 m/s on the daily used internal staircase, and was equal to 0.33 m/s when the unfamiliar external escape staircase was used.

As has been shown in previous research, movement downstairs is biomechanically more challenging than walking on a horizontal plane. This is because the centre-of-mass of the body must be lowered during descent supported by a single bent limb, and this involves higher demands on maintaining dynamic balance [29]–[31]. In the current study, the observations are consistent with theoretical expectations that walking on stairs may be even more challenging for pre-school children experiencing potentially limited balance control abilities according to their ongoing development [32], [33]. Increased consideration should be given to pre-school children's movement on stairs. Further systematic investigations on this issue are needed, with assessments of various staircase configurations.

The evacuation process in pre-school facilities is influenced not only by the specific movement abilities of the children, but also to an extreme extent by the behaviour of staff members. Although younger children may react to unexpected circumstances individually, following the role-rule model [34], their motivation to evacuate, their pre-evacuation activities, decision-making, and behavioural patterns during the movement phase seemed to depend on the instructions given by adults. This outcome therefore confirms the children's need for the presence of an authority figure who also provides emotional security for them [35]. The observations also showed that the behaviours of both children and adults during the evacuation process largely reflected the daily routine of children behaviours (under normal circumstances) in the pre-school. In fact, even in the case of the simulated emergency, the children tended to follow a sequence of memorized daily activities, such as seeking for a partner to make a pair or standing in front of the door waiting for the signal to go. Likewise, the instructions given by the staff members followed the daily procedure when leaving the building, i.e. the children in each class were organised as a separate moving group, and younger children were asked to form pairs and to hold another child's hand and keep this formation throughout the movement phase. Since procedures and practices may differ significantly across pre-school facilities, depending on the cultural background and the educational routines in different countries, this is an important matter to be taken into account when interpreting results obtained in different countries.

6. CONCLUSIONS

An evacuation procedure in pre-school buildings differs from other occupancies not only because the children have limited movement abilities, but also because the children have a lowered level of independence and decision-making capability resulting from their stage of psychological development. These differences are linked to an increased need for an organised evacuation procedure (which can vary depending on the facility). This procedure may influence both the pre-evacuation phase and the movement phase of the evacuation process.

In this paper, the primary objective was to provide a novel data-set and insights into specific movement parameters of this population. The main variables describing the movement of children used in engineering applications (i.e., total evacuation time, pre-evacuation time, and travel speeds) were assessed. In order to highlight the importance of the data collection methods and the interpretation of the results, two different approaches were adopted to describe the travel speed of children: movement speeds and modelling speeds. The obtained data shows that the movement travel speeds of Junior children (aged 3-4 years) range from 0.4 m/s to 0.87 m/s on a straight internal daily used staircase, and from 0.16 m/s to 0.47 m/s on a straight external escape staircase. The modelling speeds on the external staircase range from 0.21 m/s to 0.41 m/s. In the case of Senior children (aged 5-6 years) moving on spiral external staircases, movement travel speeds in the range from 0.38 m/s to 0.87 m/s and modelling speeds from 0.36 m/s to 0.86 m/s were observed.

The movement travel speeds on the horizontal plane were evaluated for Junior children, and they ranged from 0.69 m/s to 1.33 m/s. The modelling speeds on horizontal planes varied depending particularly on the stops included in the analysis (the mean values ranged from 0.27 m/s to 0.77 m/s). The assumptions used in the analysis should therefore always be taken into account when the values are used in further applications. The differences in the obtained results show that the full context of empirical data has to be borne in mind when using experimental results for different purposes in fire safety design.

The observed pre-evacuation times were longer in classrooms with Junior children (mean value 46 s) than in classrooms with Senior children (mean value 20 s). The differences resulted mainly from different instructions and from the level of assistance given to younger and older children by staff members.

In summary, the observed results indicated that the movement abilities and the behavioural patterns of children during the evacuation are mainly influenced by the age of the children and by the configuration of the escape route. In addition, the potential impact of children's familiarity with escape routes and with the escape environment has been discussed. Increased attention needs to be paid to escape routes via staircases, which are more challenging for younger children than for adults because of their different development levels. In addition, the observations have confirmed that children have limited self-rescue capabilities, and these must be compensated for by the physical and psychological assistance given by responsible staff members during the evacuation process. For a better understanding of this issue, further investigation on children's behavioural patterns and on their interactions with the responsible supervising personnel should be conducted in the future.

