CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Civil Engineering
Department of Architectural Engineering

EVACUATION OF PRE-SCHOOL CHILDREN AGED FROM 3 TO 6 YEARS

DOCTORAL THESIS

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Ph.D. programme: Civil Engineering
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Prohlašuji, že jsem uvedenou disertační práci vypracoval/a samostatně pod vedením školitele doc. Ing. Václava Kupilíka, CSc. a Dr. Enrica Ronchi.
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Disertační práce vznikla v souvislosti s řešením projektu:

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- SGS18/107/OHK1/2T/11 Využití pokročilých modelů požáru a pohybu osob v požárním inženýrství

V Praze dne 31. 8. 2020 ....

podpis

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DECLARATION

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Title of the doctoral thesis: Evacuation of Pre-school Children Aged from 3 to 6 Years

I hereby declare that this doctoral thesis is my own work and effort written under the guidance of the tutor doc. Ing. Václav Kupilík, CSc. and Dr. Enrico Ronchi .
All sources and other materials used have been quoted in the list of references.

The doctoral thesis was written in connection with research on the projects:

- SGS15/011/OHK1/1T/11 Evacuation Parameters and Human Behavior in Fire
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- SGS18/107/OHK1/2T/11 Advanced Fire and Pedestrian Movement Models in Fire Safety Performance-based Design

In Prague on 31.8.2020 ______________________

signature

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Abstrakt

Děti předškolního věku představují zranitelnou složku naší populace, neboť jejich potenciálně limitovaná schopnost samostatného pohybu a orientace může při mimořádné události vyústit ve velmi specifické podmínky a požadavky na evakuaci. Cílem této disertační práce je shrnout a rozšířit současný stav poznání v oblasti evakuace dětí ve věku 3–6 let z předškolních vzdělávacích institucí a získané poznatky prezentovat ve formě vhodné pro další inženýrské aplikace, zejména v požárně bezpečnostním inženýrství.

Teoretická část disertační práce poskytuje ucelený přehled dosavadních vědeckých poznatků týkajících se evakuace předškolních dětí a jejich vývojových specifik. V experimentální části disertační práce jsou prezentována nová experimentální data zaměřená na chování, pohyb, a specifické podmínky při evakuaci předškolních dětí z mateřských škol v České republice. Tato data vycházejí z analýzy 15 experimentálních cvičných evakuací uskutečněných v 10 mateřských školách za účasti 970 dětí ve věku 3–7 let a 87 osob pedagogického a pomocného personálu. Na základě vyhodnocení pořízených videozáznamů bylo shromážděno a interpretováno přes 24 800 pozorování popisujících chování dětí a personálu během celého evakuačního procesu a dále pohybové charakteristiky dětí (rychlost pohybu, specifický tok, hustota, a jejich vzájemné vztahy) na různých částech únikových cest (na chodbách, na schodištích, při průchodu dveřmi). Získané výsledky jsou diskutovány a porovnány se závěry uvedenými v dostupné literatuře. V rámci experimentálního výzkumu byl dále uskutečněn anonymní online dotazník zaměřený na provozní charakteristiku a provádění cvičných evakuací v mateřských školách. Tento dotazník byl tvořen 20 otázkami a byl distribuován do 4 903 mateřských škol v České republice s návratností 23.5%.

V aplikační části disertační práce jsou získané poznatky popisující specifika evakuace dětí z předškolních vzdělávacích institucí shrnuty pro účely další inženýrské aplikace, a to ve formě souboru 18 behaviorálních tvrzení a diskuze jejich přímého uplatnění v požárně bezpečnostní analýze a při matematickém modelování evakuace osob. Výsledky disertační práce jsou dále hodnoceny z perspektivy navrhování požární bezpečnosti staveb a jejich praktického uplatnění v provozu předškolních vzdělávacích institucí, které je prezentovaného jako soubor doporučení pro efektivní provádění cvičných evakuací v těchto provozech.

Klíčová slova: požární bezpečnost, evakuace, předškolní děti, pohybové charakteristiky, chování za požáru, cvičná evakuace, dotazník, mateřská škola

Abstract

Children at the pre-school age represent a vulnerable part of our population whose potentially limited self-rescue capabilities may result in very specific requirements on emergency evacuation. This thesis aims to review and expand our current understanding of evacuation behaviour and movement of pre-school children aged 3–6 years accommodated in early childhood educational institutions and to present the acquired knowledge in the manner suitable for further practical applications, especially in fire safety engineering.

In the theoretical part of the thesis, the general literature background summarizes the present state of knowledge describing evacuation and development of pre-school children. The experimental part of the thesis presents new experimental data-sets and information on children's movement, behaviour, and specific evacuation conditions in nursery schools in the Czech Republic. These data result from the analysis of 15 experimental evacuation drills involving 970 children aged 3–7 years and 87 staff members conducted in 10 participating nursery schools. Based on the analysis of video recordings, over 24,800 data-points describing evacuation behaviour of children and staff members in both the pre-movement and movement phase of the evacuation process as well as movement characteristics of children (travel speed, specific flow, density, and their relationships) on different parts of evacuation routes (in corridors, on staircases, and in doorways) were gathered, interpreted, and compared to results and findings available in the literature. Additionally, an anonymous online questionnaire consisting of 20 questions distributed to 4,903 nursery schools (response rate of 23.5%) revealed the details of real-life operational conditions in nursery schools in the Czech Republic and their practice with evacuation drills.

In the application part of the thesis, a set of 18 behavioural statements on pre-school children evacuation behaviour and movement in early childhood education institutions is identified for the purpose of engineering applications and their direct incorporation in a life safety analysis and egress modelling is discussed. In addition, the knowledge obtained in this study is presented in the view of a fire safety design perspective. The practical research output of this work is a set of recommendations on effective implementation of evacuation drills in educational institutions attended by children at the pre-school age.

Keywords: fire safety, evacuation, pre-school children, movement characteristics, evacuation behaviour, evacuation drill, questionnaire, nursery school

Notation

Lowercase Latin symbols

Symbol	Unit	Description
a, k	—	constants in (2.1) and (2.3)
a_d	m	major semi-axis in (5.7)
a_{IN}, a_{OUT}	m	major semi-axis in (5.6)
b	m	width
b_{cor}	m	width of a measurement area in corridors
b_d	m	minor semi-axis in (5.7)
b_{door}	m	width of a measurement area in doorways
b_{IN}, b_{OUT}	m	minor semi-axis in (5.6)
b_{space}	m	the open horizontal space between two flights
b_{spiral}	m	width of a measurement area on spiral staircases
$b_{str,flight}$	m	width of a measurement area on flights
d_{land}	m	travel path on landings
ch_b	m	chest breadth (transversal diameter)
ch_c	m	chest circumference
ch_d	m	chest depth (sagittal diameter)
h	m	length of a helix
l_{cor}	m	length of a measurement area in corridors
l_{door}	m	length of a measurement area in doorways
l_{spiral}	m	length of a measurement area on spiral staircases
$l_{str,flight}$	m	length of a measurement area on flights
s	m	travelled distance
t	s	time

Uppercase Latin symbols

Symbol	Unit	Description
A	m^2	area
A_{cor}	m^2	area of a measurement area in corridors
A_{land}	m^2	area of a measurement area on landings
A_{occ}	m^2	occupied area by a person
A_{spiral}	m^2	area of a measurement area on spiral staircases
$A_{str,flight}$	m^2	area of a measurement area on flights
D	$m^2\,m^{-2}$ or $pers \cdot m^{-2}$	density
F	$pers \cdot s^{-1}$ or $m^2\,min^{-1}$	pedestrian flow
F_s	$pers \cdot s^{-1}\,m^{-1}$	specific pedestrian flow
N	pers	number of persons
S	$m \cdot s^{-1}$	travel speed
TI	—	thoracic index

Contents

Chapter 1

Introduction

1.1 Motivation

The understanding of the evacuation processes in case of fire and the application of relevant scientific knowledge to ultimately improve safety level represent the principle goals of various disciplines, such as fire safety engineering, crowd management, or safety management. Although there are numerous factors influencing an evacuation procedure, in a simplified way, aspects of the evacuation process can be categorised as configurational, environmental, procedural, and behavioural [1]. Even though human behaviour may be highlighted as the factor which is the most difficult to predict, a couple of categories may be determined to cluster the influencing elements, namely occupant, building, and fire characteristics, which interplay during the whole event and affect both its development and outcome [2]. Looking at occupant characteristics, factors such as gender, age, movement ability and functional limitation, familiarity with the building, alertness, role, fire safety training, as well as personality traits should be considered in fire safety design [2, 3].

Increased importance to all these characteristics should be devoted especially in the occupancies, where vulnerable populations (also called "at risk" populations) are present. People with various physical and cognitive impairments or other groups, who might not be able to perform self-rescue activities can be considered as such population. Those people may be at various levels dependent on assistance in evacuating provided by others. One of these groups undoubtedly represents young children under 6 years of age, whose potentially limited self-rescue capabilities distinguish their evacuation process from that involving matured adults. A basic assumption that the young children move and behave in another way than the other age groups seems not to be difficult to establish; nevertheless, quantification of this aspect is not a trivial issue anyway.

Although a great body of research has been performed to investigate the issue of evacuation in case of fire across various occupancy, environment, and emergency conditions (for example [4–8]), the vast majority of them was focused on adult population and only a small number of studies have addressed the evacuation and movement characteristics of children under 6 years of age [9–20]. In the last 5 years, this specific matter has become an interesting issue attracting much attention by researchers in both fire safety science and pedestrian and evacuation dynamics [21–25]. Nevertheless, the number of relevant studies addressing evacuation behaviour and dynamics of pre-school children remains limited. Whereas it is mostly the data scarcity, which represents an important obstacle when modern fire engineering approaches based on performance-based design (such as computer evacuation modelling) should be responsibly applied at the practical level, further work should be done to enhance the current knowledge on movement and evacuation characteristics of pre-school children and to support limited databases available in this field. In this context, new data-sets should be presented in a comprehensive, but clear and easy understandable manner which enables an appropriate engineering application, notably in evacuation modelling.

The effort to broaden available knowledge and relevant engineering data related to the issue of pre-school children evacuation is the primary motivation as well as the goal of this study. It is believed that understanding of children's movement and behaviour specifics based on relevant scientific knowledge and its further suitable application is crucial not only in the evacuation and building design. In addition, supported by sufficient knowledge, the level of safety in buildings occupied by children at the pre-school age can be appreciably enhanced and potential risks and mistakes related to their specifics can be prevented.

1.2 Scope of the study

It may be considered that in today's society, young children under 6 years of age can be occasionally present in almost all types of occupancy in civil buildings which specific circumstances may directly impact children's evacuation and movement patterns. For this study it is therefore fundamental to specify occupancy which is the most relevant and also challenging to be investigated. Apart from locations where children of that age spend time individually with their families and locations where they may temporarily gather such as kids clubs and playrooms, the facilities with their highest proportion and regular occurrence are definitely early childhood educational institutions.

Children's attendance in early childhood education, which prepares them for their entry into compulsory primary schools and enables their parents an earlier return to working life, is a common practise in most of (not only) Western world. According to the Czech Statistical Office, more than 80% of children between 3 and 5 years of age and 97% of 6-year-olds are involved in early childhood education [27]. Looking at other European countries (see Figure 1.1), the enrolment rates of children 3–5 years old may be even higher, almost 100% in some cases [26]. It can be therefore assumed that, almost in the entire developed part of the world, a pre-school environment is a routine part of life of majority of children. Moreover, due to high concentration of children and particularly low child-to-adult ratio this occupancy represents very difficult and specific evacuation conditions. **Hence, this study focuses entirely**

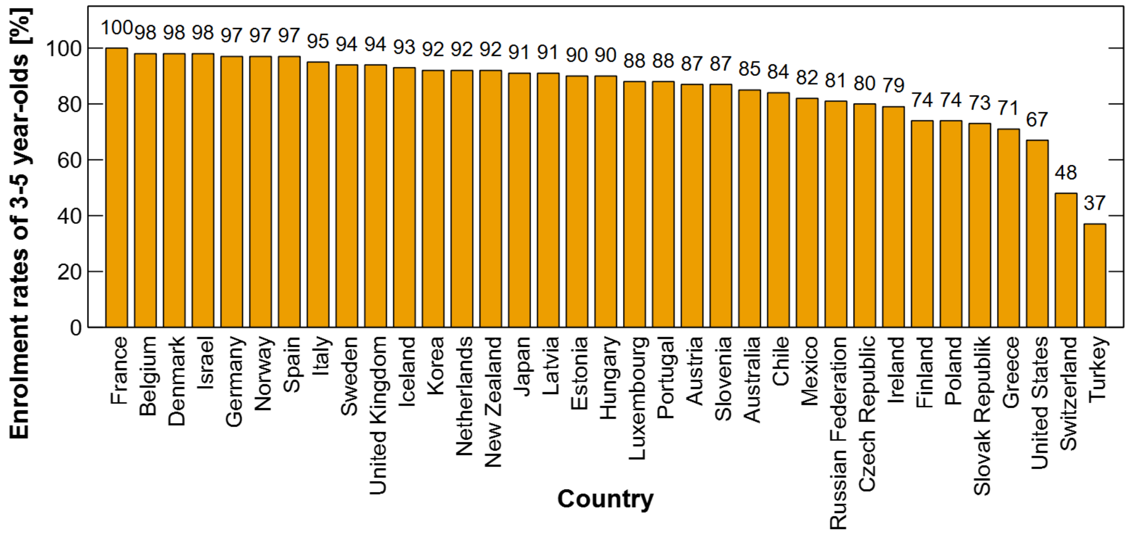


Figure 1.1: Enrolment rates of children between 3 and 5 years in early children education in OECD countries (indicators on early childhood education and care 2013, 2014 and 2015) [26]

on evacuation and movement characteristics of children accommodated in early childhood educational institutions.

Since early childhood educational systems vary across the countries, particularly in age categories of involved children or terminology, it is therefore appropriate to define the term “early childhood educational institutions” more precisely to avoid confusion. In general, very young children can be registered in special educational programs typically designed for children below the age of 3 years. These programs have different names, for instance “day nursery”, “nursery”, “nursery school”, “early childhood education”, “family day care”, “day care centre”, “child care centre” and others. On the other hand, the pre-primary educational programs are usually designed for children from the age of 3 years to the official primary school entrance age. Also in this case, names of the pre-primary programs may differ including terms such as “kindergarten”, “nursery education”, “pre-elementary school/education”, “pre-primary school/education”, or “pre-school”. It is important to mention that these programs have commonly a special subcategory which is intended solely for children they are close to compulsory schooling (around 5 and 6 years of age). These subprograms may be named for instance “preparatory classes”, “pre-primary stage”,“school kindergarten”, “pre-school classes”. Considering this fact is important for a clear definition of the frequently used term “pre-school age” [26]. In everyday language, this age interval covers the whole period that children spend in a pre-primary educational program (i.e. typically between 3–6 years of age). However, from the pedagogical point of view, the “pre-school age” labels only the short period (around 1 year) before children entry to a compulsory primary school. **In this study, the terms “pre-school age” or “pre-school children” denote the whole pre-primary educational period in line with its general sense, i.e. children typically at the age from 3 to 6 years.**

In the Czech Republic, pre-school education is institutionally provided by nursery schools (pre-schools) organised for children of the age normally from 3 to 6 years. Preparatory classes (which can be provided also by primary schools) are obligatory for children of 5 years of age. Nursery schools may be attended also by children outside the outlined age limits, i.e. over 6 years of age with postponement of the compulsory school attendance or under 3 years of age but no sooner than 2 years (details on early childhood education and care in the Czech Republic can be found in Section 6.1.1). **Based on the Czech educational system, the subject of this study are primarily children attending the pre-primary education typically in the range from 3 to 6 years of age. Here, the educational programs and (in a figurative sense also) the accommodating educational institutions are denoted as nursery schools.**

1.3 Research objectives

The main purpose of this research is to enhance our knowledge and to get new engineering data describing evacuation behaviour and movement characteristics of pre-school children during evacuation drills from nursery schools. Moreover, the research aims to investigate and discuss specific conditions of evacuation from nursery schools and to present the obtained knowledge in the manner appropriate for further practical application.

More broadly, the purpose of this study can be seen at different levels. At the scientific level, the proposed research aims to provide a comprehensive overview of our current knowledge of pre-school children's movement and evacuation behaviour available in literature extended by including new experimental findings. At the second level, the engineering level is considered, since it is believed that new experimental data acquired in this research can also help to partially expand the currently limited database of engineering data relevant for fire engineering approaches and further applications. The last level may be referred to as the practical level which aims to apply the acquired knowledge in fire safety design and also in daily life of nursery schools facilities. This application follows the main thought of this thesis to use the outcomes of this research as directly beneficial for the studied population.

The objectives of the proposed research can be summarised as follows:

1. Provide a comprehensive theoretical background on early research and children's development
2. Get new experimental data-sets and information of children's movement, behaviour, and specific evacuation conditions in nursery schools focused on:
    (a) Behaviour of children and staff members in evacuation situation (during evacuation drills from nursery schools)
        – Pre-movement times, responses and activities of children and staff members in the pre-movement period, level of assistance required by children, behaviour on different parts of escape routes

   (b) Children's movement characteristics in evacuation situation (during evacuation drills from nursery schools)
      – Travel speed, pedestrian flow, and density in corridors, on staircases, and through doorways
   (c) Specifics of evacuation procedure and complication arising during evacuation process in nursery schools during evacuation drills
   (d) Description of real-life operational conditions in nursery schools in the Czech Republic and their daily practice with evacuation drills

3. Present the obtained results and knowledge in a manner suitable for further engineering applications and for a direct application in educational institutions attended by children at the pre-school age

Within the scope of the research objectives, the following research questions are formulated:

1. What is our current knowledge of evacuation behaviour and movement characteristics of pre-school children accommodated in early childhood educational institutions?
2. What developmental changes ongoing in children during the pre-school age should be consider when their evacuation is evaluated?
3. How do children at the pre-school age move and behave during evacuation situations in nursery schools?
4. What specifics should be properly taken into account in fire safety and evacuation analyses when pre-school children are under consideration?
5. What are the real-life operation conditions and experience with evacuation drills in nursery schools in the Czech Republic and how do they impact emergency evacuation process?
6. How should the evacuation drills in early childhood educational institutions be provided to streamline the process and to improve the life safety level in this type of facilities?

1.4 Research strategy

To achieve the research objectives stated above, a research strategy following the same structure was determined and pursued:

1. In order to provide a comprehensive theoretical background on early research and children's development a detailed **literature review** in this field was carried out.
2. Based on the summarised knowledge, **experimental research** was proposed which consisted of two main parts:

(a) Children's evacuation behaviour and movement characteristics as well as specifics of evacuation procedure were observed during **experimental evacuation drills** conducted in participating nursery schools

(b) Real-life conditions for evacuation (drills) in nursery schools in the Czech Republic were studied through a **questionnaire on nursery schools in the Czech Republic and their implementation of evacuation drills** distributed among all nursery schools in the Czech Republic

3. The main outputs of the research were discussed and interpreted in the format **suitable for engineering purposes** and the acquired knowledge was used to establish a list a **suggestions for effective performing of evacuation drills** in early childhood education institutions.

The main phases of the research strategy are graphically illustrated in Figure 1.2.

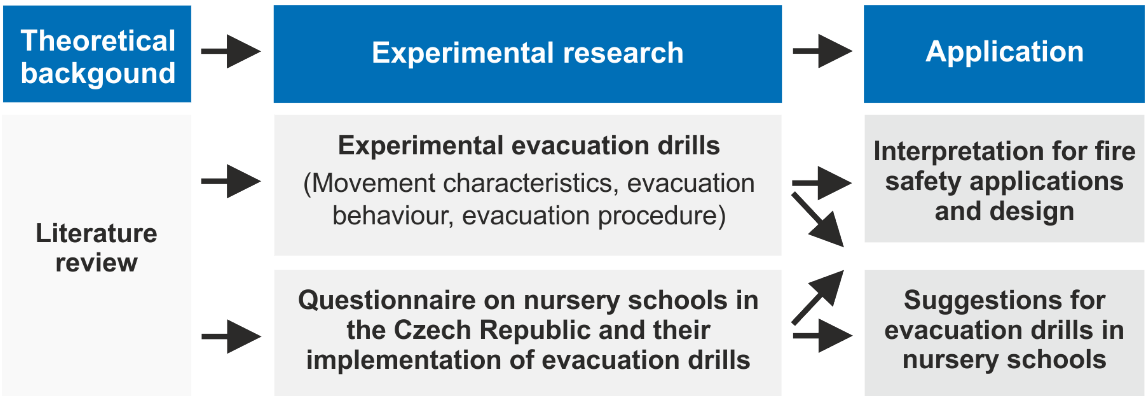


Figure 1.2: Research strategy

1.5 Outline of the thesis

In order to follow the proposed research strategy and to unify the structure with a close relation to the research objectives, the current study is divided into three main parts:

- Part I: General literature background,
- Part II: Experimental research,
- Part III: Application.

In **Part I**, the theoretical framework vital for the adopted research methods is summarised and divided into two chapters. **Chapter 2** presents an overview of our current knowledge of evacuation behaviour and movement of pre-school children and it aims to provide a comprehensive summary on research studies and engineering data dealing with this issue available in literature. The other part of the literature background in **Chapter 3** is focused on child's development during early childhood period. It intends to summarise a general background in this field, essential for further understanding how may pre-school children's developmental specifics influence their evacuation. In order to keep the structure of the study clear and to facilitate thematic reading, more specific theoretical background relevant to the used experimental methods can be found in the introductory part to each chapter in the part on experimental research.

Part II presents the experimental research carried out in this study. In **Chapter 4**, the ethical considerations of the conducted research are discussed. The following **Chapter 5** deals with the experimental evacuation drills in participating nursery schools including the employed methods, obtained results and their discussion. The part on experimental research is closed by **Chapter 6** which presents the questionnaire carried out to collect data on operational conditions and experiences with evacuation drills in nursery schools in the Czech Republic.

Finally, the application of the outcomes obtained in this study is introduced and debated in **Part III**. **Chapter 7** offers a discussion and further interpretation of the acquired results and knowledge for the purposes of fire safety engineering applications as well as for their practical use in early childhood educational institutions.

Conclusions of the presented research are summarised in **Chapter 8**. Additional and complementary material can be found in attached Appendices A–E.

Part I

General theoretical background

Chapter 2

Evacuation behaviour and dynamics of pre-school children

In this chapter, research done in the field of fire safety focused on children's evacuation from early childhood educational institutions is reviewed, whereas the research studies concerning children's evacuation behaviour and dynamics (movement characteristics) are mainly of interest. Further work dealing e.g. with educational programs intended for pre-school children [28], with the effectiveness of smoke alarms in waking up children in their home environment [29], with investigation of house fires involving children [30, 31], or with children as main actors when playing with fire are not within the scope of this study. In order to follow the timeline of the current project, the general overview of works is tabulated in the following manner: The studies presenting research on evacuation of children aged 0–6 years published prior to 2014 (the beginning of the current project) are provided in Table 2.1. Whereas the studies published in the period from 2014–2020 (the duration of the current project) are reported in Table 2.2.

2.1 Overview of conducted research studies focused on pre-school children evacuation

Considering evacuation research studies in the last century, only few works can be found which focused on the issue of evacuation of children. In most cases, specific movement factors of children were mentioned only marginally as a part of a larger research focus. One may note the work of Predtechenski and Milinskii [4] who considered different physical dimensions of children in the concept of occupied area used for expression of density. In this concept, the density is calculated as the ratio of the sum of horizontal projections of persons to the floor area occupied by the flow [$m^2\,m^{-2}$]; thus, it enables to take into consideration the body proportions of children which differ from those of adults.

A study dealing specifically with fire safety in pre-schools and day care centres was introduced by Murazaki and Ohnishi in Japan in 1985 [9]. The evacuation times

Table 2.1: Studies on evacuation of children under 6 years of age published prior to 2014

Year	Author	Title	Age [years]	Reference
1985	Murazaki and Ohnishi	A study of fire safety and evacuation planning for pre-school and day care centres	0–5	[9]
2009	Kholshchevnikov et al.	Pre-School and school children building evacuation	3–17	[10]
2009	Larusdottir and Dederichs	Evacuation dynamics of children - walking speeds. flow through doors in daycare centers	0–6	[11]
2011	Lu	The evacuate training problems of earthquake in China	3–18	[12]
2011	Larusdottir and Dederichs	A step towards including children's evacuation parameters and behavior in fire safe building design	0–6	[13]
2011	Campanella et al.	Empirical data analysis and modelling of the evacuation of children from three multi-storey day-care centres	0–6	[14]
2012	Larusdottir and Dederichs	Evacuation of children - movement on stairs and on horizontal plane	0–6	[15]
2012	Kholshchevnikov et al.	Study of Children Evacuation from Preschool education institutions	0–7	[32]
2012	Capote et al.	Children evacuation: empirical data and egress modelling	3–16	[33]
2012	Capote et al.	Children behaviour during evacuation process in school buildings	3–16	[17]
2013	Cuesta et al.	Exploring the current egress models capabilities for simulating evacuation of children through stairs	4–6, 12–16	[18]
2013	Takizawa et al.	A study for evacuation behaviour characteristic of nursery school children and evacuation planning (Part1): The survey of evacuation speed	0–7	[19]
2013	Taciuc and Dederichs	Determining Self-Preservation Capability in Pre-School Children	0–6	[20]
2013	Larusdottir et al.	Evacuation of Children: Focusing on daycare centres and elementary schools	0–15	[34]

required by children aged 0–5 years and by assisting staff were obtained during evacuation drills in pre-school buildings and effectiveness of using stairs and slides was analysed and compared. Furthermore, the authors concluded that familiarity with the system and procedures is the key factor impacting evacuation efficiency and that escape routes should correspond with circulation routes in the building which are regular used by children. In the first decades of 21th century, a growing scientific interest in describing the movement abilities and the evacuation performance of children can be observed. This trend is consistent with the widespread increasing focus on potential "at-risk" populations, i.e. vulnerable groups of people, who might not be able to perform self-rescue activities and who will need assistance in evacuating, which attracted much attention in the field of fire safety science [32, 35, 36]. As can be seen from Table 2.1 the issue of children's evacuation has been more extensively studied in the recent decades, especially by research groups in Denmark, Russia, Japan, and Spain.

Extensive research in this field has been conducted at the Technical University in Denmark by Larusdottir and Dederichs. In the project on fire evacuation of Danish daycare centres involving children aged 0–6 years [11, 13, 15, 34], empirical data on walking speed, flow, density, and evacuation behaviour were obtained in 16 full-scale evacuation experiments in 10 daycare centres. The obtained data-set that was also used for a comparative study [14] employing egress modelling of children movement using the pedestrian simulation tool Nomad [37,38]. Another study aimed to determine the self-preservation capacity in pre-school children [20].

The issue of evacuation training and related problems in education facilities in the case of earthquakes was discussed by Lu [12]. However the purpose to evacuate a building is not a fire situation in this study evacuation drills in schools (including kindergartens involving children aged 3–5 years) were observed and total evacuation times and travel speeds were measured. The results regarding pre-school children contain only the value of averaged speed equal to 222 $n{\cdot}m^{-1}$ (meaning probably 222 persons per minute) and evacuating time 4.5 minutes. Any background information on research methods or data analysis are not available.

A research study on children's evacuation has been performed by Kholshchevnikov et al. at the State Moscow University of Civil Engineering and at the Academy of State Fire Service of Russia [10, 16], where the pre-evacuation times and movement characteristics in pre-school buildings under the conditions of routine building use and during evacuation experiments were investigated. The observations were carried out in two stages: phase before the movement started and movement phase along the different sections of the circulation routes. Furthermore, in the case of the movement along circulation routes, observations were made both in daily routine use situations and in experimental situation when a group of children was asked to move through a survey plot at a usual pace. The experimental conditions employed are not described in more detail and the details on dimension of the routes are missing. Among others, the comprehensive results consist of travel speeds at various flow density intervals in different escape route sections (horizontal routes, upstairs, downstairs, openings) and basic relationships between specific flow and density.

Another investigation of the evacuation behaviour of children of pre-school age formed a part of a study conducted in Japan [19]. 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 evacuation drills conducted in a school institution attended by children aged from 3 to 16 years was analysed by the GIDAI research group in Spain. Capote et al. [17, 33] and Cuesta et al. [18] presented data-sets from three evacuation trials. The measured parameters, specifically pre-movement

Table 2.2: Studies on evacuation of children under 6 years of age published 2014–2020

Year	Author	Title	Age [years]	Reference
2016	Cuesta and Gwynne	The collection and compilation of school evacuation data for model use	4–16	[39]
2016	Najmanová et al.	Staff-to-child ratios in day-care centres: a concern with respect to fire safety	0–3	[40]
2017	Najmanová and Ronchi	An experimental data-set on pre-school children evacuation	3–6	[22]
2017	Hamilton et al.	Human behaviour during evacuation of primary schools: Investigations on pre-evacuation times, movement on stairways and movement on the horizontal plane	4–12	[23]
2019	Hamilton et al.	Toward Fire Safe Schools: Analysis of Modelling Speed and Specific Flow of Children During Evacuation Drills	4–12	[24]
2019	Fang et al.	Experimental study on the movement characteristics of 5–6-year-old Chinese children when egressing from a pre-school building	5–6	[25]
2019	Zhou et al.	The relationship between different types of alarm sounds and children's perceived risk based on their physiological responses	3–6	[41]
2020	Li et al.	A comparative study on the bottleneck flow between preschool children and adults under different movement motivations	3–5	[42]

times, stair travel speeds, and flow rates through the exit doors, were presented as input data for simulations in evacuation models in order to assess the capability of these models to represent the movement of children. In the follow-up work [39] (see Table 2.2) this data-sets were extended to five evacuation drills in total and the analysed variables comprised of pre-evacuation times, route use, travel speeds, exit use, and arrival times.

In recent years, several projects dealing with the children's evacuation issue have been presented in the literature (see Table 2.2). One of these contributions focused on experimental data from two semi-announced evacuation drills in a nursery school presented author of the current study [22]. In this work, the variables of pre-movement time, travel speed on horizontal and vertical escape routes, and total evacuation time were observed by children 3–6 years old. In addition, children's travel speeds were evaluated separately as movement speeds (speeds of continuous movement) and modelling speeds (speeds on particular parts of escape routes which may include various stops). Besides movement characteristics, considerations affecting the self-rescue abilities of pre-school children and their evacuation behaviour were discussed.

Human behaviour and movement during evacuation of primary schools was also studied at Letterkenny Institute of Technology in Ireland by Hamilton et al. [23, 24]. The authors reported results from twelve full-scale evacuation drills in four primary school educating children aged 4–12 years which consist of pre-evacuation times, horizontal travel speeds and speeds on stairs, specific flows, and densities. Moreover, the fundamental diagrams describing relations between travel speed, flow, and density and their comparison with other studies are included in the data-set. However, the results for pre-schoolers are mostly evaluated separated from the other age groups in this study.

Another experimental study focused on movement characteristics of 5–6-year-old children was carried out by Fang et al. in China [25]. The provided data-set was acquired during an evacuation drill including three classes of pre-school children evacuated from the third floor of a pre-school building. The results included a description of the movement process and evaluation of the number of children, density, flow, and travel speed in the measurement areas (corridors and stairs). Fundamental movement relationships between travel speed, flow, and density were also discussed and compared to the design curves in the fundamental diagrams presented by Gwynne and Rosenbaum in SFPE Handbook (5^{th} edition) [43].

The issue of risk perception of pre-school children to explore the mechanism behind their evacuation behaviour was addressed by Zhou et al. [41]. In this study, the authors aimed to evaluate the effects of three different alarm types (voice alert, warning alarm, and their combination) on children's physiological responses. The physiological data was collected through an on-side field experiment involving 42 children between 3–6 years of age where the physiological indicators of children were monitored by wearable sensors.

The most recent study dealing with movement characteristics of pre-school children aged 3–5 years under laboratory conditions was conducted by Li et al. [42]. This work aimed to investigate dynamics of 54 children passing through a 1.2 m long artificially constructed bottleneck of different widths. Based on video recordings obtained during the controlled experiments children's trajectories (automatically extracted), density and speed distribution, and flow were estimated in relation to a high movement motivation of children.

2.2 Evacuation behaviour of pre-school children

Based on the overview presented in the previous section, several research studies addressed issues related to pre-school children's behaviour during emergency situations in early childhood educational occupancies [9, 10, 13, 16, 20, 22, 23, 25, 33, 34]. In this section, the studies are further reviewed and their conclusions on behavioural aspects of pre-school children's evacuation are summarised. For easy of reference, the provided literature review follows the general engineering timeline of building fire evacuation, i.e. the evacuation process is roughly divided into two main phases: the pre-movement phase (also referred as pre-evacuation phase, delay time to start, response phase etc. in literature) and the movement phase [44–46].

2.2.1 Pre-movement phase

The pre-movement phase is usually assumed to start with a building alarm initiation or when occupants are exposed to cues from the fire event or are alarmed. It includes all human interpretation, reactions, and decision-making actions, and it ends with the first move made by occupants towards a safe location (i.e. purposive movement) [3]. In order to quantify this part of the evacuation process the variable referred to as the pre-movement time is often used in literature. An overview of pre-movement times experimentally measured in pre-school children occupancies is given in Table 2.3. Here, the data is summarised together with brief description of experimental background, data collection methods, and pre-movement time's definition as it may vary across research studies. Considering occupancy involving pre-school children, the end of the pre-movement time is typically defined as the moment when a child left a group cell [16, 22, 23, 33, 34]. Furthermore, the movement phase (leaving the current room or classroom) generally starts when the whole group of children is prepared to evacuate and thus, the pre-movement time can be related to the whole group [16, 22, 23, 33]. However, differences in the definition of pre-movement time amongst the research studies should be mentioned. The start of the pre-movement time can be determined either equal to alarm activation [23, 33, 34] or to the moment when the alarm was actually delivered [16, 22] (i.e. without warning time). Similarly the end of the pre-movement time can be defined either as the time when the first child left a current room [22, 23, 33] or the time when a group cell was left by the last child [16, 34].

Table 2.3: Literature review of pre-movement time in early childhood educational institutions

Reference	**Country**	**Observational conditions**	**Age [years]**	**Pre-movemenent time (mean/min/ max/SD (data-points)) [s]**	**Collection method**
Larusdottir et al. [34]	Denmark	16 announced evacuation drills in 10 day-care centres (in total 1017 persons involved)	3–6	114 / 10 / 545 / - (N/A) 54 / - / - / - (N/A) (excluding warning time)	Video-analysis; “pre-evacuation time”: from the start of the drill until the last child left the room (averaged time between the first and last child left 20 s)
Kholshchevnikov et al. [10]	Russia	Observations and experimental trials in 8 kindergartens	3–7	8 / 4 / 18 / 3 (N/A) (indoor clothing) 23 / 8 / 48/ 12 (N/A) (with blankets) 196 / 126 / 270 / 47 (N/A) (winter clothing)	Video-analysis; “pre-movement time”: a staff member started to arrange the evacuation process until the room was evacuated
Capote et al. [17, 33]	Spain	1 announced (to staff members, not to children) evacuation drill in a school institution	4–5	38 / - / - / - (1 class)	Video-analysis; “pre-movement time”: from alarm (start the drill) until children were prepared to leave a classroom (in queue)
			5–6	21 / - / - / - (1 class)	
Najmanová and Ronchi [22]	Czech Republic	2 semi-announced evacuation drills in 1 nursery school (2 buildings)	3–4	46 / 12 / 68 / 16 (6 classes)	Video-analysis; “pre-evacuation time”: from delivery of verbal warning until all children in a class were prepared to leave (the first child started to move)
			5–6	20 / 13 / 32 / 7 (4 classes)	
Hamilton et al. [23]	Ireland	12 evacuation drills in 4 mainstream primary schools (1 announced followed by 2 unannounced drills in each school)	5–6	23[1)]/5[1)]/46[1)]/- (24 classes)	Video-analysis; “pre-evacuation time”: from the first activation of the evacuation cue until the first person exited a room; number (percentage) of classes intended for 5-year-old and 6-year-old children not available
			4–12	19 / 4 / 55 / 11 (87 classes)	

[1)] the value read from the graph
N/A information not available

In relation to pre-school children's behavioural aspects during the pre-movement evacuation phase, the reviewed research studies are consistent in several findings which can be summarised as follows:

– Pre-school children do not react independently to warning signal and the pre-movement time is strongly influenced by individual decisions and reactions of responsible staff members [10, 13, 16, 17, 22, 25, 33, 34].
– Actions of staff members during pre-movement phase are dependent on age of children [22, 34]. Therefore, longer pre-evacuation times can be assumed in classes with younger children than in classes with older children [22, 23].
– Evacuation behaviour of both children and staff members reflects the daily routine and rules in the educational institution; children tend to follow a sequence of memorised daily activities (e.g. changing shoes, getting dressed, standing in front of the door waiting for the signal to go [9, 13, 22, 34].
– Pre-school children tend to use familiar exits, however the final exit choice is in competence of staff members [13, 25, 34].
– Pre-movement time can be reduced with training [9, 13, 23, 34].

Detailed observation of pre-school children's evacuation behaviour during full-scale evacuation experiments in danish daycare centres was a part of the project carried out by Larusdottir and Dederichs [13,15,34]. During the performed evacuation drills the effect of alarm type on pre-movement time was investigated [13,15]. In this study, the pre-movement time was defined as the time from the detection of emergency situation until the evacuation movement started, i.e. until persons left the current room. The pre-movement times measured in daycare centres with a warning system (in total 5 daycare centres with smoke detectors or automatic alarm and warning system) and in daycare centres without any warning system (in total 5 daycare centres where verbal warning was given by a responsible staff member personally or using internal phone system) were compared. The results showed that longer pre-movement times caused by longer warning times were observed in daycare centres without any warning system. The time delay until the warning was sounded in all classrooms was at maximum 95 s. Apart from the effect of alarm type, a need of assistance provided to children during the pre-movement phase was observed. It was found that 85.9% of children 3–6 years old evacuated without physical assistance, 12.3% required some physical assistance (e.g. hand holding, gently pushing towards exit), and only 1.8% needed to be carried. The averaged staff-to-child ratio in the groups of 3–6-year-old children was 1:6.1. Further behavioural considerations as well as comprehensive discussion related to pre-school children's evacuation acquired during this project summarised Larusdottir et al. [34], namely staff involvement during the whole evacuation process, pre-evacuation activities, and pre-evacuation times. Furthermore, behavioural aspects assessed in evacuation theory [3] such as affiliation, family bounds, helping others, or social influence were interpreted in relation to children's behaviour.

Another study conducted at the Technical University in Denmark focused on self-preservation capacity in pre-school children was presented by Taciuc and Dederichs [20]. In order to determine at what age children can be considered capable of self-preservation, 62 teachers from day-care centres and 25 experts in children development in the USA, Canada, Denmark, Germany, and Romania were addressed to response a questionnaire. Based on their answers it was concluded that most of children can understand and follow simple instructions by the age of 3 years (30–36 months), walk on the horizontal plane without assistance by the age of 2 years (24 months), and climb downstairs by the age between 2 and 2.5 years (24–30 months). In addition, the most of educationalists responded that children can be upset due to unusual events in their regular schedule by the age between 2 and 2.5 years (24–30 months), according to the experts in development this age limit ranges between 3–3.5 years of age (36–42 months) for majority of children.

The issue of children's evacuation behaviour and evacuation procedure in (early childhood) educational buildings was addressed by Kholshchevnikov et al. [10, 16]. During an unannounced evacuation drill in two children's amateur art centres accommodating children from 3 to 17 years of age it was observed that about 90% of the total evacuation time made the delay to start the evacuation movement to a place of safety [10]. The pre-movement phase, notably the impact of different dressing scenarios in different seasons (e.g. in indoor clothing, with a blanket thrown upon the shoulders, and in winter clothing) on pre-movement time was further studied in 8 kindergartens attended by children aged 3–7 years [10, 16]. Since a staff member could not start evacuation before the whole group of children was ready, the authors suggested that the pre-movement time for children should be determined by the moment they left a classroom. It was concluded that the pre-movement time can be accepted as 36 s in summer, 300 s (5 min) in spring and autumn, 460 s (7.5 min) in winter, and 66 s (1.1 min) in winter when only blanket thrown upon the shoulders were used. Another observation during the experiments showed that children did not react to warning signal without the adults' activity and they left their seats first after the intervention of the staff members. Here, the staff members had a decisive role in forming the whole pre-movement phase.

2.2.2 Movement phase

In contrast to the pre-movement phase, the movement phase usually indicates the travel process of occupants through a building which terminates at a safe place [3]. Observations of pre-school children's behaviour during the travel through a building were often made on staircases since movement on this part of evacuation routes may be challenging for children. Common findings found in reviewed research studies are following:

- When moving downstairs handrails are frequently used by pre-school children [22, 33, 34].
- Pre-school children's movement on staircases is adversely affected by a marking time pattern [22, 33].
- Children's behaviour on staircases may be affected by their familiarity with the escape route (rarely used escape versus daily used staircases), staircase

geometry (straight versus spiral staircases), and environment (internal versus external staircases) [15, 22, 34].

Level of assistance required by pre-school children on staircases investigate Larusdottir et al. [34]. The results revealed that 85.2% of children 3–6 years old moved on stairs without physical assistance, 13.9% required some physical assistance, and 0.9% were carried by staff members. Comparing these values to those describing the level of assistance required by children during pre-movement phase (mentioned in the previous Section 2.2.1), only minimal difference can be seen. Moreover, it was found that level of assistance provided to children on stairs did not affect their travel speed, i.e. children's mean travel speed was similar regardless the level of assistance. Considering children's movement on staircases, attention was also paid to handrail use and hand holding. Children 3–6 years old who did not receive any assistance from staff members used a handrail in 58.6% of the cases, which was almost the same value as for children who were assisted (44.7%). Furthermore, movement in pairs holding each other's hand was not a common practise by pre-school children. With a few exceptions, hand holding was observed only between children and staff members.

Handrail use by pre-school children was also studied by Capote at al. [33] during two evacuation drills in a school building. The staircase handrail was used by 72% of children aged 4–6 years in the first evacuation drill and by 66% of children in the second one. Moreover, an occurrence of a marking time pattern and alternating pattern (termed "two feet/step" and "one foot/step" in the study) by children climbing downstairs was observed. The percentage of children adopting the alternating pattern was approximately 44% in the first evacuation drill (mean travel speed 0.59 $m{\cdot}s^{-1}$) and 67% in the following one (mean travel speed 0.59 $m{\cdot}s^{-1}$). Travel speed of children using the marking time pattern was lower, 0.39 $m{\cdot}s^{-1}$ on average.

2.3 Movement characteristics of pre-school children

In order to evaluate occupants' movement to a place of safety or refuge, several measurable variables describing human movement are commonly used for purposes of engineering calculations and quantitative methods. Besides other movement characteristics, speed, density, and flow of persons are the variables receiving a particular attention [43, 47]. Based on the literature review provided earlier in this chapter (see Table 2.1 and Table 2.2), relevant data-sets describing movement characteristics of children at the pre-school age are further summarised in form of tables. The movement characteristics are reviewed separately as travel speeds (on a horizontal plane and on stairs), flows, densities, and fundamental diagrams presenting relations between these variables. However, data-sets presented in a tabulated and comprehensive form may tempt to be used in an oversimplified or inappropriate way. In general, the major limitation of further comparison and application of different research results is deemed to consist in various levels of details available in literature, notably details considering a description of a building enclosure and evacuation procedures, data collection methods, or assumptions made in the data analysis. Insufficient description of evacuation routes geometry or level of announcement of an evacuation drill may cause misinterpretation and subsequently misleading application of the reported results. Similarly, differences in data collection methods, measurement techniques, and data analysis may influence the meaningfulness of a direct comparison of different research results, e.g. when different methods to evaluate travel distance or density may be applied [48–50]. It is possible to mention that increasing level of details describing provided data-set can be found in the most recent research studies (hopefully thanks to general awareness of this limitation). Thus, where available, background information clarifying research methods and data analysis should be always kept in mind when engineering data-sets are interpreted and applied.

2.3.1 Travel speeds

A summary of data-sets reporting travel speeds of pre-school children on the horizontal plane and on stairs (downstairs and upstairs) is revealed in Table 2.4 and Tables 2.5 and 2.6 respectively. The overviews were adopted mostly from [22] and they were further extended by including the most recent studies and a more detailed background information. Literature review of knowledge considering speed-density relation is separately discussed in Section 2.3.4. Considering travel speed data-sets and understanding of collection and calculation methods used in the research is crucial for the interpretation of the results. Specifically, a distinction should be made whether the presented travel speed was assumed as the speed of continuous movement (usually measured in predetermined areas with a specific travel distance) or as the overall speed particular parts of escape routes which includes various stops (also known as the modelling speed [23]). An appropriate distinction of these speeds is important particularly in evacuation modelling when current evacuation models are used. The concept was acknowledged for description of pre-school children's movement by Najmanová and Ronchi [22] and later also in the recent evacuation studies [24].

Table 2.4: Literature review of children's travel speed on the horizontal plane

Reference	Country	Observational conditions	Age [years]	Speed (mean/min/max/SD) [m·s^{-1}] (data-points)	Collection method	Speed-density relationship
Larusdottir and Dederichs [13, 15]	Denmark	16 announced evacuation drills in 10 day-care centres (movement of 71 children aged 0–6 years observed)	3–6	0.84 / 0.42 / 1.36 / 0.25 (N/A) (walking) 2.23 / 0.83 / 3.24 / 0.64 (N/A) (running)	Video-analysis; unimpeded speeds at low densities (less than 0.5 pers·m^{-2}), travel distance of the measured area not available (movement speed assumed)	No
Kholshchevnikov et al. [16]	Russia	Observations and experimental trials in 8 kindergartens	3–4	1.05 / 1.00[1)]/ 1.10[1)]/ 0.22 (78) (walking) 1.78 / 1.70[1)]/ 1.86[1)]/ 0.29 (50) (running)	Video-analysis; speeds at low densities (0–1 pers·m^{-2}), values for different density intervals and age groups available; travel distance of the measured area 1 m (movement speed assumed)	Yes (for the entire age group 3–7 years)
			4-5	1.12 / 1.06[1)]/ 1.19[1)]/ 0.17 (32) (walking) 1.87 / 1.77[1)]/ 1.97[1)]/ 0.34 (45) (running)		
			5-7	1.61 / 1.54[1)]/ 1.68[1)]/ 0.22 (39) (walking) 2.30 / 2.14[1)]/ 2.47[1)]/ 0.46 (32) (running)		
Takizawa et al. [19]	Japan	3 announced evacuation drills in 2 nursery facilities (2 buildings, results presented separately for each building; 271 children aged 3–5 years involved)	3–4	1.07 / 0.65 / 1.94 / 0.30 (N/A) 1.59 / 0.93 / 2.36 / 0.41 (N/A)	Video-analysis; walking and running speeds combined; measured in corridors; travel distance of the measured area 2 m (movement speed assumed)	No
			4–5	1.47 / 0.60 / 2.47 / 0.52 (N/A) 1.43 / 0.68 / 2.70 / 0.50 (N/A)		

Continuation of Table 2.4

Reference	**Country**	**Observational conditions**	**Age [years]**	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relationship**
			5–6	1.68 / 0.85 / 2.78 / 0.50 (N/A) 1.33 / 0.85 / 1.73 / 0.20 (N/A)		
Najmanová and Ronchi [22]	Czech Republic	2 semi-announced evacuation drills in 1 nursery school (2 buildings)	3–4	1.02 / 0.69 / 1.33 / 0.17 (42) (movement speed in interior) 0.57 / 0.35 / 1.35 / 0.20 (76) (modelling speed in interior)	Video-analysis; movement speed assessed as unimpeded speed in corridors, travel distance of the measured areas 2 m; modelling speed includes acceleration, deceleration, stops, and queuing, different travel distances (horizontal movement only)	No
			5–6	0.57 / 0.38 / 0.87 / 0.09 (121) (modelling speed in exterior)		
Hamilton et al. [23, 24]	Ireland	12 evacuation drills in 4 mainstream primary schools (1 announced followed by 2 unannounced drills in each school)	5–6	1.35 / - / - / - (200) (movement speed[2)]) 0.94 / 0.37 / 1.98 / 0.32 (138) (modelling speed)	Video-analysis; movement speed assessed as unimpeded speed in corridors, travel distance of the measured areas ca 3 m; modelling speed describes overall speed when moving through a building; travel distance determined as path from a classroom's exit to a building's exit (vertical movement included)	Yes
			4–12	1.46 / 0.18 / 4.41 / 0.58 (755) (walking and running movement speed) 1.32 / 0.18 / 2.59 / 0.40 (667) (walking movement speed) 2.47 / 1.12 / 4.41 / 0.66 (89) (running movement speed) 0.99 / 0.25 / 2.28 / 0.33 (442) (modelling speed)		

Continuation of Table 2.4

Reference	**Country**	**Observational conditions**	**Age [years]**	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relationship**
Fang et al. [25]	China	1 semi-announced evacuation drill in 1 pre-school building (movement of 84 children observed)	5–6	1.90 / 1.36 / 2.43 /0.25 (23) (“free movement”) 0.81 / 0.16 / 2.28 / 0.40 (206) (“affected movement”) 1.32 / 0.96 / 2.28 /0.30 (26) (walking) 1.90 / 1.36 / 2.43 / 0.25 (23) (running)	Video-analysis; “free movement” speed assessed as unimpeded speed in a corridor, travel distance of the measured area 8.5 m (movement speed assumed); “affected movement” speed includes interactions between children and higher densities, travel distance of measured area 14.5 m; walking and running speeds at low densities (0–1 pers·m^{-2}), values for different density intervals available	Yes

[1)] 95% confidence interval
[2)] the value read from the graph
N/A information not available

Table 2.5: Literature review of children's travel speed on stairs (downstairs)

Reference	**Country**	**Age [years]**	**Staircase description** (location, type, usage) **Geometry** (rise[mm]/tread[mm]/slope[°])	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relation-ship**
Larusdottir and Dederichs [13, 15]	Denmark	3–6	internal, spiral, daily-used 190/290/33.0	0.58 / 0.25 / 1.40 / 0.31 (N/A)	Video-analysis; slope travel distance; flights considered only (landings excluded), distinction of movement and modelling speed not considered; movement of 66 persons observed)	No
			internal, spiral, escape 190/290/33.0	0.38 / 0.29 / 0.48 / 0.07 (N/A)		
			external, spiral, escape 170/290/30.0	0.13 / 0.08 / 0.33 / 0.06 (N/A)		
Kholshchevnikov et al. [16]	Russia	3–4	internal, straight, daily-used various geometry	0.50 / 0.39$^{1)}$/ 0.62$^{1)}$/ 0.29 (26)	Video-analysis; slope travel distance assumed$^{2)}$; flights considered only (landings excluded); speeds at low densities (0-1 pers·m^{-2}), values for different density intervals and age groups available; travel distance of the measured area 1 m (movement speed assumed)	Yes (for the entire age group 3–7 years)
		4–5	internal, straight, daily-used various geometry	0.67 / 0.53$^{1)}$/ 0.81$^{1)}$/ 0.17 (8)		
		5–7	internal, straight, daily-used various geometry	1.16 / 1.09$^{1)}$/ 1.23$^{1)}$/ 0.23 (45)		
Takizawa et al. [19]	Japan	3–4	internal, straight, daily-used 165/300/28.8	0.32 / 0.25 / 0.35 / 0.03 (N/A)	Video-analysis; slope travel distance; flights considered only (1 flight); distinction of movement and modelling speed not considered	No
			internal, straight, escape 170/275/31.7 175/290/31.1	0.15 / 0.09 / 0.27 / 0.04 (N/A)		
		4–5	internal, straight, daily-used 165/300/28.8	0.58 / 0.36 / 0.77 / 0.10 (N/A)		
			internal, straight, escape 170/275/31.7 175/290/31.1	0.42 / 0.34 / 0.52 / 0.05 (N/A)		
		5–6	internal, straight, daily-used 165/300/28.8	0.67 / 0.47 / 1.01 / 0.13 (N/A)		

Continuation of Table 2.5

Reference	**Country**	**Age [years]**	**Staircase description** (location, type, usage) **Geometry** (rise[mm]/tread[mm]/slope[°])	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relationship**
			internal, straight, escape 170/275/31.7 175/290/31.1	0.50 / 0.36 / 0.71 / 0.09 (N/A)		
Cuesta et al. [18], Capote et al. [17, 33]	Spain	4–6	internal, straight, daily-used 185/275/33.9	0.48 / 0.28 / 0.77 / 0.14 (45) 0.61 / 0.14 / 1.12 / 0.21 (46) 0.47 / 0.23 / 0.69 / 0.11 (46)	Video-analysis; slope travel distance; flights considered only (1 flight); distinction of movement and modelling speed not considered	No
Najmanová and Ronchi [22]	Czech Republic	3–4	internal, straight, daily-used 150/300/26.6	0.57 / 0.40 / 0.87 / 0.12 (44) (movement speed)	Video-analysis; slope travel distance; flights and landings considered (travel distance on landings a semi-circle); movement speed assessed as unimpeded speed on a flight's segment; modelling speed includes stops and queuing on the whole staircase	No
			external,straight,escape 160/260/31.6	0.34 / 0.16 / 0.47 / 0.07 (128) (movement speed) 0.30 / 0.21 / 0.41 / 0.06 (64) (modelling speed)		
		5–6	exterior,spiral,escape 165/420/21	0.57 / 0.36 / 0.87 / 0.09 (119) (movement speed) 0.53 / 0.38 / 0.87 / 0.09 (160) (modelling speed)		
Hamilton et al. [23, 24]	Ireland	5	geometry of the staircases described in detail, however, the staircase used by observed pre-school children not particularly specified	0.51 / 0.34 / 0.68 / - (11)	Video-analysis; slope travel distance; flights considered only (landings excluded); movement speed considered	Yes (for the entire 4–12 age group only)
		6		0.59 / 0.59 / 0.59 / - (2)		
		4-12		0.92 / 0.19 / 2.03 / 0.26 (1039)		

Continuation of Table 2.5

Reference	**Country**	**Age [years]**	**Staircase description** (location, type, usage) **Geometry** (rise[mm]/tread[mm]/slope[°])	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relationship**
Fang et al. [25]	China	5–6	internal, straight, daily-used 150/280/28.0	0.63 / 0.35 / 1.13 / 0.20 (61) ("affected movement")	Video-analysis; slope travel distance; 2 flights and 1 landing considered (travel distance on the landing assumed as a semicircle with radius of 0.5 m); "affected movement" speed includes interactions between children and higher densities	Yes

1) 95% confidence interval

2) Information on the travel distance calculation method not available

N/A information not available

Table 2.6: Literature review of children's travel speed on stairs (upstairs)

Reference	**Country**	**Age [years]**	**Staircase description** (location, type, usage) **Geometry** (rise[mm]/tread[mm]/slope[°])	**Speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Collection method**	**Speed-density relationship**
Kholshchevnikov et al. [16]	Russia	3–4	internal, straight, daily-used various geometry	0.69 / 0.61[1)] / 0.77[1)] / 0.22 (33)	Video-analysis; slope travel distance assumed[2)]; flights considered only (landings excluded); speeds at low densities (0–1 pers·m^{-2}), values for different density intervals and age groups available; travel distance of the measured area 1 m (movement speed assumed)	Yes (for the entire age group 3–7 years)
		4–5	internal, straight, daily-used various geometry	0.89 / 0.45[1)] / 1.33[1)] / 0.35 (5)		
		5–7	internal, straight, daily-used various geometry	1.28 / 1.36[1)] / 1.23[1)] / 0.17 (76)		
Najmanová and Ronchi [22]	Czech Republic	5–6	internal, straight, part of the classroom 155/300/27.4	0.50 / 0.37 / 0.67 / 0.08 (41)	Video-analysis; slope travel distance; flights considered only (1 flight); modelling speed includes acceleration, deceleration, and queuing	No

[1)] 95% confidence interval

2.3.2 Pedestrian flow

Specific flow of persons on escape routes (expressed conventionally as a number of persons passing a point in the exit route of a specific width per a time unit) indirectly demonstrates a capacity of escape routes and thus represents another movement variable crucial in fire safety and evacuation assessments. Similarly to travel speeds, different specific flows may be expected in various evacuation routes components such as corridors, staircases, or doorways. However, due to a potential risk of congestion at a bottleneck, specific flows through doors are mostly investigated in fire safety of buildings. An overview of conducted research on specific flows in relation to movement of children at the pre-school age is given in Table 2.7. Since the variable of pedestrian flow is commonly expressed in the relation to occupant density as a flow curve, in this review, more details can be found in Section 2.3.4.

Table 2.7: Literature review of pedestrian flow of children

Reference	**Country**	**Age [years]**	**Flow (mean/min/max/ SD) [pers·s^{-1} m^{-1}] (data-points)**	**Collection method**	**Flow-density relationship**
Kholshchevnikov et al. [16]	Russia	3–7	1.98 / - / - / - (32) (1–2 pers·m^{-2}) 2.50 / - / - / - (42) (2–3 pers·m^{-2}) 2.72 / - / - / - (11) (3–4 pers·m^{-2})	Video-analysis; flow rates through doors (0.6 m and 1.2 m) for selected density intervals displayed, values for different density intervals available	Yes (flow curves for corridors, staircases, doors)
Larusdottir and Dederichs [13, 15]	Denmark	3–6	Results presented only as flow curves	Video-analysis; a data-point marks a continuous flow of 6–51 people through doors	Yes (flow curves for doors)
Capote et al. [33]	Spain	4–6	0.74 / - / - / 0.42 (47) 0.67 / - / - / 0.53 (46)	Video-analysis; flow rates through a door (1.1 m), information on density not considered	No
Hamilton et al. [24]	Ireland	4–12	1.60 / 0.30 / 4.76/ 0.8 (1069)	Video-analysis; flow rates through 8 exit doors of various width; flow rates determined for each second the exit was in use	Yes (flow curves for doors)
Fang et al. [25]	China	5–6	Results presented only as flow curves	Video-analysis; flow assessed with correlation to instantaneous density at each second	Yes (flow curves for corridors and staircase)

2.3.3 Density

In the literature, different units of density are employed by researchers (typically pers·m^{-2}, $m^2\,pers^{-1}$, or $m^2\,m^{-2}$). This fact is important to consider when density of children is assessed, since (due to a different body size) the expression in unit of pers·m^2 might cause misleading interpretation when movement of children and adults are further compared (i.e. the same area can be used by 2 adults or almost 4 children). In this context, the concept of occupied area introduced by Predtechenski and Milinskii [4] may be useful to transform data considering persons of different body proportions in a comparable form. According to this approach, density of a flow can be expressed by the ratio of the sum of horizontal projections of people to the floor area occupied by the flow ($m^2\,m^{-2}$). Nevertheless, the assumed area of persons is a crucial parameter which can considerably influence the results and thus should be carefully selected.

Predtechenskii and Milinskii [4] considered a person as an ellipse-shaped horizontal projection whose axis represent the width of a person taken at the shoulder and the thickness of a person taken as the breadth at chest level. This assumption of an elliptical shape of the horizontal projection of a human body can be found also in other studies [2]. For computation purposes, mean dimensions for a child (without specification of age) can be assumed as follows: the width ranges 0.3-0.34 m, the thickness ranges 0.17–0.21 m, and the area of horizontal projection ranges 0.04–0.056 m^2. For comparison, the area of the horizontal projection of an adult is assumed to be 0.1 m^2 in a summer dress and 0.125 m^2 in a winter dress.

The impact of different body size assumed for a person can be demonstrated considering the most commonly known design curves presented by Gwynne and Rosenbaum (SFPE Handbook (5^{th} edition) [43]). In this case, if the density exceeds 3.8 pers·m^{-2}, it is conservatively assumed that no movement takes place until a sufficient number of persons passes from the crowded area and the density there is reduced. Moreover, if the density increases beyond 4 pers·m^{-2}, physical contacts between people may occur and crush conditions might develop (see Figure 2.1). A conservative approach suggested that density should not exceed 3.76 pers·m^{-2}. When this value is converted to the unit of $m^2\,m^{-2}$, the maximum occupied area is 0.40-0.50 $m^2\,m^{-2}$ which corresponds to 9–10 children·m^{-2} (0.36–0.56 $m^2\,m^{-2}$), see Table 2.8.