Understanding the specific conditions regarding the evacuation of pre-school children has been shown to be a complex issue. Future work is needed to explore further specific characteristics of children's movement (e.g. flow through exits or on a spiral staircase), and to provide a better insight into children evacuation dynamics, together with applicable data for use in fire safety design.

Acknowledgement

The authors wish to acknowledge Daniel Nilsson for a comprehensive review of the document before publication. The authors also wish to acknowledge Tomonori Sano and Dmitry Samoshin for providing explanations on the Japanese and Russian data-sets which have been mentioned in this paper. This work has been supported by the Ministry of Education, Youth and Sports within National Sustainability Programme I (NPU I), project No. LO1605 - University Centre for Energy Efficient Buildings – Sustainability Phase.

REFERENCES

[1] A. P. M. Adams and E. R. T. Galea, An experimental evaluation of movement devices used to assist people with reduced mobility in high-rise building evacuations, in *Pedestrian and Evacuation Dynamics*, R. D. Peacock, E. D. Kuligowski, and J. D. Averill, Eds. Boston, MA: Springer US, 2011.

[2] V. V. Kholshevnikov, D. A. Samoshin, and R. Istratov, The problems of elderly people safe evacuation from senior citizen health care buildings in case of fire, in *5th International Symposium on Human Behaviour in Fire*, Cambridge, UK, 2012, pp. 587–592.

[3] L. Kecklund, K. Andrée, S. Bengtson, S. Willander, and E. Siré, How Do People with Disabilities Consider Fire Safety and Evacuation Possibilities in Historical Buildings?—A Swedish Case Study' *Fire Technology*, vol. 48, no. 1, pp. 27–41, Jan. 2012.

[4] E. Kuligowski, R. Peacock, E. Wiess, and B. Hoskins, Stair evacuation of older adults and people with mobility impairments, *Fire Safety Journal*, vol. 62, pp. 230–237, Nov. 2013.

[5] A. R. Larusdottir and A. S. Dederichs, A step towards including children's evacuation parameters and behavior in fire safe building design, *Fire Safety Science*, vol. 10, pp. 187–195, 2011.

[6] A. R. Larusdottir and A. S. Dederichs, Evacuation of Children: Movement on Stairs and on Horizontal Plane, *Fire Technology*, vol. 48, no. 1, pp. 43–53, 2012.

[7] M. C. Campanella, A. R. Larusdottir, W. Daamen, and A. S. Dederichs, Empirical data analysis and modelling of the evacuation of children from three multi-storey day-care centres, presented at the Advanced Research Workshop Evacuation and Human Behaviour in Emergency Situations, Santander, 2011, pp. 223–226.

[8] V. V. Kholshevnikov and D. A. Samoshin, Pre-school and school children building evacuation, in *4th International Symposium on Human Behaviour in Fire*, Cambridge, UK, 2009, pp. 243–254.

[9] V. V. Kholshevnikov, D. A. Samoshin, A. P. Parfyonenko, and I. P. Belosokhov, Study of children evacuation from pre-school education institutions, *Fire and Materials*, vol. 36, no. 5–6, pp. 349–366, 2012.

[10] K. Takizawa *et al.*, A study for evacuation behavior characteristic of nursery school children and evacuation planning (Part1): The survey of evacuation speed, in *Technical papers of annual meeting*, 2013, pp. 347–350.

[11] J. A. Capote, D. Alvear, O. Abreu, A. Cuesta, and J. Hernando, Children evacuation: Empirical data and egress modelling, in *5th International Symposium on Human Behaviour in Fire*, Cambridge, 2012, pp. 109–119.

[12] A. Cuesta, O. Abreu, F. Ancona, and D. Alvear, Exploring the current egress models capabilities for simulating evacuation of children through stairs, in *Proceedings of the 13th International Interflam Conference*, Royal Holloway College, Nr. Windsor, UK, 2013, vol. 2, pp. 1013–1022.

[13] A. Cuesta, E. Ronchi, and S. M. Gwynne, Collection and Use of Data from School Egress Trials, in *6th Human Behaviour in Fire Symposium 2015*, Cambridge, UK, pp. 233–244.

[14] A. Cuesta and S. M. Gwynne, The collection and compilation of school evacuation data for model use, *Safety Science*, vol. 84, pp. 24–36, 2016.