Furthermore, a perception of the personal space influences density and human movement in a crowd as well. The concept of a body buffer zone (a space occupied by a person that includes also a free space around the body needed for a movement) was established by Fruin [5] as a part of experiments focused on evaluation of a required personal space. In the situation when the personal comfort of people did not have to be preserved, the buffer zones ranged between 0.223 m^2 and 0.26 m^2. In the opposite case the buffer zones around female participants ranged 0.372–0.465 m^2, around male participants 0.746–0.836 m^2. Considering the comfort zone, the assumption can be stated that the specific values of the personal comfort zone may differ in the case of pre-school children.

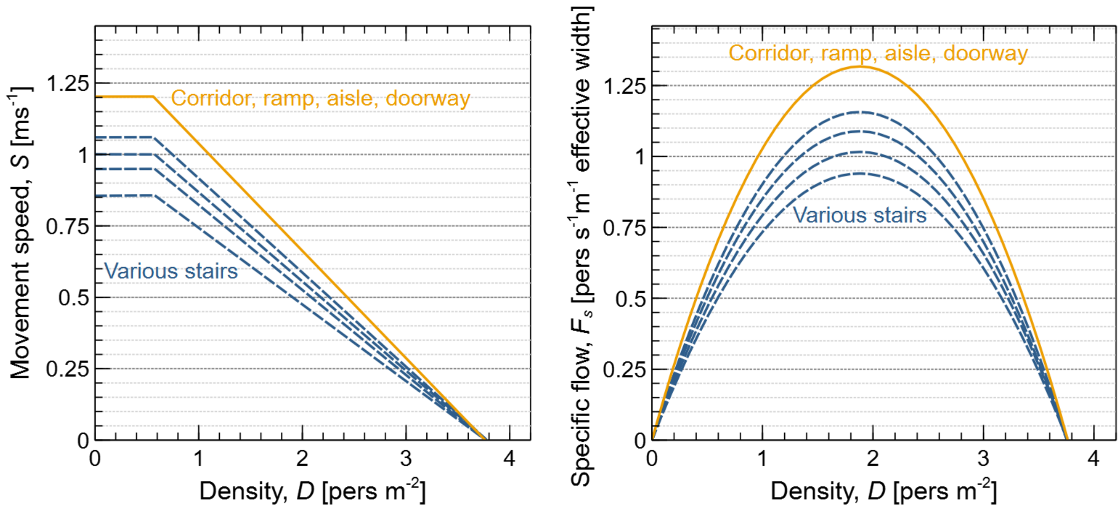


Figure 2.1: Relations between speed, density, and flow published in the SFPE Handbook (adopted from [43]): movement speed (**left**) and specific flow (**right**) as a function of density

Table 2.8: Comparison of the different occupied area by children and adults

Number of persons	**Occupied area by children** [$m^2\,m^{-2}$]		**Occupied area by adults** [$m^2\,m^{-2}$]	
	$A_{occ} = 0.04\ m^2$	$A_{occ} = 0.056\ m^2$	$A_{occ} = 0.1\ m^2$	$A_{occ} = 0.125\ m^2$
1	0.04	0.04	0.10	0.13
2	0.08	0.11	0.20	0.25
3	0.12	0.17	0.30	0.38
4	0.16	0.22	**0.40**	**0.50**
5	0.20	0.28	0.50	0.63
6	0.24	0.34	0.60	0.75
7	0.28	0.39	0.70	0.88
8	0.32	0.45		
9	**0.36**	**0.50**		
10	**0.40**	**0.56**		

Based on the above-mentioned concepts can be stated that the fundamental diagrams describing movement characteristics of adults and available in the literature or planning books [43, 47] are not fully appropriate to be applied for children. Furthermore, expression of density in unit of pers·m^{-2} may be misleading when data describing different populations are directly compared. Instead of that, the concept of occupied area established by Predtechenskii and Milinskii [4] indicated a solution how to provide those data in a comparable form.

2.3.4 Relationship between flow, density, and speed

Speed-density and flow-density relations (generally known as fundamental diagrams) are assumed as a basic tool for a capacity analysis of evacuation routes as well as for predicting a movement of a human flow in various egress components. They represent a central problem of a pedestrian flow and evacuation studies and therefore have been explored extensively [48, 51–63, 63–73]. On the other hand, a point should be made that this growing interest addressed rather adult population in general [5, 74–76]. From the overviews presented in the two previous sections (Table 2.4–Table 2.7) is apparent that only a few researchers and research teams have focused on fundamental diagrams concerning movement of children, namely Larusdottir and Dederichs [13,15] (flow-density relation only), Kholshchevnikov et al. [16], Hamilton et al. [24], and Fang et al. [25]. Moreover, not always all segments of escape routes were investigated in the above-mentioned studies (see the summary in Table 2.9 and Table 2.10 for more details).

Table 2.9: Overview of research studies focused on speed-density fundamental diagrams of pre-school children

Reference	Country	Age [years]	Corridor	Downstairs	Upstairs	Doors	Density units	Compared to
Larusdottir and Dederichs [13, 15]	Denmark	3–6	-	-	-	-	-	-
Kholshchevnikov et al. [16]	Russia	3–7	Yes	Yes	Yes	-	$m^2\,m^{-2}$	-
Hamilton et al. [24]	Ireland	4–12	Yes	Yes	-	-	$m^2\,m^{-2}$ pers·m^{-2}	[47]
Fang et al. [25]	China	5–6	Yes	Yes	-	-	pers·m^{-2}	[43]

Table 2.10: Overview of research studies focused on flow-density fundamental diagrams of pre-school children

Reference	Country	Age [years]	Corridor	Downstairs	Upstairs	Doors	Density units	Compared to
Larusdottir and Dederichs [13, 15]	Denmark	3-6	-	-	-	Yes	pers·m^{-2}	[4]
Kholshchevnikov et al. [16]	Russia	3-7	Yes	Yes	Yes	Yes	$m^2\,m^{-2}$	-
Hamilton et al. [24]	Ireland	4-12	-	-	-	Yes	$m^2\,m^{-2}$ pers·m^{-2}	[16, 47]
Fang et al. [25]	China	5-6	Yes	Yes	-	-	pers·m^{-2}	[43]

In their works which dealt with evacuation parameters of children in the age groups of 0–2 years and 3–6 years, Larusdottir and Dederichs [13, 15] reported results describing a specific flow through doors using the relationship between flow F_s [pers·m^{-1}] and density D [pers·m^{-2}]. During the flow measurements, density was collected as a local person density in front of the doors. In [13], the authors followed the expression presented by Nelson and Mowrer (SFPE Handbook (the 3rd edition) [47]):

$$F_{\mathrm{s}} = (1 - aD)\, kD \tag{2.1}$$

in order to formulate a mathematical expression of the flow curves (trend lines) by second degree polynomials. The values of the constants a and k (giving the relation between the specific flow and the density for the considered population) were calculated as $a = 0.062$ and $k = 0.339$ for children aged 3–6 years, i.e.:

$$F_\mathrm{s} = (1 - 0.062\,D)\,0.399\,D \quad \text{(the value } R^2 \text{ not provided)} \tag{2.2}$$

The authors stated that this model is more conservative than the flow rate presented in the by Nelson and Mowrer (SFPE Handbook (the 3rd edition) [47]) for the density below 3 pers·m^{-2}. However, this statement may be questionable since a further discussion on comparing design curves with experimental curves was not included in this study. Furthermore, a mention of the effective width of the doors can be found and thus that the whole free width of the door was used when needed, i.e. no boundary layer was reduced.

In the another study [15] the results of the flow measurements were compared not only with the commonly known flow curve for adults presented by Nelson and Mowrer (SFPE Handbook (the 3rd edition) [47]) but also with the flow curves derived by Predtechinskii and Milinskii [4] for children and adults. In the latter case, in order to obtain data in comparable units, the flow curves by [4] (originally in [m^2 m^{-2}] and [m^2 min^{-1})] were transformed to pers·m^{-2} and pers·s^{-1} m^{-1} employing the concept of occupied area. In this transformation the occupied area by a child was assumed as $A_{occ} = 0.028$ m^2 and the occupied area by an adult as $A_{occ} = 0.113$ m^2. The authors commented that the measured data does not show a clear peak which they explained by a lack of data at densities higher than 6 pers·m^{-2}. The data covering density 10 pers·m^{-2} were measured in situations when children were gathered in front of a door and they started to move first when a signal was given. According to the presented diagram, the highest flow of children 3–6 years old (above 3 pers·s^{-1} m^{-1}) was measured at the density 5 pers·m^{-2}. Moreover, the trend line for children aged 3–6 years indicates the maximal flow of 2.5 pers·s^{-1} m^{-1} at 9.2 pers·m^{-2}. The information on the value of R^2 of the presented trend line was not provided in the study. The absence of the limit density (3.8 pers·m^{-2} according to Nelson and Mowrer (SFPE Handbook (the 3rd edition) [47])) was interpreted as the impact of a different size of children and a different comfortable personal zone by children and adults, who generally require more personal space than children who know each other. It is concluded in the study that flow of children through doors is generally higher than data on adults found in literature.

A comprehensive study on children movement parameters including travel speed-density and flow-density observations presented Kholshchevnikov et al. [16]. The results on speed-density and flow-density relationships considered different route sections: horizontal routes, staircases (movement upstairs and downstairs), and door openings. Moreover, based on the results, the authors suggested particular speed-density and flow-density relationships for use for evacuation calculations. However, these design curves are presented only in graphs without any mathematical expression. Since in this study, the approach of horizontal projections of persons was employed to express the population density, dimensions of horizontal projections of children were also measured. The average value of 0.0247 m^2 was set down for Junior age group (3–4 years), 0.0282 m^2 for Middle age group (4–5 years), and 0.0325 m^2 for Senior age group (5–7 years). However, the accepted calculation value of the horizontal projection for all age groups of children was assumed as 0.03 m^2 (in the terminology of the previous study $A_{occ} = 0.03$ m^2).

Hamilton et al. discussed in [24] the influenced of density on horizontal and vertical travel speeds (i.e. travel speeds on stairs in slope) of children. However, the evaluation is performed only for the entire population (children aged 4–12 years) and separate discussion on fundamental diagrams of pre-schoolers was not presented in the study. Nevertheless, the speed-density and flow-density relations were assessed in a comprehensive manner including differences of running and walking speeds or usage of single and double doors. The trend lines of the experimental data were graphically expressed and correlation coefficients R^2 were provided for linear fitting of travel speeds. In order to compare the results with accepted data for adults (presented by Gwynne and Rosenbaum (SFPE Handbook (the 5th edition) [43])) the concept of a horizontal projection of persons was used by the authors when the density was calculated. Firstly, the mean density of children per second was determined in units of pers·m^{-2}, subsequently these values were transformed to units of $m^2\,m^{-2}$ using different areas of body projection for involving age groups: $A_{occ} = 0.04$ m^2 for 5–6-year-olds, $A_{occ} = 0.056$ m^2 for 7–8-year-olds, $A_{occ} = 0.067$ m^2 for 9–10-years-olds, $A_{occ} = 0.09$ m^2 for 11–12-year-olds, and $A_{occ} = 0.113$ m^2 for adults. Similarly, the design speed and flow curves presented by Gwynne and Rosenbaum (SFPE Handbook (the 5th edition) [43]) were converted to units of $m^2\,m^{-2}$. The fundamental diagrams were presented in both units variations (pers·m^{-2} and $m^2\,m^{-2}$) and the differences were debated. In brief, the reduction of speed with increased density of children was observed. However, the speed reduction appeared more salient than that for adults [47] when running and walking speeds of children were considered; while more consistent trend lines occurred when the running speeds of children (travel speed data points exceeding 2.0 m·s^{-1}) were excluded. When the horizontal travel speeds were measured, high-density scenarios did not emerge. Considering the speed-density relationship on stairs (downstairs), the speed reduction caused by increasing density of children is slower (contrary to the horizontal movement) than the trend line for adults [47]. Furthermore, the authors commented the lower standard deviation for vertical travel speeds which attributed to high level of organisation of the pupil's movement on stairs (a flow with a similar travel speed). The relationship between specific flow and density was determined at final exits from the buildings (clear width without any boundary layers) in units of pers·$s^{-1}\,m^{-1}$ and $m^2\,m^{-2}$ (pers·m^{-2}). The most frequent density interval ranged from 0.051 to 0.1 $m^2\,m^{-2}$ with the mean value of 0.076 $m^2\,m^{-2}$, densities over 0.357 $m^2\,m^{-2}$ were not recorded. The maximum specific flow of 4.76 pers·$s^{-1}\,m^{-1}$ was observed at the density of 0.165 $m^2\,m^{-2}$. The authors concluded that children 4–12 years old are capable of more than three times higher maximum specific flow than adults and their mean specific flow at low densities is also higher than that for adults. The incompatibility of the accepted data for adult [47] and primary school population was further demonstrated in a comparison to the mean data provided by Kholshchevnikov et al. [16] for children aged 3–7 years. Overall, supported by the data in [16], the authors determined the representative theoretical maximum specific flow of children at an approximate density of 0.3 $m^2\,m^{-2}$. In addition, it was assumed that children did not require any personal buffer zone and they were comfortable with minimal personal space.

An analysis of fundamental diagrams of children aged 5–6 years can be found in the study by Fang et al. [25]. Similarly to Larusdottir and Dederichs [13, 15] the equations for speed-density and flow-density relationships given presented by Gwynne and Rosenbaum (SFPE Handbook (the 5$^{\text{th}}$ edition) [43]) were followed to express the trend lines. Considering travel speed S [m·s^{-1}] and its dependency on density D [pers·m^{-2}], the expression presented by Gwynne and Rosenbaum (SFPE Handbook (the 5$^{\text{th}}$ edition) [43]) was followed:

$$S = k - a\,k\,D \tag{2.3}$$

and the obtained data-points were linearly fitted to receive this function (the value of correlation coefficient R^2 not provided):

$$S = 1.720 - 0.19D \quad \text{on the horizontal plane (in corridors)} \tag{2.4}$$

$$S = 0.913 - 0.149D \quad \text{on stairs (downstairs)} \tag{2.5}$$

Compared to the speed curves presented by Gwynne and Rosenbaum (SFPE Handbook (the 5$^{\text{th}}$ edition) [43]), the authors claimed that the same declining trend can be observed in corridors, although the values were higher in the case of pre-school children due to included running movement. Crossing of the trend lines describing the movement of pre-school children and adults [43] was explained by children's weaker athletic abilities. Additionally, the slower decrease of children's speed related to increasing density was attributed to the different body size which caused that children had more space available and thus the effect of density was less visible. In order to express the flow-density relationship, the equation (2.1) describing the dependency of specific flow F_s [pers·m^{-1}· s^{-1}] on density D [pers·m^{-2}] was applied for parabola fitting of the results. The functions (without the value of correlation coefficient R^2) were defined as

$$F_{\mathrm{s}} = 0.203\,(6.444 - D)\,D \quad \text{on the horizontal plane (in corridors)} \tag{2.6}$$

$$F_{\mathrm{s}} = 0.172\,(5.645 - D)\,D \quad \text{on stairs (downstairs)} \tag{2.7}$$

The maximum specific flow (according to the inflection points) occurred at the density of 3.2 pers·m^{-2} in corridors (the peak around 2.2 pers·s^{-1} m^{-1}) and 2.8 pers·m^{-2} on stairs (the maximum value of the flow about 1.35 pers·s^{-1} m^{-1}). Compared to the accepted data for adults presented by Gwynne and Rosenbaum (SFPE Handbook (the 5$^{\text{th}}$ edition) [43]) (around 1.35 pers·s^{-1} m^{-1} at 1.88 pers·m^{-2} in corridors and around 0.85 pers·s^{-1} m^{-1} at 1.88 pers·m^{-2}) are the experimental values for pre-school children higher. The authors assumed the results confirmed that children (thanks to smaller physical dimensions) can achieve higher evacuation efficiency with the same evacuation conditions than adults.

2.4 Summary of current knowledge on pre-school children's evacuation

In the context of fire emergency and evacuation situations, children at the pre-school age (i.e. between 3–6 years of age) are considered a vulnerable part of population. They can be seen as so called "at risk" population with limited self-rescue capabilities, whose evacuation movement and behaviour differs from that of adults. Although there has been increasing scientific interest in this specific issue in the last decade, the level of understanding of children's evacuation behaviour and dynamics is still limited. To date, research studies in this field have presented several consistent findings:

- Children's ongoing motor and cognitive development limits their self-rescue and decision-making capabilities which leads to increased need for an organised evacuation procedure.
- Evacuation procedure in early childhood education facilities is specific and strongly dependent on reactions, decisions, actions as well as on preparedness of responsible staff members.
- Level of assistance provided to children is age-dependent and highly affected by actual staff-to-child ratio.
- Evacuation behaviour of pre-school children reflects to a large extent daily routines and rules.
- Movement abilities of children differs from those of adults and are age-dependent.
- Movement characteristics of pre-school children may be influenced by permanent supervision and instructions given by responsible staff members.
- Movement on staircases may be very challenging for pre-school children and therefore a special attention should be given to appropriate design of staircases including their geometry and handrails location.
- Familiarity with evacuation routes and evacuation procedure plays an important role in evacuation efficiency.
- Evacuation procedure including both pre-movement and movement phase can be improved by regular training.

Recent research studies have indicated that understanding of evacuation behaviour and dynamics of pre-school children is a complex issue and more scientific work is needed to support and extend our knowledge and engineering data relevant for use in fire safety design. In this context, a detailed background on research methods (such as data collection and calculation approaches) as well as an area of reasonable application and possible limitations of results should be an integral part of experimental research studies.

Chapter 3

Child development

Any evaluation of children's movement abilities or behaviour must be inextricably linked to a specific level of child development, which can be in the simplest form related to the age. In the literature, different age-related development intervals can be found; however, researchers usually divide child development into five periods [77]:

- The prenatal period (from conception to birth),
- Infancy and toddlerhood (from birth to 2 years of age),
- Early childhood (from 2 to 6 years),
- Middle childhood (from 6 to 11 years),
- Adolescence (from 11 to 18 years).

In general, childhood extends from the end of infancy to the start of adolescence. Considering biological aspects, the period of childhood starts after weaning (30-36 months) and its end is related to dental development (eruption of the first permanent molars on average between the 5.5 and 6.5 years of age) and completion of growth of the brain (at a mean age of 7 years). During this stage, children require special care and protection by older individuals due to their enormously vulnerability [78]. This period of the life cycle is unique in humans; in most mammals, including chimpanzees which are closest to the humans in evolutionary hierarchy, the infancy is directly followed by the juvenility growth stage, when the juvenile mammals are largely responsible for their own care and feeding [79]. The outstanding prolonged physical immaturity when children remain dependent on adults can be understood as an adaptive approach, which allows to children extra time to acquire the knowledge and skills crucial for their life in a complex social world [77].

To classify educational objectives taxonomically, researchers commonly distinguish the four major domains: the cognitive, the affective (socioemotional), and the motor (psychomotor) [81]. This classification system is useful also when organizing research of human development where, moreover, the fourth domain named the physical domain, which involves physical change, should be considered. Albeit such a classification is enormously useful in the field of science, in the real world, all the

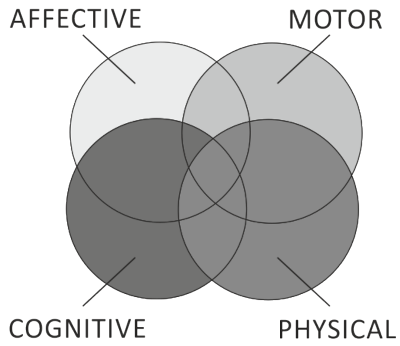


Figure 3.1: The four domains of human development and illustration of their interactions; adopted from [80]

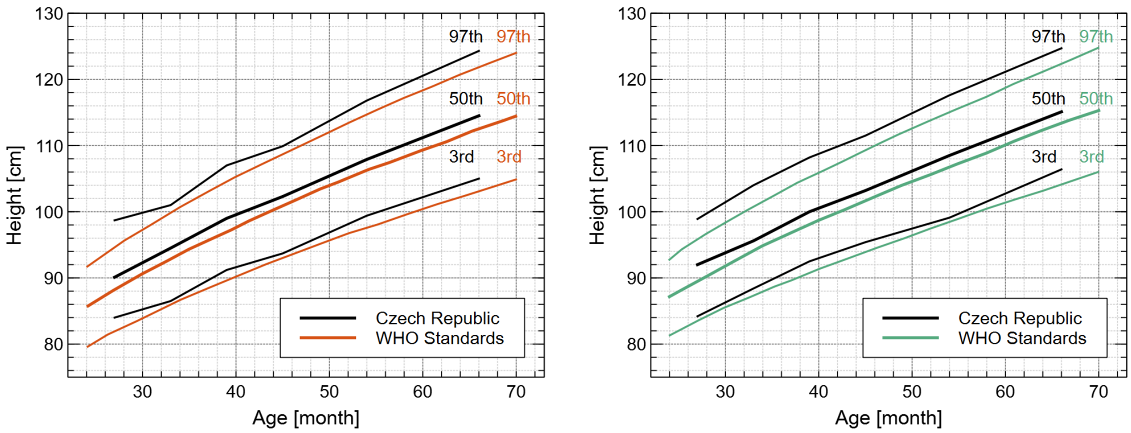
domains are not discrete, they continuously influence each other and establish the most complex system (see Figure 3.1) [80]. From a normative point of view, typical patterns and milestones of developmental change characterizing the majority of population are defined as developmental norms [82]. In these norms, typical levels of performance in different age groups and developmental stages are established in order to measure a child's development in a variety of domains. Besides a normative developmental concept, the developmental process including individual differences influenced by countless factors can be understood as a complex dynamic system adopting dynamic systems approach [83–85].

In the following sections, the four domains of child development with the main focus on the early childhood period are handled separately. This review does not make any effort to elaborate a comprehensive brief of current knowledge in human developmental science. It rather provides a general overview and background in this fascinating scientific area in order to get fundamental understanding of pre-school children's specifics which may influence their evacuation, and therefore be crucial in evacuation design and studies. These specifics and findings of this overview related to the issue of pre-school children evacuation are further summarised in Section 3.4.

3.1 Physical growth

The period of physical growth covers approximately one quarter of the human lifespan; by contrast the growing process takes around 2% of the lifespan among mice and 16% in chimpanzees [77]. As the best single predictor of growth can be assumed age. The most rapid velocity of body growth is characteristic for infancy; during the first year, body length increases approximately 50%; during the second year, the rate of body growth proceeds at 12 cm on average (i.e. 75% gain compared to the birth length). After the age of 2 years, the velocity of body growth declines. The increase in body height proceeds at steady 5–6 cm per year in early childhood. Further increase in growth velocity represents a growth spurt at the beginning of the adolescence, when about 20% of the adult stature is attained during this 2.5—3 years period [79, 80]. Similarly, the rate of physical growth is reflected by corresponding body weight. During the first year, birth weight can be expected to triple (boys weigh approximately 10.2 kilograms, girls about 9.5 kilograms). During the second year, rate of weight gain decelerates (the average gain is about about 2.5 kilograms) and remains steady for the next 3 pre-school years (with the normally developing child averaging about 2 kilograms per year). Apart from a great deal of individual variability, the weight gain is around 3 kilograms per year until the onset of adolescence. For a graphical illustration of overall changes in body size, different types of growth (height or weight) curves are used. A distance curve plots accumulative growth obtained over time, whereas a velocity curve shows the rate of change in growth per unit of time [80]. For the study of individual growth, velocity curves are commonly preferred giving detailed information on the growth dynamic in a more intuitive way [86].

Besides the overall body size, commonly represented by body weight and stature (i.e. standing height), further measurements are used in growth studies such as stature sitting height and length of the lower extremities (leg length), skeletal breadths (biacromial (shoulder) breadth, bicristal (hip) breadth, limb circumferences, head circumstances, skinfold and others [87]. Monitoring of children's growth is an important tool for assessment of their health and development. Anthropological measurements have been widely used as indicators for various conditions related to health and nutrition [88]. In general, growth charts describing the growth of a reference population thought measurements of weight and height (length) are applied for growth assessment. As reference international growth charts World Health Organisation (WHO) Child Growth Standards [89] are worldwide adopted [90]. The values of body height of children aged 3 years may range (3^{rd} and 97^{th} percentile) from 87 cm to 103 cm by girls (see Figure 3.2a) and from 89 cm to 104 cm by boys (see Figure 3.2b). Considering children 6 years old, the values of body height (3^{rd} and 97^{th} percentile) may range from 104 cm to 124 cm by girls (see Figure 3.2a) and from 106 cm to 125 cm by boys (see Figure 3.2b).



(a) Girls

(b) Boys

Figure 3.2: 3^{rd}, 50^{th}, 97^{th} centile curves describing height-for-age for girls (left) and boys (right) from 24 to 70 months (2–6 years) adopted from WHO Child Growth standards [89] and from Czech anthropological survey [91]

In the Czech Republic, the growth reference data are based on nation-wide anthropological surveys of children and adolescents regularly updated in 10-year intervals since 1951 [92]. As a part of the 6^{th} Nationwide anthropological survey of children and adolescents in the Czech Republic published by The National Institute of Public Health in 2001 [91] a detailed study on physical parameters (body measurements such as body height, body weight, sitting height, chest circumference, head and skull dimensions) of children from birth to 6 years of age was conducted comprising anthropometric measurements of 7,961 children. Based on the obtained growth charts, the values of body height of children aged 3 years may range (3^{rd} and 97^{th} percentile) from 89 cm to 104 cm by girls (see Figure 3.2a) and from 90 cm to 106 cm by boys (see Figure 3.2b). Considering children 6 years old, the values of body height (3^{rd} and 97^{th} percentile) may range from 107 cm to 126 cm by girls (see Figure 3.2a) and from 106 cm to 125 cm by boys (see Figure 3.2b). Comparing these growth charts to those in WHO Child Growth Standards [89] it can be seen that the values of body height of children population in the Czech Republic are slightly higher than the international standards. This finding is in line with statistical data on human average height across the world which ranked Czech population among the tallest populations worldwide (average height of women 168.5 cm, average height of men 180.1 cm) [93].

Besides body height, data on shoulder width (distantia biacromialis) and chest circumference taken across the mesosternal point can be found in this study [91], see Table 3.1.

Table 3.1: Mean values of shoulder width and chest circumference taken across the mesosternal point of Czech children at the pre-school age [91]

Age [years]	Shoulder width [cm]		Chest circumference [cm]	
	Girls	Boys	Girls	Boys
3.00-3.49	21.9	22.1	51.4	52.7
3.50-3.99	22.7	22.8	52.3	53.3
4.00-4.99	23.7	23.9	53.7	54.6
5.00-5.99	24.9	25.2	55.5	56.5

These variables can be used for determination of a horizontal projection of children's body (occupied area) which is essential for density assessment and related assumptions in evacuation design (refer to Section 2.3.3 dealing with density calculation). However for this purpose, the knowledge of both shoulder width and chest depth is required.

General information on chest shape can be provided employing the thoracic index TI defined [94] as

$$TI = \frac{ch_d}{ch_b} \tag{3.1}$$

where ch_d is chest depth (sagittal diameter) and ch_b is chest breadth (transversal diameter). Since the chest shape develops during the infancy and childhood, children' and adult's chest geometry differs [95, 96]. By the age of 2–3 years, a more rounded shape typical for early infancy changes to a more ovoid adult pattern [95, 97]. Hence, the thoracic index (around 0.84–1.04 in infants) substantially decreases in the first

2 years of life and according to different research studies may range between 0.63–0.79 during the early childhood period and early school years since [96, 98–101]. The thoracic index stabilizes after the age of 11 years and then no significant evolution between children and adults was observed [96]. However, there are no standards in literature concerning the thoracic index by adults due to a high variance caused by age, gender, body mass, or morphology [102], values around 0.6–0.7 have been presented in some research studies [103, 104].

Based on the assumption of the quite stable thoracic index during the pre-school years and the ellipse-shaped geometry of a thorax cage, the chest depth ch_d can be determined as

$$ch_d = \frac{ch_c\, TI}{\pi} \sqrt{\frac{2}{1 + TI^2}} \tag{3.2}$$

where ch_d is chest depth, ch_c is chest circumference, and TI is the thoracic index. Considering the thoracic index equal to 0.72 (4-year-old child according to [98]) chest depths for children at different age groups and subsequently their ellipse-shaped occupied area were calculated and are presented in Table 3.2.

Table 3.2: Mean values of shoulder width and chest circumference point of Czech children at the pre-school age [91] (data for boys and girls averaged) supplemented by calculated chest depth and assumed occupied area

Age [years]	Shoulder width [cm]	Chest circumference [cm]	Chest depth [cm]	Occupied area [m^2]
3.00-3.49	22.0	52.1	13.7	0.024
3.50-3.99	22.8	52.8	13.9	0.025
4.00-4.99	23.8	54.2	14.3	0.027
5.00-5.99	25.1	56.0	14.7	0.029
Average	**23.4**	**53.8**	**14.1**	**0.026**

Despite of the fact that children at the same age may differ significantly in their rate of physical growth, a cephalocaudal gradient of growth is natural for humans. This trend is common to all mammals and refers to the pattern of changing spatial proportions over time during growth: the head gradually becomes smaller and the legs longer, in proportion to the rest of the body [77, 105]. Consequently, as children age, the center of gravity slowly descends and varies distinctly during childhood, although it remains a relatively constant proportion of total height [80]. However the location of body center gravity referenced to crotch in the standing position remains almost constant during the human life (around 15 cm above the crotch), this position related to the whole body size differs with the growth. Specifically, this distance means that the position of body center gravity is located in the chest (below armpits) in infants, at about the tip of sternum at 1 year of age, and in the soft abdominal viscera (at the level of umbilicus) between 1–3 years of age [106]. Around the age of 5–6 years the body center of gravity decreases below the level of umbilicus which is almost similar to its location n adults when the center of gravity is at approximately 56% of the person's height [107]. Also body proportions at the age of 6 years are similar to those of adults [77]. The high center of gravity and specific ratio of trunk length to leg length in toddlers and children at the pre-school age impacts their early motor performance, especially balance tasks, and they may be prone to falls [80].

3.2 Motor development

Motor behaviour includes every kind of movement in every part of the body and its development should be understood as a continuous process during the entire lifespan. From the first fetal movement, fundamental motor systems such as postural control, locomotion control, manual and facial actions are developed, most rapidly during infancy [108]. Like other types of movement, motor development can be generally categorised as gross and fine. Gross motor skills (such as crawling, walking, and jumping) are primarily related to the large muscles or muscle groups. Fine motor skills are controlled by smaller muscle or muscle groups and enable actions such as reaching, grasping, and further movements performed with the hands (e.g. drawing). Apart from this elementary categorisation, both fine and gross movements result mostly from a combination of large and small muscle groups [80]. From another point of view, the motor skills can be divided into three types: locomotor (walking, running, jumping), object control, and stability/balance. As mentioned before, each child develops individually on its own pace, however, similarly to general patterns in growing, common characteristics can be determined in motor development [80]. In the following subsections, gains in motor development in early childhood related to children's locomotor abilities are in focus. Following the basic terminology in evacuation studies, the horizontal movement and movement on stairs is notably distinguished.

3.2.1 Movement on a horizontal plane

During the second year of life, fundamental locomotion skills including walking, running, jumping, and hopping begin to be developed and practised by children, supported by changes in their body size, proportions, and muscle strength [77, 80]. According to the Gallahue's phases of motor development [109], fundamental movement phase is typically developed between 2–7 years of age. Here, the age period from 2 to 3 years is characterised as a initial stage, the age period from 4 to 5 years as an elementary stage, and the age period from 6 to 7 years as a mature stage of the fundamental movement phase of motor development. Initially, the prewalking movement patterns of crawling and creeping acquired to cover a distance during infancy are substituted with initial walking attempts requiring sufficient leg strength to support the body weight and balance control. Overall, children are capable of walking without support around 1 year of age [80]. Subsequently, proficiency in walking develops in an exponential rate as stride length, walking speed, and cadence increase [110]. However, the mature walking pattern develops gradually after the onset of independent walking. Different opinions can be found in literature related to when children achieve an adult-like gait pattern [111]; the stride dynamics may not be mature before 4 to 7 years of children's age [110, 112–114].

Table 3.3: Time-distance walking parameters (gait parameters) in children [80], originally [117] (original speed unit [cm/s] were converted to [m/s]

Age (years)	**Step length [cm]**	**Stride length [cm]**	**Steps/ minute**	**Walking speed [m/s]**
1	21.6	43.0	175.7	0.64
2	27.5	54.9	155.8	0.72
3	32.9	67.7	153.5	0.86
7	47.9	96.5	143.5	1.14
Adult	65.5	129.4	114.0	1.22

In general, walking speed is related to step frequency and step length [110, 115]. When walking, human body follows the principle of pendulum motion. Hence, angular rotation and time of swing depends on length of the limb and the location of the center of mass. Consequently, body height and limb length can be assumed as important factors controlling time-distance parameters in children. A direct linear relationship between step length and leg length (also known as step factor) in children 1–7 years old was experimentally observed, being fixed around by age 4 of years [112]. Furthermore researchers concluded that gait patterns of normal children are both velocity and age-dependent and that time and distance measurements were found to change with age. Changes in gait pattern that could be correlated with growth were observed by normal children less than 4 years old, conversely it was found that the gait of children between 4–16 years showed no changes due to growth [116]. Detailed dataset on gait related parameters such as step length, stride length, step frequency, and walking speed of normal children aged 1–7 years was originally presented by [117] and further reproduced in literature [80] (see Table 3.3).

Between 6 to 7 months after the arise of independent walking (i.e. around 2.5 years of life) children learn to run [118]. Running is referred as a natural extension of walking characterised (besides the support phase and the recovery phase) by the flight phase. Differences can be identified in running patterns of beginners and advanced runners. During the support phase and flight phase, one leg supports the body, maintains forward motion, and accelerates the body's center of gravity. The inexperienced runner performs the foot strike with the full sole, whereas the part of the foot hitting the ground moves closer toward the ball of the foot when the running style progresses. Based on an experimental study, the angle of support ankle at contact with the floor was less than 90° by children aged 2 years and 98° by children 4–6 years old. In addition, insufficient developmental phase of the thrust leg does not allow to inexperienced runner to use the thrust leg effectively and to project the body through space for any significant distance. This ability requiring more involvement of the hip, knee, and ankle is related to developmental progresses and is more evident with increasing age. Salient developmental trends can be also observed considering the recovery phase. Whereas the experienced runner flexes the knee so the heel of the foot of the recovery leg comes very close to making contact with the buttock, the the inexperienced runner does not achieve such sufficient degree of knee and hip flexion, which may cause frequent stumbling [80]. Improvements and qualitative changes in running patterns are present as children grow. Children developmental progress and increasing efficiency in running can be demonstrated using developmental sequences for running [109]. Overall, the first run without any support phase can be observed by children between 2 and 3 years of age, efficient and refined run is improved between 4–5 years, and the developmental potential to acquire mature run occurs around 5–6 years of age [109]. Quantitative measurements are usually described using the parameters of running speed or flight time. Developmental performance trends for running can be found in Table 3.4 [80] showing consistent year-to-year improvement in running speed for both genders (the running speed peeks at about 14 to 15 years (girls) or about 17 years (boys)).

Table 3.4: Children's running speed related to developmental performance trends, adopted from [80] (original distance units (yard, feet) were converted to meters)

Age (years)	**Run distance [m]**	**Average run times [s]**		**Average speed [m/s]**	
		Boys	**Girls**	**Boys**	**Girls**
2.5	27.43	11.5	12.2	2.39	2.25
3	27.43	10.2	10.9	2.69	2.52
	12.19	3.54	3.96	3.44	3.08
4	27.43	8.60	8.80	3.19	3.12
	12.19	3.26	3.35	3.74	3.64
5	27.43	6.29	6.82	4.36	4.02
	12.19	2.74	2.88	4.45	4.23
6	27.43	5.54	5.85	4.95	4.69
	12.19	2.62	2.76	4.65	4.42
17+	45.72	6.60	7.90	6.93	5.79

Besides walking and running, gross motor development is commonly accompanied by mastering further locomotor skills such as jumping, hopping, galloping, and skipping. Mature patterns of these movement activities is for most children also acquired during the mature stage of the fundamental movement phase (6–7 years) [109]. Overall, reaching of motor development milestones depends always on both biological factors (individual) and environmental context. Thus, an evidence of large interpersonal variance as well as modern social problems including prevalence of childhood obesity [119] should be carefully considered.

3.2.2 Movement on stairs

Ascending and descending movement on stairs is specific and differs from that on a horizontal plane, since human locomotion on stairs is more biomechanically challenging. When walking on stairs, the body center-of-mass must be raised/lowered and simultaneously moved forward supported only with a single limb. Higher demands on proper foot placement and dynamic balance skills may cause difficulties in populations who experience balance deficits [120–122]. Moreover, the question of muscle fatigue during stair climbing may be a serious factor influencing an evacuation process [123].

Children usually cope with stair climbing during infancy at around 1 year of age; infants learn to ascent stairs several months after the crawling onset and several weeks prior to descent. Typical strategies for initial ascent involve crawling up on hands and knees, strategies for descent can vary from turning around and backing to sliding down backward or scooting down sitting [124]. Children around 1.5 years can walk up stairs with adult assistance; two years old do no longer need personal assistance in walking up and down stairs. In addition they are able to jump down from the first tread (one foot leading) without help. Nevertheless, this progress is compensated by using handrails and adopting a marking time pattern [125]. Marking time is referred as an action during which one foot meets the other on a riser (i.e. both feet are on the same level), before going to the next higher (or lower) riser [126]. Children get experienced in climbing down without assistance commonly between 2 and 3 years of age; however, usually without feet alternation. An alternating pattern when climbing independently upstairs emerges around three years of age; moving downstairs even later until to four years of age [77, 125]. It is suggested that the onset of the alternating pattern may be related to a more efficient movement when the foot is is brought up only high enough to clear the nosing of the stair [126]. Besides that children are also able to jump down from the bottom tread with both feet together around the age of three years [125].

In brief, movement downstairs is for children more challenging task than stepping up. This can be related to higher demands on balance control, children's safety concerns (not unlike safety concerns observed by older adults [126, 127], but also to ongoing development of visual control in stepping down. Researchers have found that 3- and 4-year-old children were capable to plan their steps down with the same sensitivity as adults when visual information was available and when the riser height was appropriately scaled to body dimensions. In other words, children scaled movements as sensitively as adults when the ratio between step riser and their leg length was the same. For comparison, the step riser of 22 cm represented 24% of leg length for adults and 44% of leg length for 3-year-old child. The study therefore suggested that usual performance when children struggle to step down is not caused by their visuomotor skills but rather by the demanding stairs geometry they are faced with [128]. Thus, the design of staircases should be considered properly in building with young children occupancies.

3.3 Psychological development

Study of the development of human's cognitive, emotional, intellectual, and social capabilities represents very diverse and comprehensive fields which have been the subject of extensive research in developmental psychology for many decades [129–132]. Both cognitive and affective (socioemotional) development noted already in the introduction part of this chapter are so much closely linked together that in the current overview they form one combined section generally focused on psychological aspects of child development and simplified termed as psychological development.

3.3.1 Cognitive development

In its broadest sense, the study of child cognitive development focuses on changes in children's mental abilities over their lifespan such as attending, perceiving, learning, thinking, and remembering [133]. According to the Piaget's theory of cognitive development [130], development of human intelligence is categorised into four stages:

- The sensory-motor stage (from birth to 2 years),
- The preoperational stage (from 2 to 7 years),
- The stage of concrete operations (from 7 to 11 years),
- The stage of formal operations (from 11 to 16 years).

Children at the pre-school age are in the pre-operational stage of development which begins around age 2, as children start to talk, and lasts until approximately age of 7 years. This stage is sometimes labeled as the "age of curiosity" since children explore and investigate surrounding environment and use their still limited experience to make up own explanations when needed. However, children are not yet able to think logically and abstractly, their representation of world depends on their own, completely egocentric, perception [134]. Above all, this period is characterised by the appearance of the symbolic function which gives to children a representational insight, i.e. even 2- to 3-year-old children can use words and images (symbols) to represents experience, reconstruct the past, and think about objects that are not longer present. The most evident form of symbolism is development of language which becomes much more similar to an adult's until the age of 5 years [133]. The pre-operational stage can be further divided into two sub-stages: the pre-conceptual (2–4 years) and the intuitive thought sub-stage (4–7 years). In the pre-conceptual stage (also called symbol function sub-stage), the child gains the capability to use and store mental images of objects and attempt to generalise in an illogical way. The most salient characteristic of this stage are egocentric behaviour (children can not distinguish between their own perspective and another person's) and animism (children believe that things are alive and capable of actions). In the intuitive thought sub-stage children tend to became very curious and learn by asking questions. They attempt to understand the world using primitive reasoning which is based more on perception than logic. Similarly, their problem-solving is more dependent on instinctive though and appearances. This thinking, called transductive reasoning, means reasoning from a particular idea to another one without any logical connection (for instance children believe that simultaneous occurrences are conditional on cause-effect relationship) [134].

During the pre-school years further changes of cognitive development are ongoing such as those in information-processing strategies including memory, knowledge base, and attention processes. During childhood, the short-term store, memory span, processing speed, and thinking strategies develop gradually and age-related. Previously it was thought that children in the pre-school age did not use any strategies when solving problems. Currently it is believed that they can be strategic in their thinking and problem approaching, although their strategies tend to be simple and become more efficient with age [133]. In early childhood, major developments occur also in memory system i.e. in short term memory, working memory, long term memory, and autobiographical memory [135]. In the context of developments in language, communication, and social interaction, autobiographical memory emerges gradually across the pre-school years. This kind of memory is defined as memory for events (in distinction from other kinds of memory such as memory for facts, lists, or skills) [136]. It was found that young children, similarly to adults, organize recurring events (routines) into scripts (script-based memory) which help them to interpret their experience and to make predictions what expect in similar situations in the future. However, forming scripts in young children may be limited by novel or atypical information [133, 137]. Pre-school children have very short attention spans, i.e. capacity for sustaining attention to a particular stimulus or activity. Hence, they cannot concentrate on any single activity for a longer time, while they can quickly lose interest and jump to another activity. The ability to better sustain attention are acquired by children as they grow [133].

3.3.2 Affective (socioemotional) development

The socioemotional development refers to a child's developing capacity to experience, manage, and express emotions, to actively explore close environment, and to establish and maintain relationships with others [138]. Human ability to impute mental states (such as beliefs, intents, desires, emotions, knowledge) to oneself and to others and to predict, explain, and interpret human behaviour on the basis of their mental states is called as a "theory of mind" [139] (introduced by chi [140]). The theory of mind, i.e. understanding that other people do not share he same thoughts and feelings, is being developed during early childhood and the pre-school years. Its foundations begin to develop during infancy involving early imitation skills, reciprocal interaction, and emotional sharing. First-order theory of mind emerges between 4 and 5 years of age when children understand that people act in different ways to get different things they want; moreover, they can think about what someone else is thinking or feeling [141]. In contrast to adults, children under 4 years do not completely understand that they can be mistaken about the world and that others may have false beliefs being capable of hiding emotions [139]. During the next several years, generally by the age of 7 years (and typically after the development of first-order) second-order theory of mind develops by children, which involves predicting what one person thinks or feels another person is thinking or feeling. Beyond this stage, development of higher order of theory of mind (e.g. recognizing lies, sarcasm, or understanding multiple embeddings) continues until 12 years of age [141] and its development can be a life-long process [142].

As they grow, children learn how to participate and be accepted by society. During the socialisation process they acquire social competence by learning the norms, values, beliefs, attitudes, and roles appropriate to their social groups [143]. Children continuously gain the skills to communicate with other people and to perceive their own individuality, e.g. through the development of the self-concept. Children at the pre-school describe themselves typically very concretely, focusing mostly on their physical features and they use the same concrete observable terms for description of friends until their age of 7 or 8 years [133]. The emerging sense of self and understanding of others is strongly supported by relationships with adults - at the beginning primarily with parents and family and later also with teachers. The importance of the parent-child relationship which influences child's subsequent development has been introduced in the attachment theory [131]. It is suggested that infants are born with biological predisposition to form attachment relationships with caregivers in order to survive. Likewise they seek and maintain proximity with those persons to receive protection and emotional support [144]. According to the emotional security theory [145, 146], the preservation and attainment of emotional security is a prominent goal for children [147]. During the early pre-school years, given the the importance of relationships with adults (primarily mothers) attention may be turned relationships with teachers [148], who can function as secondary attachment figures [149]. In view of the perspective of extended attachment, children appear to rely on teachers for support and emotional security [150]. Equally it was found that children's emotional security is positively related to children's task behaviours and their initiative and independence (or more precisely effective dependence) in social interactions [151, 152].

3.4 Summary of child development overview

In brief, during the early childhood period, children grow and progress at a rapid pace across all the areas of development including the physical, motor, cognitive, and social and emotional. As mentioned in the introduction of this chapter, the four domains of human development (usually categorised only to streamline its study) interplay closely and create a unique and dynamic system. No matter how challenging it might be task, basic understanding of those interactions of developmental procedures can give us an insight into differences in adult's and children's behaviour, thinking, and movement abilities.

In the context of fire safety ad evacuation design the main findings resulting from the performed literature review cam be summarised as follows:

– Although physical growth of children in the some age group can vary due to individual rates of physical maturation, general patterns are common in human commonly represented by growth charts (height-for-age curves). According to the WHO Child Growth Standards recommended for international use mean body height (50^{th} percentile) is 95 cm for 3-year-old child and 110 cm for 6-year-old child. Considering Czech population, these values of body height are slightly higher, notably 99 cm for 3-year-old child and 115 cm for 6-year-old child. Similarly, other body dimensions should be adequately considered when pre-school children are assessed in pedestrian movement calculations. Based on anthropological survey in the Czech Republic, averaged shoulder width of children aged 3–6 years is 25 cm and averaged chest circumference is 54 cm; in addition, averaged chest depth can be assumed as 14 cm. Provided a horizontal projection of body as an ellipse determined with main axis equal to shoulder width and chest depth, an average occupied area of children at the pres-school age (3–6 year-olds) can be assumed as 0.026 m^2.

- Since human beings follow a cephalocaudal gradient of growth, children's body proportions and location of body center gravity differs from those of adults. Hence, motor performance, stability, and balance skills of toddlers and children at the pre-school may be limited by a higher center of gravity and they may be more likely to fall.

- During early childhood, development of fundamental movement skills progresses rapidly. Children typically started to walk without support around 1 year of age; however changes in gait pattern attributed to growth can last until the age of 4 years and children's matured gait may be developed until to 7 years. Walking speed and step length is mostly impacted by children's physical size, namely by the leg length.

- Further development of dynamic balance, core strength, and multi-limb coordination leads to running attempts with an airborne phase, which occur between 2 and 3 years of age and are improved until the age around 6 and 7 years.

- Movement on staircases is for pre-school children biomechanically challenging. Downstairs climbing is for children more demanding than moving upstairs. Around 2 years of age children can go upstairs and (later) downstairs without help of adults, although they follow a marking time pattern and use handrails for a support. A marking time is replaced by feet alternation during the age period from 3 to 4 years, whereas within this interval using of handrails or other support may be needed for a longer time when walking downstairs. Appropriate design of staircase geometry, especially riser height, considering different children body dimensions is crucial.

- As children age they acquire the ability to think, speak, learn, and reason. Attainments in cognition, emotion, and behaviour progress rapidly across the pre-school years and children, gaining new skills and experience, grow in both intellectual and emotional manner. However in this age period, children's though differs most from that of adults. Although their proficiency in using symbols (including language), further skills in information-processing increase, and attention becomes more sustained and focused with age, pre-school children do not yet understand concrete logic and are not able to mentally manipulate information which leads to limited thinking in very concrete terms. In addition, children's own perspective to see the world, also termed as egocentrism, causes their incapability to recognize that other people do not share the same point of view. This state changes when theory of mind emerges around 4 and 5 year of age and when it further develops during the pre-school years. Overall, the level of cognitive development in pre-school children differs from that of adults and of children in different age period. Consequently, their evacuation behaviour, particularly abilities to properly evaluate emergency situation and self-rescue abilities may be limited.

- Being a part of a society, growing children continuously learn to interact with others around them. The developing ability to respond to and engage with adults, beginning usually with parents, is later extended to teachers who take the role of the attachment figure in educational establishments or other non-parental care. In this context, teachers represent for children a provider of emotional security and authority who they can rely on in stress or strange situations including evacuation from a building.

Part II

Experimental research

Chapter 4

Ethics

Although the present experimental research is approached solely at an engineering level without any association to clinical research, human beings are involved in the experiments, and those predominantly at the pre-school age. Therefore, appropriate ethical considerations must be carefully taken into account and protection and respect must be given to the research participants.

Since historical experience has proven the unquestionable importance of protection of human subjects in research, sets of guidelines have been developed and adopted for responsible and safe conduct of human research. Starting with the Nuremberg Code in 1947 [153], the American Psychological Association's (APA) first Code of Ethics in 1953 (the last amendment in 2017 [154]), the Helsinki Declaration in 1964 (the last amendment in 2013 [155]) or the Belmont Report in 1979 [156], ethical principles in medical, social, behavioural, and psychologist research for have been laid down in various ethical codes. Although application of these principles in evacuation studies is mostly not backed by particular, separated ethical codes, detailed and comprehensive discussion on ethical aspects in evacuation experiments can be found, namely in doctoral thesis written by Nilsson [157].

Following the well-known ethical codes mentioned above, the basic ethical principles in research involving human subjects can be summarised:

- Autonomy and informed consent,
- Beneficence and non-maleficence,
- Protection of confidentiality.

4.1 Autonomy and informed consent

The respect to autonomy and voluntary participation in research can be consider as essential. This principle implies that the participant receives sufficient information to make an individual and informed decision to be enrolled or not as well as to terminate the participation in research at any time. In this study, the participants (besides educationalists and other staff members) were children at the age from 3 to 6 years, generally considered as vulnerable population with a possibly limited capacity to understand all aspects of the experimental research. Therefore, a special attention must be paid to the protection of their rights and the process of informed consent was implemented at two levels.

4.1.1 Informed consent given by the leader

The first level comprised of a close cooperation with the leader of the participating nursery school who has been perceived as an authority, from her/his professional position, responsible to assess benefits and risks of the experimental research objectively and to act in order to protect the interests of children in all circumstances. Firstly, verbal and written summary as well as detailed information of the research ("Information for the nursery school participating in the research") was provided to the leader. The former document included understandable and comprehensive information of the purpose and goals of the research, procedures and methods used in the experiments, risks and benefits of the participation, confidentiality of personal data of the participants, access to results of the research, compensation for participation and the statements of the voluntary participation and the participant's rights to confidentiality and to withdraw from the study at any time. Consequently, experimental plans for the experimental evacuation drills describing also particular experimental setups, time schedules, and safety considerations were provided to the leader and further discussed. Subsequently, these documents were adjusted according to the requirements specified by the leader in order to maximize benefits and minimize risks of the experiments for the participating children. An understanding of the research, its risks and benefits, and a voluntary agreement to participate in the research was expressed by the leader in form of signed "Informed consent intended for the leader of the nursery school".

4.1.2 Informed consent given by parents

The second level of the information process was communication with parents of the participating children. Due to a large number of involved children in the experimental evacuation drills (more than 800 children), a parental permission consent was obtained as an opt-out consent, i.e. in a passive approval. It means that details about the research and experimental evacuation drills were provided to parents in advance who had opportunity to withdraw the participation of their child in the study by contacting the leader or the authorised staff member in the nursery school. The distribution method was chosen individually in each nursery school after consultation with the leader including sending email, explanation at parent meeting, posting on website or on information boards in the building.

4.1.3 Informed consent given by staff members

Since except children, staff members (educationalists and other staff members) were involved in the experimental research, a detailed information of the research was provided to them in both verbal and written form and informed consent ("Informed consent intended for the staff member of the nursery school") had to be signed by them as well.

Based on the decision of the leader to check out the evacuation procedure in the nursery school during the experimental evacuation drills less or more realistically, the experimental evacuation drills could be less or more announced to staff members in advance. In general, staff members were notified that the experimental evacuation drills were going to happen, however, the amount of provided information could differ (details on different levels of announcement can be found in Section 5.2.2). In announced experimental evacuation drills, the date and time (or approximate time) were known to all staff members, whereas in semi-announced experimental evacuation drills only date (approximate date) was revealed in advance. In both cases, informed consent which contains similar elementary information as informed consent intended for the leader of the nursery school was signed by participating staff members in advance. The last level of announcement were unannounced experimental evacuation drills when at most approximate month without any details was mentioned to staff members. Here, detailed information about the research was provided to participating staff members immediately after the experimental evacuation drills were finished and subsequently the participants were also asked for signing the informed consent.

In the context of unannounced experimental evacuation drills, ethical aspects should be discussed more deeply. In the present research, ethical dilemma caused by unannounced evacuation drills could be related only to the participating staff members since the leader of the nursery school as well as the parents of children were informed about the research well in advance. Notably, complications with a voluntary participation and with a withdrawal from the experiment at any time could arise. Since the research was based on observations of the experimental evacuation drills which were performed under the same circumstances as regular or additional evacuation drills, it could be assumed that the participating staff members responsible for children's safety did not have any reason neither to run an evacuation training voluntary nor to interrupt in its process. All necessary information about the research was proposed to the participating persons immediately after the experimental evacuation drills were finished.

4.1.4 Information provided to children

The amount of information provided to children, e.g. by parents or by teachers, on the experimental evacuation drills was not controlled. In each nursery school an own approach was taken how and to which extend children were informed about the planned experimental evacuation drills. According to the various level of announcement which could occur and was always chosen by the leader, the experimental evacuation drills could or could not be discussed with children beforehand in order that they could understand the situation well. Children did not receive any written information.

4.2 Beneficence and non-maleficence

As it is stated in many ethical codes, the research subjects must be protected from harm and their well-being must be secured. In Belmont Report [156], two general rules are formulated as complementary expressions to this principle: "do not harm", and "maximize possible benefits and minimize possible harms". However, these principles are mainly connected to medical ethics, both physical and psychological welfare of persons must be considered also in other research fields. Moreover, it goes without saying that risks should be always over-weighed by benefits.

All experimental evacuation drills were prepared and discussed with the leader of the nursery school in detail. The evacuation procedure during the experimental evacuation drills (including the level of announcement) was chosen in line with expressed wishes of the leader. Besides that it corresponded to the procedure followed in regular evacuation drills carried out in the nursery school, always in compliance with a fire safety documentation of the building. The participants were not exposed to any unusual circumstances (e.g. simulating fire or smoke) and the main objective of the study was observational. During the experimental evacuation drills the participants were moving through the building and a potential risk of injury had to be assessed. Since the experimental evacuation drills were carried out in a form of a regular evacuation drill, this risk was assumed as not more considerable than in the case of standard fire training. In the case that the experimental evacuation drills were realised as additional evacuation drills, the risk of injury could increase, however, the probability could be still assumed as very low. Moreover, contrary to a regular evacuation drill, the experimental evacuation drills were prepared and observed thoroughly, and potential help could be provided effectively. Generally, evacuation drills conducted on a regular basis are recommended as useful means of control of emergency plan functionality as well as of preparedness of the staff members and occupants to emergency situations. In pre-school facilities, regular evacuation drills are highly recommended if not required by fire safety regulations. The participants and the nursery schools benefited directly from the experimental evacuation drills since the evacuation procedure could be practised, potential issues with the emergency plan could be identified, the staff members could be trained and get experienced, children could be familiarised and trained in using the evacuation routes in the building, and consequently the safety of children in the institution could be improved. Besides that, the conducted observations should help at significantly level to compile a list of suggestions for carrying out evacuation drills in nursery schools. This document in form of a brief guide is intended for pre-school institutions to maximize benefits of regular evacuation drills and so increase awareness of fire safety and directly improve safety of the pre-school children occupancy.

4.3 Protection of confidentiality

The privacy and the confidentiality of personal information of the participating subjects must always be protected and the impact of the experiments on their physical, mental and social integrity must be minimized. An indispensable part of the present research was video recording that completely conditioned further analysis of the experiments and also meant the main risk related to integrity of involved persons at the same time. From this reason, all collected data have been treated as strictly confidential. All obtained footage was acquired anonymous and location and angle of cameras, if possible, were selected in such a manner to prevent potential identification of the participants. In the consequent analysis, all results were processed as anonymous with any connection to individual persons. All recordings have been used solely in connection with this research project in fire safety, and therefore has not been displayed publicly or passed on to others (third parties). The recorded data has been stored at the Czech Technical University in Prague in a password protected computer and will be damaged when the analysis is finished, up to maximum of 5 years.

In line with the Civil Code of the Czech Republic, Act no. 89/2012, Division 6 Personality rights of an individual, Subdivision 2 Image and privacy, Section 89 an image, or audio or video recording may, without the consent of an individual, also be reasonably made or used for scientific or artistic purposes and for print, radio, television or similar coverage. According to Section 90 of this Act, lawful reasons for interference with the privacy of another or for the use of his image, documents of personal nature or audio or video recordings may not be used unreasonably in conflict with the legitimate interests of the individual.

Besides the video recording, no sensitive information about the participants were collected; however, a range of the age of the children as well as gender representation in each class or group were inquired. These characteristics, always related to a whole group of persons, could not lead to the personal identification. Personal data of the involved persons was required only in the case when it was necessary from related purposes, i.e. when the informed consent had to be signed (and a name and a surname were a part of this document). This personal data (name and surname of the person who signed the consent) was collected only in order to fulfil the ethical consideration of informed consent and it has not been used for any analysis or other research purposes. Hence, the processing of this personal data has been necessary for the purposes of the legitimate interests pursed by the investigator, this data had to be processed in line with the EU GDPR regulation [158].

4.4 Ethical approval

The research project was approved by Ethical review board at Czech Technical University in Prague under reference number 0000-01/19/51902/EKČVUT. The approval document is attached in Appendix A.

Chapter 5

Experimental evacuation drills

5.1 Introduction

Evacuation drills (corresponding to fire drills in this study) conducted on a regular basis are generally recommended as a useful means of control of emergency plan functionality as well as of preparedness of staff members and occupants to emergency situations. During a simulated evacuation both evacuation procedure can be assessed and performance of involved persons can be directly or indirectly trained and improved [159]. In pre-school facilities, regular evacuation drills are highly recommended, if not required by fire safety regulations [160]. The required frequency of evacuation drills in occupancies with children at the pre-school age (pre-schools, kindergarten, day-care centres, childcare centres etc.), varies vastly among countries: monthly evacuation drills are demanded e.g. in the USA and Ireland, quarterly in the New Zealand, six-monthly in Finland and in New South Wales, yearly in the UK, Norway or Belgium [160]. In the Czech Republic, regular practising of the emergency plan in early childhood education institutions (i.e. regular evacuation drills) is not legally mandatory (for details see Section 6.1.2).

Besides the direct benefits which evacuation drills may offer to the involved population, they also represent a useful method for fire engineering data collection [161, 162]. Therefore, further studying of an evacuation process during evacuation drills in pre-school institutions can help to improve also scientific knowledge regarding movement parameters of children and the specifics conditions of their evacuation. This knowledge presented in form of engineering data and its further application in fire safety design may meaningfully contribute to improving the safety level in facilities occupied by pre-school children, notably in both design phase and everyday life in the building. This is also motivation for this part of experimental research, which aims to collect and evaluate data related to specific movement abilities of pre-school children during experimental evacuation drills in nursery schools. The label "experimental evacuation drills" has been used in this study to distinguish evacuation drills performed solely as a part of this research from any other evacuation drills (details of evacuation setup and procedure can be found in Section 5.2.2).

5.2 Methods

This part of the current experimental research aims to obtain new experimental datasets and knowledge on children's and staff members' evacuation behaviour, children's movement characteristics, and the specifics of evacuation procedure employed during experimental evacuation drills in nursery schools. To acquire the above-mentioned experimental data describing evacuation process and children's characteristics under the conditions of an evacuation situations, 15 experimental evacuation drills were designed and conducted in 10 nursery schools including 803 children and 77 adults (whereas some of whom participated in 2 experimental evacuation drills). In this section, the experimental methods including the preparatory phase of the research, involved population, observed variables, data collection and analysis methods, and limitations of the proposed research are described.

5.2.1 Participants

First contact with the nursery schools

In the initial phase, in total 45 nursery schools located in Prague and in Central Bohemian Region were addressed with an email invitation to participate in the proposed experimental research. Of these, only 5 nursery schools responded positively and confirmed their interest to participate in the project. Hence, the remainder of the nursery schools' list was contacted with a delay by phone. Finally, 10 nursery schools (i.e. around 22% of the addressed) were interested to take a part in the research. Subsequently, a personal meeting with leaders of the participating nursery schools was arranged. During the first meeting, the following information and documents (in Czech) were presented to the leader:

- Verbal and written summary of the research focused on main goals, scope of nursery school's participation and its time schedule and time costs, benefits, possible risks, and ethical considerations of the project,
- Written document "Information for the nursery school participating in the research" with detail information on procedures and methods used in the experiments as well as on risks and benefits and further ethical considerations related to the project (more details are outlined in Chapter 4 Ethics),
- Written confirmation that the research was approved by Ethical review board at Czech Technical University in Prague (Appendix A),
- Written statement confirming that the research is beneficial for further use of the Department for instruction and training services at the General directorate of fire rescue service of the Czech Republic (Appendix B),
- Written documents "Informed consent intended for the leader of the nursery school" and "Informed consent intended for the leader of the nursery school".

If the leader familiarised with research details confirmed the interest to participate, a schedule, design, and safety considerations of experimental evacuation drills were discussed. Simultaneously, information on building description (e.g. number of floors, number of attending children and their age groups, specification of fire safety devices and warning system) and fire safety management (e.g. evacuation plan, evacuation procedure, staff training, regularity of evacuation drills) was obtained. Moreover, a previously negotiated participation of the Fire rescue service of the Czech Republic in form of a special educational program for children or demonstration of firefighting equipment in the nursery school's campus was offered to the leader. On the whole, the leader decided on:

– The number, dates, and times of the experimental evacuation drills (1 or 2 experimental evacuation drills in total),
– The exact evacuation procedure followed during the experimental evacuation drills (e.g. selection of the evacuation routes and exits, emergency warning type and procedure) which was in line with the fire safety documentation of the building by default,
– The level of announcement of the experimental evacuation drills (see details in Section 5.2.2) and the form how staff members and parents of the participating children were informed,
– The participation of Fire Rescue Service of the Czech Republic.

In addition to the planned dates of the experimental evacuation drills, a visit of the researcher in the nursery school was also scheduled in order to get familiar with the building, measure exact building geometry required for further data analysis and design of the location of measurement equipment.

Overview of the participating nursery schools

The participating nursery schools varied across their building design, capacity, experience with regular evacuation drills, and evacuation procedure. Hence, the boundary conditions of the experimental evacuation drills could differ considerably. An overview of the participating nursery schools and a brief description of the above-mentioned factors is presented in Table 5.1. In order to ensure privacy of the participating subjects any information which could enable their identification is not presented in this study. Therefore, the nursery schools are labelled with letters.

As can be seen from Table 5.1, the overall capacity of the participating nursery schools varied from one-class nursery schools to institutions accommodating more than hundred children; however, four-classes nursery schools were the most frequent ones. Furthermore, there are generally two options how to divide children into classes according to their age in the Czech Republic. Children of the same age (i.e. of a narrow age range such as 3–4 years or 5–6 years) can be placed in homogeneous classes. Alternatively, children of different age (e.g. 3–6 years) can attend the same class which is here named as heterogeneous (or multi-age, mixed-age, vertical, ungraded, or non-graded as well). Among the participating nursery schools, both types of classes were represented (in Table 5.1, homogeneous classes are label-ed as HOM and heterogeneous classes are labelled as HET.)

A diversity was noticed also in frequency and regularity of evacuation drills performed in the nursery schools under consideration. Although 70% of the participating nursery schools had a prior experience with an evacuation drill during the past 5 years, only 57% of these nursery schools performed evacuation drills on a regular basis (annually or bi-annually). The remaining 43% had only rare experience which was not positive in most cases, i.e. due to experienced complications during the previous evacuation drills the nursery schools did not continue in the regular training. Gaining experience and improving of actual evacuation strategy was one of the main motivation for the nursery schools to participate in the study. Almost all nursery schools that wanted to run two experimental evacuation drills were nursery schools without prior experience with emergency training. Aware of those insufficient conditions they were motivated to find an appropriate evacuation strategy. Thanks to the repetition of the drills they aimed to enhance the evacuation procedure and to eliminate identified complications such as delays resulting from an inadequate organisation of children or from a non-optimal exit choice.

The participating nursery schools differed also in type of the employed warning signal and its dissemination in the building. In Table 5.1, voice message ("verbal"), manual sound signal such as whistle, gong, pot banging ("signal"), and acoustic signal (siren, smoke detector signal) are distinguished. Detail description on warning signal in the participating nursery schools is given in Section 5.3.2, Table 5.5.

Table 5.1: Overview of the participating nursery schools

Nursery school	Building description		Occupancy		Experimental evacuation drills					
	No. of floors	**Used staircases**	**No. of classes**	**Class type**	**Prior experience**	**No. of drill**	**Level of announcement**	**Warning signal**	**No. of children**	**No. of staff members**
A	3	External spiral	4	HET	Yes (annually)	1	Announced	Signal	74	5
B	2	Internal straight	11	HOM HET	Yes (once in the last 5 years)	1	Unannounced	Verbal+signal	207	21
C	2	Internal straight	4	HOM	Yes (bi-annually)	1	Semi-announced	Verbal+signal	75	5
D	1	-	4	HET	Yes (bi-annually)	1	Announced	Verbal+signal	63	4
						2	Semi-announced	Verbal +signal	61	4
E	2	Internal straight	6	HOM	Yes (once in the last 5 years)	1	Unannounced	Verbal	100	9
F	2	Internal straight	1	HET	No	1	Announced	Verbal	20	2
						2	Announced	Verbal	23	2
G	1	-	3	HET	Yes (once in the last 5 years)	1	Announced	Verbal+signal	52	4
						2	Semi-announced	Verbal+signal	50	3
H	2	Internal, external straight	4	HOM	No	1	Announced	Acoustic	61	4
						2	Unannounced	Verbal+signal	24	3
I	1	-	1	HET	No	1	Announced	Acoustic	12	3
						2	Semi-announced	Acoustic	12	3
J	3	Internal straight	8	HOM	Yes (annually)	1	Announced	Acoustic	136	16
Total			**46**			**15**			**970**	**87**

HOM: homogeneous class, HET: heterogeneous class

The number of children in classes of the participating nursery schools during the experimental evacuation drills ranged from 7 to 25 children in one class with the mean value of 17 children in one class (standard deviation 4.5). Frequency of classes with particular number of children is graphically displayed in Figure 5.1.

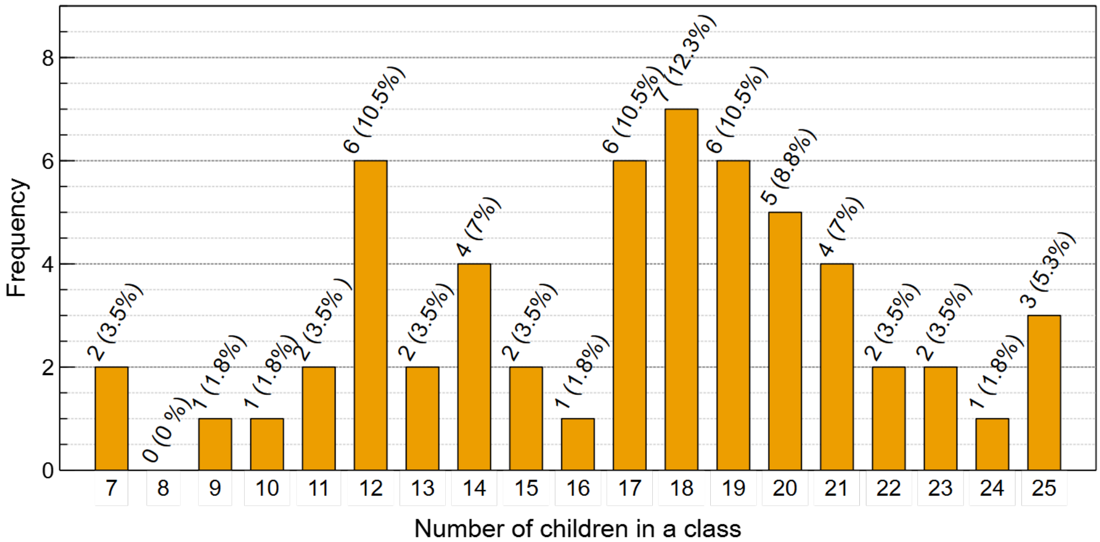


Figure 5.1: Frequency of number of children in the participating nursery schools during the experimental evacuation drills

The number of staff members in each class varied from 1 to 3 staff members. Mostly, in more than half of the classes (57.9%), only one staff member was present. Two staff members were present in 31.6% of classes and three staff members were only in 10.5% of the observed classes. The relationship between the number of children and number of staff members in a class is defined as a child-to-staff ratio. During the experimental evacuation drills, the staff-to-child ratio in the participating nursery schools ranged from 3.0 to 25.0 with the mean value of 13.1 (standard deviation 5.6). A summary of the calculated staff-to-child ratios can be found in Figure 5.2. By way of illustration, the calculated staff-to-child ratios were clustered based on standard rounding rules.

Age-related overview of the participating children

In the participating nursery schools, children were or were not divided in classes according to their age (so called homogeneous and heterogeneous classes). As outlined in the introduction part of this document, nursery schools in the Czech Republic are intended for children from 3 to 6 years of age but they may be also attended by children outside this age limit, i.e. by children at the age between 2–3 years and 6–7 years. Due to ethical considerations, age of the participating children was not identified individually while only an age range related to a whole class provided by the leader of the participating nursery school was registered.

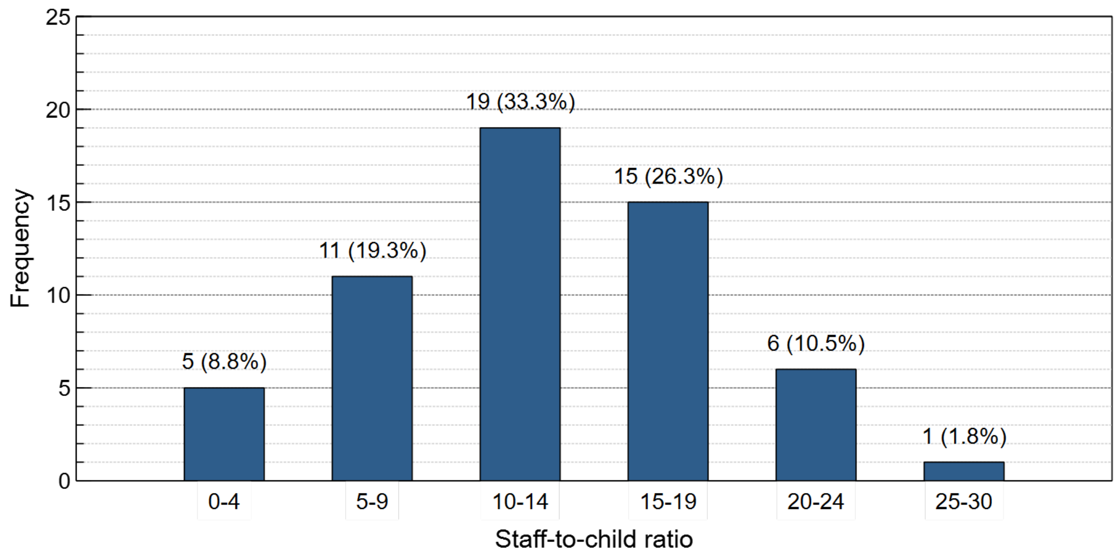


Figure 5.2: Frequency of staff-to-child ratios during the experimental evacuation drills

Table 5.2: Age-related overview of the participating children

Age group [years]	Name in this study	Number of classes	Number of children
3–4	Junior	17	265
5–6	Senior	15	295
6–7	Senior+	1	22
3–6	Mixed	24	389
	Total	**57**	**970**

In this study, the heterogeneous classes are labelled as "Mixed" classes in which typically children aged 3–6 years were involved. Considering homogeneous classes, classes involving children between 3–4 years of age are labelled as "Junior" classes and classes attended by children aged between 5–6 years are labelled as "Senior" classes. It should be noted that in both Mixed and Senior classes children at the age of 7 years (also children with postponement of the compulsory school attendance) could be exceptionally included but due to their minimal presence they ware neglected when labelling the age groups. Conversely, in one nursery school a pre-school class was intended specially for older children they were very close to compulsory schooling, i.e. at the age between 6–7 years. This class was set apart from other Senior classes and it was labelled as "Senior+" class. An overview describing age groups of the involved children is provided in Table 5.2.

5.2.2 Experimental setup and equipment

The experimental evacuation drills were carried out during the experimental phase between May and June 2019. The level of announcement as well as the amount of information communicated with staff members and children beforehand the experimental evacuation drills was based on the decision of the nursery school's leader to make the evacuation drills less or more realistic. In general, 3 differently announced situations could occurred from the perspective of involved staff members:

- **Announced evacuation drills**: Information of the date and the time of the experimental evacuation drills was provided to all staff members in advance. In this context, instructions how to run the experimental evacuation drills could be discussed.
- **Semi-announced evacuation drills**: The experimental evacuation drills were announced to all staff members in advance. Although they were notified that the evacuation drills were going to happened, a part of information was not provided to them, e.g. the date or/and the time of the experimental evacuation drills.
- **Unannounced evacuation drills**: No information about the experimental evacuation drills was provided to the staff members in advance.

The amount of information provided to children beforehand, e.g. by parents or by teachers, was not controlled and therefore, children could or could not be prepared on the evacuation situation in advance (further discussion on this issue is provided in results part in Section 5.3.3).

Based on the knowledge of the building layout obtained during the visits in the nursery schools (particularly the locations of classrooms, staircases, corridors, and exits), an experimental plan was compiled for each experimental evacuation drill. In the experimental drawing, measurement areas (described in detail in Section 5.2.3) and positions and mounting solutions of measurement equipment (cameras) were determined in advance. In general, the location of cameras was chosen to cover all checkpoints of predetermined measurement areas (see details in 5.2.3) captured either from a top view, or from a side view (see Figure 5.3 for illustration). To observe the evacuation process during the pre-movement phase, cameras were installed in classrooms in the case of announced and some semi-announced experimental evacuation drills. Conversely, during unannounced experimental evacuation drills or semi-announced experimental evacuation drills when staff members should not have been informed about their start in advance, cameras were installed only in corridors covering the doors from classrooms and all preparation actions in the building were realised discreetly as far a possible.

The date as well as the time of start of each experimental evacuation drill was scheduled in cooperation with the leader of the nursery schools. Experimental evacuation drills were mostly scheduled in the morning hours in order to avoid their beginning during particular activities such as mealtime or outdoor activities. However, there was also a case when a snack time was intentionally chosen in order to test specific circumstances during the second experimental evacuation drill. The experimental evacuation drills were run in a form of regular evacuation drills or of additional evacuation drills in the case that more than one experimental evacuation drill was conducted. Standardly, the evacuation procedure during the experimental evacuation drills followed the fire safety documentation of the building. However, in some cases, the particular evacuation routes available or the responsibility for the warning signal were specified by the leader of the nursery school.

During the day of the experimental evacuation drill the following sequence of actions was typically realised:

- Arrival at the place and contact with the leader,
- Placement of video-cameras and equipment at the predefined locations and positions,
- Turning on cameras, synchronising the recording time, recording of reference mats where required in measurement areas,
- Waiting until the evacuation drill was started by the leader or by the responsible staff member,
- Waiting until the evacuation drill is finished and everyone left the building,
- Turning off cameras,
- Discussion with the leader and staff members, encouraging the staff members to discuss the situation with children after returning into the building,
- Return of children and staff members into the building,
- When planned: educational program for children given by a representative of the Fire rescue service of the Czech Republic and/or demonstration of firefighting equipment in the nursery school's campus given by a fire brigade,
- Dismount cameras and equipment,
- Leaving the place.

Figure 5.3: Example of mounting solutions of measurement equipment using telescopic building props in combination with pipe clamps (**left**); suction cups (**middle**); flexible tripods (**right**)

The duration of the evacuation drills was recorded using outdoor digital cameras (resolution 720 × 480, frame rate 30 fps). In total 29 cameras (9 GoPro Hero3+ Silver Edition cameras and 20 Rollei ActionCam 415 cameras) were available; however, the number of used cameras differed in the experimental evacuation drills since it was not always necessary to use all of them. The cameras were temporarily installed using different mounting equipment including suction cups, flexible tripods, multipurpose clamps, and telescopic building props in combination with pipe clamps (see Figure 5.3). In addition, a stopwatch was used to synchronise the time when recording was started. Checkpoints, measurement areas, and other geometry required for further video analysis were temporarily marked on floor using different coloured tapes or defined by recording of reference mats.

5.2.3 Investigated variables

The experimental evacuation drills were proposed to describe children's movement characteristics and evacuation specifics in nursery schools. Hence, observed variables can be divided into two categories: **evacuation behaviour and procedure** and **movement characteristics**.

Evacuation behaviour and procedure

Evacuation behaviour of children and staff members was investigated both during the pre-movement phase and during their movement through a building. In addition, the overall evaluation of evacuation procedure during the whole evacuation process was performed.

Before the evacuation movement to a safety place outside a building started, the focus was on evaluation of pre-movement times. In general, pre-evacuation times were determined for each class as the time between the delivery of the warning signal and the time when the first child and the last child in the class started the evacuation by approaching the classroom door moving towards to the exit of the building (details on particular data analysis can be found in the results part in Section 5.3.2). When cameras could be installed in the classrooms (announced and particular semi-announced experimental evacuation drills) decision-making and protection activities of staff members and children, involvement and instructions of staff members, and the overall evacuation procedure performed, i.e. the way how children were organised during, were also observed.

Evacuation procedure, including group formation, children's hand holding, staff members' instructions, and assistance provided to children was observed during movement through a building. Special attention was paid to movement on staircase where using of handrails, eventually searching for other support, and of a marking time pattern was observed. Moreover, when occurred, issues and critical locations in the evacuation routes were determined.

Movement characteristics

Considering movement characteristics, the three fundamental variables describing human movement were in focus, i.e. travel speed, specific flow, and density of persons. Movement characteristics were observed in measurement areas described in detail in the following section.

Travel speed Travel speed S [m·s^{-1}] was observed in corridors and on staircases and it was determined for each person as a ratio of travelled distance s [m] over corresponding time of travel t [s] as

$$S = s \cdot t^{-1} \tag{5.1}$$

Walking and running travel speeds were distinguished based on the presence of a flight phase (see Section 3.2.1 for details) observed through the analysis of video recordings. This distinguishing mark was preferred rather than setting a fixed travel speed limit, since the same value (e.g. 2 m·s^{-1}) may denote the fastest run of a 3-year-old child but only a quicker walking pace in the case of a 6 year-old child. A distinction was also made between the speed of continuous movement (referred as movement speed) and the speed on particular parts of escape routes which could include various stops (referred as modelling speed).

Specific flow Specific flow F_s [pers·s^{-1} m^{-1}] was calculated as the number of persons N [pers] passing the checkpoint of the specified width b [m] in a given time period Δt [s], i.e.

$$F_s = N(\Delta t \cdot b)^{-1} \tag{5.2}$$

Following this approach, specific flows were calculated at exits of pre-determined measurement areas in corridors, on staircases, and in doorways (see Section 5.2.4 and Checkpoint 02 in Figure 5.4–5.13) for each second interval when those components were used [24,25]. Consequently, specific flow assigned to each person was determined knowing the times when all persons crossed the observed checkpoint. In corridors and on staircases the width of the observed checkpoint was assumed as the width of a measurement area (see Section 5.2.4 for details). Considering movement through doors the width of the observed checkpoint was assumed as the clear width of the door opening, i.e. without any boundary layers [24, 34].

Density In order to find travel speed-density and specific flow-density relationships, the variable of density was observed in measurement areas in corridors, on staircases, and in doorways. Density D [pers·m^{-2} or m^2 m^{-2}] was calculated as a ratio of number of persons in the measurement area N [pers or m^2] over the size of a measurement area [m^2]

$$D = N \cdot A^{-1} \tag{5.3}$$

The number of persons in the measurement area N was determined automatically knowing the entrance and exit times of all persons. Similarly to specific flows, density conditions in the observed measurement area were estimated for each second interval when those components were used. The density assigned to each person was determined as an average value within the time period when the person was moving inside the measurement area. As highlighted in the theoretical background of this study (see particularly Section 2.3.3 and Section 2.3.4) different methods for density expression can be found in literature (mostly units of pers·m^{-2} or m^2 m^{-2}). In the case of pre-school children, application of the unit of m^2 m^{-2} seems to be preferable to the unit of pers·m^{-2} since in the former approach children's body dimensions are taken into account and further comparison data involving different populations is enabled. In order to provide comprehensive and comparable data-sets, the variable of density was expressed both in units of pers·m^{-2} and m^2 m^{-2} in this study. A conversion of density unit from pers·m^{-2} to m^2 m^{-2} was performed employing the concept of occupied areas. The used occupied areas (horizontal projections of children's body) were adopted from Table 3.1, i.e. calculated from anthropological data acquired in nationwide anthropological survey of children and adolescents in the Czech Republic [91] in 2001 (see Section 3.1 for more details). The occupied area of a Junior child (aged 3–4 years) was assumed as $A_{occ} = 0.025$ m^2, the occupied area of a Senior child (aged 5–6 years) was assumed as $A_{occ} = 0.028$ m^2, the occupied area of a Senior+ child (aged 6–7 years) was assumed as $A_{occ} = 0.029$ m^2, and the occupied area of a Mixed child (i.e. a child in a Mixed class, aged 3–6 years) was assumed as $A_{occ} = 0.026$ m^2.

5.2.4 Measurement areas

Movement characteristics were observed in specific predetermined areas named **measurement areas** in this study. In principle, the measurement areas were determined in corridors, on staircases, and in doorways. An overview of measurement areas observed in the participating nursery schools can be found in Table 5.3 at the end of this section.

Corridors The horizontal movement was analysed mostly in corridors (occasionally in hallways) where a continuous movement of persons was enabled. In the observed corridor (hallway), measurement areas (segments) were defined. The entrance and the exit of a measurement area were assigned as checkpoints where the time when a person passed through was measured, i.e. entrance and exit times. Persons were consider as passing a checkpoint when their body centre (simplified as shoulders) crossed the plane limited by the checkpoint, see Figure 5.4. The length of measurement areas (the travel distance) in corridors l_{cor} [m] was 2 m, 3 m, or 5 m depending on the corridor's geometry and the building layout. The assumed width of a measurement area b_{cor} [m] corresponded with the effective width of the corridor (hallway) determined using the analysis of video recordings, i.e. with the part of the route which was actually used during the experimental evacuation drill (see Figure 5.5. The area of a measurement area in corridors A_{cor} [m^2] was calculated as

$$A_{cor} = l_{cor}\, b_{cor} \tag{5.4}$$

Straight staircases On straight staircases, different measurement areas were defined in order to separately evaluate movement on flights, on landings (half-landings), and on a staircase as a whole.

On flights, persons were considered to entrance/exit a measurement area when their first foot was flat on the first step in the measurement area/on the landing

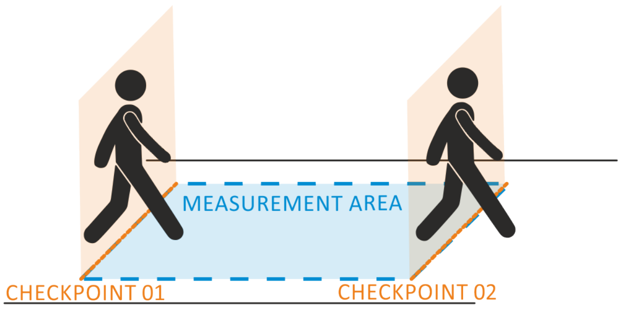


Figure 5.4: Entrance and exit checkpoints in a measurement area in corridors

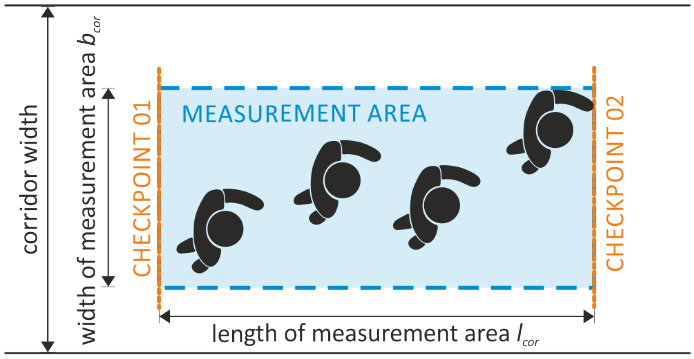


Figure 5.5: Definition of a measurement area in corridors

(half-landing). The length of a measurement area (the travel distance) $l_{str,flight}$ [m] was defined by the length of a flight in slope calculated as number of steps multiplied by distance between two steps in slope. The width of a measurement area $b_{str,flight}$ [m] was determined as the actually used (effective) width of the flight based on the analysis of video recordings. In general, during the experimental evacuation drills, the width of flights was used in two ways:

1. The whole width of the flight was used since persons were climbing downstairs in multiple lanes holding handrails on both sides of the flight (see Figure 5.6). Here, the effective width of a flight $b_{str,flight}$ [m] was assumed as the whole clear width of the flight (i.e. clear width measured between handrails).
2. Only a part of the width of the flight was used since persons were climbing downstairs in a single lane or since the width of the flight was very large (see Figure 5.7). In this case, the effective width of a flight $b_{str,flight}$ was estimated using the analysis of video recordings.

The area of a measurement area on flights $A_{str,flight}$ [m^2] was calculated as

$$A_{str,flight} = l_{str,flight}\, b_{str,flight} \tag{5.5}$$

A measurement area on landings (half-landings) was defined as the area limited by two semi-ellipses (see Figure 5.8). The outer ellipse (see the points A, B, and C in Figure 5.8) was determined by a semi-major axis a_{OUT} and by a semi-minor axis

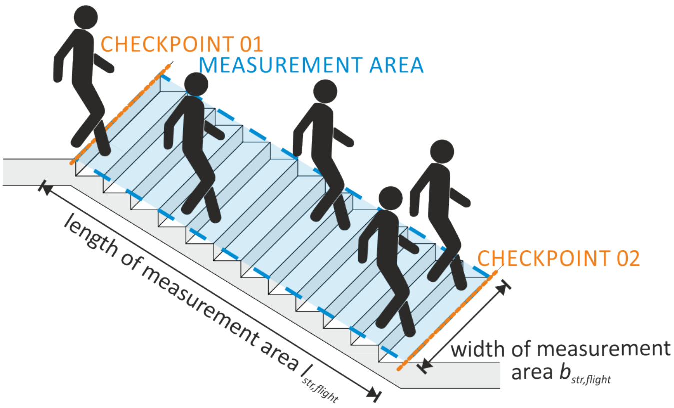


Figure 5.6: Definition of measurement area when persons were using the whole width of a flight

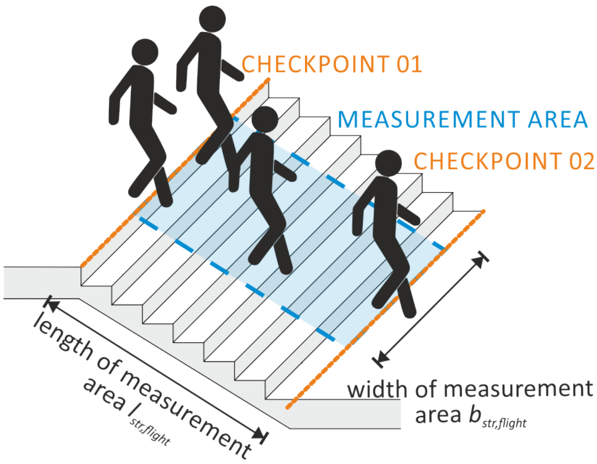


Figure 5.7: Definition of measurement area when persons were using only a part of the width of a flight

b_{OUT} and the inner ellipse (see the points D, E, and F in Figure 5.8) was determined by a semi-major axes a_{IN} and by a semi-minor axis b_{IN} equal to

$$a_{\mathrm{OUT}} = b_{land}/2 \qquad a_{\mathrm{IN}} = b_{space}/2$$
$$b_{\mathrm{OUT}} = 7\, l_{land}/8 \qquad b_{\mathrm{IN}} = l_{land}/8$$

Here, b_{space} labels the open horizontal space between two flights. The area of a measurement area A_{land} [m^2] was calculated as

$$A_{land} = \pi\, (a_{\mathrm{OUT}}\, b_{\mathrm{OUT}} - a_{\mathrm{IN}}\, b_{\mathrm{IN}})/2 \tag{5.6}$$

Aware of the considerable impact of assumed travel distance on the calculated travel speed, 9 possible travel paths (in other words, 6 different travel distances, see the Arabic numbers in Figure 5.9) were assumed and were assigned to persons individually using the analysis of video recordings. Similarly to the boundaries of a measurement area, a travel path d_{land} [m] was assumed as a semi-ellipse calculated as

$$d_{land} = \pi\, \sqrt{(a_d^2 + b_d^2)/2} \tag{5.7}$$

To define their semi-major axis a_d, inspired by Ronchi at al. [163], the assumed widths of flights (i.e. the entrance part and the exit part of a landing (a half-landing)) were divided into three subareas (see the parts I, II, III in Figure 5.9). To determine semi-minor axis b_d of the semi-ellipses the length of a landing was divided into 4 subareas (see Figure 5.9 for illustration).

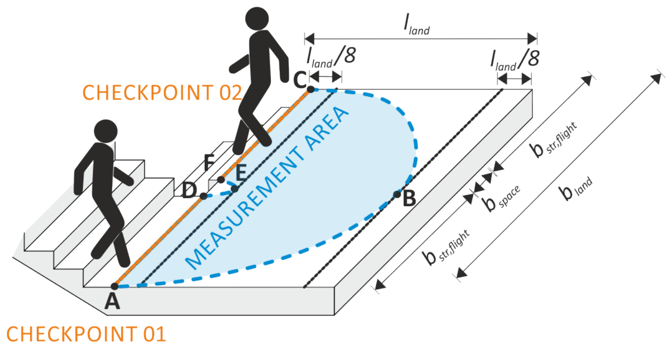


Figure 5.8: Definition of a measurement area on landings

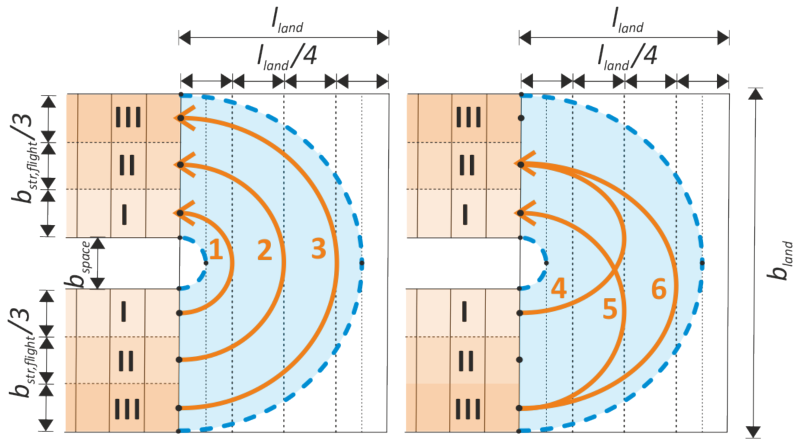


Figure 5.9: Definition of possible travel paths on landings

In addition to separate evaluations of movement on flights and on landings (half-landings), movement characteristics were observed also on whole staircases in order to provide the results neglecting the influence of different parts of a straight staircase as well as the results suitable for evacuation modelling. In this case, a measurement area was assumed as a whole staircase including all flights and landings (half-landings). A travelled distance was calculated individually for each person and it corresponded to the summary of travelled distances on all flights and landings/half-landings. The area of a measurement area on a whole staircase was not specially estimated since for further calculations the values obtained for particular flights and landings (half-landings) were assumed and used.

Spiral staircases On spiral staircases, persons were considered to entrance/exit a measurement area when their first foot was flat on the first step in/outside the measurement area. The length of a measurement area l_{spiral} [m] was defined as the length of a section (approximately the half of one shift) of a circular helix

$$h = t\sqrt{r^2 + (0.5v/\pi)^2} \tag{5.8}$$

calculated at the middle of the effective width of the spiral staircase (see Figure 5.11). In (5.8) t is in radians. The width of a measurement area b_{spiral} [m] was determined as the effective width of the spiral staircase based on the analysis of video recordings. The area of a measurement area on spiral staircases A_{spiral} [m^2] was calculated as

$$A_{spiral} = l_{spiral}\, b_{spiral} \tag{5.9}$$

It was observed that persons were climbing downstairs in two lanes side-by-side and hand holding. Hence, to evaluate the travel distance of each person more realistically two possible travel paths were assumed. Travel distances were calculated similarly as the length of a measurement area as a part of one shift of a circular helix measured in one quarter and in three quarters of the effective width of the spiral staircase (see Figure 5.11).

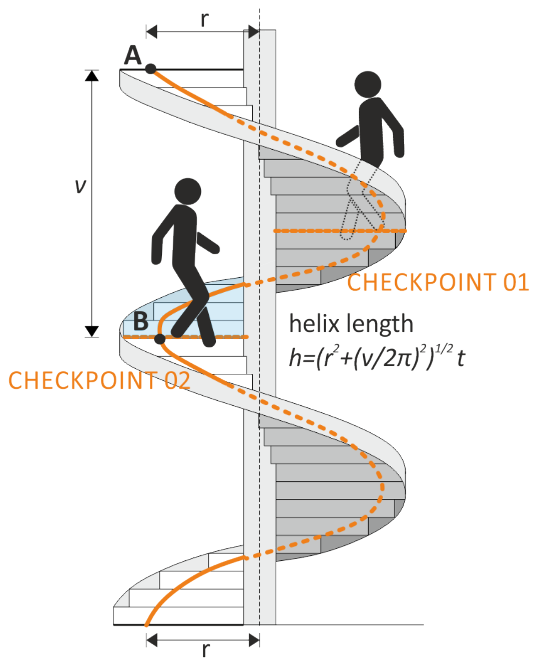


Figure 5.10: Definition of measurement area on spiral staircases

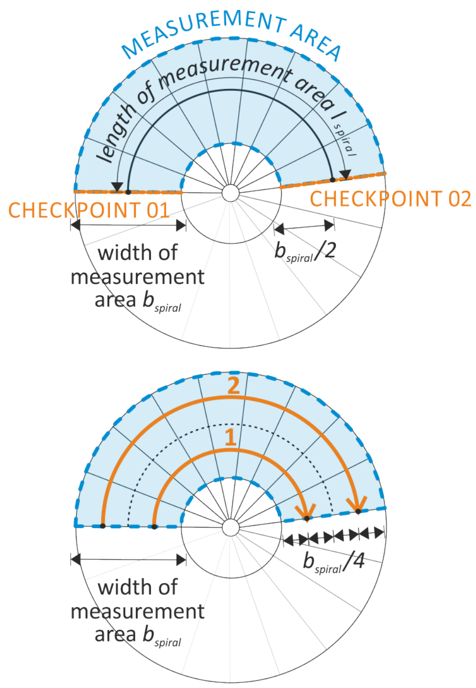


Figure 5.11: Definition of possible travel paths on spiral staircases

Doorways To evaluate movement through doors a measurement area was determined in front of the respective door. Persons were consider as entering/exiting the measurement area when their body centre (simplified as shoulders) crossed the plane limited by the enter/exit checkpoint, see Figure 5.12. The area of a measurement area was defined fixed 1 m^2, i.e. the length l_{door} [m] and the width b_{door} [m] of a measurement area were set as 1 m (see Figure 5.13).

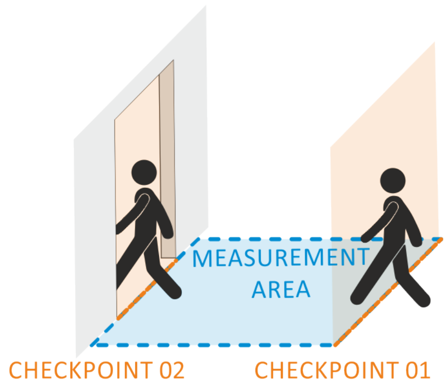


Figure 5.12: Entrance and exit checkpoints in a measurement area in doorways

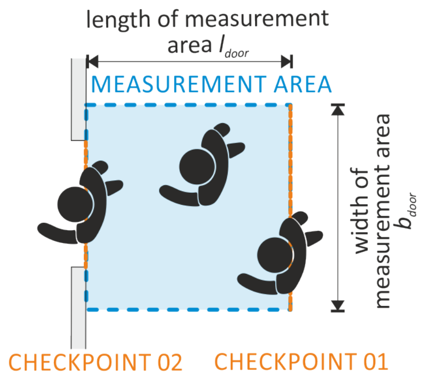


Figure 5.13: Definition of measurement area in doorways

Table 5.3: Overview of measurement areas observed in the participating nursery schools

Nursery school	Corridors	Straight staircases			Spiral staircases	Doorways
		Flight	Landing	Whole	Section	
A	-	-	-	-	8	-
B	9	5	1	1	-	2
C	2	2	1	1	-	3
D	-	-	-	-	-	1
E	3	7	3	3	-	5
F	-	3	1	1	-	3
G	1	-	-	-	-	3
H	1	4	1	1	-	4
I	2	-	-	-	-	2
J	2	6	4	2	-	2
Total	**20**	**27**	**11**	**9**	**8**	**25**

5.2.5 Data analysis and statistics

After each experimental evacuation drill was finished, acquired video recordings were transferred to an encrypted storage device and subsequently they were synchronised, cut, labelled, and stored. The videos were further analysed manually using Avidemux 2.7.3 software which enables frame by frame moving. During the video analysis, data describing when an observed person passed through predetermined checkpoints such as entrance and exit times in each measurement area and pre-movement times were noted and categorised in spreadsheets. Furthermore, data focused on evacuation behaviour of children and staff members during the pre-movement phase (e.g. organisation of children, performed activities and reactions, level of physical assistance provided to children, leaving strategy) and movement phase (hand-holding, handrail using, marking time pattern when climbing downstairs, movement in pairs, level of physical assistance provided to children and others) were observed and registered.

Data was organised and further processed (including simple calculations and statistical analysis) in spreadsheets. Resultant graphs were constructed in Veusz 3.0.1.1

software [164] which was also used for further statistical analysis, i.e. creating box plots. Box plots were made in order to illustrate differences in various children groups showing means, first and third quartiles (interquartile range IQR), minimum and maximums (at most 1.5 IQR) and outliers. In addition, where appropriate, statistical differences among various groups of the experimental data were tested using Kruskal-Wallis Test and Mood's Median Test (two different statistical test were run to increase reliability of their results).

5.2.6 Limitations

For proper interpretation of the presented data limitations related to the experimental evacuation drills should be mentioned. These limitations may be seen in several ways:

1. **Naturalistic conditions**: Despite the experimental evacuation drills were carried out in real world settings following standard evacuation procedures in the participating nursery schools, it is apparent that this empirical research method can not fully reflect real-life situations which may occur under emergency conditions. Planned evacuation drills represent always only a simplified model of a potential emergency. Therefore, a selected scenario and procedure can not cover the diversity of possible fire incidents including factors such as availability of escape routes or fire and smoke propagation and its impact on human movement and behaviour. Moreover, the level of announcement and amount information provided to participating persons varied across the experimental evacuation drills. Therefore, the impact of children's and staff members' preparedness on the obtained results cannot be quantified.

2. **Data collection and analysis methods**: The presented data-sets are further affected by uncertainties related to experimental measurements and statistical assumptions. Inaccuracies could primarily originate from manual data extraction and simplification of real travel distances. Aware of these weaknesses, data collection methods, measurement techniques, and data analysis employed in the current study were clarified in detail in order to enable a comprehensive interpretation of the results. Based on the equipment in use and analysis methods, the time when a person passed through a checkpoint was recorded to two decimal places. The results on movement characteristics were evaluated to two decimal places, the accuracy of the presented values for pre-movement times and warning times were conservatively limited to seconds. In addition, negative impact on data accuracy could have the location of cameras which could not be always placed ideally in order to be hidden from sight or to be installed discreetly.

3. **Representativeness of data-sets**: Due to limited number of observations on certain parts of escape routes (e.g. spiral stairs) or in certain age groups (e.g. only 1 class of Senior+ children) the presented data-sets might not be fully representative. Furthermore, in majority of cases, low-density conditions

occurred during the experimental evacuation drills and high-density scenarios are therefore not included in the data-sets.

5.3 Results

The results obtained in the experimental evacuation drills are presented in this section and in Appendix C. In order to follow the timeline of the drills, the findings are structured into several main sections:

- Observations and analysis of evacuation behaviour during the pre-movement phase are presented in Sections 5.3.1, 5.3.2, and 5.3.3,
- Results on movement characteristics on different parts of escape routes (in corridors, on straight and spiral staircases, through doorways) are provided in Sections 5.3.4, 5.3.5, 5.3.6 and 5.3.7,
- Evacuation behaviour during the movement phase, its specifics, and consistency with evacuation procedure including problematic parts and observed procedural issues are discussed in Section 5.3.8 and Section 5.3.9.

5.3.1 Warning times

Warning time was defined as the time interval between the alarm was raised and delivered to responsible staff members supervising children. In this study, this interval was not included in definition of pre-movement time in order to keep observed pre-movement times more comparable (refer to the following Section 5.3.2). In most of the experimental evacuation drills (notably in 84%) warning times were zero, i.e. the warning signal was delivered simultaneously in the whole building. However, in some cases, the evacuation process was delayed due to presence of warning times and they are therefore worthy to be discussed. An overview of observed warning times related to applied method for delivery of warning signal and the reason of the delay is presented in Table 5.4.

Considering the majority of the participating nursery schools (80%), the warning signal was distributed personally in corridors by a responsible staff member employing a verbal massage, a manual or acoustic signal, or their combination. Thanks to a simple building layout or a good audibility of the warning signal, this delivery method was effective in 75% of these nursery schools where no warning times occurred. In the remaining 25% of the nursery schools warning times emerged due to a specific building layout, i.e. long corridors (see the rows beginning with D1 and D2 in Table 5.4) or due to an insufficient volume of the warning signal (see the row beginning with G1 in Table 5.4). The former flaw was discussed with the leader and successfully eliminated in the second experimental evacuation drill. Another dissemination of warning signal in the building, i.e. using verbal message in broadcast, was observed only in 20% of the pre-schools. However this method seems to be basically more effective, in Nursery school B, a malfunction of the broadcast caused

Table 5.4: Warning times observed during the experimental evacuation drills

Nursery school and drill	Warning signal	Warning time [s]	Explanation
B1	Verbal message in broadcast, afterwards verbal message and whistle in corridors	85	The warning signal was not audible in the classroom (broadcast failure)
D1	Verbal message and whistle in corridors	16	Due to long corridors the warning signal was audible first the responsible person came closer to the classroom
D2		6	
		7	
G1	Verbal message and triangle in corridors	4	The warning signal was not audible, the classroom's door had to be opened
		7	

that the warning signal was not audible in one classroom which lead to the longest observed warning time of 85 s. This situation was considered as serious weakness of the evacuation procedure and the fault was corrected in the following week after the experimental evacuation drill.

5.3.2 Pre-movement times

Pre-movement time was measured in all participating nursery schools, i.e. for 57 classes involving 970 children and 87 staff members in total. Since the evacuation procedure during the experimental evacuation drills was not controlled by the researcher and it followed the practise and fire safety documentation of each participating nursery school, the boundary conditions of the experimental evacuation drills could differ considerably. The background information including details of information provided to staff members and children prior to the experimental evacuation drills, used warning signal, and placement cameras in classrooms are provided in Table 5.5 together with pre-movement times observed in each institution.

As suggested in the literature [16, 22, 23, 33, 34], pre-movement times were considered in the moment when a child left a group cell in this study (a broader discussion can be found in Section 2.2.1). Pre-movement times were calculated as the times between the warning signal was delivered to a responsible staff member (i.e. without warning intervals) and the time the first child left the current room (the group cell), see Table 5.5. Since several previous research studies assumed the end of pre-movement times first at the time when the last child of a group left a group cell [16, 34], in Table 5.5, pre-movement times determined following this approach were added for the purposes of further comparison.

Table 5.5: Pre-movement times and experimental background information

Nursery school and drill	Level of announcement: information provided to		Warning signal		IN	Pre-movement time (mean/min/max/SD) [s] (data points)	
	Staff	**Children**	**Signal**	**Method**		**First child**	**Last child**
A1	A: Date and approx. time	Motivated by a game[1]	Gong	Personally in corridors	Yes	28 / 16 / 40 / 10 (4)	25 / 60 / 15 (4)
B1	U: Approx. month	No info	Verbal, afterwards verbal and whistle	Broadcast, afterwards personally in corridors	No	33 / 15 / 59 / 14 (11)	45 / 27 / 77 / 16 (11)
C1	SA: Date	No info[1]	Pot banging	Personally in corridors	Yes	9 / 4 / 11 /3 (4)	20 / 12 / 25 / 5 (4)
D1	A: Date and approx. time	No info[1]	Verbal and whistle	Personally in corridors	Yes	29 / 17 / 46 / 14 (4)	45 / 22 / 65 / 23 (4)
D2	SA: Date	No info[1]	Verbal and whistle	Personally in corridors	Yes	26 / 10 / 41 / 13 (4)	42 / 26 / 56 / 13 (4)
E1	U: Approx. month	No info	Verbal	Broadcast	No	38 / 25 / 54 / 10 (6)	49 / 37 / 62 / 11 (6)
F1	A: Date and time	No info	Verbal	Personally in a classroom	Yes	19 / - / - / - (1)	29 / - / - / - (1)
F2	A: Date and time	No info	Verbal	Personally in a classroom	Yes	5 / - / - / - (1)	26 / - / - / - (1)
G1	A: Date and approx. time	No info	Verbal and triangle	Personally in corridors	No[2]	5 / 3 / 6 / 2 (3)	21 / 17 / 28 / 6 (3)
G2	SA: Date	No info	Verbal and triangle	Personally in corridors	No[2]	9 / 7 / 13 / 3 (3)	20 / 16 / 24 / 4 (3)
H1	A: Date and approx. time	No info	Verbal and megaphone's siren	Personally in corridors	No	14 / 8 / 19 / 5 (4)	21 / 14 / 29 / 7 (4)

H2	U: No info	No info	Verbal and pot banging	Personally in corridors	No	28 / 10 / 45 / 25 (2)	41 / 27 / 55 / 20 / (2)
I1	A:Date and approx. time	No info	Smoke detection signal	Personally in corridors	Yes	13 / - / - / - (1)	19 / - / - / - (1)
I2	SA: Date	No info	Smoke detection signal	Personally in corridors	Yes	11 / - / - / - (1)	16 / - / - / - (1)
J1	A: Date and time	Date and time	Megaphone's siren	Personally in corridors	Yes	22 / 8 / 46 / 14 (8)	32 / 17 / 61 / 15 (8)
Total						**23 / 3 / 59 / 15 (57)**	**35 / 12 / 77 / 16 (57)**

A: announced, SA: semi-announced, U: unannounced

IN: Cameras placed inside the classrooms

[1)] Exceptions could occurred in particular classes in the nursery school based on different approach taken by staff members

[2)] Cameras not placed in classrooms, observations in classrooms enabled thanks to glass walls

Considering different boundary conditions of the experimental evacuation drills as well as potential differences in reactions of staff members, taken approach to organise children, different location of children in the building, staff-to-child ratio, actual mood and atmosphere in the classroom, and many other, it is obvious that large number of factors could impacted the observed pre-movement times. Although it is not possible to isolate the effect of single variables which very likely influenced each other, the following aspects should be explained to provide a deeper insight into the measured values: age of children, level of announcement and preparedness of participants, and organisation strategy taken by staff members.

Age of children

As concluded in previous research studies on evacuation in pre-school children [22, 23, 34], longer pre-evacuation times can be expected in classes with younger children than in classes with older children. The pre-movement times measured in the current study with relation to different age groups (Junior, Senior, Senior+, and Mixed, see Section 5.2.1) are summarised in Table 5.6.

Table 5.6: Pre-movement times in different age groups

Age group	Pre-movement time (mean/min/max/SD) [s] (data points)	
	First child	**Last child**
Junior	30 / 10 / 59 / 16 (17)	41 / 15 / 77 / 17 (17)
Senior	20 / 4 / 54 / 15 (15)	32 / 12 / 62 / 17 (15)
Senior+	34 / - / - / (1)	44 / - / - / - (1)
Mixed	20 / 3 / 46 / 13 (24)	33 / 16 / 65 / 16 (24)

However, based on the results, any apparent correlation between the pre-movement time and children's age could be stated. It can be assumed that the potential effect of children's age on pre-movement time may be sidelined by other factors attributed to various boundary conditions during the experimental evacuation drills. To partly eliminate those factors, pre-movement times observed in Junior children and Senior children in the same nursery school were further compared in 3 nursery schools where at least 3 classes with each age group were present. Due to the limited number of the comparable data-points, the considered pre-movement times are illustrated in a scatter plot (see Figure 5.14).

As can be seen from Figure 5.14, in the case of Nursery school B and Nursery school J, the pre-movement times in Junior classes were considerably longer than the pre-movement times in Senior class. Considering mean values the pre-movement times in Junior classes were longer by 22 s (97%) in Nursery school B and by 22 s (205%) in Nursery school J. Conversely, in Nursery school E, longer pre-movement times were measured in Senior classes, notably by 11 s (34%) considering the mean values. Therefore, the original hypothesis adopted from the literature that pre-movement time decreases with increasing age of children can not be neither prove nor disprove. However, it can be concluded that children's age represent one of the important factors which impacted pre-movement time in the evacuation process.

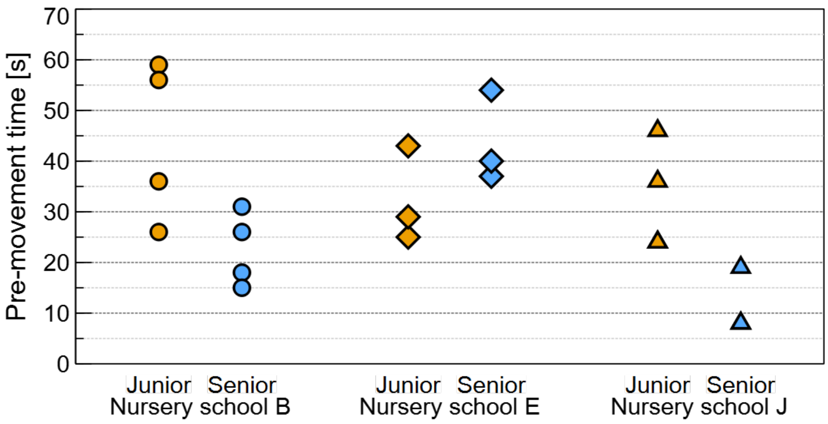


Figure 5.14: Pre-movement times observed in selected in relation to Junior and Senior children's groups in 3 selected nursery schools

Level of announcement and preparedness of participants

As already mentioned, different amount of information was provided to staff members and children prior the experimental evacuation drills in the participating nursery schools (categorised as announced (A), semi-announced (SA), and unannounced (U) in this study). Moreover, the approach how to prepare children for the coming non-standard situation taken by staff members varied amongst classes in the same nursery school. In brief, children could or could not be prepared for the experimental evacuation drills based on decision of staff members. Observed pre-movement times in relation to different level of announcement and preparedness of children are summarised in Table 5.7 and graphically illustrated as box plots in Figure 5.15.

Table 5.7: Pre-movement times in relation to level of announcement and preparedness of children

Level of announcement	**Preparedness of children**	**Pre-movement time (mean/min/max/SD) [s] (data points)**	
		First child	**Last child**
Announced (A)	Children prepared	13 / 8 / 24 / 7 (8)	22 / 14 / 37 / 8 (8)
	Children not prepared	22 / 3 / 46 / 14 (18)	36 / 17 / 65 / 16 (18)
Semi-announced (SA)	Children prepared	7 / 4 / 9 / 4 (2)	16 / 12 / 19 / 5 (2)
	Children not prepared	17 / 7 / 41 / 11 (10)	29 / 16 / 56 / 13 (10)
Unannounced (U)	Children not prepared	34 / 10 / 59 / 13 (19)	46 / 27 / 77 / 15 (19)

Based on the graphical evaluation of the box plots it can be stated that differences in pre-movement times can be identified in relation to different level of announcement of the experimental evacuation drills. The significant difference between the medians of the three independent groups was confirmed using Kruskal-Wallis Test (H=15.23, p-value= 0.001) and Mood's Median Test (p-value= 0.004). The null hypothesis that the group population medians are equal was rejected with 95% level of confidence $\alpha = 0.05$). These non-parametric statistical tests were selected due to limited and unequal sample size and presence of outliers. Specifically, longer pre-movement times were observed in the experimental evacuation drills where neither staff members nor

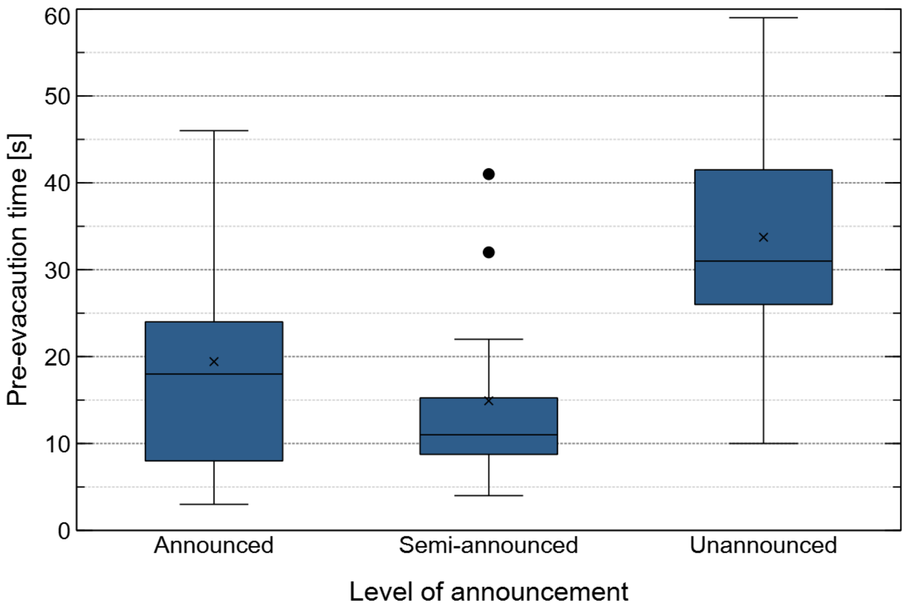


Figure 5.15: Box plots describing pre-movement time in relation to different level of announcement of the experimental evacuation drills

children were expecting the drills. Therefore it may be concluded that both level of announcement and preparedness of children affected the measured pre-evacuation times. In general, the values obtained during the unannounced evacuation drills can be considered as the most close to a real emergency situation. Moreover, regardless of the level of announcement provided to staff members, pre-movement times deemed to be shorter in the experimental evacuation drills where children were prepared on the coming situation than in the cases when children did not received any information in advance. However, this observation was not proved using statistical test due to limited number of data-points in the observed groups.

Organisation of children

Although evacuation behaviour of staff members and children during the pre-movement phase is the subject manner of the following Section 5.3.3, an organisation strategy when leaving a classroom taken by staff members considerable influenced the observed pre-movement times and should be therefore clarified in this context as well. Literature review in Section 2.2 revealed that in evacuation involving pre-school children the movement phase usually did not begin until the whole group of children was prepared to evacuate [16,22,33]. This finding was confirmed also in this study, however, not in all cases. Based on the decision of a responsible staff member, the organisation of children could differ and in some classes children, equipped by instructions were to go or where to wait for others, could also leave a classroom once they arrived at the classroom's door without waiting for the rest of the group. Those situations were typical for one-class nursery schools or for nursery schools with a simple building layout and with a short evacuation route ending in the garden. Based on the leaving strategy employed, the following situation were observed during the experimental evacuation drills (see also Figure 5.16 for the graphical interpretation):

1. Leaving as a group **at once**: All children were gathered in front of a closed exit from a classroom forming a standing queue, first the whole group was completed the door was opened and children started to leave the classroom.
2. Leaving as a group **gradually**: All children were leaving together, however they were not gathered and checked in front of an exit from a classroom but when they arrived at the door as a moving queue, the door was already opened and supervised by a staff member and they could leave the room smoothly.
3. **Individual** leaving: Even though supervised children could leave a classroom individually instructed to wait at a specified place inside or outside the building.

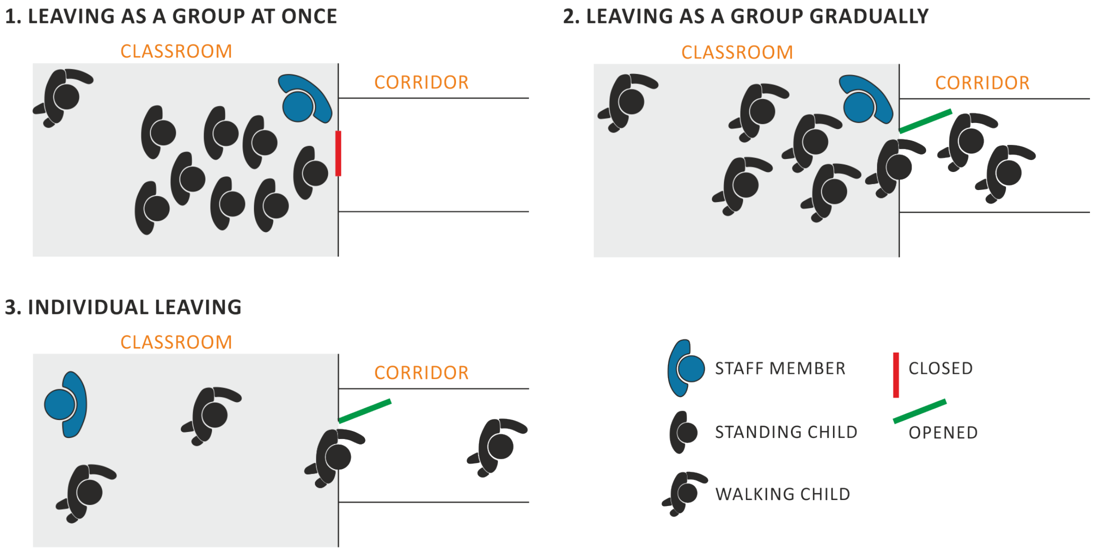


Figure 5.16: Types of leaving strategies observed during the experimental evacuation drills

Table 5.8: Pre-movement times in relation to leaving strategy

Leaving strategy	**Pre-movement time (mean/min/max/SD) [s] (data points)**	
	First child	**Last child**
Group at once	31 / 9 / 59 / 13 (33)	43 / 19 / 77 / 16 (33)
Group gradually	14 / 4 / 45 / 12 (11)	24 / 12 / 55 / 13 (11)
Individual leaving	11 / 3 / 31 / 7 (13)	24 / 16 / 45 / 8 (13)

Pre-movement times related to the described leaving strategies are displayed in Table 5.8 and as box plots in Figure 5.17. In 58% of the experimental evacuation drills, supervised children children left a classroom as a compact group, i.e. the whole group was prepared and standing in front of an exit when the movement phase started. In these classes the longest pre-movement times were observed which can be attributed to sequence of activities required for forming a group. On the other hand,

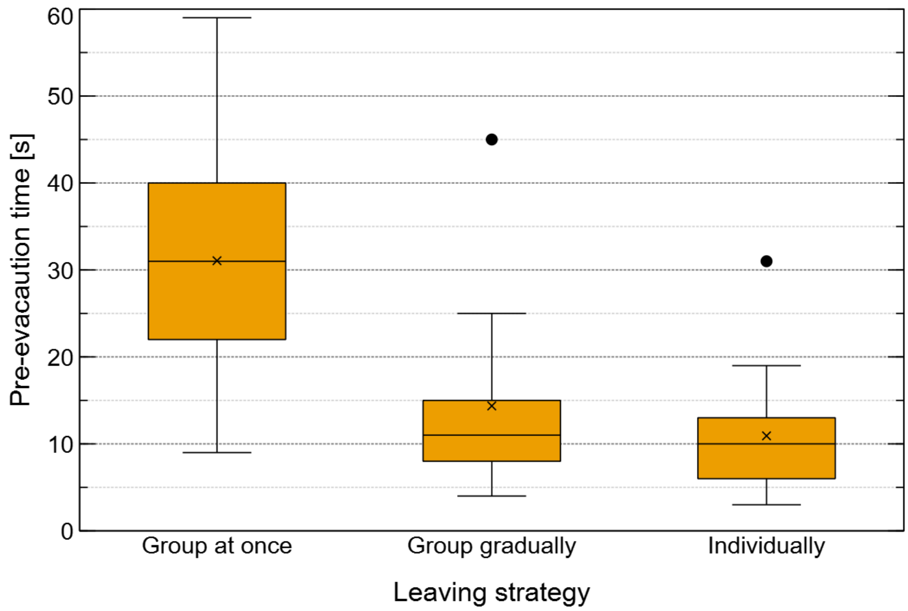


Figure 5.17: Box plots describing pre-movement time in relation to different leaving strategy

in 19% of the classes where a group of children was leaving supervised but gradually (without waiting in front of an exit) the mean pre-movement times were noticeably lower. In comparison to the previous leaving strategy, the mean pre-movement time was by 17 s (i.e. by 55%) lower. Similar pre-movement times were observed also in classes where children were leaving the classroom individually instructed to wait at a specific place. This situation occurred in 23% of the experimental evacuation drills which is surprisingly high value with regard to findings concluded in literature. A statistical difference between the different leaving strategies was confirmed also using Kruskal-Wallis Test (H=26.7, p-value$<$ 0.001) and Mood's Median Test (p-value$<$ 0.001). Similarly to the statistical tests performed in the previous paragraph, the null hypothesis that the group population medians are equal was rejected with 95% level of confidence $\alpha = 0.05$) and non-parametric statistical tests were selected due to limited and unequal sample size and presence of outliers.