[15] R. M. Malina, C. Bouchard, and O. Bar-Or, *Growth, maturation, and physical activity*, 2nd ed. Champaign, Ill: Human Kinetics, 2004.

[16] N. Cameron, Ed., *Human growth and development*. San Diego, Calif: Academic Press, 2002.

[17] D. G. Singer and T. A. Revenson, *A Piaget primer: how a child thinks*, Rev. ed. New York: Plume, 1996.

[18] D. Sutherland, The development of mature gait, *Gait & Posture*, vol. 6, no. 2, pp. 163–170, Oct. 1997.

[19] S. M. V. Gwynne, Improving the Collection and Use of Human Egress Data, *Fire Technology*, vol. 49, no. 1, pp. 83–99, Jan. 2013.

[20] A. Özkaya, A qualitative approach to children of developing countries from human behaviour in fire aspect, in *Proceedings of the Second International Symposium*, MIT, Boston, USA, 2001, pp. 531–538.

[21] E. R. T. Galea, S. Deere, G. Sharp, L. Filippidis, and L. M. Hulse, Investigating the impact of culture on Evacuation behaviour, in *Proceedings of the 12th International Fire Science & Engineering Conference*, University of Nottingham, UK, 2010, vol. 1, pp. 879–892.

[22] World Health Organization, Department of Nutrition for Health and Development, WHO Global Database on Child Growth and Malnutrition. [Online]. Available: http://www.who.int/nutgrowthdb/en/.

[23] K. Fridolf, E. Ronchi, D. Nilsson, and H. Frantzich, Movement speed and exit choice in smoke-filled rail tunnels, *Fire Safety Journal*, vol. 59, pp. 8–21, Jul. 2013.

[24] A. Taciuc and A. S. Dederichs, Determining Self-Preservation Capability in Pre-school Children, The Fire Protection Research Foundation, Technical note Final Report, 2013.

[25] Vyhláška č. 23/2008 Sb., o technických podmínkách požární ochrany staveb [Decree No. 23/2008 Coll., on technical conditions for fire protection of buildings]. .

[26] B. L. Hoskins and J. A. Milke, Differences in measurement methods for travel distance and area for estimates of occupant speed on stairs, *Fire Safety Journal*, vol. 48, pp. 49–57, Feb. 2012.

[27] E. Ronchi and D. Nilsson, Basic Concepts and Modelling Methods, in *Evacuation Modeling Trends*, A. Cuesta, O. Abreu, and D. Alvear, Eds. Cham: Springer International Publishing, 2016, pp. 1–23.

[28] S. M. V. Gwynne and K. E. Boyce, Engineering Data, in *SFPE Handbook of Fire Protection Engineering*, M. J. Hurley, D. T. Gottuk, J. R. Hall, K. Harada, E. D. Kuligowski, M. Puchovsky, J. L. Torero, J. M. Watts, and C. J. Wieczorek, Eds. New York, NY: Springer New York, 2016, pp. 2429–2551.

[29] B. J. McFadyen and D. A. Winter, An integrated biomechanical analysis of normal stair ascent and descent, *Journal of Biomechanics*, vol. 21, no. 9, pp. 733–744, Jan. 1988.

[30] A. Protopapadaki, W. I. Drechsler, M. C. Cramp, F. J. Coutts, and O. M. Scott, Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals, *Clinical Biomechanics*, vol. 22, no. 2, pp. 203–210, Feb. 2007.

[31] A. K. Silverman, R. R. Neptune, E. H. Sinitski, and J. M. Wilken, Whole-body angular momentum during stair ascent and descent, *Gait & Posture*, vol. 39, no. 4, pp. 1109–1114, Apr. 2014.

[32] C. Assaiante, Development of Locomotor Balance Control in Healthy Children, *Neuroscience & Biobehavioral Reviews*, vol. 22, no. 4, pp. 527–532, Mar. 1998.

[33] J. W. Streepey and R. M. Angulo-Kinzler, The role of task difficulty in the control of dynamic balance in children and adults, *Human Movement Science*, vol. 21, no. 4, pp. 423–438, Oct. 2002.

[34] D. Tong and D. Canter, The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire, *Fire Safety Journal*, vol. 9, no. 3, pp. 257–265, Aug. 1985.

[35] J. T. Thijs and H. M. Y. Koomen, Task-related interactions between kindergarten children and their teachers: the role of emotional security, *Infant and Child Development*, vol. 17, no. 2, pp. 181–197, Mar. 2008.