Considering different age groups of children, any clear trend showing that children's age impacted the chosen leaving strategy was indicated. In general, the observed results indicate that leaving strategy taken by staff members may have a considerable impact on pre-movement times. Detailed discussion on evacuation behaviour during the pre-movement phase in relation to leaving strategy can be found in the following Section 5.3.3.

Besides the above-mentioned aspect, it can be further assumed that other factors such number of children in a class [23], staff-to-child ratio [40], or initial activity in a class when the alarm was sounded contributed to differences in pre-movement times as well. However, due to the diversity in boundary conditions, it is not possible to indicate these factors in relation to pre-movement times more quantitatively.

5.3.3 Pre-movement behaviour

Reactions of children and staff members to the alarm as well as instructions and activities of staff members were observed in the classrooms where cameras could be discreetly placed beforehand and in the classrooms with transparent glass walls (see Table 5.5). Furthermore, thanks to cameras placed in corridors, some aspects (group organisation, physical contact, counting of children) were also possible to observe when the door of a classroom was initially open or after the door of a classroom was opened as a part of the evacuation process.

Interpretation of warning signal

During the announced and semi-announced experimental evacuation drills, i.e. when at least date of the drills was known to staff members mostly any problems with interpretation of warning signal occurred and staff members reacted promptly and adequately. Only in several cases, longer interpretation time was needed by staff members mostly due to a low audibility of the warning signal. On the other hand, during the unannounced experimental evacuation drills, the warning signal was twice ignored by staff members which lead to considerably longest pre-movement times. In the first case, the warning signal was audible in the classroom but ignored by staff members until additional instructions were personally given in the classroom which caused delay of 20 s. In the another case, the responsible staff member did not understand the warning signal and ignored it instructing children to continue in actual activity which lead to delay of 35 s. It can be therefore concluded that the appropriate audibility of a warning signal in the building as well as thorough knowledge of a warning signal by staff members is crucial for effective evacuation procedure.

In most cases, children reacted first to instructions given by adults and not on the warning signal as such. Those situations were well illustrated when a staff member required longer time for signal interpretation. Within this interval, children did not act individually on the warning signal but they waited for the adult's decision what to do. On the other hand, in one nursery school, it was observed in two classes that children left the classroom without waiting for staff member's instructions, or more precisely they reacted individually to the voice message given in corridors instructing to leave the building. Such a behaviour can be partly explained as a consequence of daily practise in the nursery school where children can move through the building without supervision at any time.

Reaction and activities of staff members and children

In the great majority of the cases, after interpretation of the warning signal, staff members reacted quickly and began to instruct children where to go and how to behave. The most common activities and instructions given by staff members to children are summarised in Table 5.9. Since some research studies focused on evacuation in pre-school children concluded that actions of staff members during pre-movement phase are dependent on age of children [22, 34], the frequency of the most common activities and instructions given by staff members were evaluated separately for different age groups as well.

The most frequent activity provided by staff members (in 50.0% of observed Junior classes, 12.5% of Senior classes, and 27.3% of Mixed classes) was going towards a desired exit of the classroom and (based on the leaving strategy employed immediately or later during the pre-movement phase) opening the door. This action seemed to be essential especially where more than one exit were available in a classroom since children, called to leave the classroom, spontaneously started heading towards the daily-used main exit. In 40% of the observed classes, the instructions given by staff members were complemented by explanation what actually happened. However, this explanation was very brief such as “There is a fire”, “Alarm”, “We have to leave”, “We have to go out”. Further clarification of the occurred situation was not notified in any class. Before leaving a classroom, children were counted approximately in a third of the cases. Based on the leaving strategy employed, in 53% of those classes, children were counted when waiting as a compact group before an exit and in the remaining 47% they were counted in the door when gradually leaving the classroom. It can be stated that the former method saved a lot of pre-movement time which is however complementary associated with the leaving strategy as such. Looking at difference among the involved age groups, particular activities such as showing the selected exit, explaining the situation, and counting children were more frequently observed in Junior and Mixed classes (i.e. in classes were children aged 3–4 years were present) than in Senior classes. On the contrary, the activity of taking a name list was seen more often in Senior classes (in almost three quarters of them).

Considering the instructions given by staff members to children, children were most frequently (in 57.5% of the classes) encouraged to be quick and react immediately. In contrast, the instruction to move slowly was noticed in 10% of cases, mostly in Senior classes (in 37.5%). In 38.6% of all classes, children were instructed to form pairs and to hold each other’s hand. However, it was also observed that especially younger children performed this action spontaneously requiring any instructions. Afterwards, the selected exit of the classroom was specified by a staff member and children were asked do form up in front of the door. With the exception of instruction to be go slowly, given instructions were most often registered in Junior classes, eventually Mixed classes. In addition, in Junior classes instructions were usually repeated many times to the children.

Children’s reactions and activities were analysed in 39 classes. In general, 90% of 649 observed children responded on instructions obtained from staff members quickly and without any complications. Only 10% of children reacted slowly, ignored the provided instructions, required a repetition of the advice, or additional physical help such as to be pushed, pulled by hand, lifted from a table, or carried. It should be noted that such behaviour was observed only in Junior children (in 3.1%) and in younger children present in the Mixed classes (in 15.5%). Children in this category typically continued in playing with toys, froze at their place, or struggle to pick up their toys. In a few cases, those children received a physical help by older children in the same group. Moreover, several children were observed following activities usual

Table 5.9: An overview of the most common instructions and activities performed by staff members in different age groups during the experimental evacuation drills

Activities	**Frequency [%] (data-points)**				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Go to the exit and open the door	55.0 (40)	50.0 (10)	12.5 (8)	N/A	27.3 (22)
Take a name list	45.6 (57)	41.2 (17)	73.3 (15)	0.0 (1)	33.3 (24)
Explain the situation briefly	40.0 (40)	50.0 (10)	12.5 (8)	N/A	45.5 (22)
Count children	32.6 (46)	44.4 (9)	16.7 (12)	0.0 (1)	37.5 (24)
Take keys/mobile phone	27.6 (57)	23.5 (17)	26.7 (15)	0.0 (1)	25.0 (24)
Turn off lights, close the door	7.8 (51)	7.1 (14)	8.3 (12)	0.0 (1)	8.3 (24)

Instructions	**Frequency [%] (data-points)**				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Instruct children to be quick	57.5 (40)	50.0 (10)	37.5 (8)	N/A	68.2 (22)
Instruct children to form pairs and hold each other's hand	38.6 (57)	58.8 (17)	46.7 (15)	100.0 (1)	16.7 (24)
Instruct which exit to use	30.0 (40)	50.0 (10)	12.5 (8)	N/A	27.3 (22)
Instruct children to make a formation	27.5 (40)	40.0 (10)	25.0 (8)	N/A	22.7 (22)
Instruct children to wait at a specific place	12.5 (40)	0.0 (10)	12.5 (8)	N/A	18.2 (22)
Instruct children to go slowly	10.0 (40)	0.0 (10)	37.5 (8)	N/A	4.5 (22)
Instruct children be quiet/not to scream/cry	10.0 (40)	30.0 (10)	0.0 (8)	N/A	4.5 (22)
Instruct children to leave toys	10.0 (40)	0.0 (10)	0.0 (8)	N/A	18.2 (22)

during daily routine, notably putting their toys, exercise aids, or cushions away or returning back to a classroom in order to leave their a think which remained in their hands during the leaving process.

Furthermore, observations showed that children's reactions were appreciably affected by their location in the building and by activities performed by children and staff members when the alarm was sounded. When the alarm was raised, in 89.5% of the experimental evacuation drills, children were located in their classrooms. In the rest of the cases, children were actually in a dinning room (5.2%), in a gym (1.8%) or in a washroom (3.5%). In classrooms, organised whole-group activities (e.g. circle time), small-group activities (e.g. drawing, creating, learning, board games), or free play were observed. Besides that, special situations occurred in the nursery school where the experimental evacuation drill was entirely announced including the exact time. Here. in four classes, the drill was expected to that degree that children and staff members were prepared in front of the exit waiting only for a signal to leave the classroom. An overview of performed activities at the moment at which experimental evacuation drills were started is given in Table 5.10.

Generally, faster reactions of children to instructions given by staff members were observed during whole-group activities when the attention of children was concentrated only on single activity coordinated by staff members. In the case of small-group activities, the attention of children was usually paid to different actions in the classroom. Therefore, reaction of children was slightly longer likewise when children were playing on their own. Quick reactions were also noticed when children

Table 5.10: Location and original activity of children when the experimental evacuation drills were started

Location	Activity	Frequency [%] (data-points)
Inside a classroom	Classrooms not observed	33.3 (19)
	Whole-group activity:	29.8 (17)
	- Circle time sitting	19.3 (11)
	- Circle time standing	5.3 (3)
	- Activity by a table	1.8 (1)
	- TV watching	3.5 (2)
	Small-group activity	8.8 (5)
	Free play	10.5 (6)
	Waiting for the alarm	7.0 (4)
Outside a classroom	Having snack	5.3 (3)
	Exercising	1.8 (1)
	Washing hands	3.5 (2)

were outside a classroom and performed standing up activities (e.g. exercising, hand washing, moving in corridors). By contrast, specific situations occurred during two experimental evacuation drills when alarm surprised children (2 Mixed classes) having a snack. An overview of children's reactions is summarised in Table 5.11 where frequency of different reactions and time required by children to get up from a table are given. To streamline the categorisation of the children's reactions, children who immediately follow staff members' instructions was assumed as a quick reaction. These children left their position at a table and they started to move towards the exit from the room. Slow reaction denotes children who needed more time (e.g. looking around and waiting for more information) or additional instructions. This group included also reactions when children finished their drink or they took their dishes to the kitchen before they started to evacuate (14% of the observed children). The last category presented in Table 5.11 includes children who ignored instructions to evacuate and continued their snack until they were individually assisted by a staff member. Such behaviour may be also attributed to respecting of daily rules which usually want children to finish a meal or to children's priority in eating. Moreover it was found that children's tendency to follow daily routines, notably the rule to drink a cup of tee before going out in the garden, affected also the movement phase of an evacuation process, further discussed in Section 5.3.9 describing the specifics of movement behaviour. Finally, it may be suggested that various activities which are a usual part of daily routine in early childhood educational institutions can considerably impact children and staff member reaction and therefore the whole pre-evacuation phase. More specifically, after lunch napping which was intentionally avoided in the experimental evacuation drills to prevent stress situation and discomfort of participating children, can represent for evacuation procedure a challenging situation. It therefore advisable to use regular evacuation drills to train as much different situations as possible.

Based on the analysis of video recordings, since children mostly did not expect to participate in the experimental evacuation drills, they may have seemed to be surprised and also confused when looking fuzzily around and waiting for staff members'

Table 5.11: An overview of children's reactions when the alarm was raised during having a snack

Reaction	**Frequency [%]**	**Time to stand up (mean/min/max/SD) [s] (data points)**
Quick reaction	46.0	5.1 / 3.0 / 8.0 / 2.1 (17)
Slow reaction	32.4	8.9 / 5.0 / 17.0 / 4.2 (12)
Any reaction before staff member's intervention	21.6	14.4 / 8.0 / 22.0 / 5.0 (8)

decision (notably in the case of Junior children and young children present in Mixed classes). Despite this, they did not look frightened or sad, no child was observed to be crying or hysterical. Conversely, especially younger children seemed to be more scared covering their mouth or face by hand when the experimental evacuation drill was motivated by a fairy tale, particularly that a fairy tale character was present in the building who wanted to eat the children they had to leave. Surprisingly, although rare in the overall view, reactions such as covering mouth, face, or ears by hand were mostly observed in the experimental evacuation drill where the situation (including the exact time of the beginning) was entirely announced and explained to children in advance. It can be assumed that for several children the experimental evacuation drill represented an occasion to show off or to be flashy.

Level of physical assistance provided to children

Involvement of staff members in term of physical support given to children was analysed during the pre-movement phase in 40 classes in total. Additional observation of physical contact between staff members and children was enabled at the moment when the door of a classroom was opened during the evacuation process. For this purpose, five categories presented with details in Table 5.12 were established. The category "Any assistance provided" includes all cases when any physical contact was noticed between a child and a staff member. Such a situation occurred most frequently, notably it was representative for 75% of the observed children. The most common kind of physical contact was a gentle pushing on children's back, shoulders, arms, or head which was observed in 18.7%. However, this contact was not always necessary to proceed the evacuation process, i.e. it was done by staff members also in the cases when children reacted and behaved smoothly and independently not requiring any assistance. Most frequently, a gentle physical contact was observed when children were counted or when they were exiting through the classroom's door. This type of physical contact may be more attributed to its psychological effect such as emphasising the active and supportive presence of the adult as a provider of emotional security and authority [148–150]. Physical contact provided by a staff member to a child necessary for a successful evacuation process (e.g. redirecting and pushing a child to a right exit, pick up a child from a table) was registered for 3.6% of children. Moreover, only several children (0.3%) had to be carried during the pre-movement phase.

Table 5.12: Level of physical assistance provided to children in different age groups during the experimental evacuation drills

Physical assistance provided	Frequency [%] (data-points)				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Any assistance provided	75.0 (441)	73.7 (81)	89.2 (121)	81.8 (18)	67.7 (244)
Gentle pushing	18.7 (181)	20.8 (55)	10.2 (30)	18.2 (4)	23.7 (92)
Physical contact needed	3.6 (24)	2.1 (3)	0.0 (0)	N/A	5.7 (21)
Hand holding	2.3 (15)	2.8 (4)	0.7 (1)	N/A	2.7 (10)
Carried	0.3 (2)	0.7 (1)	0.0 (0)	N/A	0.3 (1)

Leaving strategy

Potential impact of different leaving strategy, i.e. different organisation of children when leaving a classroom, on pre-movement times was outlined in Section 5.3.2 where three different types of leaving strategy were introduced as well. In 58% of the experimental evacuation drills, children were leaving a classroom as a compact group, in 19% of the drills they were leaving as a supervised group but gradually (without waiting until the group was completed), and in 23% of the drills children were allowed to exit a classroom individually.

It can be assumed that the decision to follow one of these strategies could be impacted by personal decision of staff members and general evacuation strategy in the nursery school which may be among others further influenced by capacity of the nursery school, number of children in a class, or length of the connecting escape route leading to the place of safety (i.e. building layout). Nevertheless, as typical for most observations of human behaviour, a large diversity in potentially influencing factors does not enable correct quantitative analysis, several trends may be indicated. In Table 5.13, possible relations between chosen leaving strategy and the three above-mentioned aspects are summarised. As can be seen from the table, a correlation between leaving strategy and capacity of a nursery school (and consequently also building layout) can be identified. These results may be explained that need of more strict and rigid organisation increases with increasing capacity and layout complexity of an educational institution. It is obvious that simultaneous evacuation process in large nursery schools (in this case accommodating more than hundred persons) has to be more hedged by stronger rules of the evacuation procedure. On the other hand, the assumption that leaving strategy may be influenced by number of children in a class was not traced.

Another aspect related to leaving strategy was a position of staff members in the leaving group, i.e. if the first (last) person leaving a classroom who lead (closed) the group was a staff member or a child. Observations of all 57 participating classes showed that in 61.4% the first person leaving a class was a child and in 38.6% a staff member. By contrast, a child left a classroom as the last person only in 21.1% of observed classes, whereas it was a staff member in the remaining of 78.9%. It can be assumed that a position of staff members in the leaving group was to large extent depended of number of staff members present in a class. Regarding this aspect, different leaving strategies and their frequency during the experimental evacuation drills are listed in Table 5.14.

Table 5.13: Possible relation of leaving strategy to nursery school's capacity, number children in a class, and dimensions of used evacuation routes (building layout)

Leaving strategy	**Frequency** [%] (data-points)							
	Capacity (total number of classes)			**Number of children in a class**			**Escape route distance [m]**	
	1 (small)	**2–5 (medium)**	**6–11 (large)**	**≤ 10**	**11–20**	**> 20**	**≤ 10**	**> 10**
Group at once	0.0 (0)	39.4 (13)	60.6 (20)	12.1 (4)	57.6 (19)	30.3 (10)	36.4 (12)	63.6 (21)
Group gradually	0.0 (0)	63.6 (7)	36.4 (4)	0.0 (0)	90.9 (10)	9.1 (1)	36.4 (4)	63.6 (7)
Individually	30.8 (4)	61.5 (8)	7.7 (1)	0.0 (0)	92.3 (12)	7.7 (1)	84.6 (11)	15.4 (2)

The additional impact of staff members' decision from what position to control the leaving group of children on evacuation efficiency can be best described by situations where only one staff member was present in a class. In this case, the staff member had to decide whether to lead or rather close the children's flow. Considering the former choice (labelled as SM-C in Table 5.14 and Figure 5.18), the staff member could control a proper selection of an escape route and took the role of a leader. On the other hand, the classroom and the tail end of children's group remained unsupervised and the staff member was loosing sight of all children, especially whether someone was missing. The former disadvantages could be eliminated in the cases when a staff member decided to leave the classroom as the last person (see C-SM in Table 5.14 and Figure 5.18). This evacuation strategy proved to be effective in the classes with a direct entry to a garden or with a single evacuation route available. However, observations showed that children leading the whole group could easily took a wrong direction and used undesirable evacuation routes. Consequently, an ideal strategy appears to be when staff members can both lead and close the children's flow. However, as illustrated in Table 5.14 and Figure 5.18), this option was not always seen during the experimental evacuation drills even in the classes where more than two staff members were present. In addition, it was not unusual that the first staff member left a classroom somewhere in the middle of the group (e.g. C-SM-C in Table 5.14 and Figure 5.18). It is interesting to note that this situation was often caused by a self-closing door which had to be hold by the staff member who was initially positioned at the head of the flow.

Table 5.14: Position of staff members in the leaving group in relation to number of staff members present in a class

Number of staff members	Frequency [%] (datapoints)	Symbolic description	Explanation	Frequency [%] (datapoints)
1	59.7 (33)	SM-C	The staff member left the classroom as the first person followed by children	27.3 (9)
		C-SM	The staff member left the classroom as the last person following all children	63.6 (21)
		C-SM-C	The staff member left the classroom following several children before the remaining children	9.1 (3)
2	31.6 (18)	SM-C-SM	The staff members left the classroom as the first and last person closing the group of children from both sides	61.1 (11)
		C-2SM	Both staff members left the classrooms as two last persons following all children	22.2 (4)
		C-SM-C-SM	The first staff member left the classroom following several children, the another staff member left the classroom as the last person	16.7 (3)
3	10.5 (6)	SM-C-2SM	The staff members left the classroom as the first person and as two last persons closing the group of children from both sides	33.3 (2)
		C-SM-C-2SM	The first staff member left the classroom following several children, other two staff members left the classroom as two last persons	66.7 (4)

SM: staff member/s
C: children

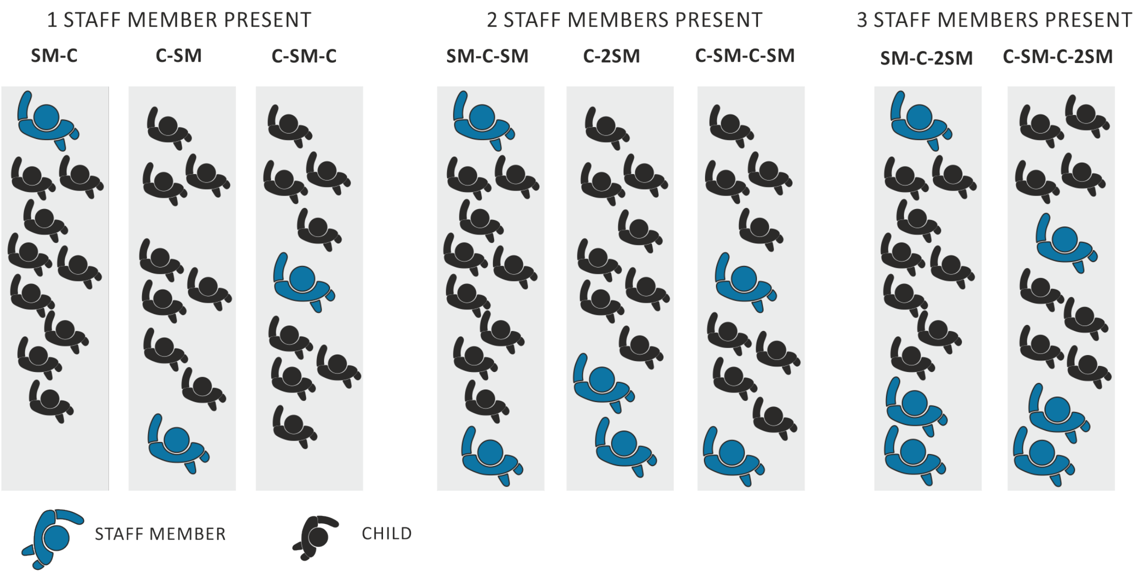


Figure 5.18: Various positions of staff members in the leaving group in relation to number of staff members present in a class

5.3.4 Movement in corridors

This section summarises results on movement characteristics of children in corridors (occasionally in hallways) studied during the experimental evacuation drills. Travel speed, pedestrian flow, and density were measured in 20 pre-determined measurement areas in 7 participating nursery schools during 8 experimental evacuation drills (see Section 5.2.4 for details).

Travel speed

In the majority of the cases, the presented travel speeds were measured during continuous movement of children, i.e. movement which was not influenced by acceleration or deceleration phases, waiting, or queuing, and thus they were referred as movement speeds. However, for one Senior class moving in one measurement area (in total 21 children and the same number of data-points) different conditions occurred. In this case, the group of children had to make a stop inside the measurement area following the instruction given by the staff member who wanted to count the children once more. In order to evaluate the travel speed of these children as the movement speed, the time spent with waiting inside the measurement area was excluded and the obtained time of movement was used to calculate the travel speeds. Since for this group of children appreciably higher density conditions occurred, the modified data-points are explained in detail where appropriate. Walking and running travel speeds were analysed separately for the involved age groups (Junior, Senior, Senior+, and Mixed, see Section 5.2.1). Combined results on walking and running speeds (all travel speeds measured) together with corresponding density intervals are summarised in Table 5.15, results on walking speeds and running speeds are provided separately in Table 5.16 and Table 5.17 respectively. Furthermore, probability distributions for travel speeds and density evaluated separately for walking and running conditions are illustrated in Figure 5.19. Probability distributions for travel speeds and density for different age groups can be found in Appendix C in Figure C.1.

Table 5.15: Travel speed of children measured in corridors during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval [m^2 m^{-2}]**	**Travel speed (mean/min/max/SD) [$m \cdot s^{-1}$] (data points)**	**Density (mean/min/max/SD) [m^2 m^{-2}] (data-points)**
Junior	0.00–0.05	1.25 / 0.42 / 2.78 / 0.45 (186)	0.02 / 0.01 / 0.05 / 0.01 (186)
Senior	0.00–0.05	1.97 / 0.54 / 4.36 / 0.92 (236)	0.02 / 0.01 / 0.05 / 0.01 (236)
	0.06–0.10	0.88 / 0.66 / 1.08 / 0.12 (21)	0.08 / 0.07 / 0.09 / 0.01 (21)
Senior+	0.00–0.05	3.10 / 1.03 / 5.25 / 1.01 (88)	0.01 / 0.00 / 0.03 / 0.01 (88)
Mixed	0.00–0.05	2.02 / 0.39 / 4.65 / 0.74 (176)	0.02 / 0.00 / 0.05 / 0.01 (176)
Total		**1.90 / 0.39 / 5.25 / 0.96 (707)**	**0.02 / 0.00 / 0.09 / 0.01 (707)**

The results showed that the observed travel speeds changed with the age of children, notably they increased with the increasing age. Junior children moved with

Table 5.16: Walking travel speed of children measured in corridors during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\,m^{-2}$]	**Travel speed (mean/min/max/SD)** [$m{\cdot}s^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\,m^{-2}$] **(data-points)**
Junior	0.00–0.05	1.06 / 0.42 / 1.85 / 0.26 (139)	0.03 / 0.01 / 0.05 / 0.01 (139)
Senior	0.00–0.05	1.38 / 0.54 / 3.00 / 0.57 (132)	0.03 / 0.01 / 0.05 / 0.01 (132)
	0.06–0.10	0.88 / 0.66 / 1.08 / 0.12 (21)	0.08 / 0.07 / 0.09 / 0.01 (21)
Senior+	0.00–0.05	1.92 / 1.40 / 2.98 / 0.55 (15)	0.02 / 0.01 / 0.03 / 0.01 (15)
Mixed	0.00–0.05	1.55 / 0.39 / 3.22 / 0.68 (50)	0.02 / 0.01 / 0.04 / 0.01 (50)
Total		**1.27 / 0.39 / 3.22 / 0.53 (357)**	**0.03 / 0.01 / 0.09 / 0.02 (357)**

Table 5.17: Running travel speed of children measured in corridors during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\,m^{-2}$]	**Travel speed (mean/min/max/SD)** [$m{\cdot}s^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\,m^{-2}$] **(data-points)**
Junior	0.00–0.05	1.82 / 1.12 / 2.78 / 0.42 (47)	0.02 / 0.01 / 0.05 / 0.01 (47)
Senior	0.00–0.05	2.73 / 1.27 / 4.36 / 0.69 (104)	0.02 / 0.01 / 0.04 / 0.01 (104)
Senior+	0.00–0.05	3.35 / 1.03 / 5.25 / 0.91 (73)	0.01 / 0.00 / 0.03 / 0.01 (73)
Mixed	0.00–0.05	2.21 / 1.11 / 4.65 / 0.68 (126)	0.02 / 0.00 / 0.05 / 0.01 (126)
Total		**2.55 / 1.03 / 5.25 / 0.87 (350)**	**0.02 / 0.00 / 0.05 / 0.01 (350)**

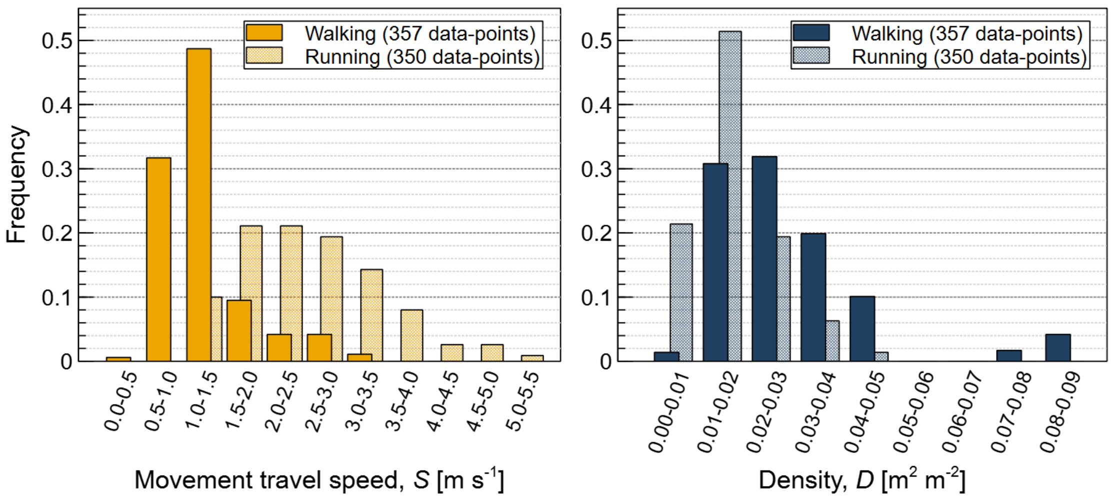


Figure 5.19: Probability distribution for travel speeds (**left**) and density (**right**) measured in corridors during the experimental evacuation drills

lower travel speed than Senior children regardless if whether walking or running. On average, walking Junior children moved at travel speed of 1.06 $m{\cdot}s^{-1}$ and their maximum walking travel speed was less than 2 $m{\cdot}s^{-1}$. On the other hand, in the same density interval Senior children walked 1.38 $m{\cdot}s^{-1}$, Senior+ children even 1.92 $m^2\,m^{-2}$ on average and their maximum walking speed was around 3 $m{\cdot}s^{-1}$. The measured maximum values of walking travel speed observed in all age groups were relatively high and at the first sight they could appear rather as running speeds than walking speeds. However, based on careful analysis of video recordings, any flight phase occurred during the gait cycle in those cases, i.e. the children had always at least one foot touching the ground. Consequently, the walking gait looked more like a fast walking, with slight exaggeration maybe even "race-walking". It may be assumed that such children's movement behaviour was motivated by a desire to move fast on the one hand and by instructions not to walk given by staff members on the other hand. When running, the mean travel speed of Junior children was 1.82 m·s^{-1} and the maximum travel speed was around 2.78 m·s^{-1}. It means that the maximum value of running speed in Junior children was lower than the maximum walking speed observed by Senior children. This finding confirmed the hypothesis that travel speed of children is highly age-dependent and differences between children at different age (and thus different level of development) such as between Junior and Senior children should be considered properly. On average, running Senior children travelled at speed of 2.72 m·s^{-1} and Senior+ children at speed of 3.35 m·s^{-1}. At maximum, Senior children reached travel speed approaching 4.36 m·s^{-1}, Senior+ children even 5.25 m·s^{-1}. It should be noted that the highest running speeds were measured in the nursery school where a more than 30 m long corridor was present which provided children enough space to accelerate.

Looking at the observed density intervals, only low-density conditions (less than 0.1 $m^2 m^{-2}$) occurred in the measurement areas in corridors. The mean density observed was 0.02 $m^2 m^{-2}$ (i.e. approximately 0.8 children·m^{-2}) and the maximum density measured was 0.09 $m^2 m^{-2}$ (i.e. approximately 3.4 children·m^{-2}). In general, lower density occurred in children whose running. Moreover, when only continuous movement of children was observed (686 data-points) the density ranged only from 0.00 to 0.05 $m^2 m^{-2}$ (i.e. to approx. 1.9 children·m^{-2}) with the mean value of 0.02 $m^2 m^{-2}$. The higher density conditions between 0.07 and 0.09 $m^2 m^{-2}$ (mean value 0.08 $m^2 m^{-2}$) were registered only in the case when one Senior class had to make a stop inside the measurement area (21 data-points).

In addition, differences between children's age groups were found also when comparing frequency of walking vs. running children. The results provided in Table 5.18 suggested that older children such as Senior and especially Senior+ children tended to run more frequently than Junior Children. This observation may be attributed to both different movement abilities (notably proficiency in running) and evacuation behaviour of involved children as different instructions and level of supervision and were given by staff members to children in particular age groups.

Table 5.18: Frequency of children who were walking and running during the experimental evacuation drills

Age group	Frequency of walking children [%] (data-points)	Frequency of running children [%] (data-points)
Junior	74.7 (139)	25.3 (47)
Senior	59.1 (153)	40.9 (104)
Senior+	17.0 (15)	83.0 (73)
Mixed	28.4 (50)	71.6 (126)
Total	**50.4 (357)**	**49.6 (350)**

Relationships between travel speed and density in corridors were further described through fundamental diagrams. In Figure 5.20, dependence of movement travel speed S [m·s^{-1}] on density D in the unit of [m^2 m^{-2}] on the left and in the unit of [pers·m^{-2}] on the right are represented. Here, walking and running travel speeds observed in all children's age groups are combined. To acquire trend lines of the speed-density relationships the experimental data were fitted and the correlation coefficients R^2 were calculated. Based on the curve shape and the relatively smallest difference between the observed values and their fitted values exponential and logarithmic functions were selected to express the trend lines of the experimental data-set. Despite of higher coefficient of determination obtained for logarithmic fitting, exponential fitting was also considered showing better agreement with the experimental data at higher densities and more realistic prediction when approaching zero density values. Furthermore, the given speed-density relationships provided a visible determination of the data-points obtained in the situation when children in one Senior class made a stop inside the measurement area resulting in higher densities (see the modified data-points indicated with cross symbols in Figure 5.20). Thus, because of lack of experimental data at higher densities the application range of the given trend lines should be seen as limited to densities lower than 0.05 m^2 m^{-2} (approximately 1.9 children·m^{-2}; see the solid parts of the trend lines in Figure 5.20 and Figure 5.21). Alternatively, the speed-density relationships with the calculated trend lines of data-sets where the outliers (21 modified data-points) were excluded are given in Appendix C in Figure C.2.

Fundamental diagrams showing separately walking and running travel speeds and indicating different values obtained for different age groups (colour-coded) are displayed in Figure 5.21 (for greater degree of detail, separate speed-density relationships for different age groups are provided in Appendix C in Figure C.3). Similarly to the previous evaluation, the data-sets for walking and running children were fitted using exponential and logarithmic functions. In addition, based on the relatively satisfactory goodness-of-fit linear fitting was also performed and displayed. It can be seen that the shape differences in the curves under consideration are quite small. Therefore in this case, the linear fitting can be considered as an appropriate alternative to the exponential function. Looking at the plotted data-sets, high values of travel speed discussed earlier in this section can be clearly identified. Considering walking children, travel speeds between 2 and 3 m·s^{-1} (i.e. race-walking gait looking) were measured in Senior, Senior+, and older children in Mixed classes moving at very low densities. In line with this finding which highlights the influence of children's age on their travel speed, the fastest running pace was observed at low densities in Senior+ children and older children in the Mixed groups. In the data-set describing walking travel speed of children (Figure 5.21 on the left) the cluster of the modified data-points determined for one class of Senior children can be clearly identified (cross symbols). Similarly to the previous evaluation, the trend lines of the data-sets without the outliers are illustrated in Appendix C in Figure C.4.

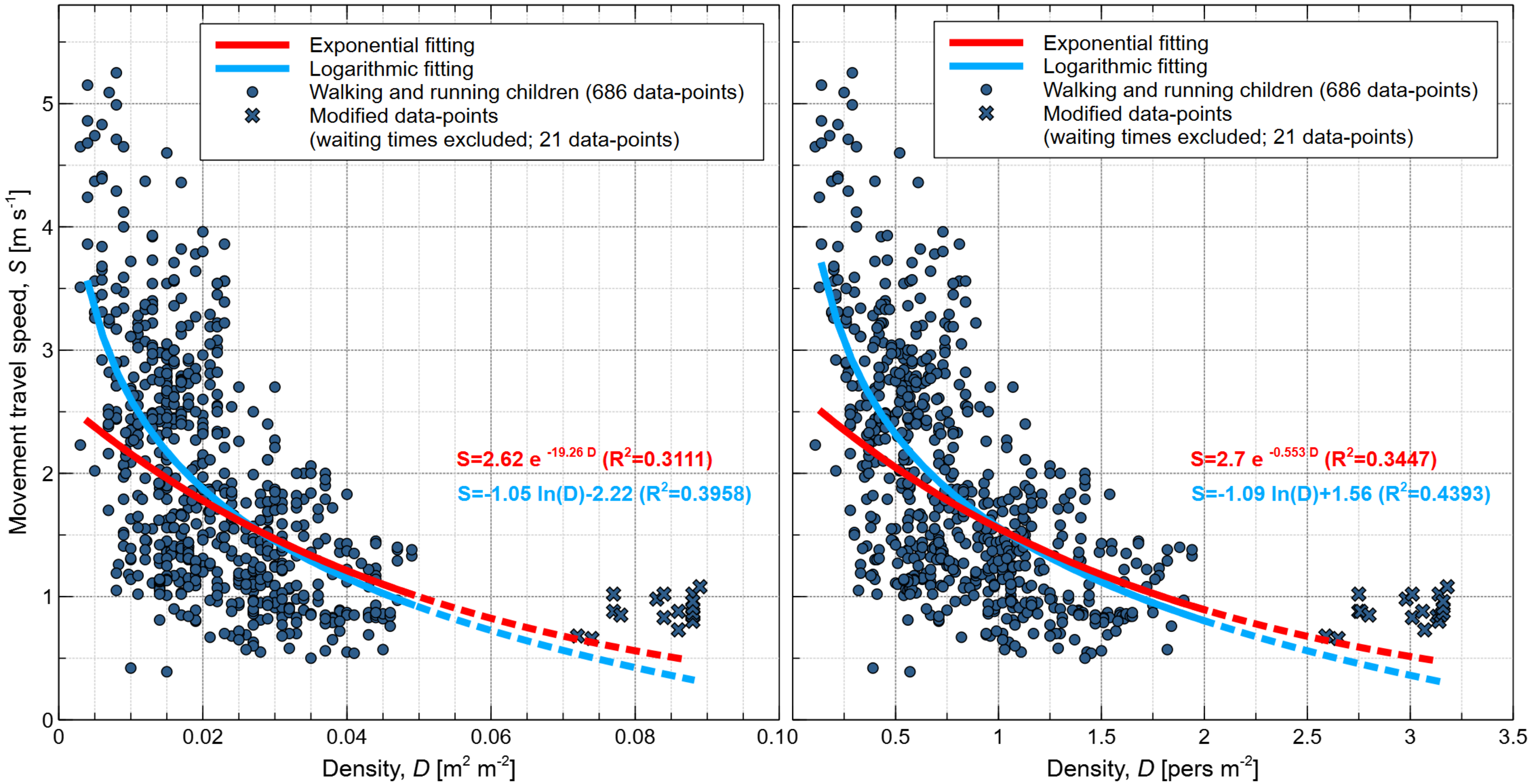


Figure 5.20: Travel walking and running speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with calculated trend lines measured in corridors

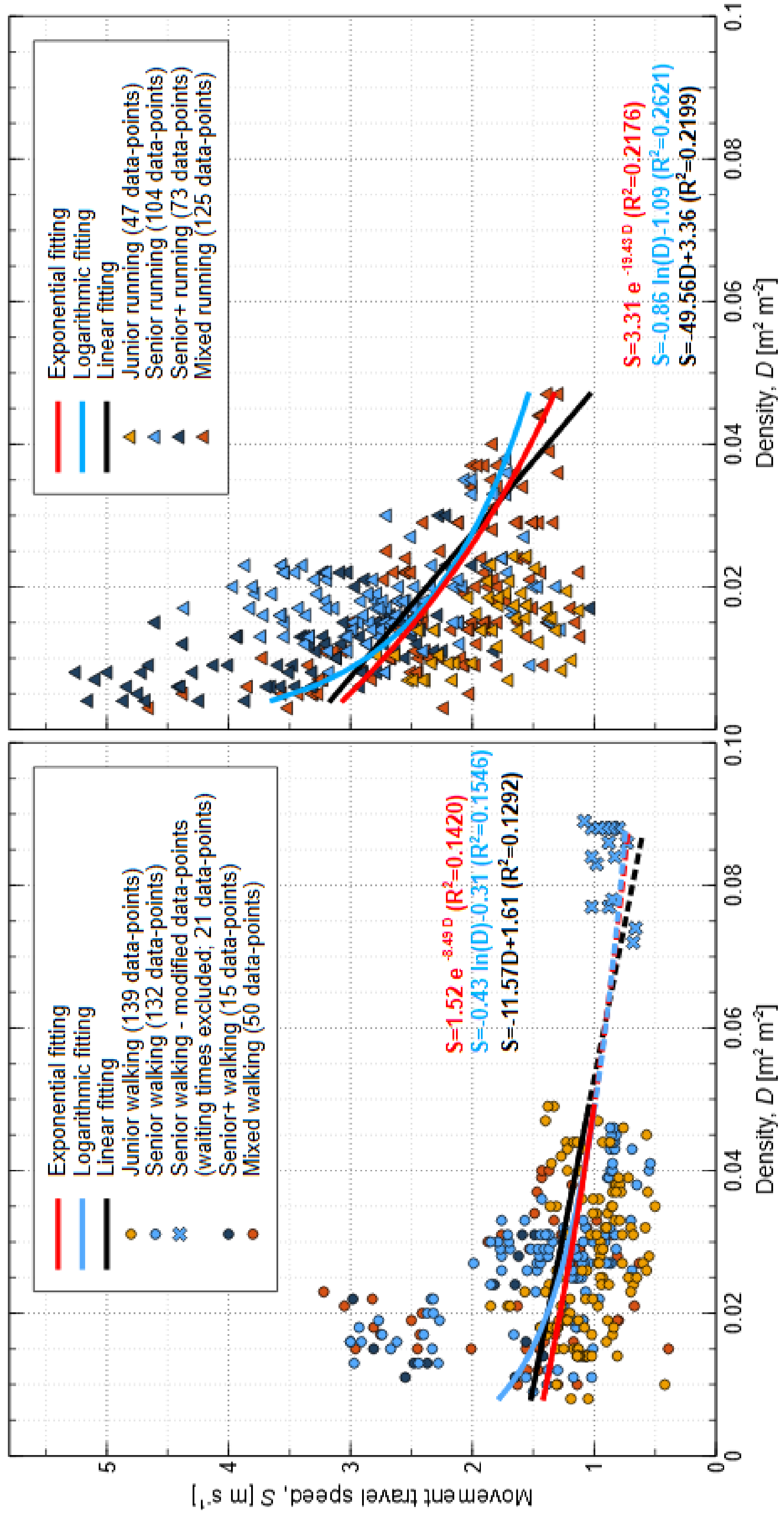


Figure 5.21: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] with calculated trend lines measured in corridors for different age groups

Specific flow

In addition to travel speeds, pedestrian flow related to 1 m of effective width of the corridor [pers·s^{-1} m^{-1}], i.e. specific flow, was evaluated. Specific flow was not distinguished for walking and running children since both movement options could simultaneously occurred when the flow was calculated in the measurement area. However, specific flows were analysed separately for the involved age groups (Junior, Senior, Senior+, and Mixed, see Section 5.2.1 for further description). The obtained results for specific flow and corresponding density intervals for different age groups are summarised in Table 5.19 and the probability distributions of the presented variables are given in Figure 5.22. Probability distributions for specific flow and density for different age groups can be found in Appendix C in Figure C.5.

Table 5.19: Specific flow of children measured in corridors during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval [m^2 m^{-2}]**	**Specific flow (mean/min/max/SD) [pers·s^{-1} m^{-1}] (data points)**	**Density (mean/min/max/SD) [m^2 m^{-2}] (data-points)**
Junior	0.00–0.05	1.72 / 0.65 / 4.17 / 0.80 (186)	0.02 / 0.01 / 0.05 / 0.01 (186)
Senior	0.00–0.05	2.00 / 0.67 / 4.17 / 0.90 (236)	0.02 / 0.01 / 0.05 / 0.01 (236)
	0.06–0.10	1.68 / 1.33 / 2.67 / 0.54 (21)	0.08 / 0.07 / 0.09 / 0.01 (21)
Senior+	0.00–0.05	1.61 / 0.83 / 3.33 / 0.79 (88)	0.01 / 0.00 / 0.03 / 0.01 (88)
Mixed	0.00–0.05	1.63 / 0.67 / 4.17 / 0.79 (176)	0.02 / 0.00 / 0.05 / 0.01 (176)
Total		**1.78 / 0.65 / 4.17 / 0.84 (707)**	**0.02 / 0.00 / 0.09 / 0.01 (707)**

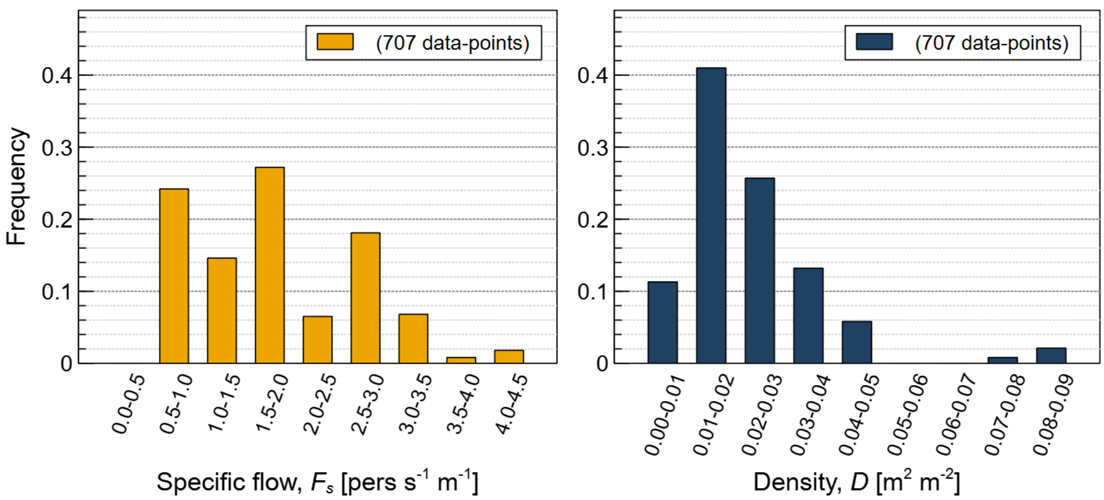


Figure 5.22: Probability distribution for specific flow (**left**) and density (**right**) measured in corridors during the experimental evacuation drills

As can be seen from Table 5.19, the observed specific flow in corridors ranged from 0.65 pers·s^{-1} m^{-1} to 4.17 pers·s^{-1} m^{-1} with the mean value of 1.78 pers·s^{-1} m^{-1}. As commented in the section focused on travel speed in corridors, only low-density conditions were observed during the experimental evacuation drills in corridors.

The measured density ranged from 0.00 $m^2\,m^{-2}$ to 0.09 $m^2\,m^{-2}$ (i.e. approximately 3.4 children·m^{-2}), whereas the values higher than 0.05 $m^2\,m^{-2}$ (approximately 1.9 children·m^{-2}) were observed only in the specific case of one Senior class (21 data-points) discussed earlier. These results can be generally attributed to free movement conditions in the corridors and to relatively high travel speed reached by the observed children, especially by the running children who accounted for 50% of the involved population. Furthermore, in contrast to results of travel speed, it can be stated that any considerable impact of children age on measured specific flow in corridors was noted. The minimum, mean, and maximum values as well as standard deviations of specific flow in different age groups were similar.

The acquired results for specific flow in corridors were further related to appropriate density conditions and their relationships were demonstrated using fundamental diagrams. The dependence of specific flow F_s [pers·$s^{-1}\,m^{-1}$] on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right in different age groups (colour-coded) is demonstrated in Figure 5.23. Specific flow-density relationships provided separately for different age groups can be found in Appendix C in Figure C.6. The presented data-sets represent combined data for walking and running children. To express trend lines of the given flow-density relationships polynomial fitting was used and the corresponding correlation coefficients R^2 were calculated. When selecting an appropriate fitting function, the shape of the curve was preferred which is known to be relevant for adults (e.g. SFPE handbook curve [43]). Similarly to the given speed-density relationships, the group of the modified data-points representing densities higher than 0.05 $m^2\,m^{-2}$ (approximately 1.9 children·m^{-2}) can be graphically identified in Figure 5.23 (cross symbols). Due to the lack of experimental data above this interval, the application range of the provided trend line is limited for lower densities than 0.05 $m^2\,m^{-2}$ (see solid lines in Figure 5.23). In addition, the flow-density relationships and the calculated trend lines of data-sets without the modified data-points can be found in Appendix C in Figure C.7.

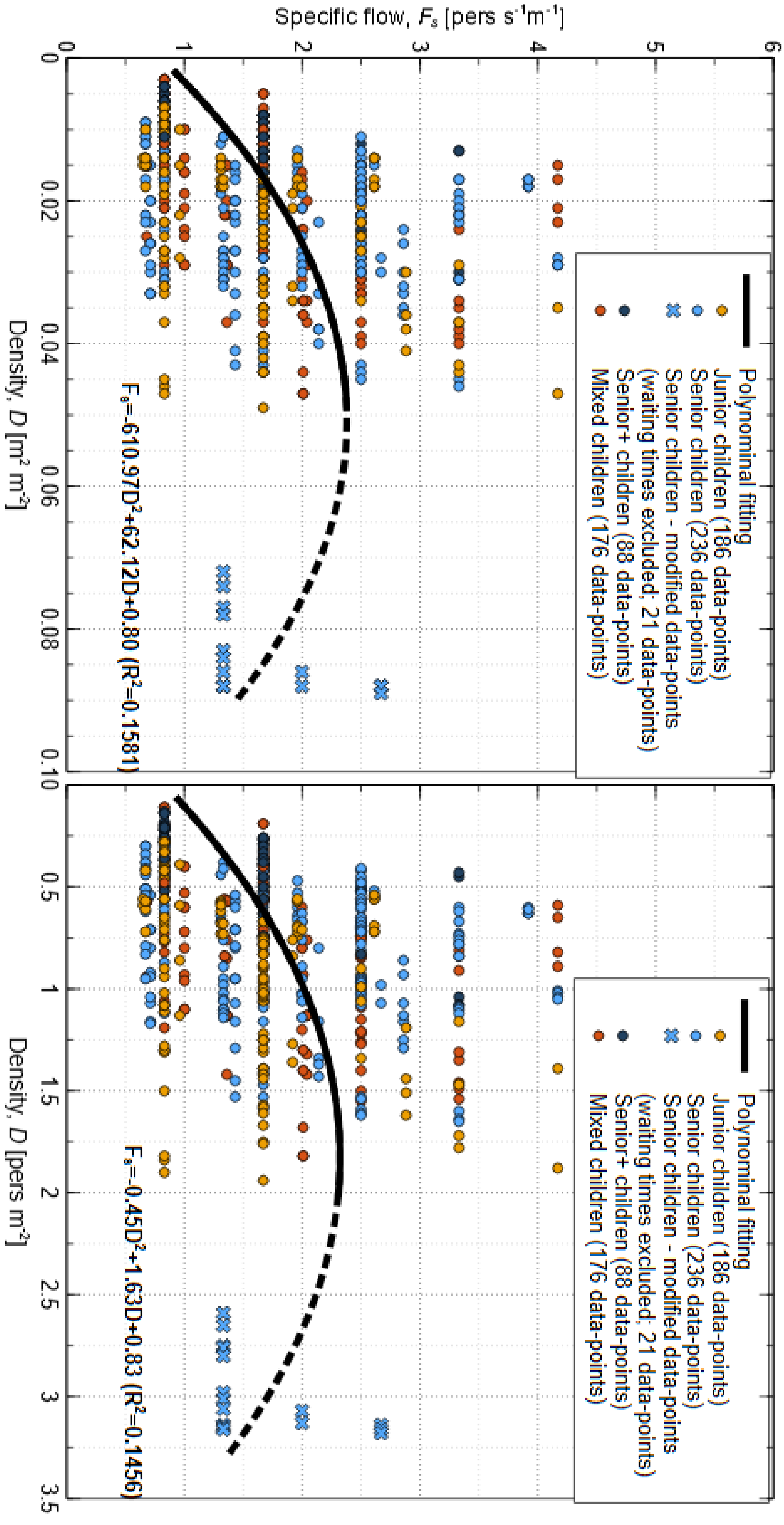


Figure 5.23: Specific flow per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers$\cdot m^{-2}$]) with calculated trend lines measured in corridors

5.3.5 Movement on straight staircases

The results on movement characteristics of children moving downstairs on straight staircases observed during the experimental evacuation drills are presented in this section. Travel speed, pedestrian flow, and density were analysed separately on flights (27 measurement areas), on landings (11 measurement areas), and on the staircases as wholes (9 measurement areas) in 6 nursery schools during 7 experimental evacuation drills. The latter case represents a combination of movement on flights and landings. For example, when the observed straight staircase consisted of two flights and one landing (the most frequent option), the movement characteristics of children were evaluated separately on the flights (2 measurement areas), on the landing (1 measurement area), and on the whole area of the staircase (1 measurement area which included two flights and one landing). The beginning of the whole area of the staircase was assumed the same as the beginning of the first flight and the end of this area was the same as the end of the other flight. The evaluated movement characteristic were estimated as weighted average values over time measured on particular flights and landings. The movement on whole staircases was evaluated only in the cases when the observed staircase consisted at least of one flight and one landing, i.e. the one-flight straight staircases were not included in this category. In total, 13 straight staircases were observed when children, details of their geometry are listed in Table 5.20.

As can be seen from Table 5.20, the majority of the observed straight staircases were located indoor. These staircases were a part of daily used circulation routes. Only in one nursery school, two external staircases were also used during the experimental evacuation drills. However, these one-flight staircases were also designed for daily use connecting the building with the garden and therefore well known for all children and staff members such standard circulation routes. Hence, the impact of different environment and different familiarity with the escape route on children's movement characteristics suggested in the literature [22, 34] was not studied in this research.

Travel speed on flights

In the measurement areas on flights, travel speed of children was observed during continuous movement and therefore it is referred as movement travel speed. Travel speed was analysed separately for the involved age groups (Junior, Senior, Senior+, and Mixed); however, walking and running travel speed was not distinguished on flights. Conversely to the horizontal movement it was not possible to identify the flight phase in the children's movement and thus also not to distinguish fast walking pace from running. The obtained results on travel speed and corresponding density are summarised in Table 5.21. Probability distributions for the evaluated travel speed and density are demonstrated in Figure 5.24 (separate evaluation for different age groups can be found in Appendix C in Figure C.8).

In general, considerably more data-points were measured for Senior children than for other age groups, since Senior classes were more often located on upper floors.

Table 5.20: Geometry of the straight staircases observed during the experimental evacuation drills

Staircase label	**Location**	**Rise height [mm]**	**Tread depth [mm]**	**Slope of stair [°]**	**Handrail height [mm]**	
					Standard	**Children's**
B1	INT	155	290	28.1	950 [1)]	-
B2	INT	160	310	27.3	900 [1)]	500 [1)]
C1	INT	160	300	28.1	1040 [1)]	660 [1)]
E1	INT	130	310	22.7	1100 [2)]	510 [1)]
E2	INT	160	310	27.3	-	-
E3	INT	170	280	31.3	1000 [2)]	550 [1)]
E4	INT	130	310	22.7	1100 [2)]	510 [1)]
F1	INT	150	310	25.8	900 [2)]	600 [2)]
F2	INT	150	310	25.8	-	600 [2)]
H1	INT	140	290	25.8	1060 [1)]	-
H2	INT	140	290	25.8	980 [1)]	-
H3	EXT	160	270	30.7	900 [2)]	440 [2)]
H4	EXT	160	270	30.7	900 [2)]	440 [2)]
J1	INT	150	300	26.6	1080 [1)]	430 [1)]
J2	INT	150	300	26.6	1080 [1)]	430 [1)]

INT: internal staircase, EXT: external staircase
[1)] handrail available on both sites of the flight
[2)] handrail available only on one site of the flight

Table 5.21: Travel speed of children measured on flights of straight staircases during the experimental evacuation drills

Age group	**Density interval [$m^2\,m^{-2}$]**	**Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)**	**Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)**
Junior	0.00–0.05	0.71 / 0.28 / 1.21 / 0.21 (132)	0.03 / 0.01 / 0.05 / 0.01 (132)
	0.06–0.10	0.77 / 0.49 / 1.13 / 0.17 (27)	0.06 / 0.05 / 0.06 / 0.01 (27)
Senior	0.00–0.05	0.94 / 0.33 / 1.74 / 0.27 (346)	0.03 / 0.01 / 0.05 / 0.01 (346)
	0.06–0.10	0.78 / 0.44 / 1.17 / 0.19 (45)	0.06 / 0.05 / 0.07 / 0.01 (45)
Senior+	0.00–0.05	0.94 / 0.65 / 1.35 / 0.18 (66)	0.02 / 0.01 / 0.04 / 0.01 (66)
Mixed	0.00–0.05	0.73 / 0.32 / 1.62 / 0.26 (128)	0.02 / 0.01 / 0.05 / 0.01 (128)
	0.06–0.10	0.79 / 0.53 / 1.14 / 0.30 (4)	0.05 / 0.05 / 0.05 / 0.00 (4)
Total		**0.85 / 0.28 / 1.74 / 0.26 (748)**	**0.03 / 0.01 / 0.07 / 0.01 (748)**

It can be seen from Table 5.21 that travel speed of children moving on flights is age-dependent. Junior children moved with lower speeds (the mean value 0.71 $m{\cdot}s^{-1}$ in the density interval 0.00-0.05 $m^2\,m^{-2}$) than Senior and Senior+ children (the mean value 0.94 $m{\cdot}s^{-1}$ in the same density interval); this trend followed also the measured maximum travel speeds. Nevertheless, the age differences in travel speed on flights were not as striking as in the case of travel speeds in corridors when older children reached almost double travel speeds than younger children (compare the results with Table 5.15, Table 5.16, and Table 5.17). This finding may be attributed to the fact that movement on stairs is for children more challenging than walking and running on the horizontal plane. Thus, the developmental differences in children of various age do not result in such visible differences in their movement abilities. Correspondingly,

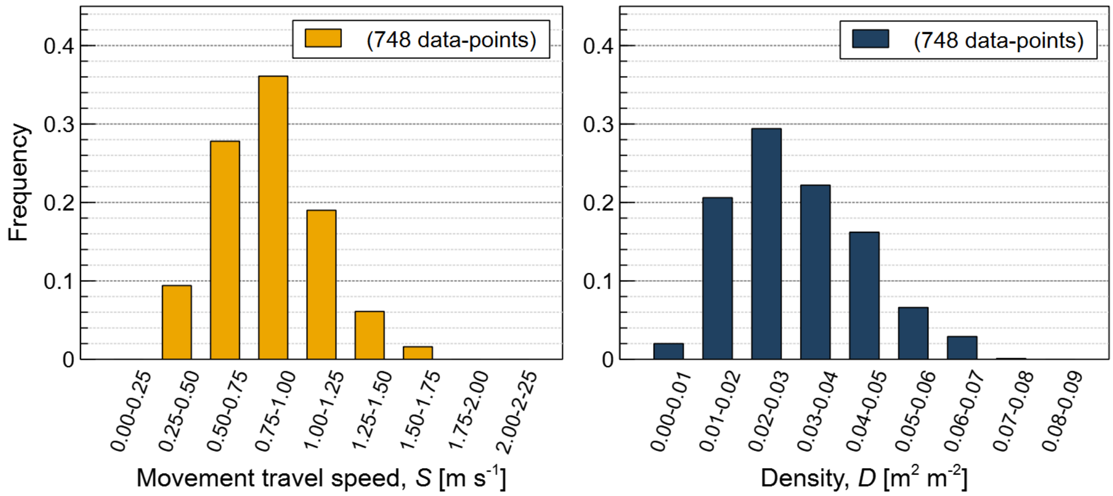


Figure 5.24: Probability distribution for travel speed (**left**) and density (**right**) measured on flights of straight staircases during the experimental evacuation drills

the travel speeds observed on flights of straight staircases were considerably lower than the travel speeds measured in corridors.

Considering the density conditions, only movement at low densities (less than 0.1 $m^2\,m^{-2}$) was observed in the measurement areas on flights which corresponds to the continuous movement of children without any stops or crowding. The mean density observed was 0.03 $m^2\,m^{-2}$ (i.e. approximately 1.2 children·m^{-2}) and the maximum density measured was 0.07 $m^2\,m^{-2}$ (i.e. approximately 2.7 children·m^{-2}). In addition, similar density intervals were identified when observing children in different age groups.

The relationship between travel speed and density on flights can be seen from the scatter plot presented in Figure 5.25. In this figure, the dependence of movement travel speed S [m·s^{-1}] on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right is displayed for different age groups of children (colour-coded). Separate plots demonstrating speed-density relationships for different age groups are provided in Appendix C in Figure C.9. Based on the best goodness-of-fit (the correlation coefficients R^2) and the curve shape, the linear fitting was selected to express the trend lines of the presented data-set. However, it can be seen from the plot that the presented data-set was quite scattered without any clear trend. This outcome may be attributed to a large diversity of the measured values resulting from various staircases observed as well as from the variability of pedestrian dynamics. Furthermore, due to the absence of experimental data at higher densities the application range of the trend lines should be seen as limited to densities lower than 0.07 $m^2\,m^{-2}$ (approximately 2.7 children·m^{-2}).

Specific flow on flights

Pedestrian flow related to 1 m of effective width of the measurement areas (flights) [pers·$s^{-1}\,m^{-1}$] was analysed for children in different age groups (walking and run-

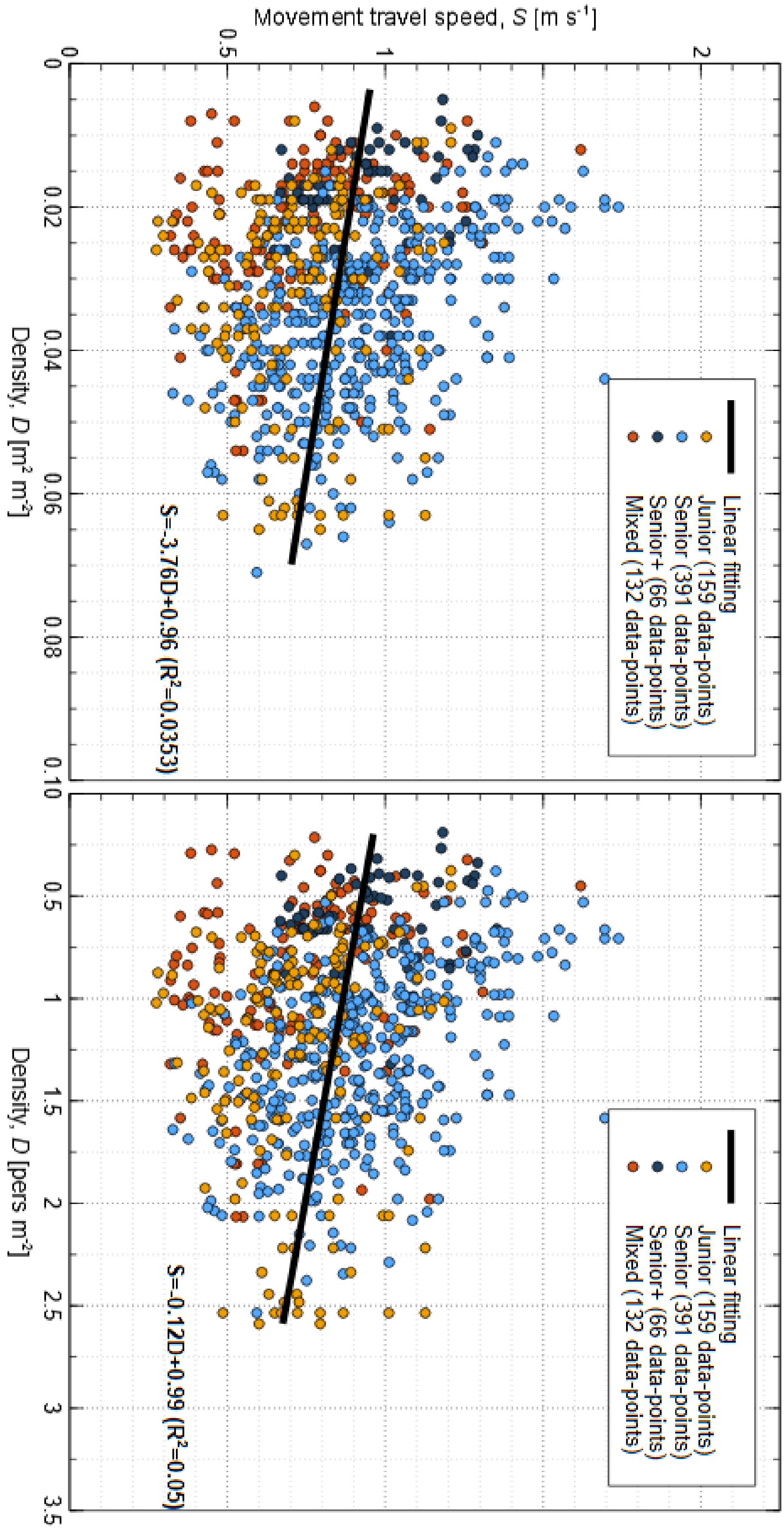


Figure 5.25: Travel walking and running speed per density (**left**: [$m^2\,m^{-2}$]; **right**: [$pers{\cdot}m^{-2}$]) with calculated trend lines measured on flights of straight staircases for different age groups

ning movement not distinguished). The obtained results on specific flow and corresponding density intervals are given in Table 5.22, their probability distributions are provided in Figure 5.26 (probability distributions for different age groups can be found in Appendix C in Figure C.10).

Table 5.22: Specific flow of children measured on flights of straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\,m^{-2}$]	**Specific flow (mean/min/max/SD)** [pers·$s^{-1}\,m^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\,m^{-2}$] **(data-points)**
Junior	0.00–0.05	1.13 / 0.45 / 3.57 / 0.53 (132)	0.03 / 0.01 / 0.05 / 0.01 (132)
	0.06–0.10	1.64 / 0.71 / 3.57 / 0.88 (27)	0.06 / 0.05 / 0.06 / 0.01 (27)
Senior	0.00–0.05	1.49 / 0.50 / 2.73 / 0.58 (346)	0.03 / 0.01 / 0.05 / 0.01 (346)
	0.06–0.10	1.64 / 0.83 / 2.50 / 0.55 (45)	0.06 / 0.05 / 0.07 / 0.01 (45)
Senior+	0.00–0.05	0.72 / 0.53 / 1.58 / 0.29 (66)	0.02 / 0.01 / 0.04 / 0.01 (66)
Mixed	0.00–0.05	0.91 / 0.53 / 2.00 / 0.43 (128)	0.02 / 0.01 / 0.05 / 0.01 (128)
	0.06–0.10	1.81 / 1.25 / 2.00 / 0.38 (4)	0.05 / 0.05 / 0.06 / 0.01 (4)
Total		**1.28 / 0.45 / 3.57 / 0.61 (748)**	**0.03 / 0.01 / 0.07 / 0.01 (748)**

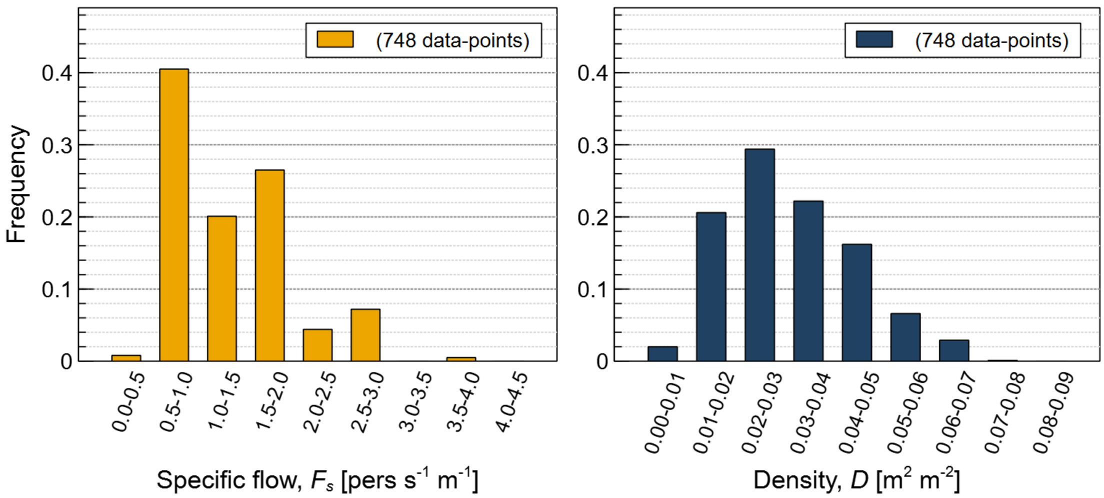


Figure 5.26: Probability distribution for specific flow (**left**) and density (**right**) measured on flights of straight staircases during the experimental evacuation drills

The observed values of specific flow on flights of straight staircases were between 0.45 pers·$s^{-1}\,m^{-1}$ and 3.57 pers·$s^{-1}\,m^{-1}$ with the mean value of 1.28 pers·$s^{-1}\,m^{-1}$, i.e. slightly lower than the results obtained in corridors. In general, higher specific flow was measured in higher density intervals (from 0.06 $m^2\,m^{-2}$) than in lower density intervals for all age groups. At the very low densities (0.00–0.05 $m^2\,m^{-2}$) higher values of specific flow can be identified for Senior children in comparison to Junior children. However, this trend can not be confirmed also for Senior+ children and at higher density conditions.

The dependence of specific flow F_s [pers·$s^{-1}\,m^{-1}$] on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right is illustrated in

Figure 5.27. The results obtained in different age groups are colour-coded; separate flow-density relationships for different age groups can be found in Appendix C in Figure C.11. In Figure 5.27, trend lines of the presented data-sets were fitted using a polynomial function and the corresponding correlation coefficients R^2 were calculated. Following the estimated trend lines, the peak of specific flow (1.7 pers·s^{-1} m^{-1}) can be identified at the density around 0.055 m^2 m^{-2}, i.e. approximately 2 children·m^{-2}. The application range of the provided trend lines is limited for lower densities than 0.07 m^2 m^{-2}.

Travel speed on landings

Similarly to the observations on flights, travel speed of children investigated on landings of straight staircases was mostly observed during continuous movement and it is further referred as movement travel speed. However, in one nursery school for two Senior classes (in total 35 children, 3 measurement areas, 50 data-points) the continuous movement on landings was disturbed. In these classes, children received instructions to wait on the landings until the staff member was sure she saw all children moving in a compact group and in the right direction. Thus, the children were instructed to wait inside the measurement area for a specific amount of time. To obtain the time intervals appropriate for the calculation of movement travel speed the waiting times on the landings were excluded (the same modification was used for one Senior class when evaluating movement travel speeds in corridors). The described stops resulted also in higher densities observed on the landings (the highest densities in the whole data-set reaching the value of 0.14 m^2 m^{-2}, i.e. approximately 5.2 children·m^{-2}). Therefore, additional explanation is provided when the modified data-points were further interpreted. Walking and running travel speeds were analysed separately for all age groups. The overall results for both walking and running children with corresponding density intervals are given in Table 5.23. In Table 5.24 and Table 5.25, walking and running speeds are presented separately. In addition, probability distributions for travel speeds and density (separately for walking and running children) are given in Figure 5.28 (probability distributions travel speeds and density for different age groups can be found in Appendix C in Figure C.12).

Table 5.23: Travel speed of children measured on landings of straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval [m^2 m^{-2}]**	**Travel speed (mean/min/max/SD) [m·s^{-1}] (data points)**	**Density (mean/min/max/SD) [m^2 m^{-2}] (data-points)**
Junior	0.00–0.05	0.94 / 0.17 / 1.86 / 0.38 (49)	0.02 / 0.00 / 0.04 / 0.01 (49)
Senior	0.00–0.05	1.24 / 0.36 / 2.55 / 0.53 (82)	0.03 / 0.01 / 0.05 / 0.01 (82)
	0.06–0.10	0.73 / 0.22 / 1.60 / 0.34 (73)	0.07 / 0.05 / 0.10 / 0.01 (73)
	0.11–0.15	0.51 / 0.22 / 0.83 / 0.19 (29)	0.12 / 0.10 / 0.14 / 0.01 (29)
Mixed	0.00–0.05	1.31 / 0.56 / 2.25 / 0.52 (19)	0.02 / 0.01 / 0.05 / 0.01 (19)
	0.06–0.10	1.20 / 0.75 / 1.54 / 0.34 (4)	0.05 / 0.05 / 0.06 / 0.01 (4)
Total		**0.96 / 0.17 / 2.55 / 0.50 (256)**	**0.05 / 0.00 / 0.14 / 0.03 (256)**

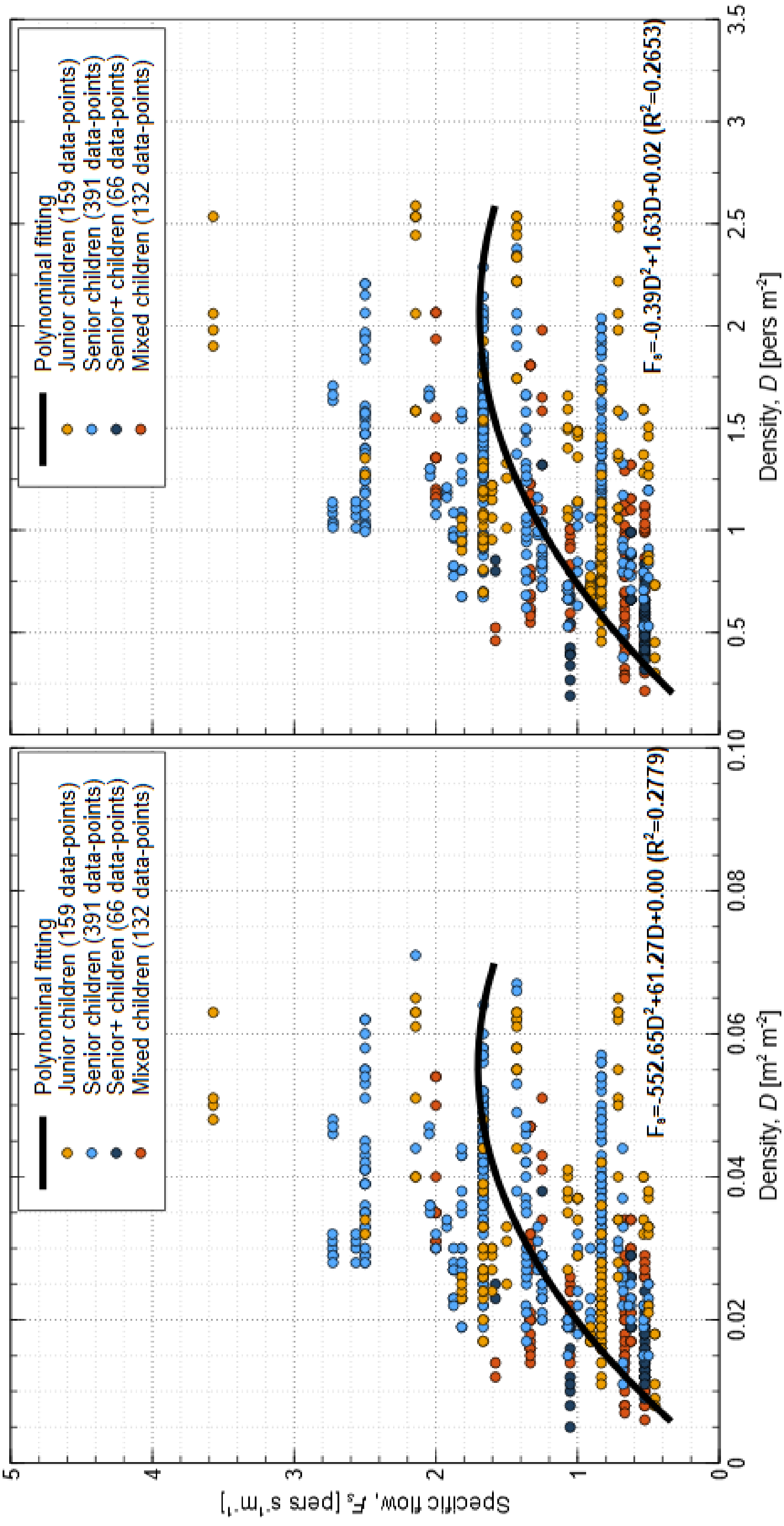


Figure 5.27: Specific flow per density (**left**: $[\mathrm{m}^2\,\mathrm{m}^{-2}]$; **right**: $[\mathrm{pers}{\cdot}\mathrm{m}^{-2}]$) with calculated trend lines measured on flights of straight staircases

Table 5.24: Walking travel speed of children measured on landings of straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\ m^{-2}$]	**Travel speed (mean/min/max/SD)** [$m{\cdot}s^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\ m^{-2}$] **(data-points)**
Junior	0.00–0.05	0.84 / 0.17 / 1.31 / 0.28 (43)	0.02 / 0.00 / 0.04 / 0.01 (43)
Senior	0.00–0.05	1.03 / 0.36 / 1.86 / 0.40 (43)	0.03 / 0.01 / 0.05 / 0.01 (43)
	0.06–0.10	0.68 / 0.22 / 1.60 / 0.34 (56)	0.07 / 0.05 / 0.10 / 0.02 (56)
	0.11–0.15	0.51 / 0.22 / 0.83 / 0.19 (29)	0.12 / 0.10 / 0.14 / 0.01 (29)
Mixed	0.00–0.05	0.65 / 0.59 / 0.70 / 0.05 (3)	0.02 / 0.02 / 0.03 / 0.01 (3)
Total		**0.78 / 0.17 / 1.86 / 0.37 (174)**	**0.06 / 0.00 / 0.14 / 0.04 (174)**

Table 5.25: Running travel speed of children measured on landings of straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\ m^{-2}$]	**Travel speed (mean/min/max/SD)** [$m{\cdot}s^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\ m^{-2}$] **(data-points)**
Junior	0.00–0.05	1.65 / 1.45 / 1.86 / 0.17 (6)	0.02 / 0.01 / 0.03 / 0.00 (6)
Senior	0.00–0.05	1.47 / 0.44 / 2.55 / 0.56 (39)	0.03 / 0.01 / 0.05 / 0.01 (39)
	0.06–0.10	0.89 / 0.43 / 1.43 / 0.31 (17)	0.06 / 0.05 / 0.08 / 0.01 (17)
Mixed	0.00–0.05	1.44 / 0.56 / 2.25 / 0.47 (16)	0.02 / 0.01 / 0.05 / 0.01 (16)
	0.06–0.10	1.20 / 0.75 / 1.54 / 0.34 (4)	0.05 / 0.05 / 0.06 / 0.01 (4)
Total		**1.35 / 0.43 / 2.55 / 0.52 (82)**	**0.04 / 0.01 / 0.08 / 0.02 (82)**

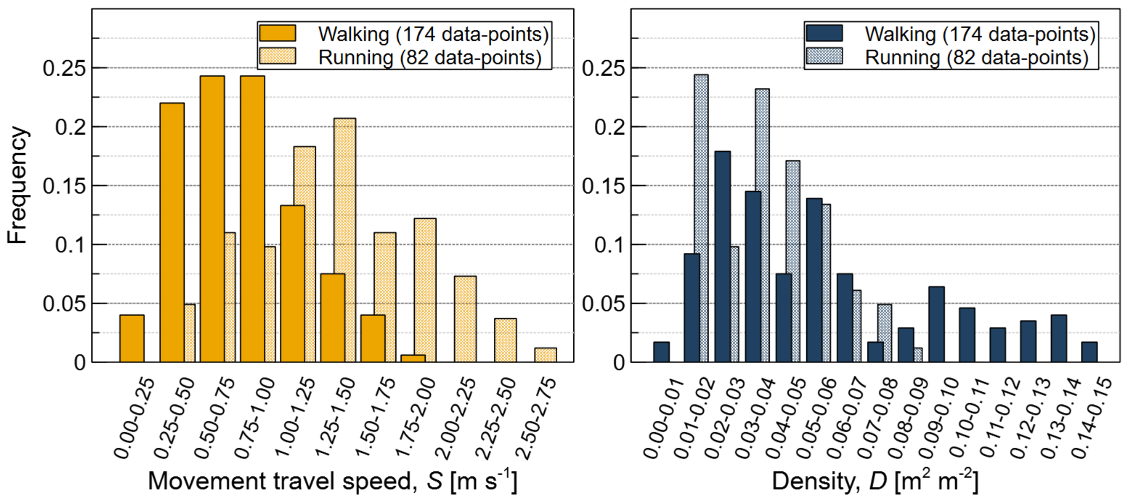


Figure 5.28: Probability distribution for travel speed (**left**) and density (**right**) measured on landings of straight staircases during the experimental evacuation drills

The results revealed that on straight staircases children moved faster on landings (average value for all children 0.96 $m{\cdot}s^{-1}$) than on flights (average value for all children 0.85 $m{\cdot}s^{-1}$). Similarly, the maximum travel speeds reached by children of various age are higher on landings (2.55 $m{\cdot}s^{-1}$) than on flights (1.74 $m{\cdot}s^{-1}$). This fact corresponds with the hypothesis that the horizontal plane enables children to move at higher speeds. However, the walking and running travel speeds observed on landings are considerably lower than the travel speeds in corridors (compare the presented results with Table 5.15, Table 5.16, and Table 5.17). This may be explained such a consequence of both limited space for movement and different shape of movement trajectories on landings. Furthermore, the age-dependence of travel speed can be identified comparing the results for Junior and Senior children, especially when walking travel speed is under consideration. However, the observations showed that Senior children reached on average lower travel speeds when running on landings (mean value 1.47 $\mathrm{m{\cdot}s^{-1}}$ in the density interval 0.00-0.05 $\mathrm{m^2\,m^{-2}}$) than Junior children (mean value 1.65 $\mathrm{m{\cdot}s^{-1}}$ in the density interval 0.00-0.05 $\mathrm{m^2\,m^{-2}}$), this output may be attributed to the limited number of data-points available for running Junior children (only 6 data-points). Looking at the maximum running speeds, the difference between Junior children (1.86 $\mathrm{m{\cdot}s^{-1}}$ in the density interval 0.00-0.05 $\mathrm{m^2\,m^{-2}}$) and Senior children (2.55 $\mathrm{m{\cdot}s^{-1}}$ in the density interval 0.00-0.05 $\mathrm{m^2\,m^{-2}}$) confirmed the hypothesis that older children move faster than younger ones.

In comparison to the movement on flights or in corridors, higher densities (over 0.1 $\mathrm{m^2\,m^{-2}}$ with the maximum value of 0.14 $\mathrm{m^2\,m^{-2}}$, i.e. approximately 5.2 children$\cdot\mathrm{m^{-2}}$) occurred on landings of straight staircases. It is important to highlight that these higher density conditions were observed only in Senior children, namely in two Senior classes where children had to wait on the landings for a while following the instructions of the staff members. As a result more crowded conditions occurred on the landings impacting both measured density and calculated travel speed which can be even more visible in the evaluation of speed-density relationship (see the cross symbols in Figure 5.29).

The speed-density relationships describing combined walking and running travel speeds observed in children in all age groups on landings is illustrated in Figure 5.29. Travel speed S [$\mathrm{m{\cdot}s^{-1}}$] is plotted as dependent on density D expressed in the unit of [$\mathrm{m^2\,m^{-2}}$] on the left and in the unit of [pers$\cdot\mathrm{m^{-2}}$] on the right. To determine the trend lines of the presented data-set exponential and polynomial functions were selected based on the calculated correlation coefficients R^2 and the shape of the fitting curves. In addition, the data-points measured under crowded conditions on the landings in two Senior classes are highlighted as cross symbols. It can be seen that in these cases the lowest travel speeds were measured for the Senior children. The application range of the given trend lines is limited to densities lower than 0.14 $\mathrm{m^2\,m^{-2}}$ (approximately 5 children$\cdot\mathrm{m^{-2}}$).

In Figure 5.30 the speed-density relationships for walking and running children in different age groups (colour-coded) are illustrated separately (for greater degree of detail, separate speed-density relationships for different age groups are provided in Appendix C in Figure C.13). Consistently with the previous evaluation, the presented experimental data-sets were fitted using exponential and polynomial functions. Additionally, linear fitting was also performed and displayed showing relatively good agreement with the experimental data. The shape of all the determined trend lines is quite similar. The highest travel speeds were observed for running children at lower densities under 0.05 $\mathrm{m^2\,m^{-2}}$ (approximately 1.9 children$\cdot\mathrm{m^{-2}}$). When children were running on landings, the density did not exceed the value of 0.08 $\mathrm{m^2\,m^{-2}}$

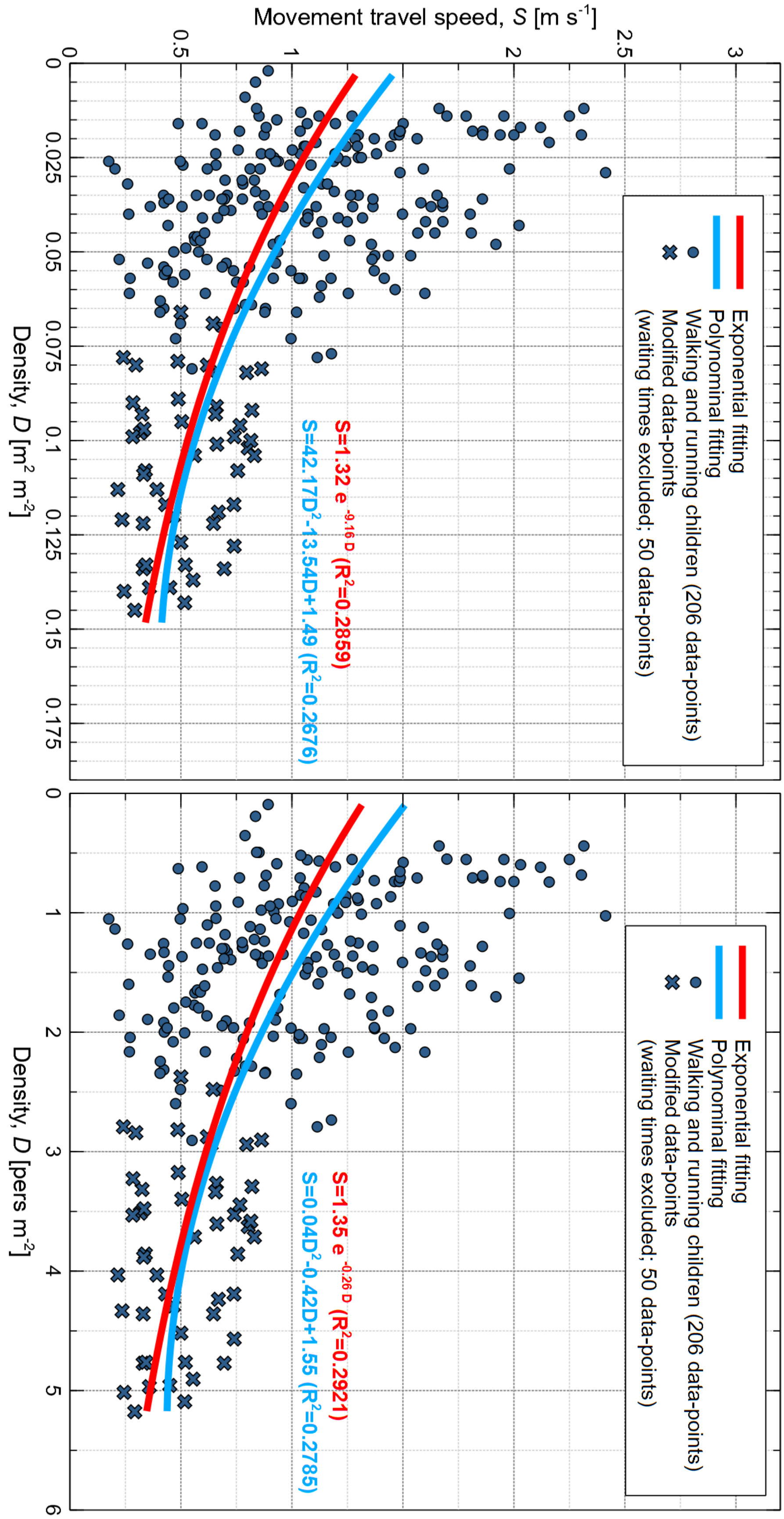


Figure 5.29: Travel walking and running speed per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers$\cdot m^{-2}$]) with calculated trend lines measured on landings of straight staircases

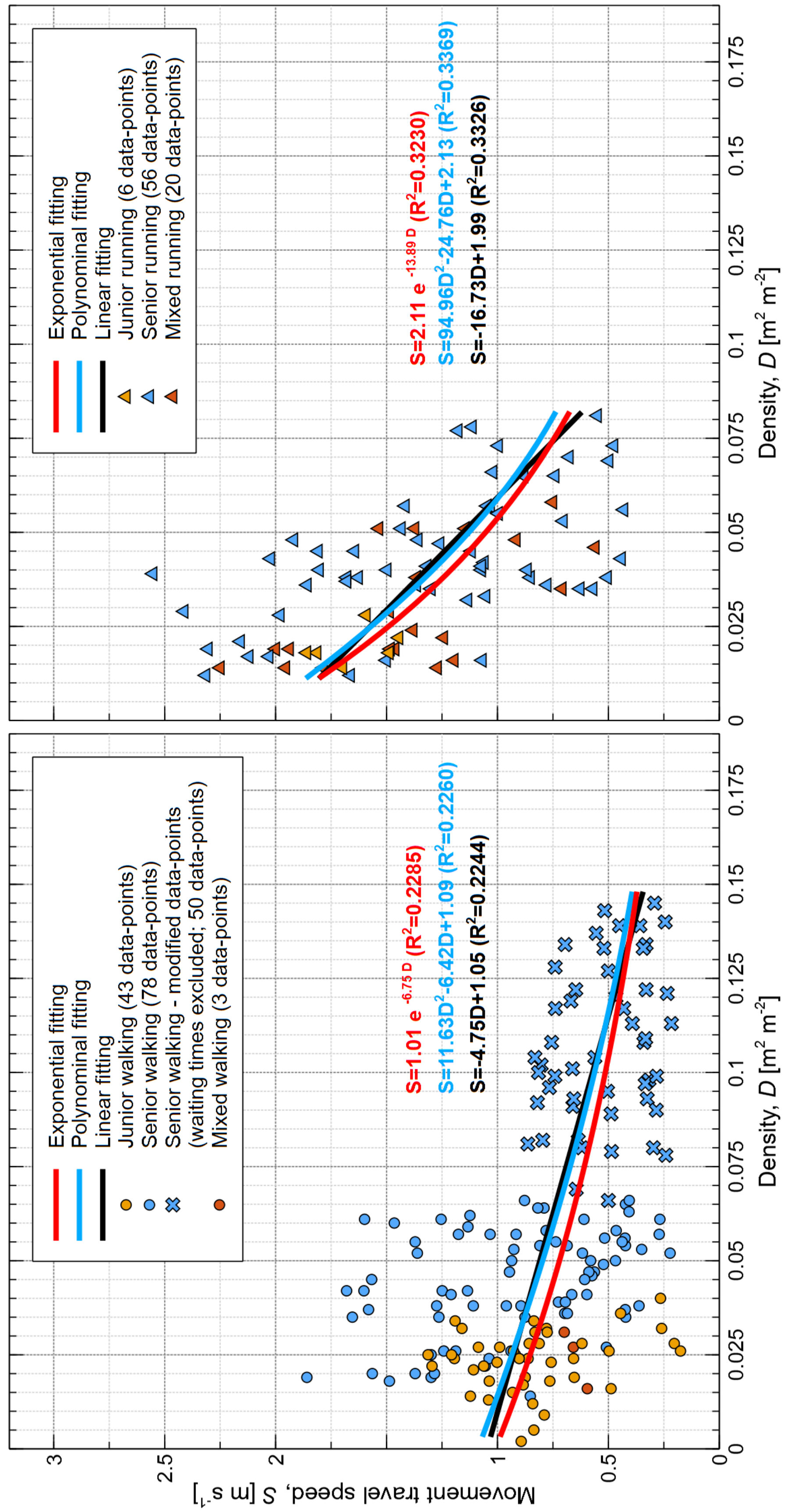


Figure 5.30: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] with calculated trend lines measured on landings of straight staircases for different age groups

(approximately 3.1 children·m^{-2}). Furthermore, different density intervals and corresponding walking travel speeds for Junior and Senior children can be identified from the left plot. The data-set for walking Junior children is limited to densities lower than 0.04 m^2 m^{-2} (approximately 1.5 children·m^{-2}). In this density interval, higher maximum walking travel speeds were measured for Senior children.

Specific flow on landings

Similarly to pedestrian flow in corridors, specific flow on landings of straight staircases (related to 1 m of effective width of the measurement areas [pers·s^{-1} m^{-1}]) was not distinguished for walking and running children. The results on specific flow on landings for different age groups together with the corresponding density intervals are demonstrated in Table 5.26. Probability distributions of the analysed variables are summarised in Figure 5.31 (results for different age groups are provided separately in Appendix C in Figure C.14).

Table 5.26: Specific flow of children measured on landings of straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	Density interval [m^2 m^{-2}]	Specific flow (mean/min/max/SD) [pers·s^{-1} m^{-1}] (data points)	Density (mean/min/max/SD) [m^2 m^{-2}] (data-points)
Junior	0.00–0.05	1.39 / 0.83 / 2.50 / 0.55 (49)	0.02 / 0.00 / 0.04 / 0.01 (49)
Senior	0.00–0.05	1.45 / 0.63 / 3.64 / 0.78 (82)	0.03 / 0.01 / 0.05 / 0.01 (82)
	0.06–0.10	1.67 / 0.64 / 3.21 / 0.50 (73)	0.07 / 0.05 / 0.10 / 0.01 (73)
	0.11–0.15	2.01 / 0.83 / 3.33 / 0.76 (29)	0.12 / 0.10 / 0.14 / 0.01 (29)
Mixed	0.00–0.05	0.77 / 0.67 / 1.33 / 0.25 (19)	0.02 / 0.01 / 0.05 / 0.01 (19)
	0.06–0.10	1.83 / 1.33 / 2.00 / 0.33 (4)	0.05 / 0.05 / 0.06 / 0.01 (4)
Total		**1.52 / 0.63 / 3.64 / 0.69 (256)**	**0.05 / 0.00 / 0.14 / 0.03 (256)**

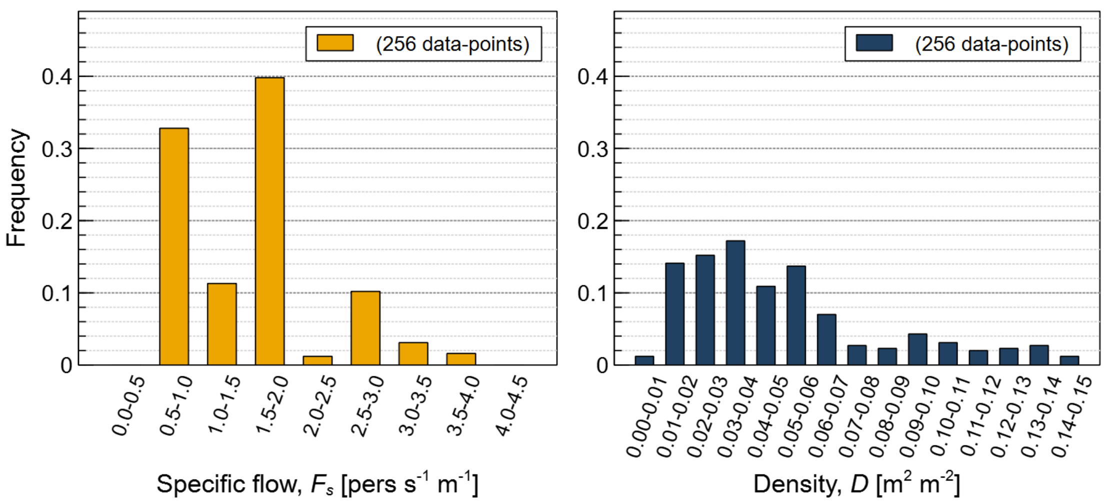


Figure 5.31: Probability distribution for specific flow (**left**) and density (**right**) measured on landings of straight staircases during the experimental evacuation drills

The results on specific flow on landings ranged from 0.63 pers·s^{-1} m^{-1} and 3.64 pers·s^{-1} m^{-1} (the mean value of 1.52 pers·s^{-1} m^{-1}) which were higher values in comparison to the observations on flights. Furthermore, although lower, the results of specific flow measured on landings were closer to the values of specific flow recorded in corridors. This outcome is in the line with the findings provided in the part on travel speed: first, children moved faster on the horizontal plane (i.e. in corridors and on landings) than on flights and, second, children's movement on landings is more limited by the space and trajectory present there in comparison to the movement in straight corridors. Consistently with the results on specific flow on flights, higher values of specific flow were measured in higher density intervals in all age groups. In addition, comparing the values obtained in the same density intervals, higher values of specific flow can be identified for Senior children than for Junior children.

The flow-density relationships describing the dependence of specific flow F_s [pers·s^{-1} m^{-1}] on density D in the unit of [m^2 m^{-2}] on the left and in the unit of [pers·m^{-2}] on the right are demonstrated in Figure 5.32. The results obtained on landings in different age groups are colour-coded (separate flow-density relationships for different age groups are given in Appendix C in Figure C.15). The trend lines of the experimental data-sets were polynomially fitted and the correlation coefficients R^2 were calculated. In comparison to the trend lines describing the flow-density relationships on flights, the curve shape of the trend lines suggested for the experimental data measured on landings seemed to be less appropriate. This may be caused by the limited number of data-points measured in a larger density interval which resulted in scattering of the results. Moreover, due to this limitation, the impact of data analysis method (see Section 5.2.3 for details) is more visible in this data-set where discrete jumps in specific flow resulted from similar effective widths of the observed landings. Apart from that, the peak of the suggested trend lines (close to the value of 2.0 pers·s^{-1} m^{-1}) can be estimated at the density 0.13 m^2 m^{-2}, i.e. approximately 5 children·m^{-2}. The application range of the provided trend lines is limited for lower densities than 0.14 m^2 m^{-2}.

Travel speed on whole staircases

Besides the measurement areas which covered separately flights and landings, travel speed of children was further analysed on straight staircases as wholes, i.e. including both flights and landings. As children's movement on flights and landings was evaluated as continuous (or was modified so it could be assumed as continuous in some cases), travel speed investigated on the whole area of staircases is also considered as movement travel speed. The obtained results on travel speed (walking and running combined) and corresponding density intervals for the involved age groups (Junior, Senior, and Mixed) are provided in Table 5.27. Probability distributions for the evaluated characteristics are given in Figure 5.33 (separate evaluation for different age groups can be found in Appendix C in Figure C.16).

As the presented travel speeds on whole straight staircases were evaluated as the combination of the values observed on the particular flights and landings, the general trends described in the separate section focused on travel speeds on flights

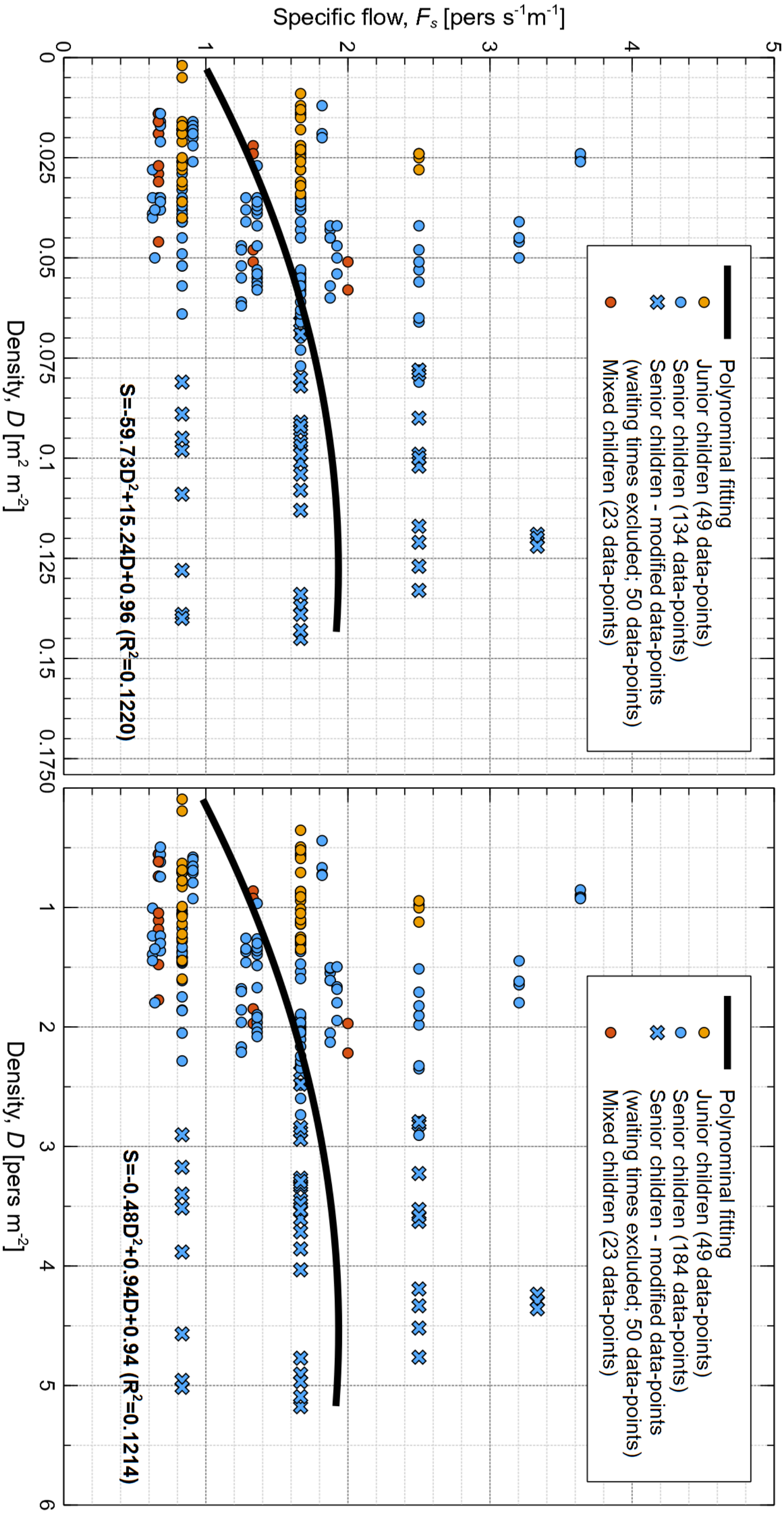
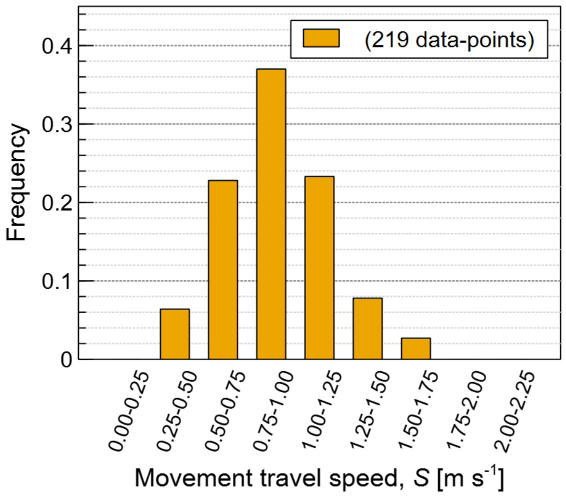


Figure 5.32: Specific flow per density (**left**: [m^2 m^{-2}]; **right**: [pers·m^{-2}]) with calculated trend lines measured on landings of straight staircases

Table 5.27: Travel speed of children measured on whole straight staircases (flights and landings combined) during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval** [$m^2\,m^{-2}$]	**Travel speed (mean/min/max/SD)** [$m{\cdot}s^{-1}$] **(data points)**	**Density (mean/min/max/SD)** [$m^2\,m^{-2}$] **(data-points)**
Junior	0.00–0.05	0.77 / 0.34 / 1.11 / 0.17 (49)	0.02 / 0.01 / 0.04 / 0.01 (49)
Senior	0.00–0.05	1.03 / 0.37 / 1.66 / 0.27 (108)	0.03 / 0.01 / 0.05 / 0.01 (108)
	0.06–0.10	0.68 / 0.42 / 1.14 / 0.18 (39)	0.06 / 0.05 / 0.08 / 0.01 (39)
Mixed	0.00–0.05	0.90 / 0.51 / 1.30 / 0.22 (23)	0.02 / 0.01 / 0.04 / 0.01 (23)
Total		**0.90 / 0.34 / 1.66 / 0.27 (219)**	**0.04 / 0.01 / 0.08 / 0.02 (219)**



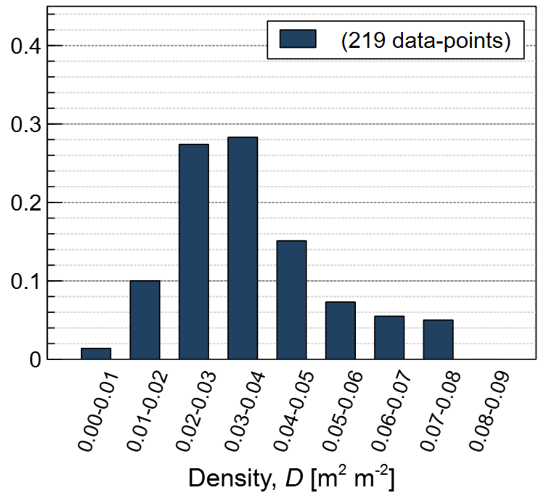


Figure 5.33: Probability distribution for travel speed (**left**) and density (**right**) measured on whole straight staircases during the experimental evacuation drills

and landings can be identified. Notably, the impact of age and density on travel speed is apparent from the results. Since on straight staircases children spent more time on flights than on landings the provided results are closer to the values provided in Table 5.21. Considering the calculated density intervals only movement at low densities (less than 0.1 $m^2\,m^{-2}$) can be assumed on the straight staircases as wholes. The mean calculated density was 0.04 $m^2\,m^{-2}$ (i.e. approximately 1.5 children·m^{-2}) and the maximum calculated density was 0.08 $m^2\,m^{-2}$ (i.e. approximately 3.1 children·m^{-2}). Consistently with the results reported in the previous section, higher density conditions were estimated for Senior children.

The relationship between travel speed and density estimated on whole straight staircases is given in Figure 5.34. Similarly to the previous plots describing speed-density relationships, travel speed S [$m{\cdot}s^{-1}$] is illustrated as dependent on density D expressed in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right. The data-points calculated for different age groups of children are colour-coded (separate plots providing speed-density relationships for different age groups can be found in Appendix C in Figure C.17). To show the trend line of the experimental data-set, the data was linearly fitted (the linear function was selected based on the calculated correlation coefficients R^2 and the overall curve shape). The application range of the illustrated trend lines is limited to the low density conditions (0.08 $m^2\,m^{-2}$, i.e. approximately 3.1 children·m^{-2}).

Specific flow on whole staircases

In addition to travel speeds, specific flow [pers·$s^{-1}\,m^{-1}$] of children moving on whole staircases (including both the flights and landings) was investigated. The results on specific flow (walking and running movement combined) and corresponding density intervals are summarised in Table 5.28. Probability distributions for specific flow and density estimated across all age groups of the involved children can be found in Figure 5.35, a separate evaluation for different age groups is provided in Appendix C in Figure C.18).

Table 5.28: Specific flow of children measured on whole straight staircases during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval [$m^2\,m^{-2}$]**	**Specific flow (mean/min/max/SD) [pers·$s^{-1}\,m^{-1}$] (data points)**	**Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)**
Junior	0.00–0.05	1.27 / 0.83 / 2.20 / 0.38 (49)	0.02 / 0.01 / 0.04 / 0.01 (49)
Senior	0.00–0.05	1.55 / 0.68 / 2.79 / 0.46 (108)	0.03 / 0.01 / 0.05 / 0.01 (108)
	0.06–0.10	1.70 / 1.31 / 2.25 / 0.25 (39)	0.06 / 0.05 / 0.08 / 0.01 (39)
Mixed	0.00–0.05	0.98 / 0.67 / 1.75 / 0.31 (23)	0.02 / 0.01 / 0.04 / 0.01 (23)
Total		**1.45 / 0.67 / 2.79 / 0.45 (219)**	**0.04 / 0.01 / 0.08 / 0.02 (219)**

Similarly to the travel speeds described in the previous section, specific flow on whole straight staircases was analysed based on the results obtained separately on flights and landings. Thus, the acquired results reflected the early interpreted trends with a more dominant impact of the values observed on flights. The mean value of specific flow on whole staircases was 1.45 pers·$s^{-1}\,m^{-1}$. Specific flow of children on straight staircases was affected by both age of children and density conditions. A higher specific flow can be seen in Senior group than in Junior group in the same density interval and higher values of specific flow can be identified in higher density intervals in all age groups.

The flow-density relationships estimated for whole straight staircases for different age groups (colour-coded) are demonstrated in Figure 5.36 where specific flow F_s [pers·$s^{-1}\,m^{-1}$] is expressed as dependent on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right. Separate flow-density relationships for different age groups can be found in Appendix C in Figure C.19. To express trend lines of the presented data-set a polynomial function was used and the correlation coefficients R^2 were calculated. According to the provided trend lines, the peak of specific flow (almost 1.8 pers·$s^{-1}\,m^{-1}$) occurred at the density 0.05 $m^2\,m^{-2}$, i.e. approximately 2 children·m^{-2}. The application range of the provided trend lines is defined for lower densities than 0.08 $m^2\,m^{-2}$.

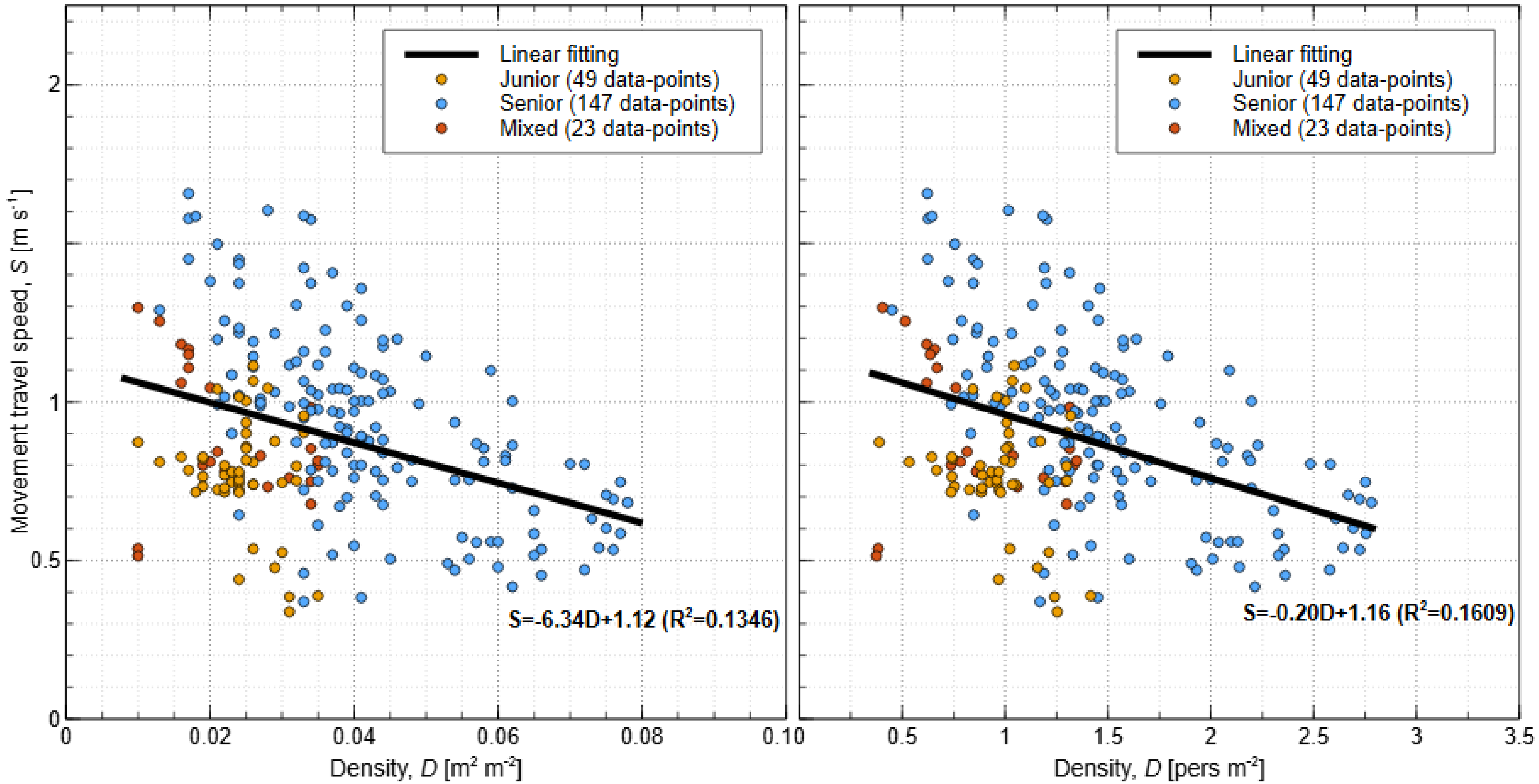


Figure 5.34: Travel walking and running speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with calculated trend lines measured on whole straight staircases for different age groups

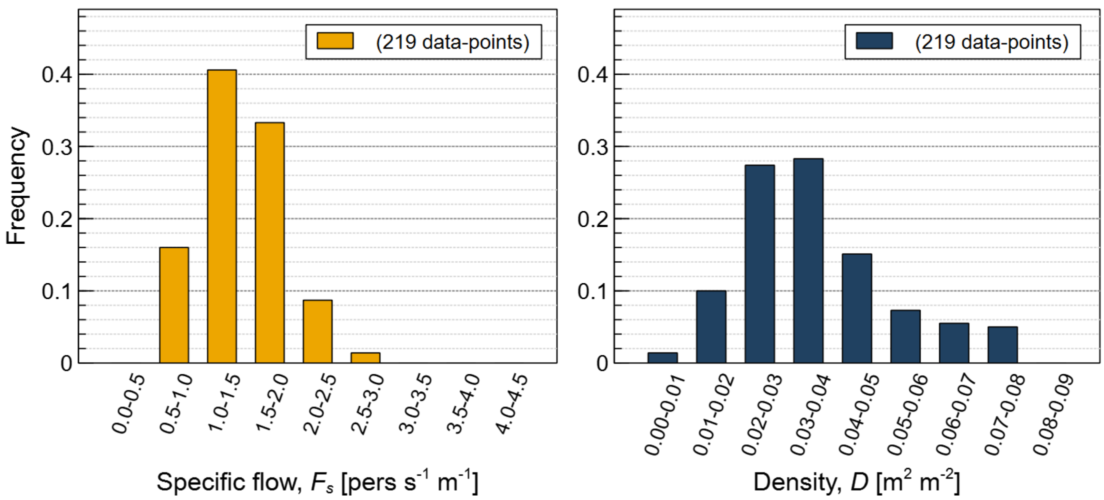


Figure 5.35: Probability distribution for specific flow (**left**) and density (**right**) measured on whole straight staircases during the experimental evacuation drills

5.3.6 Movement on spiral staircases

In this section, the results on movement characteristics of children climbing downstairs spiral staircases are reported. Travel speed, pedestrian flow, and density were investigated on 2 identical spiral staircases (8 measurement areas) in one nursery school during one experimental evacuation drill. Details on the geometry of the staircases are listed in Table 5.29. As defined in Section 5.2.4, two possible travel paths of children were assumed on spiral staircases (Travel path 1 and Travel path 2). Therefore, with regard to the variable tread depth with the effective width of the staircases, two different tread depths and slope of staircase were considered at the points of the travel paths. It can be seen from Table 5.29 that the difference in slope between the assumed travel path was almost 10°. Both observed spiral staircases were located outside the building and they were design solely for emergency situations. Thus, the staircases were not daily used by children; however, children could get familiarised with them during regularly evacuation drills conducted in the nursery school annually. Since the classes in the participating nursery school were attended by children of different age (Mixed children 3–6 years), the impact of children age was not studied on spiral staircases.

Travel speed

Travel speed of children on spiral staircases was evaluated during continuous movement and thus it is referred as movement travel speed. In one measurement area, a class escaping from the upper floor had to yield to the children in another class who reached the external staircase first. As it was not possible to precisely identified the waiting times of children in the measurement area (i.e. to distinguish the waiting phase from the very slow movement in the waiting group), the observations in this measurement area were not included in the data-set. Similarly to the movement on flights of straight staircases, walking and running travel speed was not distinguished.

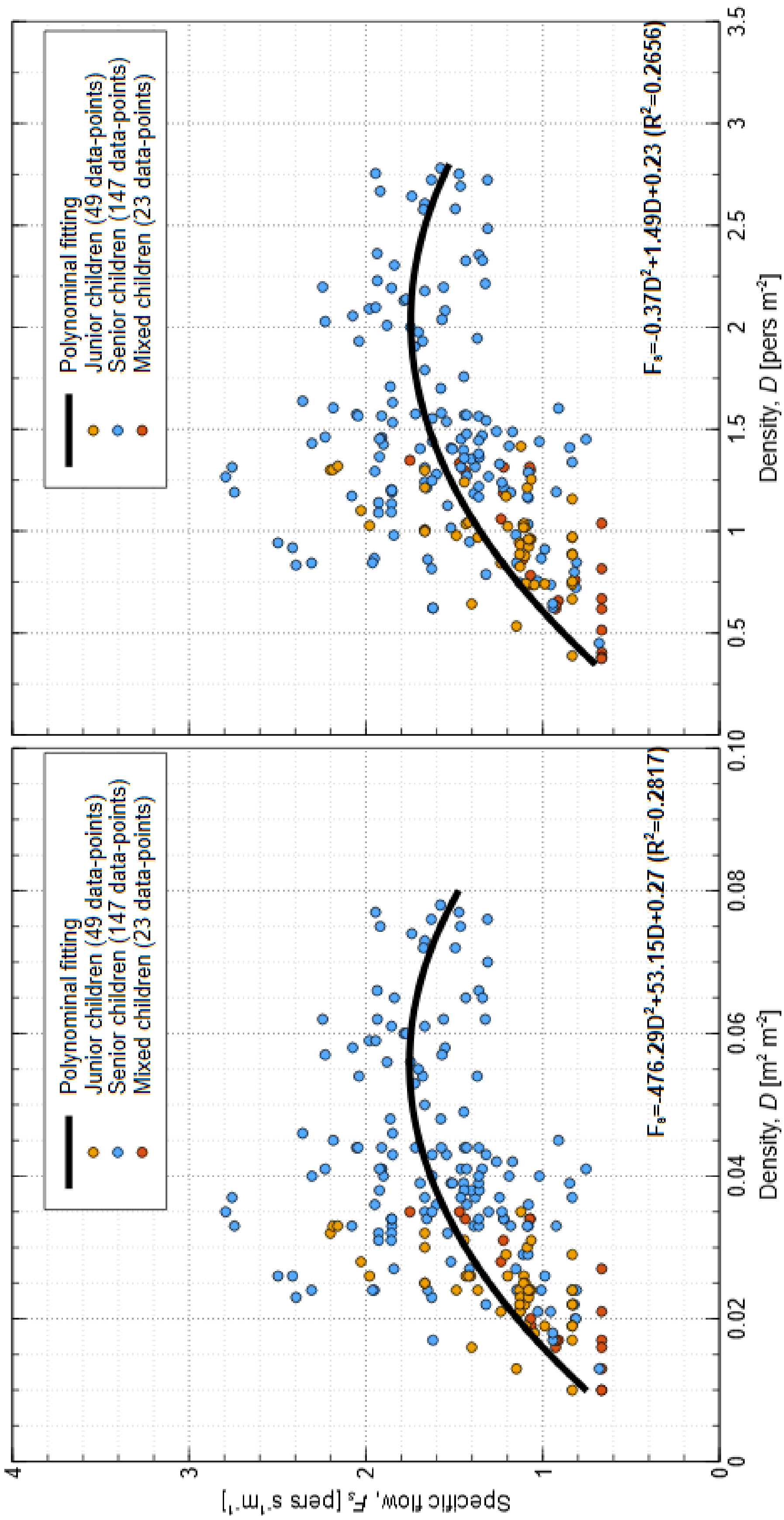


Figure 5.36: Specific flow per density (**left**: [m^2 m^{-2}]; **right**: [pers·m^{-2}]) with calculated trend lines measured on whole straight staircases

Table 5.29: Geometry of the spiral staircases observed during the experimental evacuation drills

Staircase label	Location	Rise height [mm]	Tread depth [mm]	Slope of stair [°]	Handrail height [mm]	
					Standard	Children's
A1	EXT	195	300 [1)] 450 [2)]	32.2 [1)] 22.3 [2)]	1000 [3)]	450 [3)]
A2	EXT	195	300 [1)] 450 [2)]	32.2 [1)] 22.3 [2)]	1000 [3)]	450 [3)]

INT: internal staircase, EXT: external staircase
[1)] at the point of Travel path 1
[2)] at the point of Travel path 2
[3)] handrail available on both sites of the staircase

The acquired results on travel speed and corresponding density intervals are provided in Table 5.30. Probability distributions for the evaluated travel speed and density are demonstrated in Figure 5.37. In addition, to analyse the potential impact of the different staircase geometry (tread depth and slope) travel speeds observed in children moving on Travel path 1 and Travel path 2 were analysed separately (see Table 5.31 and Table 5.32).

Table 5.30: Travel speed of children measured on spiral staircases during the experimental evacuation drills

Age group	Density interval [$m^2\ m^{-2}$]	Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\ m^{-2}$] (data-points)
Mixed	0.00–0.05	0.79 / 0.31 / 1.41 / 0.25 (107)	0.04 / 0.02 / 0.05 / 0.01 (107)
	0.06–0.10	0.61 / 0.27 / 1.29 / 0.21 (130)	0.07 / 0.05 / 0.10 / 0.01 (130)
Total		**0.69 / 0.27 / 1.41 / 0.25 (237)**	**0.05 / 0.02 / 0.10 / 0.02 (237)**

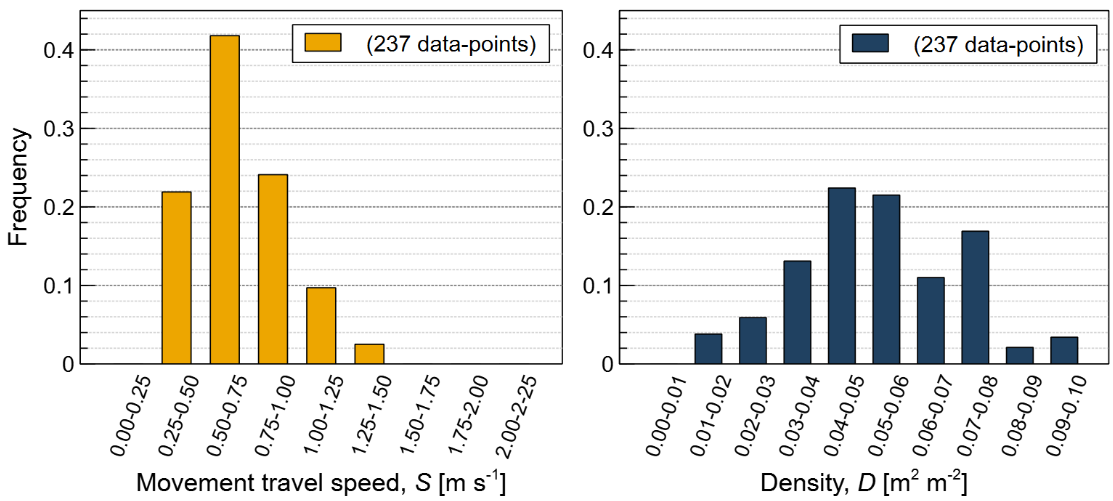


Figure 5.37: Probability distribution for travel speed (**left**) and density (**right**) measured on spiral staircases during the experimental evacuation drills

The observed travel speed of children moving on external spiral staircases ranged from 0.27 $m{\cdot}s^{-1}$ to 1.41 $m{\cdot}s^{-1}$ (with the mean value of 0.69 $m{\cdot}s^{-1}$) whereas higher

Table 5.31: Travel speed of children measured on spiral staircases on Travel path 1 (tread depth = 300 mm, slope of the path = 32.3°)

Age group	Density interval [$m^2\,m^{-2}$]	Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)
Mixed	0.00–0.05	0.67 / 0.31 / 1.01 / 0.14 (48)	0.04 / 0.02 / 0.05 / 0.01 (48)
	0.06–0.10	0.58 / 0.31 / 0.99 / 0.19 (66)	0.07 / 0.05 / 0.10 / 0.01 (66)
Total		**0.61 / 0.31 / 1.01 / 0.18 (114)**	**0.05 / 0.02 / 0.10 / 0.02 (114)**

Table 5.32: Travel speed of children measured on spiral staircases on Travel path 2 (tread depth = 450 mm, slope of the path = 22.3°)

Age group	Density interval [$m^2\,m^{-2}$]	Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)
Mixed	0.00–0.05	0.89 / 0.36 / 1.41 / 0.27 (59)	0.04 / 0.02 / 0.05 / 0.01 (59)
	0.06–0.10	0.65 / 0.27 / 1.29 / 0.23 (64)	0.07 / 0.05 / 0.10 / 0.01 (64)
Total		**0.76 / 0.27 / 1.41 / 0.27 (123)**	**0.05 / 0.02 / 0.10 / 0.02 (123)**

travel speed were identified in the lower density interval (0.00-0.05 $m^2\,m^{-2}$). Comparing these results to the data-set describing travel speeds in Mixed children on flights of internal straight staircases, it can be concluded that the travel speeds reached by children are similar (see Table 5.21 for more details). Furthermore, the effect of a different stair geometry can be identified when the data-sets measured in Travel Path 1 and Travel path 2 presented in Table 5.31 and Table 5.32 are compared. Lower travel speeds were observed in children moving on Travel path 1 (mean value 0.61 $m{\cdot}s^{-1}$]) where the space for movement was more limited than on Travel path 2 (mean value 0.76 $m{\cdot}s^{-1}$). This trend may be found in both density intervals; however, greater differences in travel speeds occurred at lower densities (0.00-0.05 $m^2\,m^{-2}$). Moreover, the video-analysis showed that in many cases when children were moving in pairs (i.e. in two lanes) the child who climbed on Travel path 2 had to slow down to adjust her/his travel speed to the child travelling on Travel path 1. Hence, the impact of the stair geometry may be considered even more considerable than it was revealed in the measured values.

The movement on spiral staircases was observed at low densities (equal to or less than 0.1 $m^2\,m^{-2}$). However, conversely to the observations on flights of straight staircases, higher density conditions were identified with the mean value of 0.05 $m^2\,m^{-2}$ (approximately 1.9 children$\cdot m^{-2}$) on spiral staircases. This outcome may be attributed to a more limited staircase width of the spiral staircases while the same tendency of children to climb downstairs in two lanes.

The overall speed-density relationships on spiral staircases are demonstrated in Figure 5.38 showing travel speed S [$m{\cdot}s^{-1}$] as dependent on density D expressed in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers$\cdot m^{-2}$] on the right. Separate results on the relationships between travel speed and density on Travel path 1 and Travel path 2 are visualised in Figure 5.39. In all presented data-sets, the trend lines were defined as linear functions based on the calculated correlation coefficients R^2 and the overall curve shape. In addition, polynomial or exponential function were also used due to relatively the smallest difference between the observed values and their fitted values and the curve shape. The application range of the provided trend lines should be seen as limited to the low density conditions (0.1 $m^2 m^{-2}$, i.e. approximately 3.8 children·m^{-2}).

Specific flow

Besides travel speeds, pedestrian flow related to 1 m of effective width of the measurement areas (specific flow [pers·$s^{-1} m^{-1}$]) was investigated on spiral staircases. Similarly to the movement on flights of straight staircases, specific flow was not distinguished for walking and running children. The acquired results on specific flow and corresponding density intervals are provided in Table 5.33 and probability distributions for the presented variables are demonstrated in Figure 5.40.

Table 5.33: Specific flow of children measured on spiral staircases during the experimental evacuation drills

Age group	**Density interval [$m^2 m^{-2}$]**	**Specific flow (mean/min/max/SD) [pers·$s^{-1} m^{-1}$] (data points)**	**Density (mean/min/max/SD) [$m^2 m^{-2}$] (data-points)**
Mixed	0.00–0.05	1.78 / 1.21 / 3.64 / 0.77 (107)	0.04 / 0.02 / 0.05 / 0.01 (107)
	0.06–0.10	2.14 / 1.21 / 3.64 / 0.79 (130)	0.07 / 0.05 / 0.10 / 0.01 (130)
Total		**1.98 / 1.21 / 3.64 / 0.77 (237)**	**0.05 / 0.02 / 0.10 / 0.02 (237)**

The obtained results on specific flow ranged between 1.21 pers·$s^{-1} m^{-1}$ and 3.64 pers·$s^{-1} m^{-1}$ with the mean value of 1.98 pers·$s^{-1} m^{-1}$. In comparison to the specific flow measured on other parts of evacuation routes and described in the previous sections, the highest values of specific flow were observed on spiral staircases. This outcome may be notably related to narrower width of spiral staircases and therefore more crowded conditions when two children side-by-side were walking downstairs. In addition, higher specific flow was measured in the higher density interval (0.06–0.10 $m^2 m^{-2}$) than in the lower density interval (0.00–0.05 $m^2 m^{-2}$). Looking at the diagram representing the probability distribution for specific flow (Figure 5.40 on left) it can be seen that the values were observed only in several intervals. This output is primarily related to the data analysis method (see Section 5.2.3 for details) which consequences are more visible and further explained in the following paragraph focused on flow-density relationships.

In Figure 5.41, the dependence of specific flow F_s [pers·$s^{-1} m^{-1}$] on density D in the unit of [$m^2 m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right is illustrated. As outlined in the previous paragraph, discrete values of the presented specific flow causing jumps in the plotted data-points are obvious in Figure 5.41. Therefore, the presented data-set is very scattered without any clear trend and corresponding trend lines for the data-set were not estimated in this case due to low correlation coefficients R^2 calculated. The effect of scattered data-points should be attributed to the data analysis method employed (see Section 5.2.3 for details). Due to the limited number of data-points measured on identical staircases with the same effective width, the discrete jumps between the presented values occurred. A similar

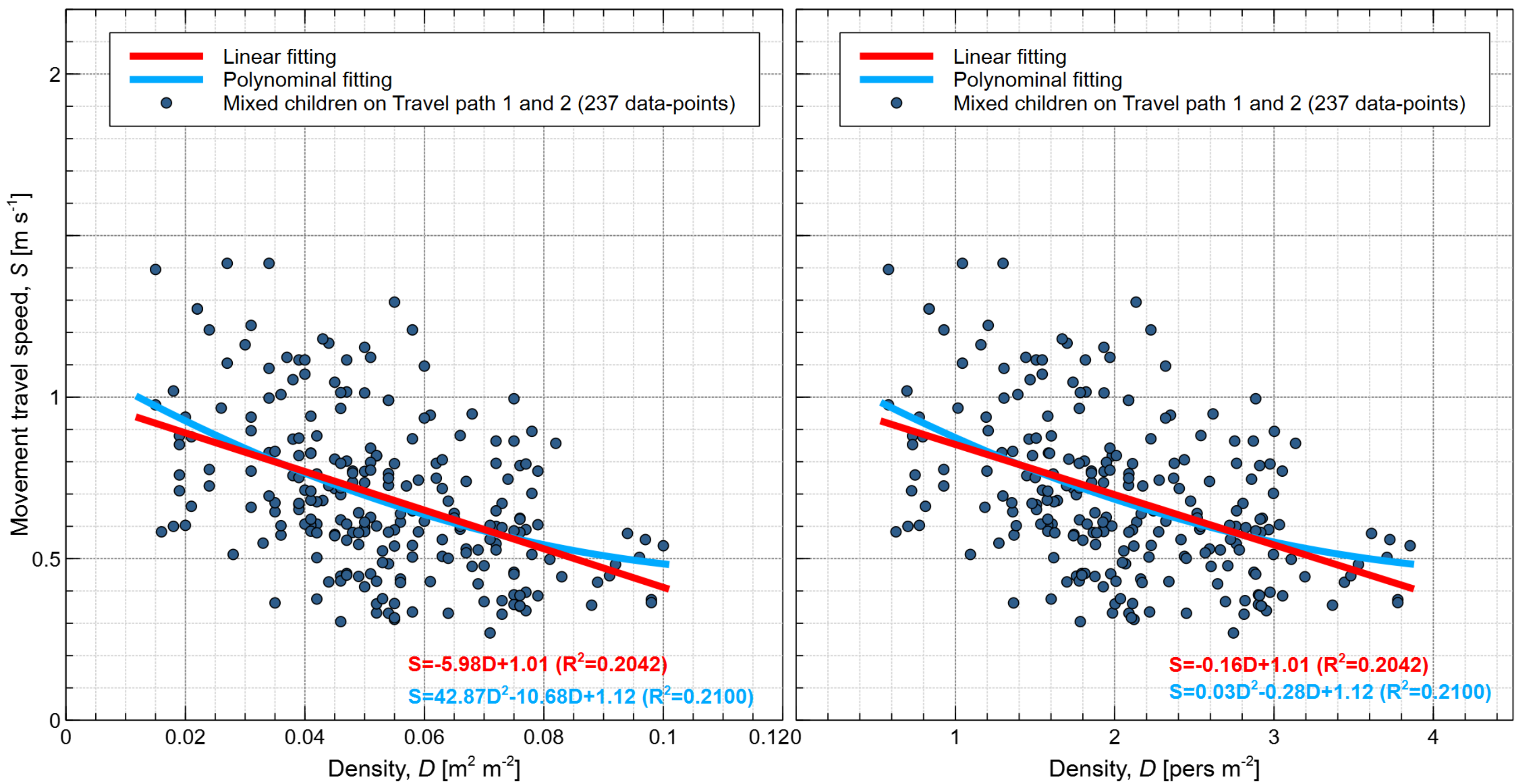


Figure 5.38: Travel walking and running speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with calculated trend lines measured on spiral staircases for Mixed children moving on Travel path 1 and Travel path 2 (combined)

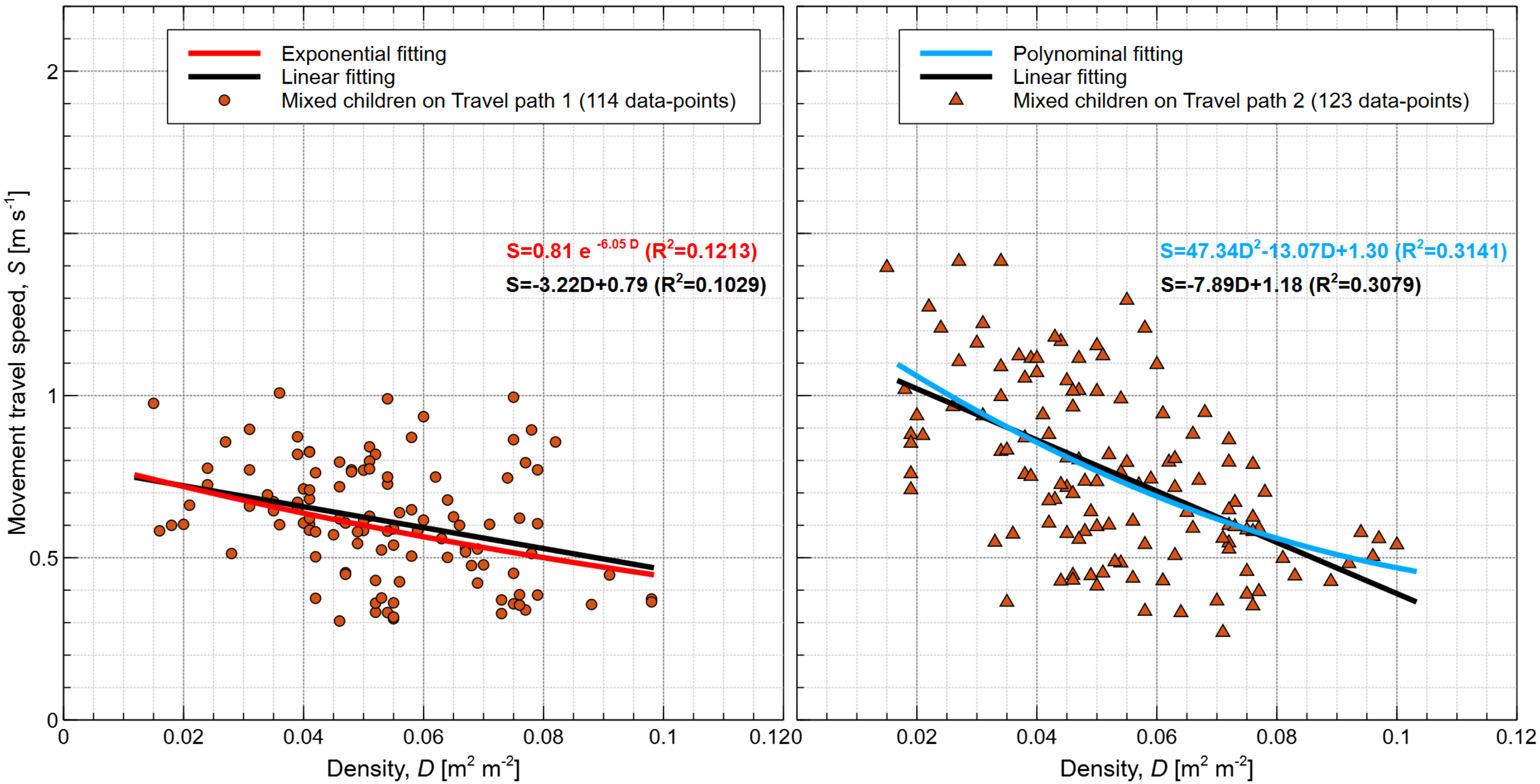


Figure 5.39: Travel walking and running speed per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers·m^{-2}]) with calculated trend lines measured on spiral staircases for Mixed children moving on Travel path 1 and Travel path 2

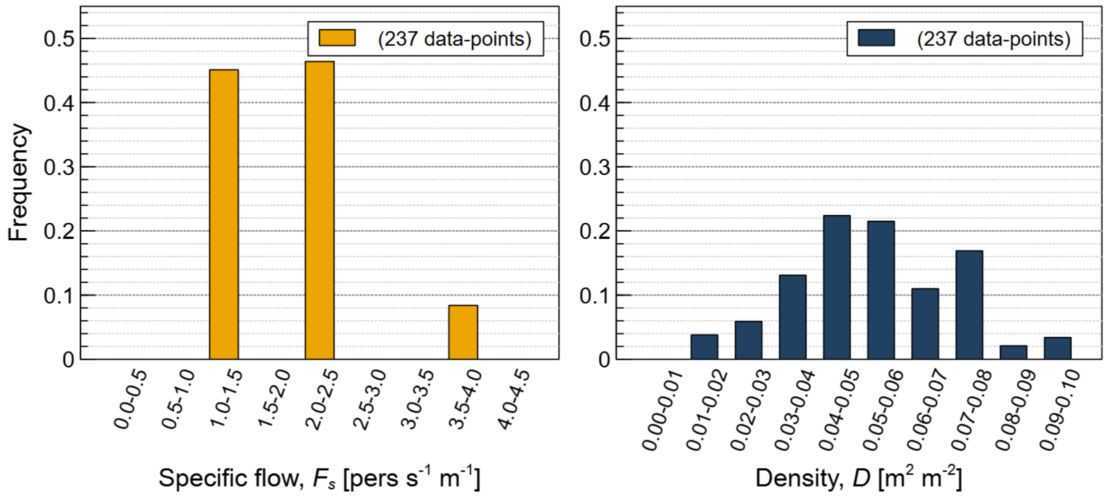


Figure 5.40: Probability distribution for specific flow (**left**) and density (**right**) measured on spiral staircases during the experimental evacuation drills

effect was identified in the flow-density data-set describing children's movement on landings of straight staircases; however, due to the equal effective width of the observed spiral staircases, the consequences of the data analysis method are even more evident. Apart from that, following the estimated trend lines, the peak of specific flow (almost 2.2 pers·s^{-1} m^{-1}) can be identified at the density around 0.08 m^2 m^{-2}, i.e. approximately 3.1 children·m^{-2}. The application range of the provided trend lines should be seen as limited for densities lower than 0.1 m^2 m^{-2}.

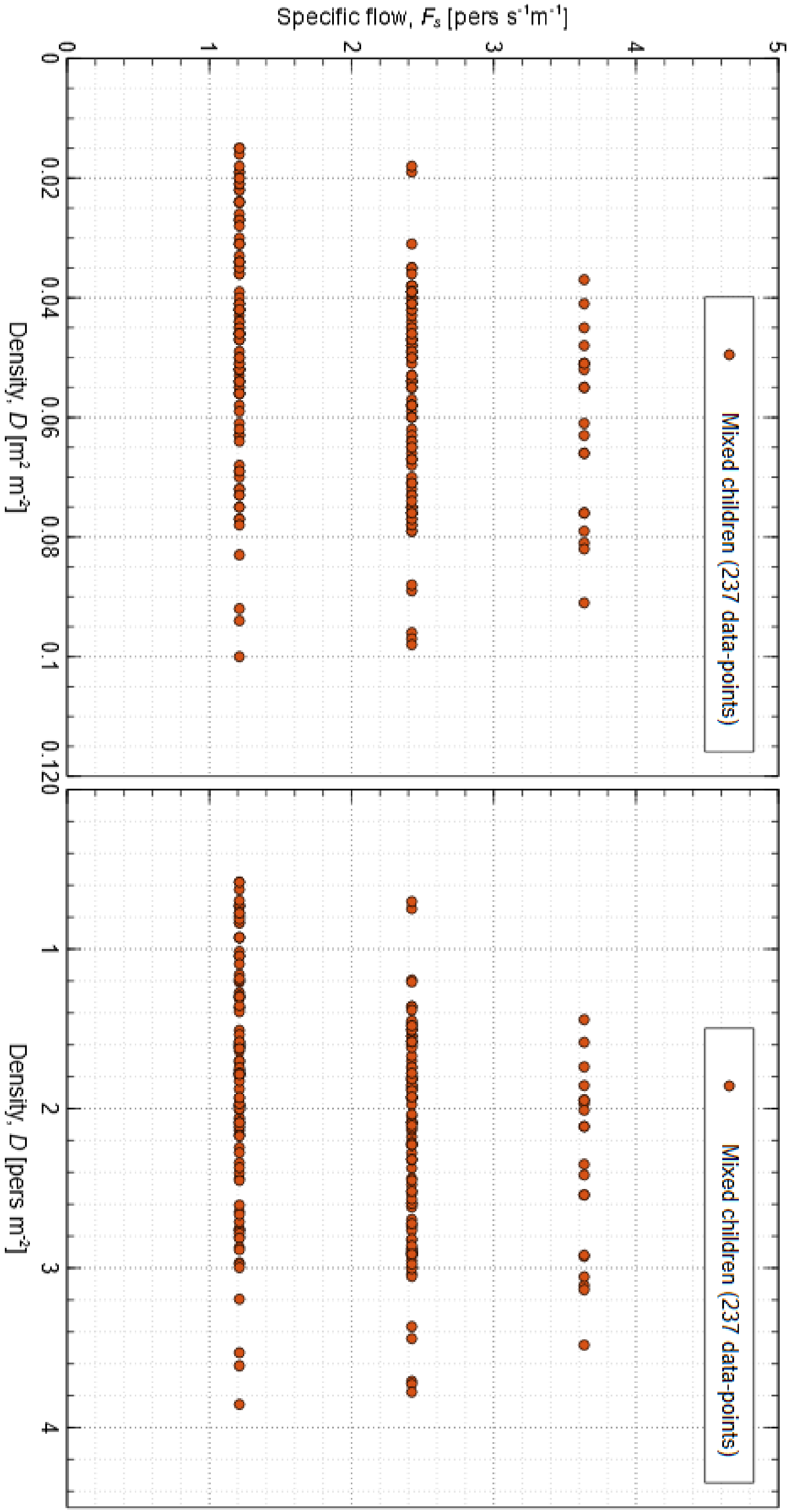


Figure 5.41: Specific flow per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers$\cdot m^{-2}$]) with calculated trend lines measured on spiral staircases

5.3.7 Movement through doorways

The results on children's movement characteristics when passing through doorways are summarised in this section. Travel speed, pedestrian flow, and density were measured in 25 measurement areas in 9 participating nursery schools during 14 experimental evacuation drills. The width of the observed door varied between 0.7 and 1.4 m (average value of 0.88 m).

Travel speed

In the measurement areas of doorways, it was no exception that children had to make a stop inside a measurement area because of a closed or locked door, waiting for instructions, or having troubles with opening of a self-closing door. Those observations were excluded and only data-points of travel speed observed during continuous movement of children were included in the presented data-set. Walking and running travel speeds were analysed separately for all involved age groups (Junior, Senior, Senior+, and Mixed). Combined results on walking and running speeds (all travel speeds measured) together with corresponding density intervals are given in Table 5.34, results on walking speeds and running speeds are summarised separately in Table 5.35 and Table 5.36 respectively. Probability distributions for travel speeds and density evaluated separately for walking and running conditions are demonstrated in Figure 5.42. Probability distributions for travel speeds and density measured for different age groups can be found in Appendix C in Figure C.20.

Table 5.34: Travel speed of children measured in doorways during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	**Density interval [$m^2\,m^{-2}$]**	**Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)**	**Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)**
Junior	0.00–0.05	1.13 / 0.40 / 2.78 / 0.49 (48)	0.03 / 0.03 / 0.04 / 0.00 (48)
	0.06–0.10	0.88 / 0.12 / 2.00 / 0.34 (155)	0.07 / 0.06 / 0.09 / 0.01 (155)
	0.11–0.15	0.68 / 0.27 / 1.30 / 0.31 (68)	0.11 / 0.11 / 0.14 / 0.01 (68)
	0.16–0.20	1.01 / 0.76 / 1.20 / 0.23 (3)	0.17 / 0.16 / 0.18 / 0.01 (3)
Senior	0.00–0.05	1.39 / 0.67 / 3.45 / 0.48 (54)	0.03 / 0.03 / 0.04 / 0.00 (54)
	0.06–0.10	1.06 / 0.33 / 2.13 / 0.35 (213)	0.07 / 0.06 / 0.10 / 0.01 (213)
	0.11–0.15	0.80 / 0.37 / 1.92 / 0.25 (79)	0.12 / 0.11 / 0.14 / 0.01 (79)
Senior+	0.06–0.10	0.64 / 0.51 / 0.78 / 0.10 (7)	0.09 / 0.09 / 0.09 / 0.00 (7)
	0.11–0.15	0.71 / 0.50 / 1.67 / 0.29 (15)	0.12 / 0.11 / 0.15 / 0.01 (15)
Mixed	0.00–0.05	1.73 / 0.49 / 3.70 / 0.73 (55)	0.03 / 0.03 / 0.04 / 0.00 (55)
	0.06–0.10	1.06 / 0.38 / 2.50 / 0.47 (95)	0.07 / 0.06 / 0.10 / 0.01 (95)
	0.11–0.15	0.67 / 0.27 / 1.25 / 0.19 (76)	0.12 / 0.11 / 0.14 / 0.01 (76)
	0.16–0.20	0.59 / 0.33 / 0.83 / 0.19 (6)	0.16 / 0.16 / 0.16 / 0.00 (6)
Total		**0.99 / 0.12 / 3.70 / 0.47 (874)**	**0.07 / 0.03 / 0.18 / 0.03 (874)**

Considering the results presented in Table 5.34, Table 5.35, and Table 5.35, the dependency of travel speed on both the age of children and on density conditions can be identified where the travel speed increased with the increasing age of children

Table 5.35: Walking travel speed of children measured in doorways during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	Density interval [$m^2\,m^{-2}$]	Travel speed (mean/min/max/SD) [$m\cdot s^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)
Junior	0.00–0.05	0.92 / 0.40 / 1.59 / 0.30 (35)	0.03 / 0.03 / 0.04 / 0.00 (35)
	0.06–0.10	0.84 / 0.12 / 2.00 / 0.31 (143)	0.07 / 0.06 / 0.09 / 0.01 (143)
	0.11–0.15	0.68 / 0.27 / 1.30 / 0.31 (68)	0.11 / 0.11 / 0.14 / 0.01 (68)
	0.16–0.20	1.01 / 0.76 / 1.20 / 0.23 (3)	0.17 / 0.16 / 0.18 / 0.01 (3)
Senior	0.00–0.05	1.09 / 0.67 / 1.35 / 0.19 (25)	0.03 / 0.03 / 0.04 / 0.00 (25)
	0.06–0.10	0.96 / 0.33 / 2.00 / 0.26 (168)	0.07 / 0.06 / 0.10 / 0.01 (168)
	0.11–0.15	0.79 / 0.37 / 1.92 / 0.24 (78)	0.12 / 0.11 / 0.14 / 0.01 (78)
Senior+	0.06–0.10	0.64 / 0.51 / 0.78 / 0.10 (7)	0.09 / 0.09 / 0.09 / 0.00 (7)
	0.11–0.15	0.71 / 0.50 / 1.67 / 0.29 (15)	0.12 / 0.11 / 0.15 / 0.01 (15)
Mixed	0.00–0.05	0.95 / 0.49 / 1.32 / 0.24 (15)	0.03 / 0.03 / 0.04 / 0.00 (15)
	0.06–0.10	0.84 / 0.38 / 1.35 / 0.23 (71)	0.07 / 0.06 / 0.09 / 0.01 (71)
	0.11–0.15	0.67 / 0.27 / 1.25 / 0.19 (76)	0.12 / 0.11 / 0.14 / 0.01 (76)
	0.16–0.20	0.59 / 0.33 / 0.83 / 0.19 (6)	0.16 / 0.16 / 0.16 / 0.00 (6)
Total		**0.84 / 0.12 / 2.00 / 0.29 (710)**	**0.08 / 0.03 / 0.18 / 0.03 (710)**

Table 5.36: Running travel speed of children measured in doorways during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	Density interval [$m^2\,m^{-2}$]	Travel speed (mean/min/max/SD) [$m\cdot s^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)
Junior	0.00–0.05	1.70 / 1.03 / 2.78 / 0.48 (13)	0.03 / 0.03 / 0.03 / 0.00 (13)
	0.06–0.10	1.35 / 0.73 / 1.75 / 0.32 (17)	0.06 / 0.06 / 0.08 / 0.01 (17)
Senior	0.00–0.05	1.64 / 0.83 / 3.45 / 0.52 (29)	0.03 / 0.03 / 0.03 / 0.00 (29)
	0.06–0.10	1.45 / 0.71 / 2.13 / 0.35 (45)	0.06 / 0.06 / 0.08 / 0.01 (45)
	0.11–0.15	0.79 / 0.37 / 1.92 / 0.24 (78)	0.12 / 0.11 / 0.14 / 0.01 (78)
Senior+	0.06–0.10	0.64 / 0.51 / 0.78 / 0.10 (7)	0.09 / 0.09 / 0.09 / 0.00 (7)
	0.11–0.15	1.43 / 1.43 / 1.43 / - (1)	0.14 / 0.14 / 0.14 / - (1)
Mixed	0.00–0.05	2.02 / 1.18 / 3.70 / 0.63 (40)	0.03 / 0.03 / 0.03 / 0.00 (40)
	0.06–0.10	1.70 / 1.03 / 2.50 / 0.42 (24)	0.07 / 0.06 / 0.10 / 0.02 (24)
Total		**1.67 / 0.71 / 3.70 / 0.52 (164)**	**0.04 / 0.02 / 0.14 / 0.02 (164)**

and decreased with the growing density. This outcome is in line with the findings observed also on other parts of evacuation routes (i.e. in corridors, on straight staircases). However, the differences in the measured travel speed in the different age groups of children were not as salient as in the case of movement in corridors when older children reached almost double travel speeds than younger children (compare the results to the values in Table 5.15, Table 5.16, and Table 5.17). At the lowest density interval (0.00–0.05 $m^2\,m^{-2}$), walking Junior children in doorways reached on average travel speeds around 0.92 $m\cdot s^{-1}$, Senior children walked on average at travel speed of 1.01 $m\cdot s^{-1}$. Comparing the presented data-set on walking travel speed with the results measured on other horizontal parts of evacuation routes (i.e. in corridors and on landings of straight staircases), the values measured in doorways were similar to the observations on landings of straight staircases (in the density interval 0.00–

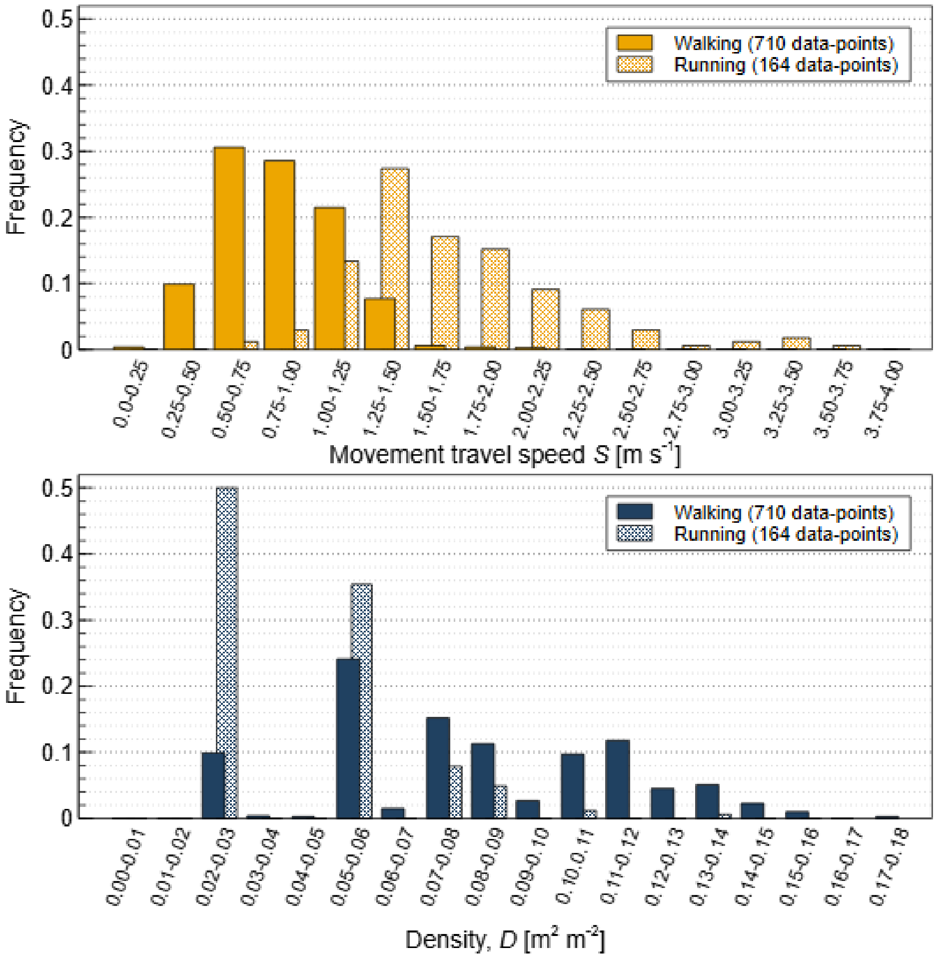


Figure 5.42: Probability distribution for travel speeds (**left**) and density (**right**) measured in doorways during the experimental evacuation drills

0.05 $m^2\,m^{-2}$ averaged value for Junior children 0.84 $m{\cdot}s^{-1}$, averaged value for Senior children (1.03 $m{\cdot}s^{-1}$) and thus noticeably lower than in corridors. The similarity between the values of travel speed observed in doorways and on landings of straight staircases can be seen also in running children (compare average values for Junior children and Senior children with the corresponding results in Table 5.25). Nevertheless, in doorways, higher maximum values can be identified in all age groups which are little closer to the observations in corridors. These findings may be attributed to the specific conditions for movement in the measurement areas of doorways (the space of 1 m^2 in front of a door). Here, in comparison to corridors, the movement of children was more restricted by a bottleneck (a door). On the other hand, when the evacuation route through doorways was free, the conditions for the movement of individuals through a bottleneck were more similar to those in corridors.

The specific movement conditions in doorways mentioned above resulted also in high density conditions on this part of evacuation routes. As can be seen from Table 5.34, Table 5.35, Table 5.35, and Figure 5.42, density up to 0.18 $m^2\,m^{-2}$ (i.e. approximately 7 children$\cdot m^{-2}$) occurred in doorways which is almost double the values observed in corridors or on staircases (less than 0.1 $m^2\,m^{-2}$; except for the situations when children had to make a stop on landings of straight staircases and the observed density reached 0.14 $m^2\,m^{-2}$). Moreover, the most of data-points in doorways were measured in the density interval from 0.06 $m^2\,m^{-2}$ to 0.15 $m^2\,m^{-2}$. The relationships between travel speed and density measured in doorways describing combined walking and running children in all age groups is demonstrated in Figure 5.43. The movement travel speed S [$m{\cdot}s^{-1}$] is represented as dependent on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [$pers{\cdot}m^{-2}$] on the right. Based on the curve shape and the relatively smallest difference between the observed values and their fitted values exponential and logarithmic functions were selected to express the trend lines of the experimental data-set. The application range of the given trend lines should be seen as limited to densities lower than 0.18 $m^2\,m^{-2}$ (approximately 7 children$\cdot m^{-2}$). Similarly to several graphical evaluations interpreted in previous parts of the results section (e.g. flow-density relationships on landing of straight staircases or on spiral staircases), consequences of the data analysis method employed can be identified in the plots as jumps representing discrete values of density. This effect resulted primarily from the fixed size of the measurement areas of doorways as well as from assuming persons as discrete units. Thus, this impact is even more evident in the plot where the unit of [$pers{\cdot}m^{-2}$] was used (see Figure 5.43 on the right).

The separate speed-density relationships for walking and running children in different age groups (colour-coded) are illustrated in Figure 5.44 (separate speed-density relationships for different age groups are provided in Appendix C in Figure C.21). Consistently with the previous evaluation, the data-sets for walking and running children were fitted using exponential and logarithmic functions. Due to a relatively good agreement with the experimental data-set these trend lines were complemented by a linear fitting. The highest travel speeds were observed in running Mixed and Senior children under very low density conditions (less than 0.05 $m^2\,m^{-2}$ (approximately 1.9 children$\cdot m^{-2}$). Furthermore, the most of running children moved at densities less than 0.1 $m^2\,m^{-2}$ (approximately 3.8 children$\cdot m^{-2}$). Conversely, lower travel speeds distributed at a broader density range (up to 0.18 $m^2\,m^{-2}$ (approximately 7 children$\cdot m^{-2}$) were measured when children moved at the walking pace.

Specific flow

In addition to travel speeds, pedestrian flow related to 1 m of effective width of a door (specific flow [$pers{\cdot}s^{-1}\,m^{-1}$]) was studied in doorways. Similarly to observations in corridors, specific flow was not distinguished for walking and running children since both movement options could simultaneously occurred when the flow was calculated in the measurement area. The results on specific flow obtained for different age groups were evaluated separately and they are summarised in Table 5.37 together with the corresponding density intervals. Probability distributions for the presented specific flow and density are demonstrated in Figure 5.45 (separate evaluation for different age groups can be found in Appendix C in Figure C.22).

Considering all age groups of children and density intervals, the observed specific flow in doorways ranged from 0.11 $pers{\cdot}s^{-1}\,m^{-1}$ to 6.25 $pers{\cdot}s^{-1}\,m^{-1}$ with the mean

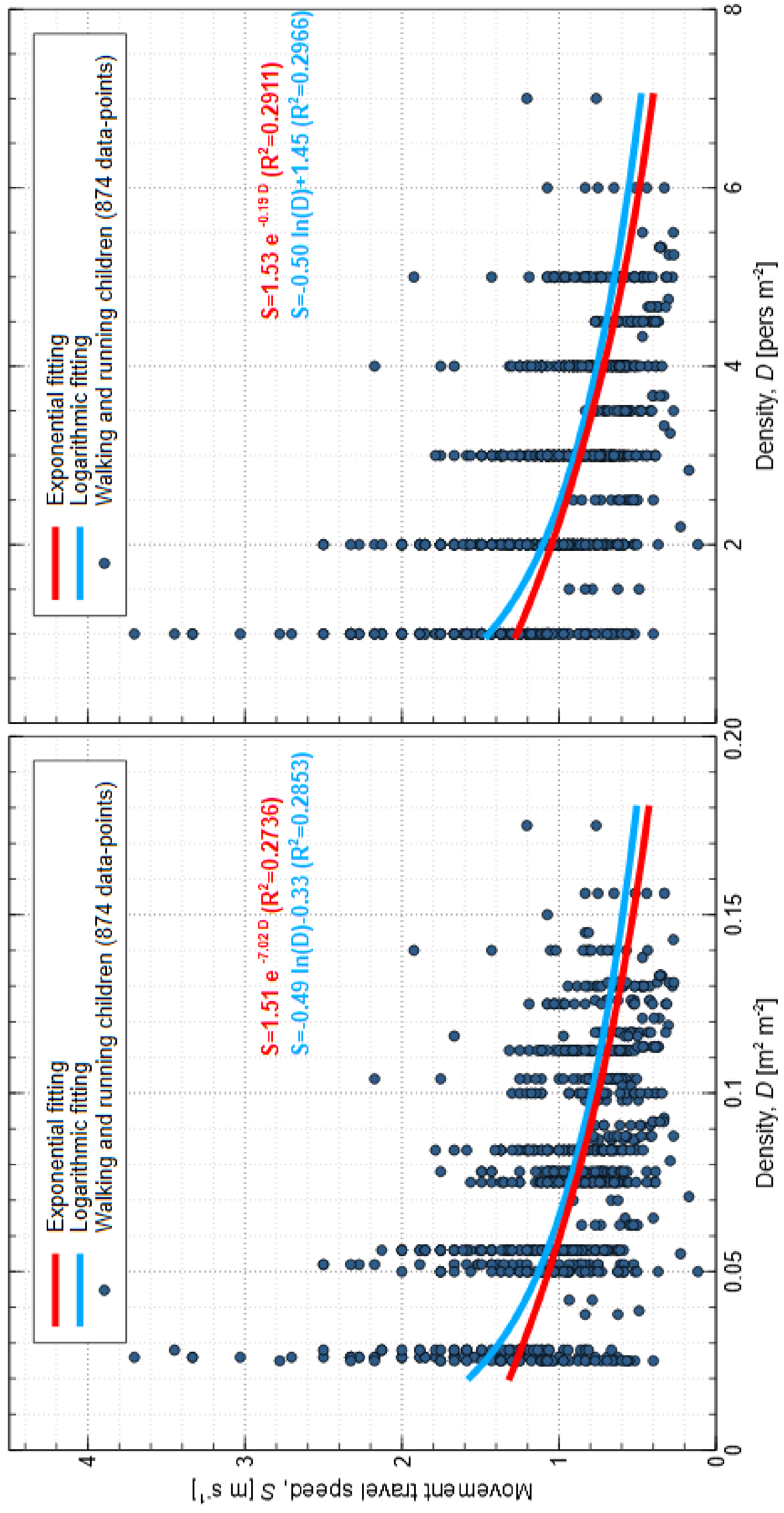


Figure 5.43: Travel walking and running speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with calculated trend lines measured in doorways

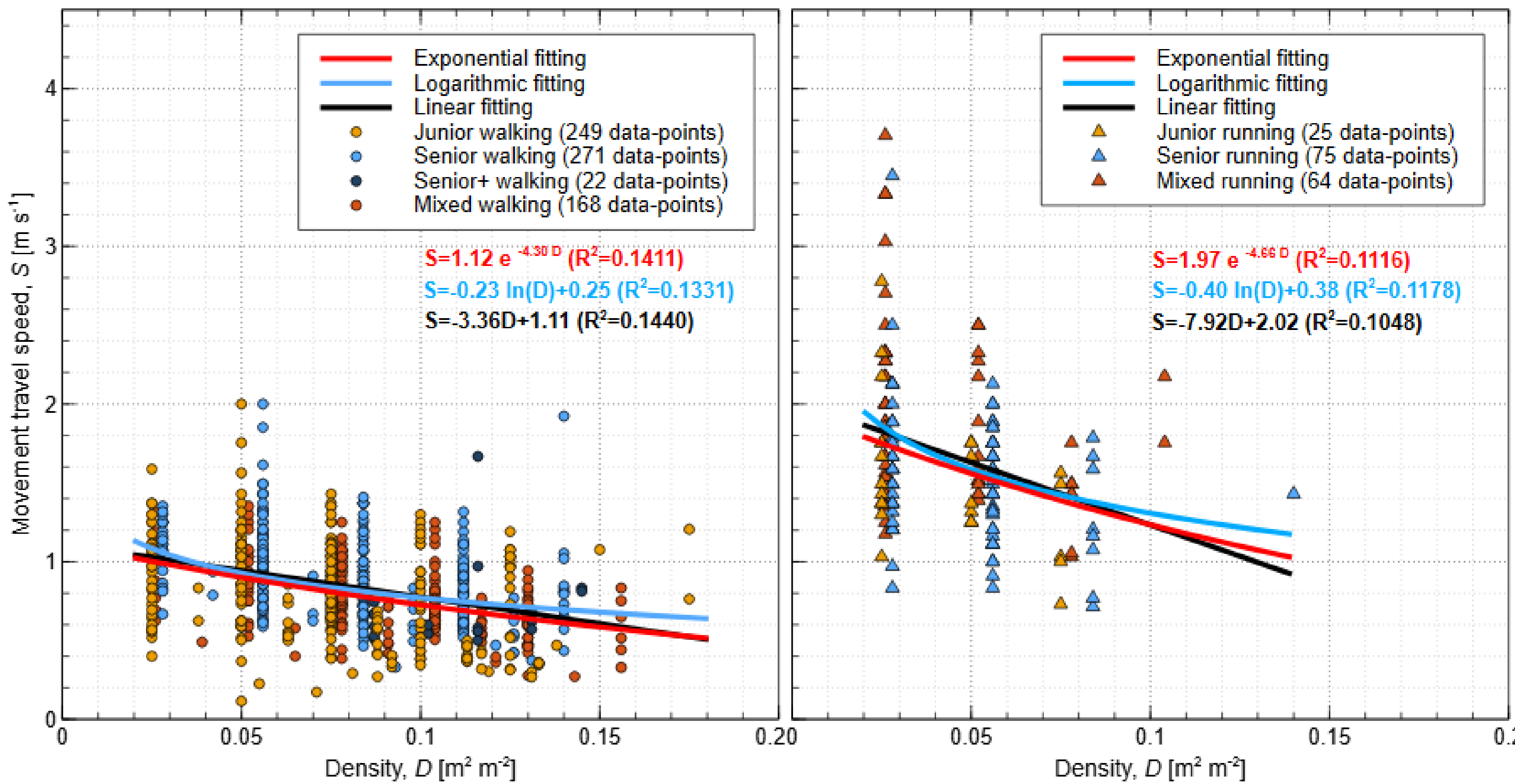


Figure 5.44: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] with calculated trend lines measured in doorways for different age groups

Table 5.37: Specific flow of children measured in doorways during the experimental evacuation drills (the values in the row Total indicated the results over the total sample, i.e. all age groups and density intervals)

Age group	Density interval [$m^2\,m^{-2}$]	Specific flow (mean/min/max/SD) [pers·$s^{-1}\,m^{-1}$] (data points)	Density (mean/min/max/SD) [$m^2\,m^{-2}$] (data-points)
Junior	0.00–0.05	1.32 / 0.71 / 3.75 / 0.42 (49)	0.03 / 0.03 / 0.05 / 0.00 (49)
	0.06–0.10	2.55 / 1.00 / 6.25 / 0.88 (165)	0.07 / 0.05 / 0.09 / 0.01 (165)
	0.11–0.15	2.89 / 1.11 / 6.25 / 1.21 (81)	0.11 / 0.11 / 0.14 / 0.01 (81)
	0.16–0.20	2.27 / 2.22 / 2.35 / 0.07 (5)	0.16 / 0.15 / 0.18 / 0.01 (5)
Senior	0.00–0.05	1.53 / 1.11 / 3.75 / 0.62 (54)	0.03 / 0.03 / 0.04 / 0.00 (54)
	0.06–0.10	2.66 / 1.11 / 5.56 / 0.79 (228)	0.07 / 0.06 / 0.10 / 0.01 (228)
	0.11–0.15	3.23 / 1.11 / 5.71 / 1.03 (82)	0.12 / 0.11 / 0.14 / 0.01 (82)
	0.16–0.20	3.33 / 3.33 / 3.33 / 0.00 (2)	0.16 / 0.16 / 0.16 / 0.00 (2)
Senior+	0.06–0.10	2.70 / 1.11 / 3.33 / 0.87 (7)	0.09 / 0.09 / 0.09 / 0.00 (7)
	0.11–0.15	3.26 / 2.22 / 3.33 / 0.29 (15)	0.12 / 0.11 / 0.14 / 0.01 (22)
Mixed	0.00–0.05	1.47 / 0.11 / 5.00 / 0.80 (57)	0.03 / 0.03 / 0.04 / 0.00 (57)
	0.06–0.10	2.29 / 0.91 / 5.00 / 0.89 (109)	0.07 / 0.05 / 0.10 / 0.01 (109)
	0.11–0.15	2.99 / 1.11 / 6.25 / 0.15 (90)	0.12 / 0.11 / 0.15 / 0.01 (90)
	0.16–0.20	3.40 / 2.22 / 6.25 / 1.05 (11)	0.16 / 0.16 / 0.18 / 0.01 (11)
Total		**2.51 / 0.11 / 6.25 / 1.04 (955)**	**0.08 / 0.03 / 0.18 / 0.03 (955)**

value of 2.51 pers·$s^{-1}\,m^{-1}$. Higher values of specific flow were measured in higher density intervals in all age groups. Furthermore, higher specific flow was observed in Senior children comparing to Junior children in the same density intervals. In comparison to the measurements performed in corridors and on staircases, these results represent the highest values of specific flow. In general, this finding is in line with the assumption that more crowded conditions may occur in doorways and that the present bottleneck results in a higher pedestrian flow. This assumption was further confirmed by high density conditions which were observed in the measurement areas of doorways ranging from 0.03 $m^2\,m^{-2}$ to 0.18 $m^2\,m^{-2}$ (i.e. approximately 7 children·m^{-2}). As already mentioned in the part focused on travel speed in doorways, the maximum density observed was almost twice as high as the maximum density observed in corridors or on staircases.

The flow-density relationships related to the children's movement in doorways is demonstrated in Figure 5.46 where the dependence of specific flow F_s [pers·$s^{-1}\,m^{-1}$] on density D in the unit of [$m^2\,m^{-2}$] on the left and in the unit of [pers·m^{-2}] on the right is distinguished for different age groups (colour-coded). Specific flow-density relationships provided separately for different age groups can be found in Appendix C in Figure C.23. In Figure 5.46, trend lines of the provided data-sets were expressed using a polynomial function and the corresponding correlation coefficients R^2 were calculated. Following the given trend lines, the peak describing the maximum specific flow (approximately 3 pers·$s^{-1}\,m^{-1}$) can be identified at the density around 0.12 $m^2\,m^{-2}$, i.e. approximately 4.6 children·m^{-2}. The application range of the demonstrated trend lines should be seen as limited to the density conditions lower than 0.18 $m^2\,m^{-2}$, i.e. approximately 7 children·m^{-2}.

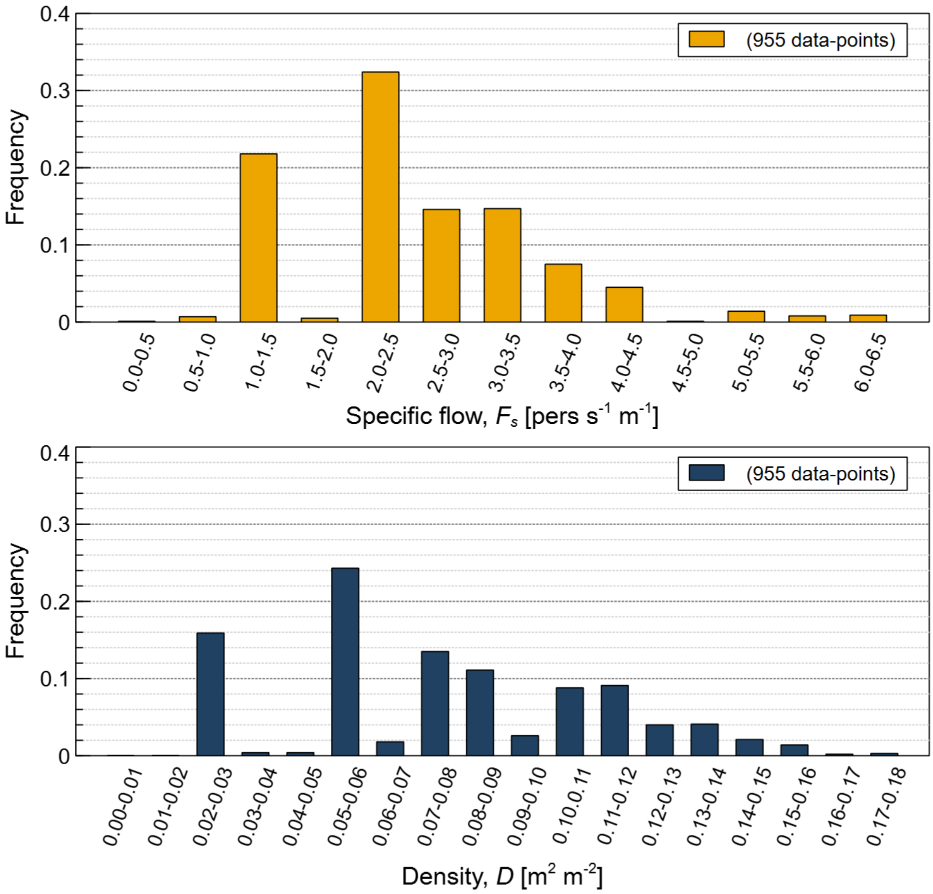


Figure 5.45: Probability distribution for specific flow (**left**) and density (**right**) measured in doorways during the experimental evacuation drills

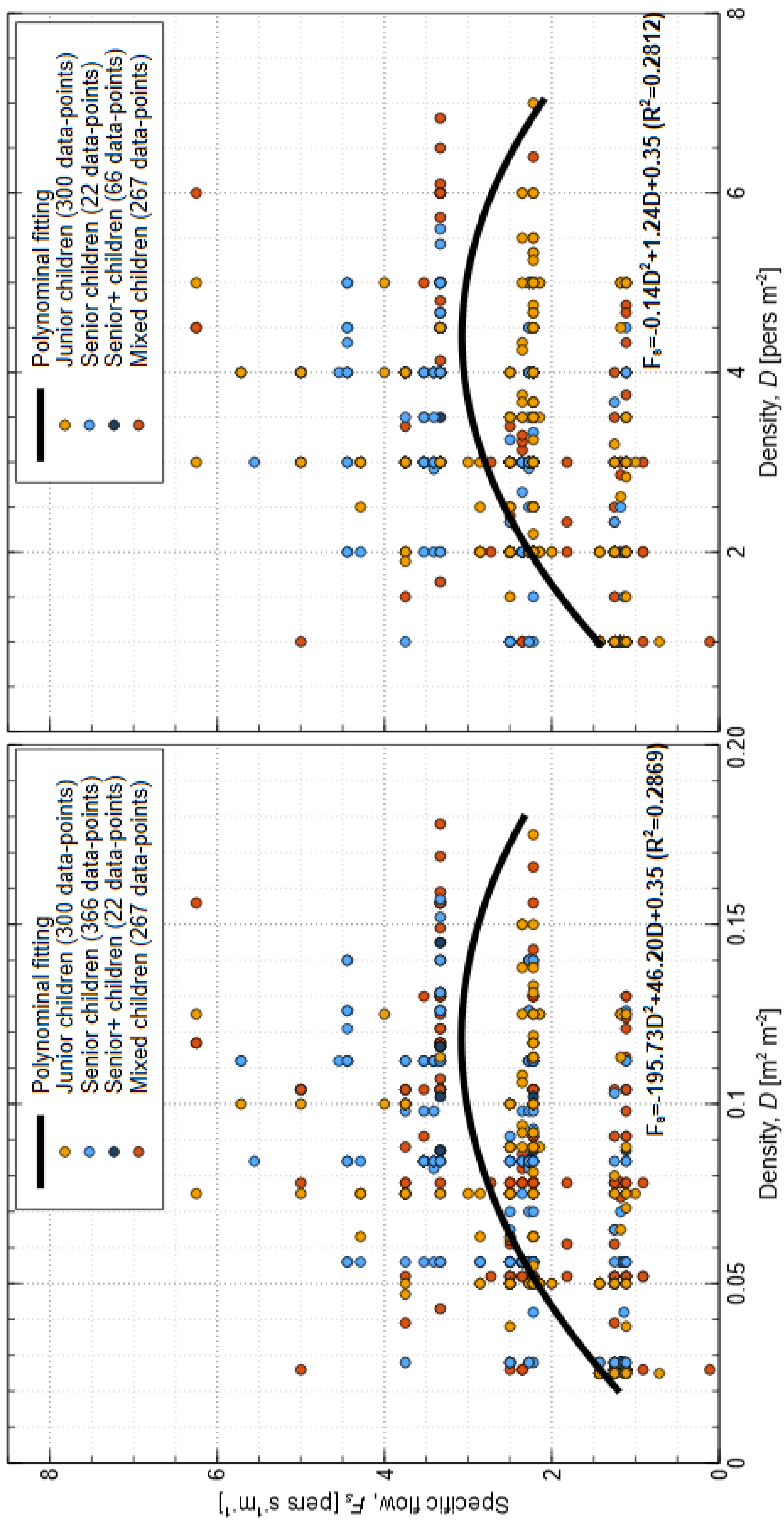


Figure 5.46: Specific flow per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers·m^{-2}]) with calculated trend lines measured in doorways

5.3.8 Movement behaviour

In this section, the observations of children's and staff members' behaviour during the movement phase of the evacuation process are analysed. Self-prevention capability of children (need for assistance given by staff members), group formation, and hand holding were studied when children were moving through a building. In addition, using of handrails and using of a marking time pattern by children was observed on staircases. For the observations, the video recordings obtained in measurement areas in corridors, on straight and spiral staircases, and in doorways obtained in all experimental evacuation drills were used. In corridors, the above-mentioned characteristics were tracked separately in the first and in the second halves of each measurement area. Similarly on staircases, movement behaviour was monitored in the first and in the second halves of flights (on straight staircases) and segments (on spiral staircases). This method was selected since children often changed their behaviour when moving inside the observed part of evacuation routes. In doorways, due to smaller size of measurement areas (1 m^2) only one observation (data-point) for each child was made in each measurement area.

Group formation

The organisation of children was observed in the video recordings considering their movement throughout the building. It can be concluded that the group formation in a class usually followed the leaving strategy taken in the pre-movement phase. This issue was discussed in detail in Section 5.3.3; however it can be summarised that when a class left a classroom as a compact group ("Leaving as a group at once" and "Leaving as a group gradually"; in total 77% of the observed classes) it kept this formation also during the movement phase. Moreover, staff members mostly supervised and instructed children not to mix and to keep separate groups which resulted in yielding the way notably on staircases and in doorways. In the cases, when children left a classroom individually (typically in the one-class nursery schools and in the nursery schools with a simple building layout and with a short evacuation route); in total in 23% of the observed classes) they usually travelled through a building individually as well until reaching a place where they were instructed to wait or a closed exit.

Furthermore, it was observed that in most cases (82.5%) the position of staff members in the moving group was the same as in the moment when the group left a classroom (see Table 5.13 for details). In the remainder 17.5% a staff member changed her/his position in a group mostly from the following reasons. When only one staff member was present and she was the leading person in a group (also labelled "SM-C" in Table 5.13), she could decide to make a stop, instruct children to keep on moving, and check the rest of the group (10.5%). In the contrary, when the only staff member was the the last person who left a classroom, she could caught up the group afterwards, overtook the children and took the leading position or the position in the middle of the group (7.0%). In addition, the position of staff members often changed when a group arrived at an exit. At this point, the leading staff member could stop the movement to unlock or open the exit door. Subsequently, knowing that the outdoor conditions were safe (e.g. the exit went to the garden) she instruct children to go out and waited at the exit supervising the rest of the group. In other cases, a group of children had to wait at the exit until the staff member coming as the last person unlocked or opened the exit whereas she left as the first one the building afterwards.

Level of physical assistance provided to children

Physical support given by staff members to children during the movement phase of the experimental evacuation drills was separately observed on different parts of evacuation routes (in corridors, on staircases, in doorways). In order to describe the observations in the quantitative way, the five categories established for describing evacuation behaviour during the pre-movement phase of experimental evacuation drills (see Section 5.3.3, Table 5.45) were employed. Similarly to the pre-movement phase, the category "Any assistance provided" includes all cases when any physical contact between children and staff member was recorded. The category "Gentle pushing" indicates the situations when a physical contact between a staff member and a child was noted; however, this contact was evaluated as not necessary for the prompt evacuation process and it did not represent any physical support for the touched children. Typically, a gentle pushing on children's back, shoulders, arms, or head (e.g. when being counted in doorways) represented this type of contact. In contrast, physical contacts provided by staff members to children necessary for further evacuation process were classified as "Physical contact needed". This category includes the situations when staff members had to grab children's hand, arm, back, or shoulder to pull them in the desired direction, to speed them up, or to keep them moving. As separate categories were evaluated the physical contacts when a staff member held child's/children's hand and when a child was carried.

The results obtained for different age groups of children on different parts of evacuation routes are summarised in Table 5.38. It can be seen from this table that in 90.1% of all observations no physical contact between children and staff members occurred. In general, lower values in this category (i.e. more physical contact) can be identified in corridors (88.1%) and doorways (86.6%) than on staircases (92.2% on straight staircases, 97.6% on spiral staircases). The outcomes resulted mainly from higher values in category "Gentle pushing" in corridors (6.2%) and doorways (8.1%) than on staircases (1.6% on straight staircases, 0.0% on spiral staircases). These values correspond to different type of supervision which was observed on a horizontal plane and on staircases. In corridors and doorways, staff members often stopped their movement (letting children to keep on moving) and visually checked how the evacuation process of their children group proceed. Simultaneously, they occasionally touched the passing children. A similar kind of "Gentle pushing" contact was frequently seen in doorways where staff members stopped in front of an exit and they counted the children passing through touching them gently on heads, arms, or shoulders. On the contrary, staff members usually did not make similar stops on staircases being busy providing help to slower or less experienced children. Moreover,

Table 5.38: Level of physical assistance provided to children in different age groups and on different parts of evacuation routes during the movement phase of the experimental evacuation drills

Physical assistance provided	Frequency [%] (data-points)				
	Total	Junior	Senior	Senior+	Mixed
Corridors					
Any assistance provided	88.1 (1099)	88.5 (314)	90.0 (448)	100.0 (132)	77.9 (205)
Gentle pushing	6.2 (77)	4.5 (16)	9.4 (47)	0.0 (0)	5.3 (14)
Physical contact needed	1.3 (16)	2.5 (9)	0.0 (0)	0.0 (0)	2.7 (7)
Hand holding	4.2 (53)	4.5 (16)	0.6 (3)	0.0 (0)	12.9 (34)
Carried	0.2 (3)	0.0 (0)	0.0 (0)	0.0 (0)	1.1 (3)
Straight staircases					
Any assistance provided	92.2 (1414)	90.4 (310)	95.1 (796)	94.5 (104)	84.0 (204)
Gentle pushing	1.6 (24)	0.0 (0)	0.8 (7)	0.0 (0)	7.0 (17)
Physical contact needed	0.5 (8)	1.2 (4)	0.0 (0)	0.0 (0)	1.6 (4)
Hand holding	5.7 (87)	8.5 (29)	4.1 (34)	5.5 (6)	7.4 (18)
Carried	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Spiral staircases					
Any assistance provided	97.6 (321)	N/A	N/A	N/A	97.6 (321)
Gentle pushing	0.0 (0)	N/A	N/A	N/A	0.0 (0)
Physical contact needed	0.9 (3)	N/A	N/A	N/A	0.9 (3)
Hand holding	1.5 (5)	N/A	N/A	N/A	1.5 (5)
Carried	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
Doorways					
Any assistance provided	86.6 (806)	86.2 (238)	88.3 (323)	90.9 (20)	84.3 (225)
Gentle pushing	8.1 (75)	6.2 (17)	8.5 (31)	9.1 (2)	9.4 (25)
Physical contact needed	2.3 (21)	2.9 (8)	0.5 (2)	0.0 (0)	4.1 (11)
Hand holding	3.1 (29)	4.7 (13)	2.7 (10)	0.0 (0)	2.2 (6)
Carried	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
All types of evacuation routes					
Any assistance provided	**90.1 (3640)**	88.5 (862)	92.1 (1567)	97.0 (256)	86.7 (955)
Gentle pushing	**4.4 (176)**	3.4 (33)	5.0 (85)	0.8 (2)	5.1 (56)
Physical contact needed	**1.2 (48)**	2.2 (21)	0.1 (2)	0.0 (0)	2.3 (25)
Hand holding	**4.3 (174)**	6.0 (58)	2.8 (47)	2.3 (6)	5.7 (63)
Carried	**0.1 (3)**	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (3)

due to space limitations, any “Gentle pushing” contacts were recorded on spiral staircases.

Considering different age groups of children, more physical assistance received children in Junior classes and in Mixed classes. In Mixed classes, staff members typically gave more attention to younger children present in a group. Furthermore, it can be identified that different kinds of physical contact were more frequently observed in different age groups. In Junior and Mixed classes, higher values in category “Physical contact needed” and “Hand holding” and lower values in category “Gentle pushing” are evident in comparison to the results observed in Senior and Senior+ classes. These findings confirmed the general hypothesis that the approach and behaviour of staff members to children is to a large extend influenced by children’s age whereas younger children required more care and attention during the movement through a building.

Table 5.39: Hand holding observed in different age groups and on different parts of evacuation routes during the movement phase of the experimental evacuation drills

Hand holding	**Frequency [%] (data-points)**				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Corridors					
Any hand holding	49.4 (617)	36.9 (131)	32.7 (163)	78.8 (104)	83.3 (219)
With another child	46.3 (578)	58.6 (208)	66.7 (332)	21.2 (28)	3.8 (10)
With a staff member	3.8 (48)	3.4 (12)	0.4 (2)	0.0 (0)	12.9 (34)
With another child and a staff member at once	0.4 (5)	1.1 (4)	0.2 (1)	0.0 (0)	0.0 (0)
Straight staircases					
Any hand holding	63.0 (966)	64.1 (220)	50.8 (425)	87.3 (96)	92.6 (225)
With another child	31.3 (480)	27.4 (94)	45.2 (378)	7.3 (8)	0.0 (0)
With a staff member	5.2 (79)	6.7 (23)	3.8 (32)	5.5 (6)	7.4 (18)
With another child and a staff member at once	0.5 (8)	1.7 (6)	0.2 (2)	0.0 (0)	0.0 (0)
Spiral staircases					
Any hand holding	78.1 (257)	N/A	N/A	N/A	78.1 (257)
With another child	20.4 (67)	N/A	N/A	N/A	20.4 (67)
With a staff member	1.5 (5)	N/A	N/A	N/A	1.5 (5)
With another child and a staff member at once	0.0 (0)	N/A	N/A	N/A	0.0 (0)
Doorways					
Any hand holding	59.3 (552)	49.6 (137)	41.5 (152)	63.3 (14)	93.3 (249)
With another child	37.6 (350)	45.7 (126)	55.7 (204)	36.4 (8)	4.5 (12)
With a staff member	2.6 (24)	2.9 (8)	2.7 (10)	0.0 (0)	2.2 (6)
With another child and a staff member at once	0.5 (5)	1.8 (5)	0.0 (0)	0.0 (0)	0.0 (0)
All types of evacuation routes					
Any hand holding	**59.2 (2392)**	50.1 (488)	43.5 (740)	81.8 (214)	86.2 (950)
With another child	**36.5 (1475)**	43.9 (428)	53.7 (914)	16.7 (44)	8.1 (89)
With a staff member	**3.9 (156)**	4.4 (43)	2.6 (44)	2.3 (6)	5.7 (63)
With another child and a staff member at once	**0.4 (18)**	1.5 (15)	0.2 (3)	0.0 (0)	0.0 (0)

Hand holding

In addition to the level of physical support given by staff members to children. hand holding was investigated in children on different parts of evacuation routes (in corridors, on staircases, in doorways) during the movement phase of the experimental evacuation drills. For this purpose, four categories of hand holding were determined ("Any hand holding", "With another child", "With a staff member", "With another child and a staff member at once") and he results for different age groups of children on different parts of evacuation routes are summarised in Table 5.39. Considering all age groups of involved children on all types of evacuation routes, children moved separately (without hand holding) in 59.2% of the observations. In 36.5% of the observations, children formed pairs with another child (exceptionally triples with two other children). In 3.9% of the observations, they walked hand in hand with a staff member and in 0.4% they held another child's and staff member's hand at once. Higher frequency of hand holding can be identified on a horizontal plane (in corridors and doorways) than on staircases. This may be related, first, to the daily routine when children can be used to move in pairs when walking in corridors or outside a building and, second, to physically more challenging climbing on staircases which can create uncomfortable conditions for movement in pairs. Furthermore, on staircases, children were often instructed to hold a handrail which simultaneously eliminated the option walking in pairs due to a large width of a flight. This factor was important primarily for Junior children resulting in the considerably lower (nearly halved) value of hand holding on staircases in comparison to corridors. A special case represented climbing on spiral staircases, where hand holding was further restricted due to a more complicated geometry, notably a limited effective width and a steeper slope.

Differences in the frequency of hand holding can be also seen comparing the results obtained for different age groups. Considering hand holding with another child (moving in pairs), surprisingly, higher values were observed for Senior children than for Junior children. Furthermore, the lowest values can be identified in Mixed children. This outcome may be attributed to different leaving strategy and organisation of children when travelling through a building across the participating nursery schools. In general, Mixed classes were mostly present in the nursery schools with a smaller capacity, i.e. one-class nursery schools, nursery schools located in one-storey buildings with a simple layout, see Table5.1. In these institutions, less organised leaving strategy (e.g. individual leaving of children from a classroom and through a building) was employed during the experimental evacuation drills. It can be assumed that such an approach corresponded with daily practise in the nursery schools when children were used to move individually (not in pairs) when walking on circulation routes. On the other hand, in larger nursery schools where children were typically divided into Junior and Senior classes, the need of increased level of organisation during both everyday and non-standard situations influenced the pattern how children travelled through a building (e.g. in a compact group and in pairs). It can be therefore concluded that daily routine and rules in a nursery school influenced hand holding of children in pairs more considerably than their age. In contrast, the impact of age can be clearly seen in the categories focused on hand holding between children and staff members. Here, the majority of observations were made in Junior classes and in Mixed classes where the attention of staff members was implicitly gave to younger children in a group.

Using of handrails on staircases

Observations focused on using of handrails by children were performed on staircases. For this purpose, using of handrails at a standard height (standard handrail), at a lower height (children's handrail), and using of baluster or other support (e.g. a wall) were distinguished. Since different types of handrails were available to children on the observed staircases, the obtained results are presented separately for the situations when only standard handrails, only children's handrails, and both standard and children's handrails were present (see Table 5.20 for more details). The results acquired on one straight staircases where any handrail was available to children are not included in the presented data-set. A summary of the observations made on straight staircases can be found in Table 5.40, the results obtained on spiral staircases are provided separately in Table 5.41.

Table 5.40: Handrails using observed in different age groups and on straight staircases during the movement phase of the experimental evacuation drills

Using handrails on straight staircases	**Frequency [%] (data-points)**				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Only standard handrail available					
Without the use of handrails	22.7 (83)	53.9 (41)	45.3 (34)	2.7 (3)	4.8 (5)
Standard handrail	76.5 (280)	42.1 (32)	54.7 (41)	97.3 (107)	95.2 (100)
Baluster or other support	0.8 (3)	3.9 (3)	0.0 (0)	0.0 (0)	0.0 (0)
Only children's handrail available					
Without the use of handrails	73.9 (34)	N/A	N/A	N/A	73.9 (34)
Children's handrail	26.1 (12)	N/A	N/A	N/A	26.1 (12)
Baluster or other support	0.0 (0)	N/A	N/A	N/A	0.0 (0)
Both standard and children's handrail available					
Without the use of handrails	34.1 (346)	18.6 (37)	35.8 (259)	N/A	54.3 (50)
Standard handrail	33.1 (336)	57.3 (114)	30.1 (218)	N/A	4.3 (4)
Children's handrail	29.8 (302)	20.1 (40)	30.9 (224)	N/A	41.3 (38)
Baluster or other support	3.1 (31)	4.0 (8)	3.2 (23)	N/A	0.0 (0)
All combinations					
Without the use of handrails	**32.4 (463)**	28.4 (78)	36.7 (293)	2.7 (3)	36.6 (89)
Standard handrail	**43.2 (616)**	53.1 (146)	32.4 (259)	97.3 (107)	42.8 (104)
Children's handrail	**22.0 (314)**	14.5 (40)	28.0 (224)	0.0 (0)	20.6 (50)
Baluster or other support	**2.4 (34)**	4.0 (11)	2.9 (23)	0.0 (0)	0.0 (0)

Considering the overall results for all age groups and combinations of handrails available, it can be seen from Table 5.40 that children did not use any handrail in 32.4% of the observations, whereas in 43.2% they used a standard handrail, in 22.0% a children's handrail, and in 2.4% another support such as a baluster or a wall. When only standard handrail was available to children, it was used in 76.5%, more frequently in age groups of Senior, Senior+, and Mixed children. The situation when only children's handrail was available to children occurred only on one flight in one nursery school, therefore the number of data-points is limited to only one Mixed class. When both a standard and a children's handrail were present, their usage by children was approximately the same (33.1% standard handrail, 29.8% children's handrail). In those cases, a children's handrail was more frequently used by Mixed children and a standard handrail by Junior children. In Senior age group, the frequency of usage was roughly equal. Hence, a general assumption that Junior children would more incline to prefer a lower handrail due to their smaller physical dimensions was not confirmed. Their choice of a standard handrail may be explained as an attempt to demonstrate their own ability to use the same things as adults do. Apart from that, Junior children used the support of handrails in 71.6% of the observations which is the highest value amongst all age groups. It should be also highlighted that (similarly to hand holding) usage of handrails by children may be to a large extent influenced by daily routine in a nursery schools as well as by actual instructions received by staff members. On the whole the results revealed that, being used by the majority of children, the presence of handrails is an important element for the evacuation process in nursery schools and installation of handrails in both heights can be highly recommended.

This conclusion was confirmed also by the results obtained on spiral staircases given in Table 5.41 which showed that children did not hold on a handrail only in 13.4% of the observations. Comparing the usage of a standard handrail (42.2%) and a children's handrail (30.7%), a standard handrail was used more often by down climbing children. Moreover, the frequency of usage of a baluster (13.7%) is considerably higher than on straight staircases (2.4%). This output may be attributed to the spiral shape of children's movement trajectory which cause that it could be more comfortable for them to locally hold a vertical element (a pole of the baluster) than a handrail. The spiral shape of staircases proved to be more challenging also for the children who used both hands to hold a handrail and moved hand over hand when climbing downstairs (in 2.4% of the observations).

Table 5.41: Handrails using observed in different age groups and on spiral staircases during the movement phase of the experimental evacuation drills

Using handrails on spiral staircases	**Frequency [%] (data-points)**				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Both standard and children's handrail available					
Without the use of handrails	13.4 (44)	N/A	N/A	N/A	13.4 (44)
Standard handrail	42.2 (139)	N/A	N/A	N/A	42.2 (139)
Children's handrail	30.7 (101)	N/A	N/A	N/A	30.7 (101)
Baluster or other support	13.7 (45)	N/A	N/A	N/A	13.7 (45)

Marking time pattern on staircases

In addition to using of handrails, feet alternation in children was analysed on straight and spiral staircase during the experimental evacuation drills. Following the definition provided in Section 3.2.2, a marking time is referred as an action during which one foot meets the other on a riser (i.e. both feet are on the same level), before going to the next higher (or lower) riser [126]. The results summarised in Table 5.42 demonstrate that irrespective of the age categories of children a marking time pattern was identified in 9.8% of the observations on straight staircases and in 18.8% of the observations on spiral staircases. Considerably higher frequency of using a marking time pattern was observed in Junior children and Mixed children (especially younger children in a group). These results are in line with the literature suggesting that an alternating pattern when moving independently downstairs emerges until to four years of age [77,125]. In general, it was observed that a marking time pattern in children was caused by their limited movement abilities, by insufficient room available for feet alternating (when the step in front of a child is blocked by another child), or by playing. Furthermore it was observed that younger children using the marking time pattern often changed to the alternating pattern on the last flight of a staircase, eventually on the last steps of this flight. This finding may be explained as obtaining more confidence on a staircase. Besides switching to the alternating pattern on the final part of a staircase, younger children were also often seen jumping down from the bottom tread with both feet together. This kind of jumping representing a play for younger children, was identified also in older children. In their case, the number of jumped steps was even higher and the activity was motivated by a need to move faster.

Table 5.42: Using of marking time pattern observed in different age groups and on straight and spiral staircases during the movement phase of the experimental evacuation drills

Marking time pattern	Frequency [%] (data-points)				
	Total	**Junior**	**Senior**	**Senior+**	**Mixed**
Straight staircases					
Used	9.8 (150)	19.8 (68)	4.5 (38)	0.0 (0)	18.1 (44)
Not used	90.2 (1383)	80.2 (275)	95.5 (799)	100.0 (110)	81.9 (199)
Spiral staircases					
Used	18.8 (62)	N/A	N/A	N/A	18.8 (62)
Not used	81.2 (267)	N/A	N/A	N/A	81.2 (267)

5.3.9 Specifics of movement behaviour and procedure

Following the observations reported in the previous section, specifics of children's behaviour during the movement phase and related impacts on evacuation procedure are presented and discussed in this section. In addition, flaws and problematic parts of the evacuation process observed during the experimental evacuation drills are commented. The main findings can be summarised as follows:

– During the movement throughout a building, children at the pre-school age did not avoid any close physical contact among each other. Following the concept of a body buffer zone [5], the comfort zone and personal space required by children was markedly smaller than can be assumed for adults. Children often touched each other and their different perception of the personal space was evident also when they did not hesitate to speed up the movement pushing other children ahead with their arms and hands. This behaviour was the most frequently observed in doorways but also on other parts of evacuation routes when children appraised a child in front of them to be too slow. Moreover, when waiting in front of a door children could form so compact crowd that staff members had problems to squeeze through (e.g. to open the door or to take the leading position in the group). When the door had to be opened against the direction of escape problematic situation occurred causing delays in the evacuation process.

– In comparison to adults, children perceived the movement more as a game. They were running with outstretched arms pretending flying planes or they hooped, galloped, and jumped (two-footed or only on one foot) instead on standard walking in corridors. On staircases, they were seen hanging themselves on handrails, hopping or jumping down from the bottom treads with both feet together.

- Movement behaviour of children often changed when the end of the evacuation route (e.g. the end of a staircase or an exit) was visible to them. On staircases, they often accelerated and changed their travel path from the side where they were holding a handrail to the centre where their kept on climbing downstairs without any holding. Moreover, children using a marking time pattern often started to alternate their feet at the final part of staircases. Those changes in movement patterns may be attributed to both becoming more confident and feeling that the movement on particular part of escape route was getting to be soon over. In this context, several questions arise, such as how would children's movement look like on long staircases and it would be influenced by fatigue.
- Children did not constructively solve barriers accidentally occurred on evacuation routes as it would be expected by adults. In those cases, when an opened door reduced the effective width of an evacuation route and it limited the continuous movement, children did not close the door in order to make the evacuation route free but rather squeeze around even though they considerably slowed down the movement of the whole flow and they created a bottleneck. Similarly, when a small children's chair blocked a walkway and only free width around of 300 mm was available, children did not put the chair back under the table. They went rather around and tried to squeeze through the narrow space.
- After leaving a classroom without any staff member at the leading position, children could easily take wrong a direction of the movement or miss an exit. Generally, children tended to use familiar exit paths and their ability to choose an appropriate evacuation route seemed to be limited. In the case when the instructions given by staff members where brief and lacked of the specification which evacuation route should be used (e.g. "go out"), children usually selected the daily used option. Subsequently, they had to be caught up by a staff member and redirected to the desired direction which caused delays in evacuation and confusing in children. During one experimental evacuation drill, children were briefly instructed to leave the building whereas the staff members were convinced that children were going to use the main exit in the building (used for coming to and leaving the nursery school). Nevertheless, children decided to exit to the garden using a door which they commonly used during the day. This door was also in the direction where the first staff member went in order to inform other classes about the situation. When the second staff member left the classroom as the last person, she was not able to find the children at the expected place and started to search them in the building. This example confirmed that even in a building with very simple layout and short evacuation routes the evacuation does not have to proceed as initially planned.
- When instructed to hold each other's hand and form a pair, children were observed to strongly insist on performing this activity. In several cases they intensively struggled to persuade other children to make a pair with them,

stopped completely their movement until having a pair partner, or kept on hand holding even when the other child was notably slower and she/he considerably impeded the common movement. In contrast, younger children could easily loose their pair partner and they needed additional help to find her/him back.

- Children were seen not to hesitate to suddenly stop their movement in order to run backwards to the classroom to return a toy, or to turn around and walk back to gather a dropped thing.
- When children who moved through a building without any supervision arrived at a closed door, they either stopped and waited, or they opened the door individually and continued in the movement. It can be assumed that their behaviour was to a large extent dependent not only on received instructions but also on individual child's personality. In cases in which children trying to open a door using a handle found out that the door was locked, they decided to wait for a staff member even though the key was available in the lock.
- Before leaving a building children tended to follow daily routines and rules such as putting on shoes and clothing in order not to get cold. During one experimental evacuation drill, children who were instructed to leave the building and to gather to the garden made automatically a stop in the dinning room to drink a cup of tee as usual before going to the garden. In the arose situation, all presented staff members tried to convince the children to stop drinking. Nevertheless, the evacuation path was crowded and blocked, children were confused, and a noticeable delay in evacuation occurred which finally enabled several children to peacefully finish their cups.
- When moving through a building, children reacted to the non-standard situations differently. Some children may have seemed to be surprised and confused (especially younger children), some children looked around curiously, and other children, excited that something new happened, enjoyed the experimental evacuation drill as a game or an opportunity for racing. In several experimental evacuation drills, children were observed covering their ears because of a very loud alarm signal (e.g. siren, benching on a pot). In other cases, children's behaviour proved to be very curious. For instance, when a staff member left a group of moving children in order to inform another class about the current situation, children stopped their movement on a staircase, turned around, and ran to check where the staff member went.
- In several cases, a spontaneous helping behaviour was observed in children in Mixed classes. Typically, older children decided by themselves to help children who were younger, slower, or less experienced when holding their hands, assisting them on staircases, or repeating them instructions and supporting them verbally.
- Children's movement behaviour can be influenced by special occasions specific for the occupancy of nursery schools. For instance, in one participating nursery school, the experimental evacuation drill was carried out on the day of a costume party. Children in several classes were dressed in witch and wizard costumes which long cloaks could influence their movement. Moreover, chil-

dren were holding parts of the costumes such as magic wands and hats in their hands and they conformed their behaviour to the interrupted wizard's play.

5.4 Discussion

In this section, the presented results and findings obtained in the experimental evacuation drills are discussed in the context of research focused on children's evacuation summarised in Chapter 2. Following the structure of the presented literature review, evacuation behaviour and movement characteristics of pre-school children are discussed separately in Section 5.4.1 and Section 5.4.2 respectively.

5.4.1 Evacuation behaviour

Pre-movement phase

Human behaviour and response activities during the pre-movement phase of an evacuation process are often quantified using the variable of pre-movement time. A comparison of the current data-set describing pre-movement times data available in the literature [10, 17, 22, 23, 33, 34] is summarised in Table 5.43. For the simplification

Table 5.43: Comparison of the observed pre-movement times with available literature

Reference	Level of announcement (number of drills)	Leaving strategy	Mean pre-movement time [s] (data-points)	
			First child	Last child
Larusdottir et al. [34]	Partly announced (16)	N/A	-	54 (N/A)
Kholshchevnikov et al. [10]	N/A	N/A (indoor clothing)	N/A	8 (N/A)
Capote et al. [17, 33]	Announced to staff members (1)	Group at once	30 (2 classes)	N/A
Najmanová and Ronchi [22]	Semi-announced (2)	Group at once	36 (10 classes)	N/A
Hamilton et al. [23]	Announced (1) and unannounced (3)	N/A	23 (24 classes)	N/A
Current study	Announced (8) Semi-announced (4) Unannounced (3)	-	19 (26 classes) 15 (12 classes) 34 (19 classes)	31 (26 classes) 27 (12 classes) 46 (19 classes)
	-	Group at once Group gradually Individually	31 (33 classes) 14 (11 classes) 11 (13 classes)	43 (33 classes) 24 (11 classes) 24 (13 classes)
	In total (15)		22	34

N/A information not available

of the comparison, only mean values of pre-movement times are displayed in the table and the age ranges of children are not included; a comprehensive overview of literature data can be found in Section 2.2.1. Following the previously discussed findings that both level of announcement and leaving strategy potentially impact pre-movement times—when provided in the literature—information on these aspects is also included in Table 5.43. Nevertheless, due to a large number of factors which could have impact on the presented values, a comparison can have more informative than definitive character. Overall, the pre-movement times measured in the current study (especially those during unannounced experimental evacuation drills) appear to be in agreement with the values presented in the literature. Furthermore, due to various factors to different boundary conditions during the experimental evacuation drills and limited sample size of the experimental data, the hypothesis that longer pre-evacuation times can be assumed in classes with younger children than in classes with older children [22, 23] was neither confirmed nor ruled out. Nevertheless, the observations highlighted the influence of children's age on pre-movement time and evacuation process during the pre-movement phase.

Based on the literature review, several behavioural aspects considering pre-school children's evacuation behaviour during pre-movement phase were identified (see Section 2.2.1 for details). In addition to observations described in the results part, a summary of the presented outcomes in relation to those findings is provided in Table 5.44 and commented briefly in the following paragraphs.

Table 5.44: Summary of behavioural aspects considering pre-school children's evacuation behaviour during the pre-movement phase presented in the current study and in the literature

Finding [references]	**The current study**
Pre-school children do not react to a warning signal independently [10, 13, 16, 17, 22, 25, 33, 34]	Confirmed with exceptions
Actions of staff members during pre-movement phase are dependent on age of children [22, 34]	Confirmed
Evacuation behaviour reflects the daily routine and rules; pre-school children tend to follow a sequence of memorised daily activities [9, 13, 22, 34]	Confirmed
Pre-school children tend to use familiar exits; the final exit choice is in competence of staff members [13, 25, 34]	Confirmed

The hypothesis that pre-school children react first to instructions given by adults and not on the warning signal as such was confirmed in the most nursery schools and classes observed. Only in one nursery school, children in two classes started to evacuate individually following the voice message given by the leader in corridors which instructed to leave the building. Such a reaction of children may be explained as a result of daily practise in the nursery school since there children are used to move through the building without supervision at any time. Therefore it can be concluded that common practises as well as educational programmes and approach to children in early childhood education institutions may considerably influenced reactions and behaviour in emergency situations.

The observations of evacuation behaviour during the pre-movement phase further revealed that the activities taken by staff members and their instructions given to children were dependent on age of children. In Junior classes and in Mixed classes where children between of 3–4 years of age were accommodated, staff members more often instructed children which exit to use, explained the situation to them, and counted them before leaving a classroom. Moreover, younger children were often asked to be quiet or to stop playing and to follow given instructions which had to be repeated many times to them. The assumption that young children required more care and attention given by staff members was fully confirmed. Slow reaction to provided instructions was observed only by younger children who in those cases required also additional physical help. In addition, it can be stated that the evacuation behaviour of staff members followed the concept known as the role-rule model [165]. According to this model, behaviour of individuals in case of emergency is guided by their "role" (i.e. a set of expectations) in which they expect themselves to be in the actual context, i.e. the coping strategy and engaged activities taken by staff members were determined by their social role and position of responsible adults.

It can be also concluded that evacuation behaviour of both staff members and pre-school children reflects the daily routine common in the early childhood education institution. What is more, children incline to respect well-known learned rules under all circumstances (e.g. children insisted on finishing their snack or drink before leaving a room). Generally, this behaviour was observed in children located in different locations in the building and carrying out various activities when the alarm was sounded. Besides following familiar rules of conduct, children also tended to use familiar exits. If the instructions "go to the door" or "go outside" given by staff members lacked of the specification which exit from the classroom is meant, children automatically chose the main or daily used door. Similarly, a familiar exit route leading from the building was preferred by children who were moving in corridors without any supervision. Therefore, it may be concluded that the affiliation model (theory of affilition) in escape behaviour proposed by Sime [166, 167] is applicable also to children at the pre-school age. Moreover, it should be assumed that pre-school children's capacity to choice appropriate exit route may be limited.

As a part of the results of the experimental evacuation drills, the level of physical support given by staff members to children during the pre-movement phase was analysed. At this point, the obtained results for all age groups (3–6 years) are further compared to findings available in the literature reported by Larusdottir et al. [34]. In this study, the level of assistance received by children aged 3–6 years was divided into three groups: "No physical assistance", "Some physical assistance" (which included all forms of physical help, except for carrying such as hand holding and gently pushing towards to the exit), and "Carried" (see Table 5.45). The observations performed in the presented experimental evacuation drills distinguished in total four categories (explained in detail in Section 5.3.3), where physical contact between staff members and children (excluding carrying) was seen at two levels: physical assistance necessary to proceed the evacuation process ("Physical contact needed and hand holding") and gentle contact when staff members touched back, shoulders, arms, or head of children who obviously did not require any assistance in the most cases ("Gentle pushing"). Therefore, to compare the results with the literature data [34], the category "Gentle pushing" should be divided into the category "Any assistance provided" (to the large extend) and the category "Physical contact needed". Nevertheless, the percentage of such a regrouping can not be exactly estimated, it may be concluded that the compared findings are in a good agreement and show similar trends.

Table 5.45: Comparison of level of assistance required by children during the pre-movement phase presented in the current study and the literature

<table>
<tr><th colspan="2">Larusdottir et al. [34]</th><th colspan="2">The current study</th></tr>
<tr><td>Assistance</td><td>Frequency [%]</td><td>Assistance</td><td>Frequency [%]</td></tr>
<tr><td>No physical assistance</td><td>85.9</td><td>Any assistance provided</td><td>75.0</td></tr>
<tr><td rowspan="2">Some physical assistance</td><td rowspan="2">12.3</td><td>Gentle pushing</td><td>18.7</td></tr>
<tr><td>Physical contact needed and hand holding</td><td>5.9</td></tr>
<tr><td>Carried</td><td>1.8</td><td>Carried</td><td>0.3</td></tr>
</table>

Movement phase

Considering children's behaviour during the movement phase of an evacuation process, several findings can be found in the previous studies [15, 22, 33, 34] (see Section 2.2.2 for more details). In this context, it can be noted that children's movement on staircases has been mainly in focus in the literature. In addition to children's need for physical support during the pre-movement phase commented in the previous section, Larusdottir et al. [34] reported also on level of assistance required by pre-school children on staircases. For this purpose, the authors used the same categories as for the analysis of pre-movement phase, i.e. "No physical assistance", "Some physical assistance" (including hand holding), and "Carried". The presented results for children aged 3–6 years are summarised in Table 5.46 and they are compared with the results obtained for all age groups (including observations on both straight and spiral staircases) in the current study. The four categories used in the current study are identical as described in the previous section on children's behaviour during the pre-movement phase. The comparison shows that less physical assistance was provided to children during the presented experimental evacuation drills on staircases. This output may be primarily related to the evacuation procedure and strategy taken by staff members. Based on the current observations, children climbed downstairs in the most cases independently and staff members gave their attention to the overall supervision of the situation, providing verbal instructions to children, and eventually helping to the slowest and less experienced (typically younger) children in a group. Moreover, specific conditions were observed on spiral staircases where the physical support provided to children by staff members was scarce also due to the limited stair geometry.

Table 5.46: Comparison of level of assistance required by children during the movement phase (on staircases) presented in the current study and the literature

<table>
<tr><th colspan="2">Larusdottir et al. [34]</th><th colspan="2">The current study</th></tr>
<tr><td>Assistance</td><td>Frequency [%]</td><td>Assistance</td><td>Frequency [%]</td></tr>
<tr><td>No physical assistance</td><td>85.2</td><td>Any assistance provided</td><td>93.9</td></tr>
<tr><td rowspan="2">Some physical assistance</td><td rowspan="2">13.9</td><td>Gentle pushing</td><td>1.3</td></tr>
<tr><td>Physical contact needed and hand holding</td><td>5.5</td></tr>
<tr><td>Carried</td><td>0.9</td><td>Carried</td><td>0.0</td></tr>
</table>

Further outcomes related to children's movement behaviour on staircases which can be found in the literature and their relation to the current results are summarised in Table 5.47 (see Section 2.2.2 for details). As suggested in the literature, handrails on staircases represent an important and frequently used aid component. Larusdottir et al. [34] reported that 58.6% of children aged 3–6 years, who did not received any other physical support, used a handrail on staircases during the observed evacuation drills (the information on the type and height of the handrails was not provided). In the study focused on two evacuation drills involving pre-school children, Capote et al. [33] mentioned that 72% of children at the age 4–6 years used a handrail during the first evacuation drill whereas 66% of children in the second one (the type and height of the handrail was not specified in the study). Considering the results presented in the current study for all age groups and handrail configurations (both on straight and spiral staircases), a handrail was used 67.1% of children climbing downstairs (a standard handrail in 40.5%, a lowered handrail in 22.3%, and baluster in 4.2%). It can be therefore concluded that the observed result are in line with the values early presented in the literature and that the presence of handrails is an important element for the evacuation process in nursery schools.

Table 5.47: Summary of behavioural aspects considering pre-school children's evacuation behaviour during the movement phase presented in the current study and in the literature

Finding [references]	The current study
Handrails are frequently used by pre-school children when climbing downstairs [22, 33, 34]	Confirmed
Pre-school children's movement on staircases is adversely affected by a marking time pattern [22, 33]	Confirmed
Children's behaviour on staircases may be affected by their familiarity with the escape route, staircase geometry, and environment [15, 22, 34]	Partially confirmed

According to other finding, a marking time pattern used by pre-school children can considerably influence their movement behaviour on staircases. Capote et al. [33] concluded that 55.8% (or 33.3% in the following evacuation drill) of children aged 4–6 years used a marking time pattern when walking downstairs on a flight of a straight staircase. In addition, their travel speed was evaluated as around a third less than the travel speed in children who alternated their feet. Comparing to these values, considerably lower percentage of children who used a marking time pattern when walking downstairs on straight staircases (9.8% for all age groups) was measured during the current experimental evacuation drills. Moreover, using of marking time pattern was more frequently observed in children at the age around 3–4 years (i.e. in Junior classes and Mixed classes). Looking at the results observed in Senior children (5–6 years old), the percentage of children who did not alternate their feet was even lower (4.5%). in this context, it can be noted that the current outcomes seem to be in a good agreement with the findings of the literature review on children's motor development which suggested that an alternating pattern when moving independently downstairs emerges in children until to four years of age [77, 125]. Nevertheless, further observations of the children using a marking time pattern confirmed that their movement behaviour on staircases was less confident, slower, and required more often assistance provided by staff members or older children. Therefore, the conclusion can be stated that using of a marking time pattern occurred in children at the pre-school age (especially in younger ones) and this movement pattern impeded their walking abilities when walking independently downstairs. Although the impact of different familiarity with an escape route and environment (indoor vs. outdoor) of staircases was not studied during the presented experimental evacuation drills due to a limited diversity of observed staircases, the influence of staircase geometry on movement behaviour of children was confirmed. This finding was clearly visible notably on spiral staircases where two travel path with a considerably different slope and stair depth were used by children walking in pairs (which would not be expected by adults anyway). Children climbing downstairs on the steeper travel part with narrower depth of stairs reached lower travel speeds, treaded more carefully, and searched more often the support in holding a handrail.

5.4.2 Movement characteristics

Travel speed and speed-density relationships

Corridors The results on travel speed in corridors obtained in the current study were introduced in Section 5.3.4. In Table 5.48, the experimental data-set was compared with data available in the literature [16,19,22,23,25,34]. For the purpose of the comparison, only movement travel speeds observed at low densities were taken into account. Notably, travel speeds at densities less than 1 pers·m^{-2} were adopted from the literature and compared with the current results on travel speeds measured in the lowest density interval (0.00–0.05 m^2 m^{-2}, i.e. approximately 0–1.9 children·m^{-2}).

Considering walking speed, the current results describing mean travel speed of Junior (aged 3–4 years) and Senior (aged 5–6 years) children are in a very good agreement with corresponding values presented in the literature [16, 19, 22, 23, 25], even though the measured maximum values of walking travel speed are higher. The mean travel speed of Senior+ children (aged 6–7 years) is slightly higher which may be associated with the higher age of the children in this age group. The mean running speed of Junior children observed in the current study is in line with the literature data [16], the mean running speed of Senior children is however higher. Moreover, similarly to walking speeds, the maximum values of running speed observed in children in the current study are considerably higher by all age groups, especially in Senior+ children. Besides that, higher running speed may be attributed to different motivation of children to run.

In the literature, only a few research studies have provided fundamental diagrams describing speed-density relationship in pre-school children on a horizontal plane [16,24,25] (see Section 2.3.4 for more details). To compare the results obtained in the current study with the literature data, the trend lines of speed-density relationships presented in the literature were plotted in a common graph with the current results in Figure 5.47. For this purpose, the current data-set describing walking travel speeds of children in all age groups was displayed. Moreover, the linear fitting was chosen to express the trend line of the experimental data-set in order to ensure a

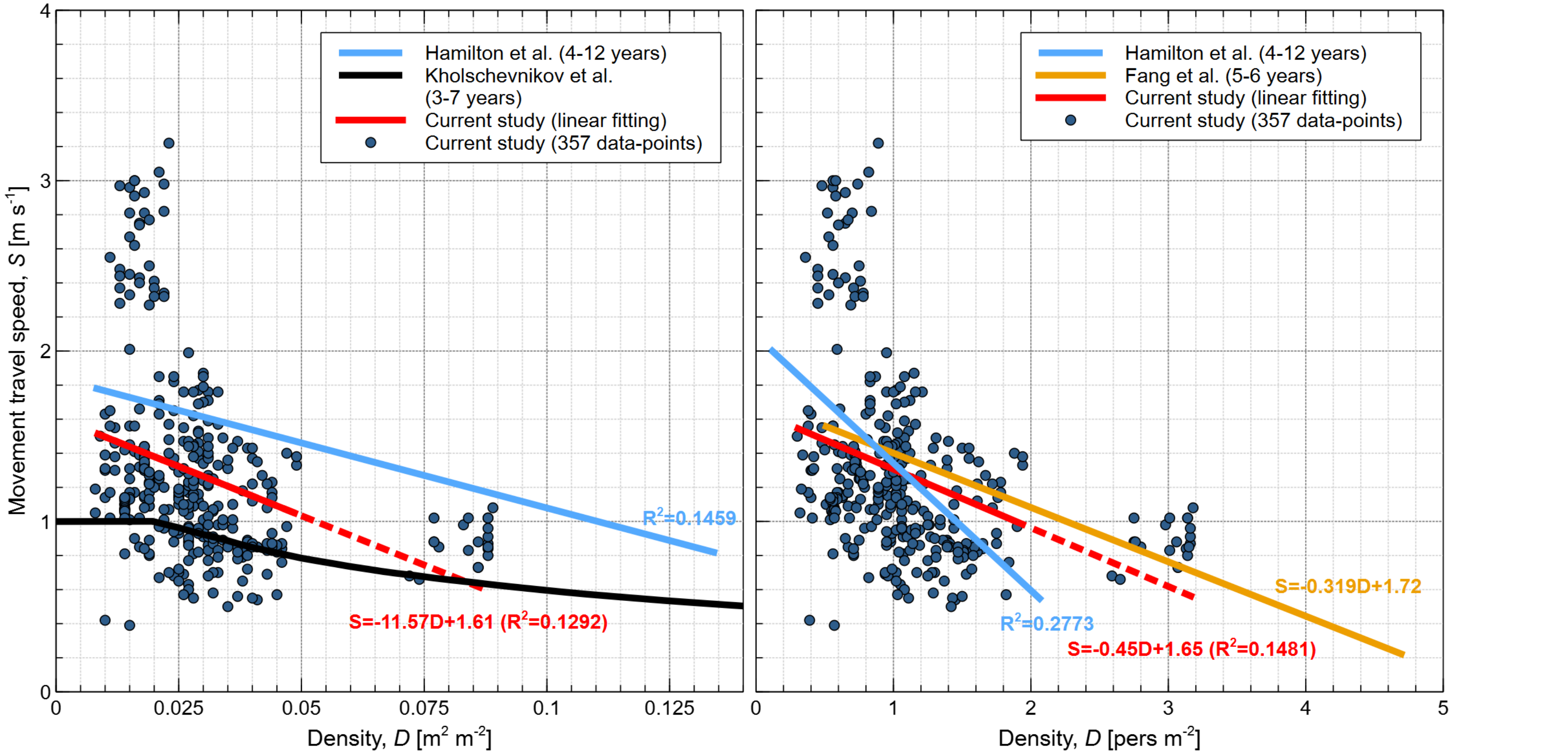


Figure 5.47: Walking travel speed per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers·m^{-2}]) with the linear trend line measured in corridors during the experimental evacuation drills and comparisons to Kholshchevnikov et al. [16], Hamilton et al. [24], and Fang et al. [25] (the dashed parts represent the trends including the outliers; see Section 5.3.4 for more details)

Table 5.48: Comparison of the measured walking and running speed in corridors during the experimental evacuation drills with available literature

Reference	**Age [years]**	**Travel speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	
		Walking	**Running**
Larusdottir et al. [34]	3–6	0.84 / 0.42 / 1.36 / 0.25 (N/A)	2.23 / 0.83 / 3.24 / 0.64 (N/A)
Kholshchevnikov et al. [16]	3–4	1.05 / 1.00[1)] / 1.10[1)] / 0.22 (78)	1.78 / 1.70[1)] / 1.86[1)] / 0.29 (50)
	4–5	1.12 / 1.06[1)] / 1.19[1)] / 0.17 (32)	1.87 / 1.77[1)] / 1.97[1)] / 0.34 (45)
	5–7	1.61 / 1.54[1)] / 1.68[1)] / 0.22 (39)	2.30 / 2.14[1)] / 2.47[1)] / 0.46 (32)
Takizawa et al. [19]	3–4	1.07 / 0.65 / 1.94 / 0.30 and 1.59 / 0.93 / 2.36 / 0.41 (N/A)	
	4–5	1.47 / 0.60 / 2.47 / 0.52 and 1.43 / 0.68 / 2.70 / 0.50 (N/A)	
	5–6	1.68 / 0.85 / 2.78 / 0.50 and 1.33 / 0.85 / 1.73 / 0.20 (N/A)	
Najmanová and Ronchi [22]	3–4	1.02 / 0.69 / 1.33 / 0.17 (42)	-
Hamilton et al. [23]	5–6	1.35 / - / - / - (200)	
	4–12	1.32 / 0.18 / 2.59 / 0.40 (667)	2.47 / 1.12 / 4.41 / 0.66 (89)
Fang et al. [25]	5–6	1.32 / 0.96 / 2.28 / 0.30 (26)	1.90 / 1.36 / 2.43 / 0.25 (23)
Current study	3–4	1.06 / 0.42 / 1.85 / 0.26 (139)	1.82 / 1.12 / 2.78 / 0.42 (47)
	5–6	1.38 / 0.54 / 3.00 / 0.57 (132)	2.73 / 1.27 / 4.36 / 0.69 (104)
	6–7	1.92 / 1.40 / 2.98 / 0.55 (15)	3.35 / 1.03 / 5.25 / 0.91 (73)
	3–6	1.55 / 0.39 / 3.22 / 0.68 (50)	2.21 / 1.11 / 4.65 / 0.68 (126)

1) 95% confidence interval
N/A information not available

compatibility of the consider trend lines (a comparison including all calculated trend lines of the presented data-sets (linear, exponential, and logarithmic fitting) can be found in Appendix C in Figure C.24). The resulting low R^2 values of the linear regression lines should therefore be considered as a limitation while analysing those trend lines. Since different units of density were used in the related research studies, the comparison was performed separately for units of pers·m^{-2} and m^2 m^{-2}. As Fang et al. [25] described the trend line quantitatively as an equation, the speed density function was adopted directly. Kholshchevnikov et al. [16] and Hamilton et al. [24] presented the trend lines graphically and thus the functions had to be digitised from the original graphs. In addition, data presented by Kholshchevnikov et al. [16] were transformed from the unit of m·min^{-1} to [m·s^{-1}]. It should be also highlighted that the speed-density relationship given by Kholshchevnikov et al. [16] represents a suggested design curve for evacuation calculations and thus not an experimental curve.

As can be seen from Figure 5.47, all displayed trend lines confirm the general assumption that the travel speed decreases with the increasing density. Despite its application range limited to lower densities, the linear trend line of the current data-set is in overall agreement with the curve presented by Fang et al. [25]. Comparing to the trend line presented by Hamilton et al. [24] the impact of using of different density units can be visible. Whereas in the current study similar occupant areas of the involved children were assumed (for children aged 3–6 years ranged their occupant area from A=0.025 m^2 to A=0.029 m^2), Hamilton et al. [24] described the movement of children at the age 4–12 years with the body ellipse areas varying from 0.04 m^2 to

0.09 m^2. Therefore, a more significant variance between the results in pers·m^{-2} and $m^2\,m^{-2}$ can be identified.

Staircases In Table 5.49, the current results describing travel speed on straight and spiral staircases presented in Section 5.3.5 and Section 5.3.6 are compared with data-sets available in the literature [13, 15–19, 22–25, 33]. Considering straight staircases, experimental data on travel speed on flights (landings excluded) were mostly reported in the literature [16–19, 22–24, 33]. Combined results for flights and landings were presented only by Fang et al. [25] and separate results for landings were not identified during the literature review (see Section 2.3 for more details). Moreover, density intervals where the reported values of travel speed were obtained were not always described in the research studies [13, 15, 17–19, 22, 23, 25, 33]. Since the influence of density on travel speed is non-negligible, these limitations were mentioned in Table 5.49 and it should be taken into account carefully when the results on travel speed are further compared.

In that regard, the current data-sets on travel speed on flights of straight staircases (measured in the density interval (0.00–0.05 $m^2\,m^{-2}$, i.e. approximately 0–1.9 children·m^{-2})) can be directly compared with the values presented by Kholshchevnikov et al. [16]. Considering Junior (3–4 years) and Senior children (5–6 years), slightly higher travel speeds were observed during the presented experimental evacuation drills. On the contrary, the results obtained for Senior+ children (6–7 years) can be assumed as slightly lower. Nevertheless, a similar trend indicating the impact of children's age on their travel speed can be identified in both data-sets. Considering other references and results summarised in Table 5.49 for movement on straight and spiral staircases, an appropriate comparison is limited due to the lack of density conditions provided [13, 15, 17–19, 22, 23, 25, 33] or their disparity [24]. In general, it can be stated that the travel speeds measured during the presented experimental evacuation drills are mostly higher than the data available in the literature. However, the extent to which this outcome may be attributed to potentially different density conditions is unknown.

A better insight into the relationship between travel speed and density on staircases can be obtained from experimental data-sets presenting a speed-density dependency. Nevertheless, only a small number of research studies provided speed-density relationships of children's movement on staircases [16, 24, 25]. Kholshchevnikov et al. [16] and Hamilton et al. [24] presented data-sets obtained on flights of straight staircases. Fang et al. [25] provided experimental data describing children's movement on combined two flights and one landing of a straight staircase. Further results for separate landings of straight staircases and spiral staircases were not identified in the literature review.

Similarly to the evaluation of the speed-density relationships in corridors, a comparison of the results obtained in the current study with the literature data was plotted in common graphs using the given trend lines displayed in Figure 5.48. For the adopting of the trend lines from the literature, the same method as described in the previous part focused on corridors was used. In Figure 5.48, the trend lines describing children's movement on flights of straight staircases are provided on the left (in density units of $m^2\,m^{-2}$) and speed-density data-sets on children's movement on whole straight staircases (flights and landings combined) are given on the right (in density of $pers{\cdot}m^{-2}$). It can be seen that all provided trend lines follow the same trend when travel speed decreases with the increasing density. Furthermore, the slope of the illustrated trend lines seems to be in a good agreement. However, it should noted that the application range of the trend line presenting the current experimental data-set is limited to densities lower than $0.07\,m^2\,m^{-2}$. Considering the data-sets describing movement of children on whole straight staircases (flights and landings combined, see Figure 5.48 right), the density conditions of the observations and the compared trend lines of travel speeds are quiet similar.

Doorways Considering travel speeds of children at the pre-school age through doorways, no related experimental data-sets were explored within the literature review. Therefore, a further comparison of this current experimental data-set was not provided.

Table 5.49: Comparison of the measured walking and running speed on staircases during the experimental evacuation drills with available literature

Reference	**Age [years]**	**Staircase description and geometry (slope[°])**	**Travel speed (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Density**
Flights of straight staircases				
Kholshchevnikov et al. [16]	3–4	internal,daily-used various geometry	0.50 / 0.39$^{1)}$/ 0.62$^{1)}$/ 0.29 (26)	0–1 pers·m^{-2}
	4–5		0.67 / 0.53$^{1)}$/ 0.81$^{1)}$/ 0.17 (8)	
	5–7		1.16 / 1.09$^{1)}$/ 1.23$^{1)}$/ 0.23 (45)	
Takizawa et al. [19]	3–4	internal,daily-used (28.8)	0.32 / 0.25 / 0.35 / 0.03 (N/A)	N/A
		internal,escape (31.7, 31.1)	0.15 / 0.09 / 0.27 / 0.04 (N/A)	
	4–5	internal,daily-used (28.8)	0.58 / 0.36 / 0.77 / 0.10 (N/A)	
		internal,escape (31.7, 31.1)	0.42 / 0.34 / 0.52 / 0.05 (N/A)	
	5–6	internal,daily-used (28.8)	0.67 / 0.47 / 1.01 / 0.13 (N/A)	
		internal,escape (31.7, 31.1)	0.50 / 0.36 / 0.71 / 0.09 (N/A)	
Cuesta et al. [18], Capote et al. [17,33]	4–6	internal,daily-used (33.9)	0.48 / 0.28 / 0.77 / 0.14 (45) 0.61 / 0.14 / 1.12 / 0.21 (46) 0.47 / 0.23 / 0.69 / 0.11 (46)	N/A
Najmanová and Ronchi [22]	3–4	internal,daily-used (26.6)	0.57 / 0.40 / 0.87 / 0.12 (44)	N/A
		external,escape (31.6)	0.34 / 0.16 / 0.47 / 0.07 (128)	
Hamilton et al. [23,24]	5	internal,N/A$^{2)}$ (N/A$^{2)}$)	0.51 / 0.34 / 0.68 / - (11)	N/A
	6		0.59 / 0.59 / 0.59 / - (2)	
	4–12	internal,daily-used,escape,(various)	0.92 / 0.19 / 2.03 / 0.26 (1039)	0.02–0.37 $m^2\,m^{-2}$
Current study	3–4	internal,external,daily-used (22.7–31.3)	0.71 / 0.28 / 1.21 / 0.21 (132)	0.00–0.05 $m^2\,m^{-2}$
	5–6		0.94 / 0.33 / 1.74 / 0.27 (346)	
	6–7		0.94 / 0.65 / 1.35 / 0.18 (66)	
	3–6		0.73 / 0.32 / 1.62 / 0.26 (128)	
Flights and landings of straight staircases				
Fang et al. [25]	5–6	internal,daily-used (28.0)	0.63 / 0.35 / 1.13 / 0.20 (61)	N/A
Current study	3–4	internal and external,daily used (22.7–31.3)	0.77 / 0.34 / 1.11 / 0.17 (49)	0.00–0.05 $m^2\,m^{-2}$
	5–6		1.03 / 0.37 / 1.66 / 0.27 (108)	
	3–6		0.90 / 0.51 / 1.30 / 0.22 (23)	
Spiral staircases				
Larusdottir and Dederichs [13,15]	3–6	internal,daily-used (33.0)	0.58 / 0.25 / 1.40 / 0.31 (N/A)	N/A
		internal,escape (33.0)	0.38 / 0.29 / 0.48 / 0.07 (N/A)	
		external,escape (30.0)	0.13 / 0.08 / 0.33 / 0.06 (N/A)	
Current study	3–6	external,escape (22.3)	0.89 / 0.36 / 1.41 / 0.27 (59)	0.00–0.05 $m^2\,m^{-2}$
		external,escape (32.3)	0.67 / 0.31 / 1.01 / 0.14 (48)	

$^{1)}$ 95% confidence interval

$^{2)}$ description provided; however, the staircases used by the pre-school children not specified

N/A information not available

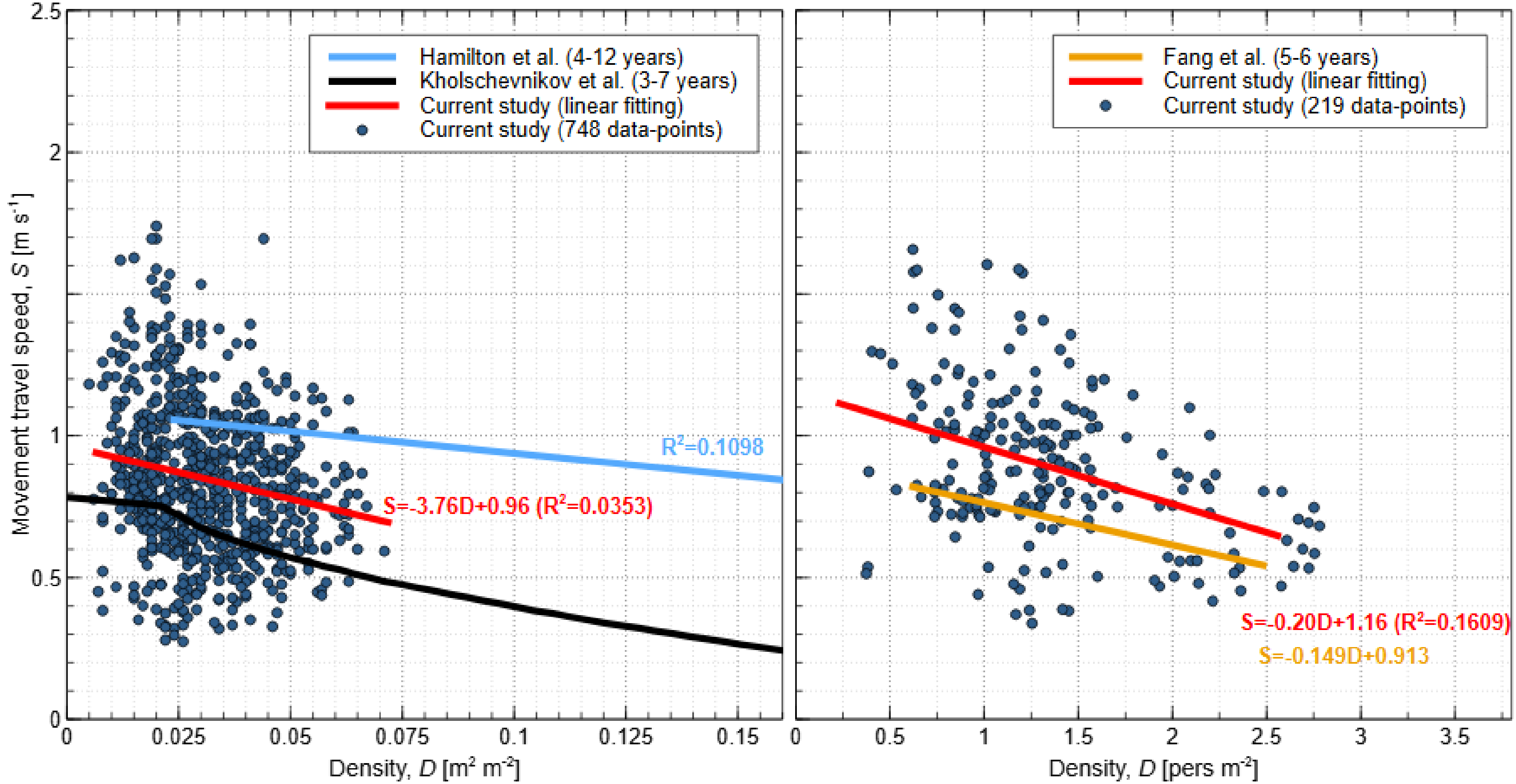


Figure 5.48: Travel speed per density (**left**: [$m^2\,m^{-2}$]; **right**: [$pers{\cdot}m^{-2}$]) with the linear trend line measured on straight staircases ((**left**: on flights; **right**: on whole staircases (flights ad landings combined)) during the experimental evacuation drills and comparisons to Kholshchevnikov et al. [16], Hamilton et al. [24], and Fang et al. [25]

Pedestrian flow and flow-density relationships

Corridors Based on the earlier literature review (see Section 2.3.2 and Section 2.3.4 for more details), only two research studies were found which provided flow-density relationships in pre-school children on a horizontal plane [16, 25]. The current data-sets and the relationships available in the literature were compared in Figure 5.49. The obtained experimental results were compared to literature data either in units of pers·m^{-2} or $m^2\,m^{-2}$ according to the referenced research studies. Whereas the quantitatively expressed trend line of experimental data-set presented by Fang et al. [25] was adopted directly, the design curve suggested by Kholshchevnikov et al. [16] was digitised and subsequently transformed from the unit of $m^2\,m^{-1}\,min^{-1}$ to pers·$s^{-1}\,m^{-1}$.

Comparing the current study with the trend line given by Fang et al. (Figure 5.49 right) a similar curve shape and peak values between 2.0 pers·$m^{-1}\,s^{-1}$ and 2.5 pers·$m^{-1}\,s^{-1}$ can be identified. However, differences are visible in the corresponding density where Fang et al. reported the highest specific flow at 3.2 pers·m^{-2}. In contrast, the maximum specific flow of the current data-set deemed to be at lower densities around 2 pers·m^{-2}. However, this interpretation is limited by the fact that the application range of the provided trend line can be assumed only for lower densities than 0.05 $m^2\,m^{-2}$. In comparison to the design curve proposed by Kholshchevnikov et al. [16] (Figure 5.49 left) the trend line of the current results showed a similar upward part; however, the peak occurred at considerably lower densities. Also in this case, the limited application range of the presented trend line should be kept in mind. In addition, it is important to note that the curve given by Kholshchevnikov et al. represents a suggested design curve and it exterminates at the density of 0.2 $m^2\,m^{-2}$ without a clear peak location.

Staircases Similarly to the previous evaluation in corridors, only two research studies were found discussing flow-density relationships in pre-school children climbing downstairs on staircases [16, 25]. The results published in these studies were used for a comparison with the current experimental data-sets provided in Figure 5.50. Kholshchevnikov et al. [16] presented a suggested design curve for flow-density relationship on flights of straight staircases (in density units of $m^2\,m^{-2}$, see Figure 5.50 left). Fang et al. [25] provided an experimental data-set observed on a straight staircase (two flights and one landing combined) in the form of a scatter plot with a quantitatively expressed trend line (in density units of pers·m^{-2}, see Figure 5.50 right)). The trend lines were adopted from the above-mentioned research studies using the same method as described in the part focused on children's flow-density relationships in corridors.

Looking at Figure 5.50, analogous trends may be identified as in the comparison of flow-density relationships in corridors (see Figure 5.49). Considering the comparison of the current results with the design curve suggested by Kholshchevnikov et al. [16], a similar upward part of the trend lines can be observed; however, the trend line from the literature does not showed a clear peak and it exterminates at considerably higher densities (around 0.2 $m^2\,m^{-2}$). When comparing the results obtained on whole straight staircases, the displayed curves show a similar shape and peaks between 1.4 pers·$m^{-1}\,s^{-1}$ and 1.8 pers·$m^{-1}\,s^{-1}$; nevertheless, the trend line given by Fang et al. [25] has the peak at higher densities (around 3 pers·m^{-2}) than the trend line of the presented data-set (around 2 pers·m^{-2}). Moreover, higher density conditions up to 5 pers·m^{-2} were observed during the experimental study presented by Fang et al. [25].

Doorways Considering pedestrian flow and its dependence on density, doorways represent the part of evacuation routes which is very commonly of interest by researches in both fire safety and pedestrian dynamics [4, 168, 169]. As they usually form narrow bottlenecks, doorways may cause crowded situations and considerably restrict the evacuation process. It is therefore not surprising that the largest number of research studies focused on movement characteristics of pre-school children discussed this variable [13,15,16,24,33]. A summary of the data-sets on pedestrian flow through doors available in the literature complemented with the results obtained in the current study for all age groups is provided in Table 5.50.

Table 5.50: Comparison of the observed pedestrian flows in doorways during the experimental evacuation drills with available literature

Reference	**Age [years]**	**Width [m]**	**Specific flow (mean/min/max/SD) [m·s^{-1}] (data-points)**	**Density**
Kholshchevnikov et al. [16]	3–7	0.6, 1.2	1.98 / - / - / - (32)	1–2 pers·m^{-2}
			2.50 / - / - / - (42)	2–3 pers·m^{-2}
			2.72 / - / - / - (11)	3–4 pers·m^{-2}
			3.03 / - / - / - (51)	4–5 pers·m^{-2}
			3.10 / - / - / - (80)	5–6 pers·m^{-2}
Capote et al. [33]	4–6	1.1	0.74 / - / - / 0.42 (47) 0.67 / - / - / 0.53 (46)	N/A
Hamilton et al. [24]	4–12	0.76–1.65	1.60 / 0.30 / 4.76/ 0.8 (1069)	0.01–0.36 $m^2\,m^{-2}$
Current study	3–7 (all age groups)	0.7–1.4	1.44 / 0.11 / 5.00 / 0.64 (160)	0.00–0.05 $m^2\,m^{-2}$
			2.55 / 0.91 / 6.25 / 0.85 (509)	0.06–0.10 $m^2\,m^{-2}$
			3.05 / 1.11 / 6.25 / 1.09 (268)	0.11–0.15 $m^2\,m^{-2}$
			3.08 / 2.22 / 6.25 / 0.95 (18)	0.16–0.20 $m^2\,m^{-2}$

N/A information not available

Based on the reported density intervals, the current data-set can be directly compared to the results presented by Kholshchevnikov et al. [16]. Since the authors assumed the horizontal projection for all age groups of children as 0.03 m^2, the density interval 1–2 pers·m^{-2} corresponds approximately to the density interval 0.00-0.05 $m^2\,m^{-2}$, the density interval 2–3 pers·m^{-2} approximately to the density interval 0.06-0.10 $m^2\,m^{-2}$, the density interval 3–5 pers·m^{-2} approximately to the density interval 0.11-0.15 $m^2\,m^{-2}$, and the density interval 5–6 pers·m^{-2} approximately to the density interval 0.16-0.20 $m^2\,m^{-2}$. In this view, a very good agreement can be seen between the compared data-sets. Considering the values provided in the study by Hamilton et al. [24], the current results on specific flow are higher despite of lower density conditions observed during the experimental evacuation drills. Nevertheless, it should be highlighted that the data-set presented in [24] included observations of children in a broader age range (4–12 years).

Flow-density relationships describing movement of pre-school children through doors demonstrated in a form of plots can be found in several research studies [13, 15, 16, 24]. A graphical comparison of these relationships with the current results is showed using trend lines in Figure 5.51. The dependency of specific flow on density was expressed either in units of pers·m^{-2} or $m^2\,m^{-2}$ according to the referenced research studies. The trend lines were adopted either directly [13, 15] or they were digitised from the original graphs when a mathematical expression was not available in the literature [16, 24]. In the case of the study published by Kholshchevnikov et al. [16], the extracted values of flow rates were further transformed from the unit of pers·$m^{-1}\,min^{-1}$ to pers·$s^{-1}\,m^{-1}$.

The comparison in Figure 5.51 showed that the trend lines presenting the current data-sets reach higher specific flows (approximately 3 pers·$s^{-1}\,m^{-1}$) at lower densities (around 0.12 $m^2\,m^{-2}$, i.e. approximately 4.6 children·m^{-2}). This finding may be related to lower density conditions observed during the experimental evacuation drills which did not exceed 0.18 $m^2\,m^{-2}$, i.e. approximately 7 children·m^{-2}. Looking at the trend lines adopted from the study presented by Hamilton et al. [24] where the movement of children at the age 4–12 years with different body ellipse areas was analysed (0.04–0.09 m^2), the impact of using of different density units can be clearly seen. This output confirmed the assumption that the density unit of $m^2\,m^{-2}$ may be more appropriate when heterogeneous population (such as children) is under consideration.

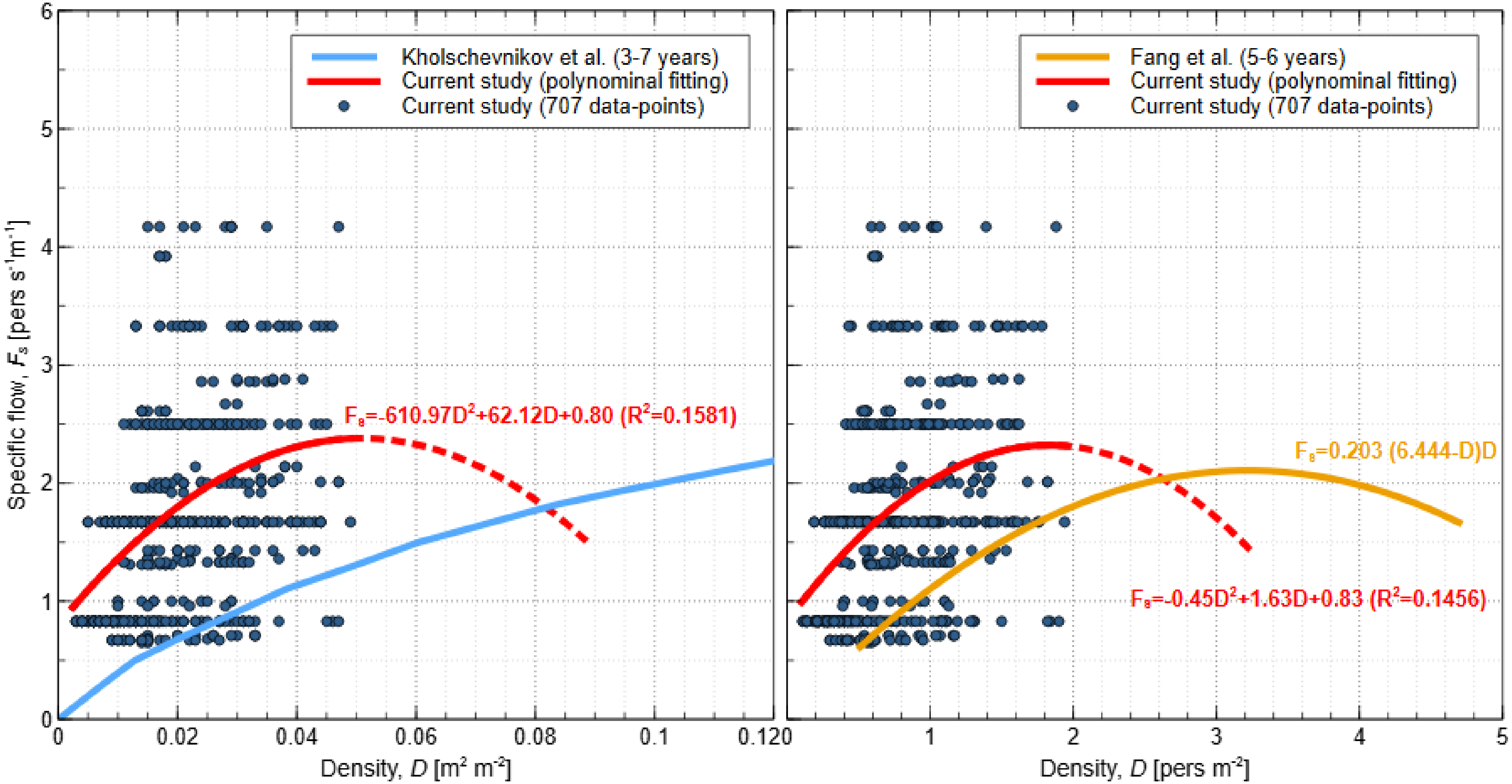


Figure 5.49: Specific flow per density (**left**: [m^2 m^{-2}]; **right**: [pers·m^{-2}]) with the polynomial trend line measured in corridors during the experimental evacuation drills compared to Kholshchevnikov et al. [16] and Fang et al. [25]

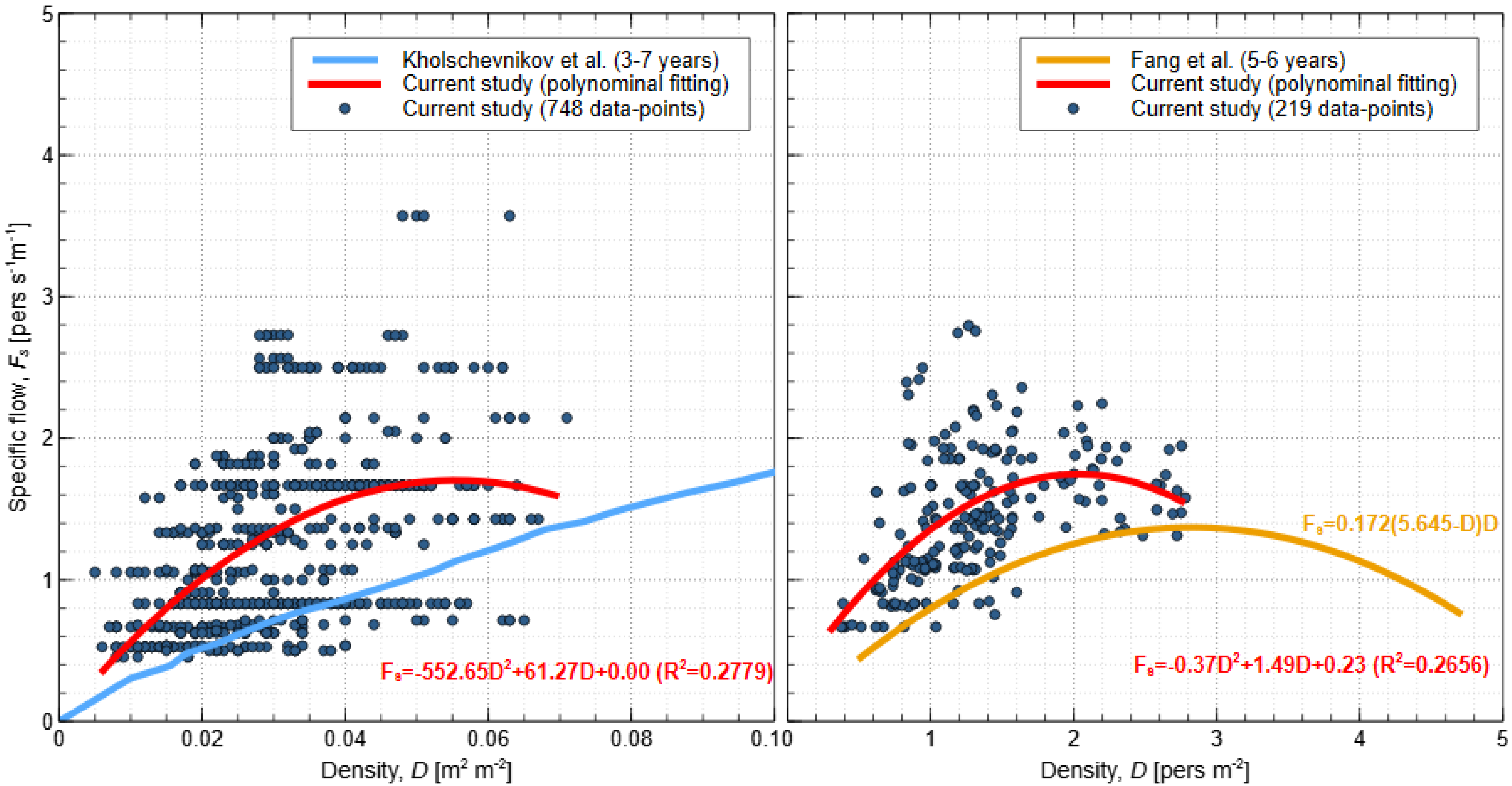


Figure 5.50: Specific flow per density (**left**: [$m^2\,m^{-2}$]; **right**: [pers·m^{-2}]) with the polynomial trend line measured on straight staircases ((**left**: on flights; **right**: on whole staircases (flights ad landings combined)) during the experimental evacuation drills compared to Kholshchevnikov et al. [16] and Fang et al. [25]

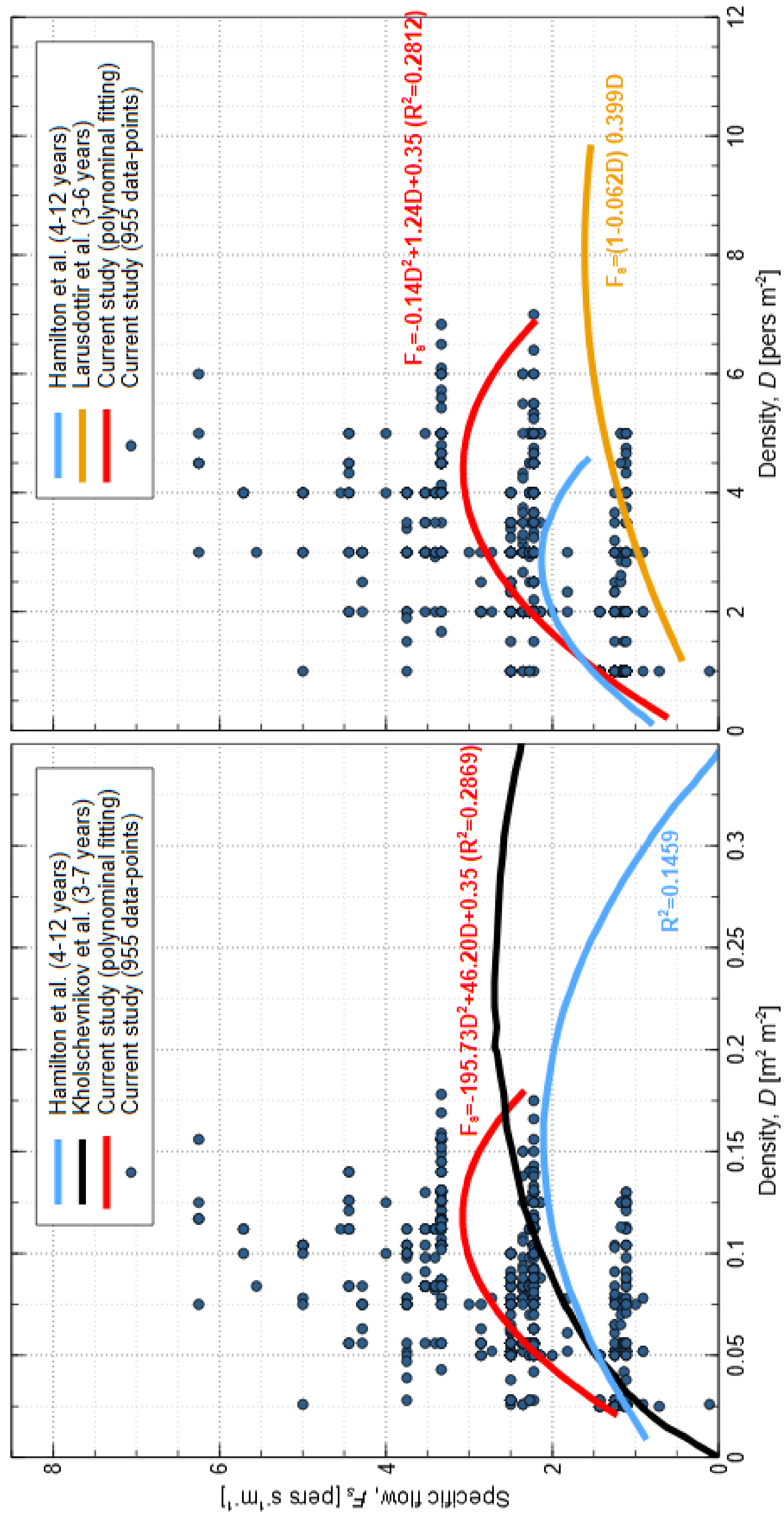


Figure 5.51: Specific flow per density (**left**: [$m^2\,m^{-2}$]; **right**: [$pers{\cdot}m^{-2}$]) with the polynomial trend line measured in doorways during the experimental evacuation drills compared to Kholshchevnikov et al. [16], Hamilton [24], and Larusdottir and Dederichs [13, 15]

5.5 Summary of the experimental evacuation drills

As a part of the current study, 15 experimental evacuation drills were conducted in 10 participating nursery schools in the Czech Republic during the period between May and June 2019. In total 803 children and 77 staff members were involved in the experimental evacuation drills, some of them participated in two experimental evacuation drills. The participating nursery schools varied across their building design, capacity, experience with regular evacuation drills, and evacuation procedure. Children in the participating nursery schools attended both homogeneous and heterogeneous types of classes. For the purpose of further analysis, different age groups of children were distinguished: Junior (3–4 years), Senior (5–6 years), Senior+ (6–7 years), and Mixed children (3–6 years). Based on the decision of the leader of each participating nursery school, the experimental evacuation drills were either announced, semi-announced, or unannounced to staff members and children. All experimental evacuation drills were video recorded and the acquired recordings were used for subsequent analysis of children's and staff members' behaviour as well as children's movement characteristics. A detailed description of the research methods employed was provided in Section 5.2.

Evacuation behaviour was observed in both the pre-movement and movement phase of the evacuation process. During the pre-movement phase, warning times, pre-movement times, and evacuation behaviour including interpretation of warning signal, reactions and activities of staff members and children, level of physical assistance provided to children by staff members, and leaving strategy were observed resulting in more than 1,800 data-points for the further analysis. In order to study movement characteristics of children and their evacuation behaviour when travelling through a building, in total 100 measurement areas were defined in advance on different parts of evacuation routes (in corridors, on staircases, and in doorways). Considering movement characteristics, in total 11,000 data-points were gathered to investigate movement travel speed, specific flow, and density of children and their relationships. On a horizontal plane (in corridors, on landings of straight staircases, and in doorways), movement travel speed was evaluated separately for walking and running children. The walking and running movement was distinguished based on the presence/absence of the flight phase using the video recordings. On straight staircases, the movement on flights and landings was analysed separately; moreover, combined results describing children's movement on whole straight staircases (flights and landings combined) were provided. The determined measurement areas located in different parts in a building were simultaneously used for observation of movement behaviour of children and the overall evacuation procedure, complications, and problematic parts in the experimental evacuation drills (in total around 12,000 data-points). The obtained findings and outcomes were presented and interpreted in Section 5.3 and can be summarised as follows:

- Evacuation of pre-school children in the participating early childhood educational institutions was mostly highly organised as well as strongly dependent on reactions, decisions, actions, and preparedness of responsible staff members.

- Pre-movement times measured during the experimental evacuation drills ranged from 3 to 59 s depending on specific conditions of the experimental evacuation drills. Besides other aspects (e.g. potential differences in reactions of staff members, location of children in the building, staff-to-child ratio and actual state of mind of the participants), the age of children, level of announcement, preparedness of the participants, and organisation strategy taken by staff members were identified as the factors most impacting the pre-movement time in the evacuation process.
- Pre-school children mostly did not respond to a warning signal independently and additional impulse and instructions given by responsible staff members were necessary to trigger the evacuation process. Reactions of children and staff members to alarm were affected by their current activity and location in the building.
- Evacuation behaviour of pre-school children and staff members reflected to a large extent daily practice which tightly connected to educational programmes employed in the early childhood education institution. Pre-school children tended to follow a sequence of memorized daily activities. Behaviour of staff members was influenced by ordinary practise established in the institution. The principles of the affiliation model and role-rule model were identified during the experimental evacuation drills.
- Pre-school children tended to use familiar exits and escape routes; however, the final exit choice was usually in competence of staff members.
- Physical help (gentle pushing, physical contact, hand holding, carrying) was provided by staff members to 25% of the participating children during the pre-movement phase and to 9.9% of the children travelling through a building. The level of assistance required by children during the evacuation process and actions and instructions given by staff members were age-dependent (more physical assistance received younger children under 4 years of age) and affected by the actual staff-to child ratio as well as by daily routines in the early childhood educational institution.
- Movement travel speed of children measured on different parts of evacuation routes was dependent on the age of children and actual density conditions. In general, in contrast to the older children above 4 years of age (Senior children, Senior+ children) a slower movement (walking or running) was observed in the case of younger children under 4 years of age (Junior children, Mixed children). The most remarkable differences in travel speed between younger and older children were identified in corridors where the travel speed of the older children reached almost double the value of the younger children. Regardless of age, children travelled at higher travel speeds on horizontal parts of evacuation routes (in corridors, on landings of straight staircases, in doorways) than on flights of straight staircases and on spiral staircases. Furthermore, the walking and running travel speeds observed on landings and in doorways were considerably lower than the travel speeds measured in corridors. The relationships between travel speed and density was demonstrated graphically

and the calculated trend lines confirmed the general assumption that the travel speed decreases with increasing density on all types of the observed evacuation routes.

– Pedestrian flow of children on different parts of evacuation routes was considered as specific flow related to 1 m of effective width of the measurement area. Similarly to movement travel speeds, the obtained results indicated the influence of children's age (increasing specific flow with increasing age of children); however, in this case this influence was not so pronounced and apparent. Furthermore, higher values of specific flow were measured under the higher density conditions.

– With the exception of the situations when the movement of children was disturbed with stops, only low-density conditions (less than 0.1 $m^2\,m^{-2}$, i.e. approximately 3.8 children·m^{-2}) occurred in the measurement areas in corridors and on staircases. Higher density conditions (up to 0.18 $m^2\,m^{-2}$ (i.e. approximately 7 children·m^{-2}) were observed only in doorways.

– The most challenging part for the pre-school children was movement downstairs on staircases when travelling through a building. Handrails were used in 67.6% of the participating children. Movement abilities especially of younger children under 4 years of age may be considerably impeded by the ongoing developmental changes compensated by using of marking time pattern (19.8% of Junior children). Children's movement behaviour on staircases can be substantially affected by the staircase geometry.

– When travelling through a building, hand holding was observed in 41.8% of the children (in 36.5% between children, in 4.3% between children and staff members). Moreover, close physical contact (such as touching and pushing) between each other was common among the children. Under higher density conditions the children could form a very compact crowd with a minimal body buffer zone.

– Children's movement behaviour such as hand-holding, moving in pairs, moving in compacted groups, using of handrails, independent manipulation with doors (i.e. their opening, unlocking), can be strongly influenced by instructions given by staff members as well as by daily routine, rules, and educational practises employed in the early childhood education institution.

– Familiarity with evacuation routes and evacuation procedure played an important role in evacuation efficiency. Evacuation procedure including both pre-movement and movement phase can be improved by regular training.

The presented results on evacuation behaviour and movement characteristics of children were further compared with the relevant data-sets available in the literature (Section 5.4). In addition, the summarised findings on behavioural aspects resulting from the literature review provided in Chapter 2 were discussed and assessed in the light of the current outcomes. The obtained results and knowledge concerning evacuation behaviour, movement, and procedure involving pre-school children in nursery schools are also interpreted in the application part of this study, Chapter 7. In that chapter, the practical application of the current research findings in fire safety design and in educational institutions attended by children at the pre-school age is further elaborated and developed.

Chapter 6

Questionnaire on nursery schools in the Czech Republic and their implementation of evacuation drills

6.1 Introduction

In this section, the current experimental research carried out on the basis of a questionnaire focused on real operational conditions in nursery schools in the Czech Republic and their daily practise with evacuation drills (also called fire drills) is presented. In order to put this issue into context, basic information on early childhood education and care in the Czech Republic as well as specific fire safety requirements for nursery schools in the Czech Republic are briefly introduced.

6.1.1 Pre-school education in the Czech Republic

As mentioned in the introduction part of this study, in the Czech Republic, preschool education is institutionally provided by nursery schools and it is normally designed for children of the age from 3 to 6 years. However, nursery schools can be attended also by children aged over 6 years (by those with postponement of the compulsory school attendance) or under 3 years (but not by those aged less 2 years). The pre-school education is obligatory for children in the pre-primary year, i.e. for children aged at least 5 years (preparatory classes). Children from 5 years of age are also given preference in the acceptance process and, by contrast to children whose attendance is not compulsory, the education is provided free of charge for them. In addition, on the basis of parental interest, pre-primary education must be ensured for children who reach at least 3 years of age [170, 171]. Enrolment rates of children in nursery schools related to their age actual for the school year 2018/2019 are displayed in Figure 6.1.

Under the Education Act [173], nursery schools are legislatively embodied within the educational system under the purview of the Ministry of Education, Youth and

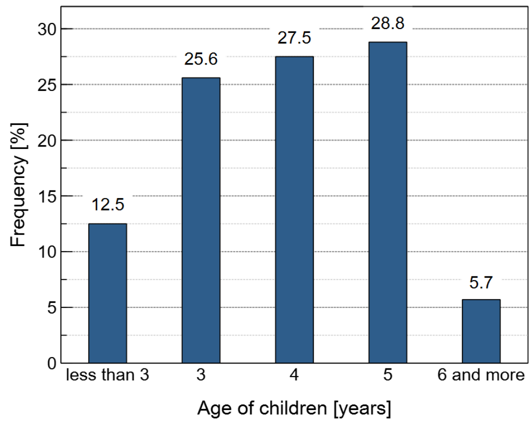


Figure 6.1: Enrolment rates related to children's age in nursery schools in the Czech Republic in the school year 2018/2019 [172]

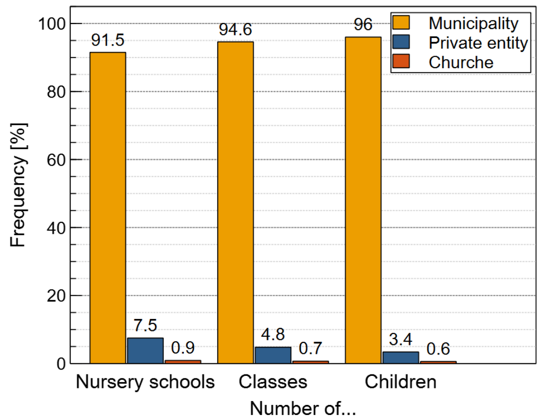


Figure 6.2: Number of nursery schools, corresponding classes, and attending children in related to the different founding entities in the Czech Republic in the school year 2018/2019 [172]

Sports as a type of school. Organisationally, they are divided into classes which are filled up to 24 children (an exception up to 4 children over this limit is legislatively allowed but it must be made by the founding entity). The minimum number of children in a class is 13 children in one-class nursery schools if they are the only early childhood education institution in a municipality. In terms of children's age, classes can be organised as homogeneous or heterogeneous; in other words, in is possible to place children of the same or different age in one class. Similarly, it is allowed to integrate children with special educational needs into a class of a mainstream nursery school (integrated class). In the case that support measures given in inclusive conditions are not sufficient to meeting the educational needs of children, children with special educational needs or health disabilities (such as mental, visual, hearing, physical disabilities, serious developmental learning impairments or speech impediments, multiple impairment, autism) can be educated separately in special classes or in independent special nursery schools [170, 171].

The great majority of nursery schools are founded by the municipality, only a small number of nursery schools have been established by private founding entities and denominational founders (see Figure 6.2). Nursery schools for children with special educational needs are established by a regional authority or the Ministry of Education, Youth and Sports. In general, nursery schools are established with full-day operation (6.5–12 hours a day), half-day operation (at maximum 6.5 hours a day) and boarding operation (full-day and night care). Children's attendance in nursery schools can be full-time or part-time based on the decision of parents and the present educational programme. The main requirements, conditions and rules for the institutional education of children of preschool age are specified by The Framework Education Programme for Preschool Education issued by the Ministry of Education, Youth and Sports. However, nursery schools can have their own educational programmes focused on aesthetic or movement activities and they can include some of the alternative programmes, e.g. Montessori pedagogy, Waldorf pedagogy, Dalton pedagogy, outdoor pre-school education. In nursery schools, children are taught by teachers whose education must always be specialised in pre-school pedagogy, mainly by graduates of secondary pedagogical schools. The extent of direct pedagogical activity of a nursery-school teacher is 31 hours a week [170, 171].

According to the Czech Statistical Office, there have been 5,287 nursery schools with 16,064 classes attended by 363,776 children (22.6 children in a class on average) in the Czech Republic in the school year 2018/2019. In addition, 3.1% from the total number of children were children with special educational needs who attended either integrated classes in mainstream nursery schools (39%) or separate classes intended for children with special educational needs in mainstream nursery schools and in special nursery schools (61%). Related to full-time equivalent, 30,404 teachers have been employed in nursery schools which indicates an average staff-to-child ratio of 11.9.

6.1.2 Specific fire safety requirements for early childhood education institutions

Institutions providing pre-school education represent occupancies with very high ratio between adults and children between 3–6 years of age and with specific operational and daily regime. Challenging evacuation conditions resulting from high proportion of vulnerable population with limited self-rescue capabilities are usually reflected in national building codes and fire safety standards in form of special or additional requirements. An interesting overview of international fire design requirements for single and multi-story childcare centres has been provided as a part of study by Page and Norman [160] focused on fire safety in early childhood centres in multi-story buildings in New Zealand. This study offers a comprehensive summary of fire safety regulations in the US, UK, Singapore, Finland, Western Australia, Sweden, Ireland, New South Wales, Norway, Belgium and Denmark.

In the Czech Republic, fire safety protection and design is regulated by the Czech codex of fire standards which consists of number of laws, regulatory instruments (decrees and government regulations), technical standards, and Eurocodes. As the key documents, the Act No. 133/1985 Coll. on fire protection [173] and related regulations the Decree No. 23/2008 Coll., on technical conditions for fire protection of buildings [174] and the Decree No. 246/2001 Coll. on fire prevention [175] can be mentioned. In these documents, general requirements as well as specific requirements for particular building occupancies are laid down superior to the technical standards. However, the complex system of regulations and requirements related to fire safety is dealt with in more than 100 Czech technical standards focused on fire safety design, testing, values, and classification. New buildings of nursery schools have to be designed in according to the generic fire Czech Technical Standard (ČSN) 73 0802 Fire protection of buildings - Non-industrial buildings. In addition, specific requirements for nursery schools located in new buildings are set down by the Decree

No. 23/2008 Coll., on technical conditions for fire protection of buildings [174]. The requirements related to evacuation are summarised as follows:

– Buildings of nursery schools may have at maximum two floors (the ground floor and the first floor); a space intended for children may not be designed in a basement. In multi-storey buildings which include also other occupancies than nursery schools, a nursery school may be located not higher than on the first floor level.
– A nursery school for more than 20 children has to be designed with two escape routes. In nursery school occupancies, swing doors and turnstiles are not permitted on escape routes.
– A nursery school for more than 100 children has to be equipped with a broadcast capable to be operational during a fire.

Besides, in buildings of nursery schools, load-bearing structures and fire structures and elements from flammable materials without any non-combustible covering (a DP3 type of structure) are not permitted. When new nursery schools shall be located in old buildings, fire requirements are less stringent, since 2011 regulated by the design Czech Technical Standard (ČSN) 73 0834 Fire protection of buildings - Changes of buildings. Evacuation conditions for those occupancies are set down as prescribed number and type of evacuation routes. If no direct exit to outside is available: from a classroom for less than 12 children located at maximum on the first floor only one partially protected escape route is required; from a classroom with more than 12 children or located on the second floor one protected escape route is required, two protected escape routes are required if there are more than 20 children a in a class or more classes in a building. Nevertheless, it should be mentioned that large number of nursery schools were built before these standards have been effective and therefore real evacuation conditions can considerably differ.

In line with the Act No. 133/1985 Coll. on fire protection [173] and the Decree No. 246/2001 Coll. on fire prevention [175] emergency evacuation plans are required in nursery schools which are attended also by 2-year-old children (not in nursery schools attended only by older children, i.e. at least 3-year-olds). If required in the fire safety documentation of the building the emergency evacuation plan shall be regularly examined during evacuation drills. In other words, according to the Czech legislation there is not a specific requirement on regular evacuation drills in early childhood education occupancies. The mandatory requirement to held evacuation drills on a regular basis may or may not be included in fire safety documentation of the building processed by a professionally competent person at the fire prevention section.

6.2 Methods

Actual knowledge describing real operational conditions in nursery schools in the Czech Republic and their daily life experiences and practices related to performing of evacuation drills was collected via an anonymous online questionnaire. The questionnaire was designed in consultation with the Prevention department and the Department for instruction and training services at the General directorate of Fire rescue service of the Czech Republic in order to provide results beneficial for its further use.

6.2.1 Questionnaire description

The questionnaire was divided into two main parts:

- Part 1 - General information was focused on mapping of basic data describing construction and operational conditions in nursery schools such as characteristic of a building enclosure or occupancy characteristic and capacity. This part of the questionnaire aimed to acquire relevant background information for fire safety design and useful also for forthcoming revision of Czech Technical Standards for Fire protection of buildings.
- Part 2 - Evacuation drills looked solely at actual practice and experiences of nursery schools with performing of evacuation drills.

Part 1 was intended for all invited nursery schools. Part 2 was available only to those nursery schools which positively replied to the last question of Part 1 which asked whether evacuation drills are performed in the nursery school or not. In total, the questionnaire included 20 questions; each part consisted of 10 questions. The used question type varied: 3 questions were close-ended and remaining 17 questions multiple-choice (in 3 cases more than one option could be selected and in 12 cases the editable “Other” category was included). Moreover, 19 questions included additional space for further comments. None of the questions were mandatory. The complete questionnaire in the original language (in Czech) and its translated version in English are attached in Appendix D.

6.2.2 Data collection and analysis

The questionnaire was intended for leaders of the nursery schools registered in the Register of Education Institutions at the Ministry of Education, Youth and Sports with available e-mail contact information (i.e. independently of the founding entity or educational programme). In total, 4,930 nursery schools were invited to participate in the survey through emails linking to the questionnaire. The questionnaire was created using the tool Google Forms and it was available online in June and July 2019.

Before the distribution of the questionnaire, a pilot study involving 5 leaders of nursery schools was performed to ensure that the questions are clear and easily understandable and to obtain a feedback on the questionnaire design and time costs.

Responses were received in electronic form. Obtained data was organised and processes in spreadsheets, while the graphs presenting the results were developed in Veusz 3.0.1.1 software [164].

6.2.3 Limitations

Despite a questionnaire may be a useful instrument for collecting data in survey research, several limitations should be considered to appropriate interpretation of the obtained results. First, the response rate of the questionnaire was not 100% (see details in Section 6.3.1) and thus results being prone to response-rate bias [176]. Second, the trade-offs between the use of technical words and the knowledge of respondents of terminology should be considered when designing such type of questionnaires. This is a known issue in online questionnaire design [177] which may make it difficult to use this method of investigation to obtain technical information from non-technical respondents. Nevertheless, the great advantage of online questionnaires are the possibility to have a broad dissemination and obtain a great body of information within limited time. This would not be possible with alternative methods such as structured or semi-structured interviews.

6.3 Results and discussion

6.3.1 Response rate

The invitation to participate in the survey was sent to 4,930 nursery schools; however, in 203 cases the contact email address referred in in the Register of Education Institutions at the Ministry of Education was invalid and valid contact information had to be found. In total, 4,903 invitation emails were successfully delivered and 1,157 responses were received. Calculated as a ratio between the number of the returned questionnaires divided by the number of the sent invitations, **the response rate was 23.5%**. Several questionnaires were completed only partially where some questions were left out. As can be seen in Figure 6.3, obtained responses had a balanced geographical coverage of the Czech Republic (***Question 1: In which region is the nursery school located?*** (multiple-choice, “Other” category not available).

As a part of the responses, in total 1,472 comments were received (378 comments in Part 1 and 1,094 comments in Part 2). All comments given by respondents were evaluated in detail and they were integrated into the results interpretation (when applicable). Besides the questionnaire replies, additional 28 email responses were received out of which 15 nursery schools expressed interest in the results of the survey, 10 nursery schools apologised and explained why they did not fill out the questionnaire, and 3 nursery schools just confirmed their participation in the survey.

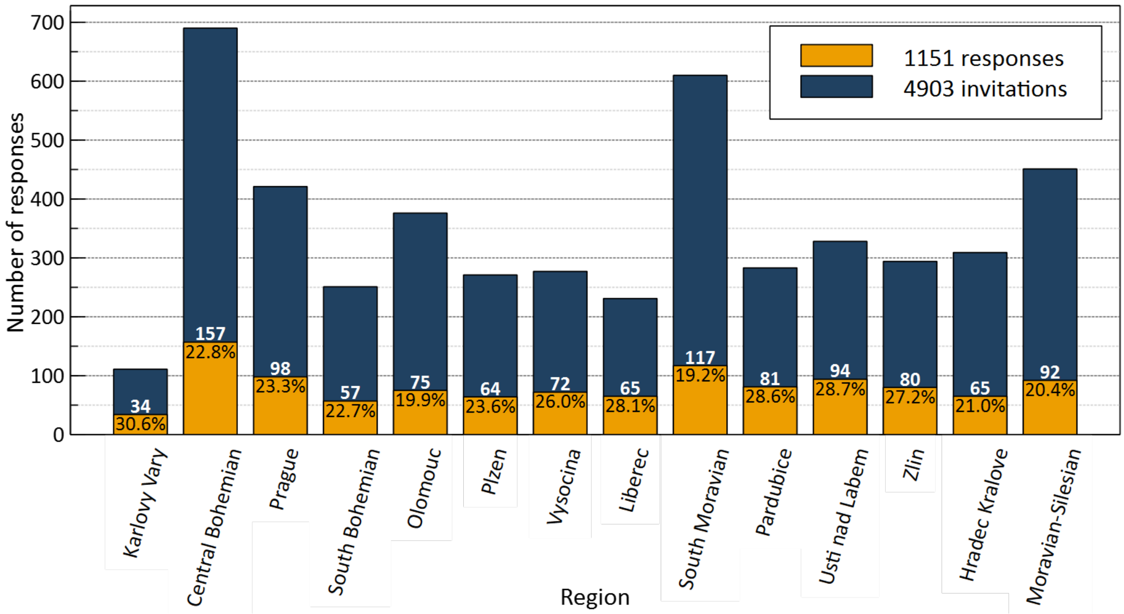


Figure 6.3: Number of responses and response rate received in different regions of the Czech Republic

6.3.2 Part 1: General information

The first part of the questionnaire intended for all invited nursery schools focused on general description of building enclosures in which nursery schools are located, their capacity and occupancy (e.g. assumed number of persons and their staff-to-child ratio), and their experiences with fire safety documentation and performing of evacuation drills.

Capacity and occupancy

One of the objectives of the questionnaire was to get an overview about the capacity of nursery schools, i.e. how many classes can be commonly found in one building of a nursery school. This issue was tackled in ***Question 2: How many classes are in the nursery school?*** (close-ended, "Other" category not available). However, the comments showed that it is not uncommon that a nursery school (as an institution) is located in more than one building. Furthermore, a nursery school as a legal entity can associate more nursery schools together. For these reasons, respondents may have indicated the total number of classes present in all buildings of the nursery school under scrutiny rather than the number of classes in each of the building. These circumstances can explain replies stating that the nursery school has 16 or 20 classes, evidently not located in one building. A better assessment of the number of classes could have been performed in parallel with reviewing the buildings in which they were located. Key information about multiple buildings and workplaces were frequently disclosed in comments. In those cases it was possible to determine the real number of buildings and classes. Therefore, in total 1,150 replies were elaborated into 1,218 values graphically illustrated in Figure 6.4. However, it could not be excluded that some of the respondents misinterpreted the question while leaving any explaining comment.

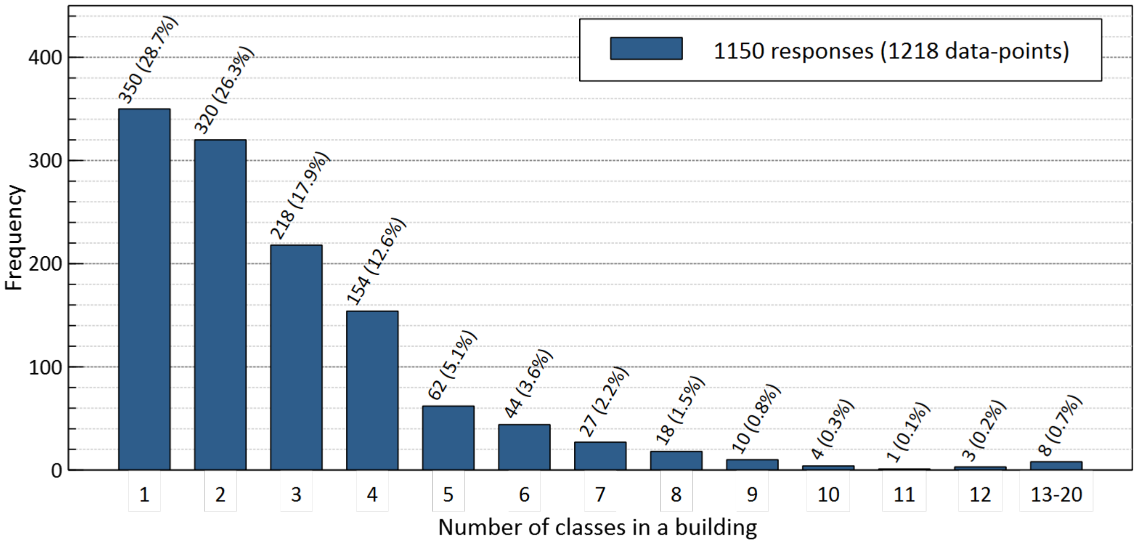


Figure 6.4: Number of classes in a building of a nursery school

The results showed that most frequent are one-class nursery schools (28.7%) followed by nursery schools with 2 to 4 classes (56.8%), together 90.6% of the responses. Nursery schools with more than 4 classes are less common (9.4%); nevertheless, it can be assumed that a nursery school with 5 to 10 classes can be still located in one building (8.5%). Here, the fact should be taken into account that nursery schools as legal entities may group more buildings or workplaces and the real number of classes in one building may be lower. Despite of their lower frequency, nursery schools which building capacity is higher (e.g. 8, 9, or 10 classes in one building) should also be borne in mind.

The questionnaire further aimed to obtain information about occupant characteristics especially expected number of children and staff members in a class resulting in the variable of staff-to-child ratio. Information about number of children and staff members was obtained through two separated questions (***Question 3: How many children are on average in a class?*** (close-ended, "Other" category not available) and ***Question 4: How many teaching staff members (teacher, teacher's assistant, educator) are on average in a class?*** (close-ended, "Other" category not available)). The obtained results are shown respectively in Figure 6.5 and Figure 6.6.

Considering the question on the average number of children in a class it should be clarified that the question formulation was not precise in the term of average number of which children is questioned, i.e. if average number of enrolled children or usually present children. This shortage was pointed out by several respondents who also reported both options in their comments. In those cases, the values of enrolled children were considered following the original purpose of the question. Neverthe-

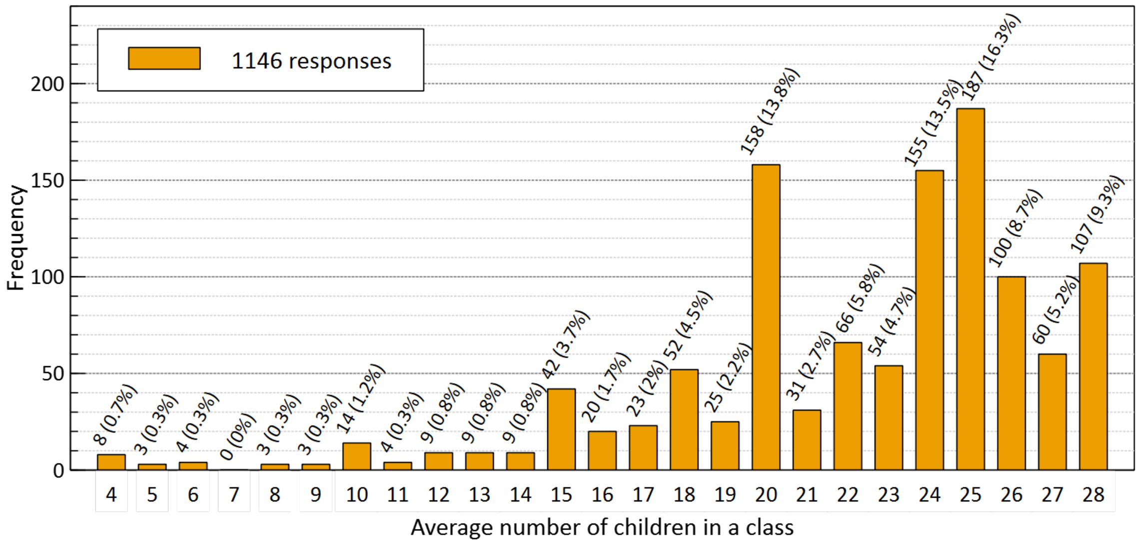


Figure 6.5: Average number of children in a class

less, it can not be ruled out that both meaning of the wording were understood by the respondents. On average, the most frequent number of children in a class ranged between 20 and 28 children (80.1%) with the median value of 24 children. In 8 cases, those values were negatively commented by the respondents as too high or at the expense of children's safety. Besides that, lower values of children's number in a class should be considered in separate classes intended for children with special educational needs in mainstream nursery schools or in classes in special nursery schools. Based on 20 comments, the average number of children in those classes ranged between 6 and 10 children. Moreover, lower number of children in a class can be expected in classes intended for younger pre-school children. In Figure 6.6 the results on average number of staff members in a class are illustrated. In this context, similarly to the whole study, staff members should be understood as teacher staff members (e.g. teachers, teacher's assistants, educators). The replies containing decimal numbers were rounded in line with standard rounding up rule, i.e. they were rounded down to the nearest unit when the first decimal was 0 to 4 and rounded up when the first decimal was 5 to 9. The results showed that most frequently there are 2 staff members in a class (66.4%), followed by 3 staff members in a class (20.7%). More than 3 staff members in a class were stated by 3.5% of respondents and only one staff member in a class by 5.9% of respondents. For clear interpretation of the results should be also mentioned that respondents could consider both number of physical persons or full-time units. In addition, the comments revealed that number of physical persons is mostly higher than number of full-time units. Different values should be assumed in separate classes intended for children with special educational needs in mainstream nursery schools, in classes in special nursery schools, and in classes intended for toddlers and younger pre-school children. In those cases, the average number of staff members in a class may be consider higher, e.g. 3–4 staff members in a class regardless of lower number of present children. Furthermore, it should be borne in mind that overlapping of staff members in a class in different day time may often occur. In such situation, 2 staff members are present in a class only 2.5-3 hours a day typically at moon (e.g. leaders of a nursery school have a reduced part-time teaching activities to 6 hours daily). In the remaining parts of a day, only one staff member is present in a class. This model is common especially in smaller nursery school (e.g. one-class nursery schools) where only 2 staff members are employed. Consequently, the situation when only one staff member is available for a whole class may be more frequent in reality. This assumption confirm also observations obtained during experimental evacuation drills performed as a part of the experimental research of this work (see Section 5.2.1 for details). In total in 46 classes in 15 nursery schools, the number of staff members in each class varied from 1 to 3 staff members. In more than half of the cases (57.9%), only one staff member was present, whereas 2 staff members were present in 31.6% and 3 staff members were only in 10.5% of the observed classes. It is important to mention that these values were observed in morning hours, i.e. in the time when work shifts of staff members does not usually overlap. Apart from that the comments stated that besides 2 teachers the third person of present staff in a class is usually a teacher's assistant or an educator (a nanny).

The above mentioned values describing average number of children and staff members in a class were further used for calculation on average staff-to-child ratio graphically displayed in Figure 6.7. Average staff-to-child ratio was calculated separately for each responding nursery school as a ratio between the provided number of children in a class and the provided number of staff members in a class. For reasons of clarity, the calculated ratios were clustered into several groups bounded by whole figures in the following way:

– Numerical interval ⟨X.0–Y.5) labeled as X–Y; e.g. ⟨0.0–4.5) labeled as 0–4
– Numerical interval ⟨Y.5–Z.5) labeled as Y–Z; e.g. ⟨4.5–9.5) labeled as 5–9

It can be seen that the most frequent calculated staff-to-child ratio varied between 10 and 14 children per a staff member (59.2%) and then between 5 and 9 children per a staff member (31.3%). Values higher than 15 children per a staff member occurred only in 4.8% of the cases. Since these results were directly calculated from the values of average number of children and staff members discussed above their interpretation should be always linked to the additional explanations and clarifying comments discussed above.

In addition to information concerning number of persons who may occur given the nursery school occupancy and staff-to-child ratio, the focus was set on the organisation of classes in terms of children's age. As noted in the introduction of this section, in the Czech Republic, both homogeneous and heterogeneous classes can be found in nursery schools. During evacuation, classes in nursery schools are typically organised and moved through a building as whole groups (see Section 6.3.3, Question 16 and Question 17) and therefore impacted by the age of each child in the group. Evacuation process of heterogeneous classes with broader age range of children may be specific. Due to different physical and cognitive abilities of children at different age, the group may be spontaneously divided into a slower and faster

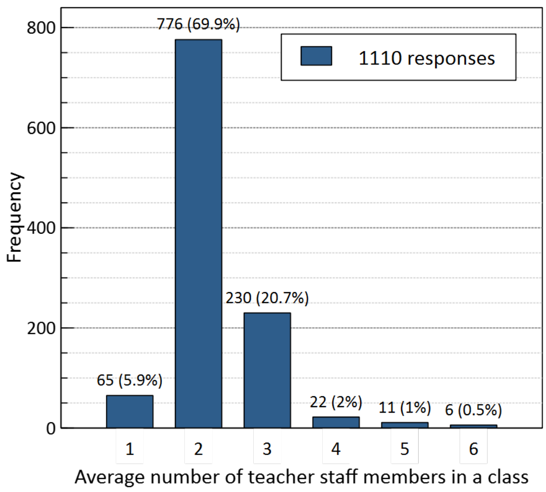


Figure 6.6: Average number of teacher staff members in a class

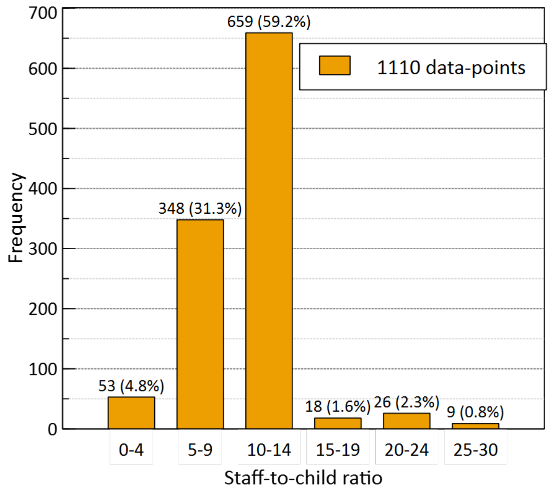


Figure 6.7: Average staff-to-child ratio

part making the supervision of children more difficult. By contrast, older and more experienced children may assist the staff members by providing help to younger children (e.g. by hand holding or giving personal contact). On the contrary, neglecting the interpersonal diversity, it can be assumed that in homogeneous classes (intended for children of the same or similar age and thus with similar skills) the evacuation process may be expected to be more consistent. In any case, during evacuation, staff-to-child ratio plays an important role. Based on the above mentioned results of the questionnaire, in heterogeneous classes with younger children, lower staff-to-child ration may be expected.

The issue of representation of homogeneous and heterogeneous classes in nursery schools was investigated in ***Question 5: Are children divided into classes based on their age?*** (multiple-choice: *No, classes are heterogeneous; Yes, classes are homogeneous*; “Other” category available). In the case that the responded chose the second option (homogeneous classes), a sub-question was applicable: *Which age categories do correspond to the particular classes?*. Based on 56 replies in “Other” category which referred that there are both types present in a nursery school, a separate category labeled “Combination” was subsequently created. A graphical summary of the results is provided in Figure 6.8.

In more than half of the cases (56.8%), the nursery schools responded that children are organised in heterogeneous classes (i.e. with the eventual age range from 3 to 6 years; in special cases from even 2 to 7 years). In contrast, homogeneous classes were identified by 37.4% of the participating nursery schools. In 4.9% of the responses, both options were indicated in the “Other” category. From those replies it was apparent that there is common a combination of heterogeneous classes (e.g. for children aged 3–5 years) and separated preparatory classes (e.g. for children aged 5–7 years) or separated classes for very young children (e.g. aged 2–3 years).

The sub-question focused on the specification of age groups in homogeneous classes was answered in 158 comments and in 5 replies in “Other” category. In

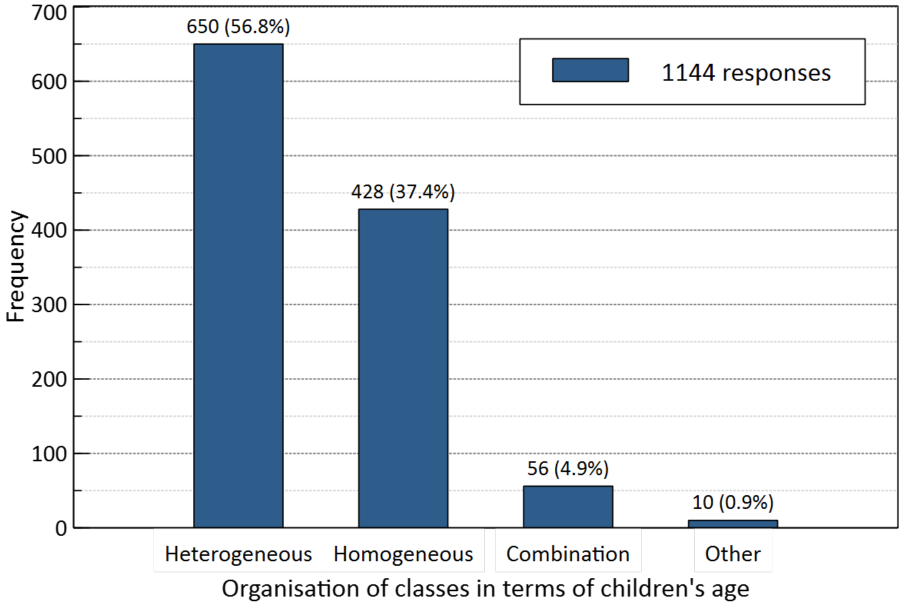


Figure 6.8: Organisation of classes in terms of children's age

total, 148 data-points regarding number of age groups and 379 data-points related to the age range were obtained. The result are given in Figure 6.9 and Figure 6.10. The results showed that most frequently (in total in 87.1%) there are 2 or 3 age

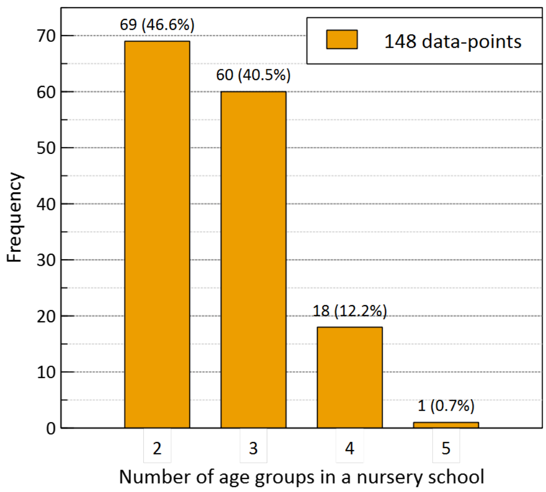


Figure 6.9: Number of age groups (different homogeneous classes based on children's age) in nursery schools

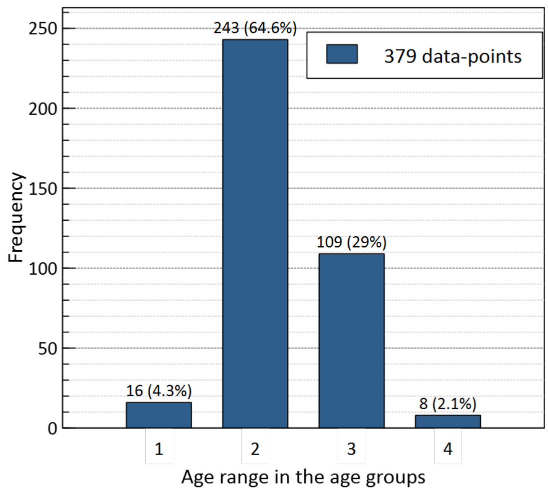


Figure 6.10: Age range of the age groups (different homogeneous classes based on children's age) in nursery schools

groups (in terms of different homogeneous classes based on children's age), less frequently than 4 age groups (12.2%) in the responding nursery schools. In the case of 2 age groups, younger children (e.g. aged 3–4 years) and older children (e.g. aged 5–6 years) are divided into separated classes. The age range in homogeneous classes is most frequently 2 years (64.6%), followed by 3 years (29.0%).

Building enclosure

The questionnaire was further focused on a basic description of building enclosures in which the nursery schools are located, specifically on which floors spaces intended for children are located and if an external escape staircase or staircases are available in the buildings. These issues were questioned separately in two questions: ***Question 6: On which floors the spaces intended for children are located in the nursery school?*** (multiple-choice, more choices possible: *Ground floor; First floor; Second floor*; "Other" category available) and ***Question 7: Is an external escape staircase/staircases available in the building of the nursery school?*** (multiple-choice: Yes; No; "Other" category available).

The results concerning the location of spaces intended for children (such as classrooms, lunchrooms, bedrooms, gyms) were evaluated in two ways:

- The frequency of the floors combination where children can be present was calculated (i.e. at how many and on which floors spaces for children are located in the building), see Figure 6.11,
- The frequency of floors where children can be present was evaluated, see Figure 6.12.

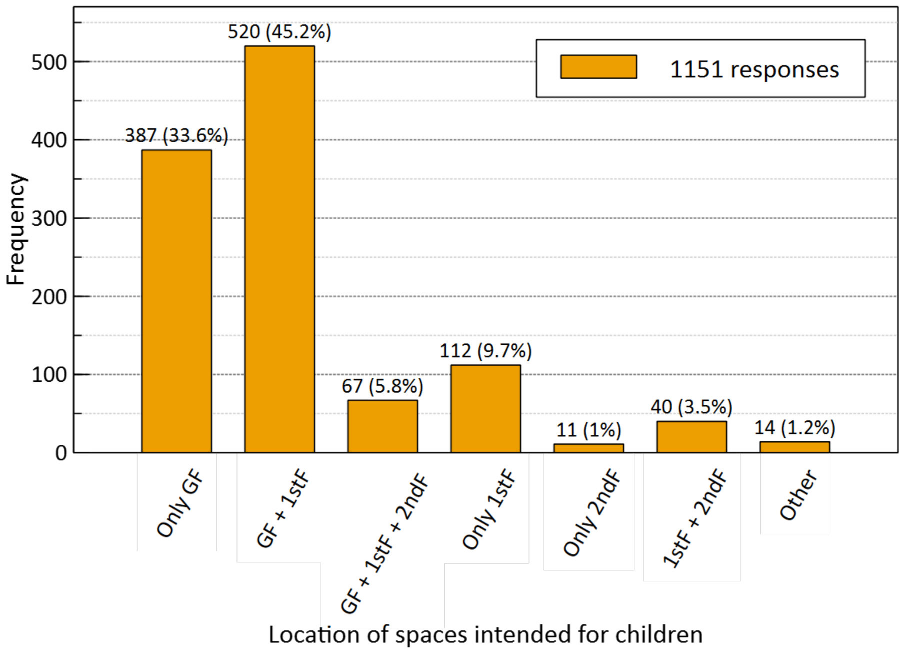


Figure 6.11: Floors combination where children can be present in nursery schools (GF–ground floor, 1stF–the first floor, 2ndF–the second floor)

It can be summarised that spaces intended for children are in the most cases of responses located on the ground floor and/or on the first floor (in total 88.51%). In 33.6% of the responses these spaces are located only on the ground floor (i.e. in one-storey buildings or on the ground floor of multi-storey buildings which include

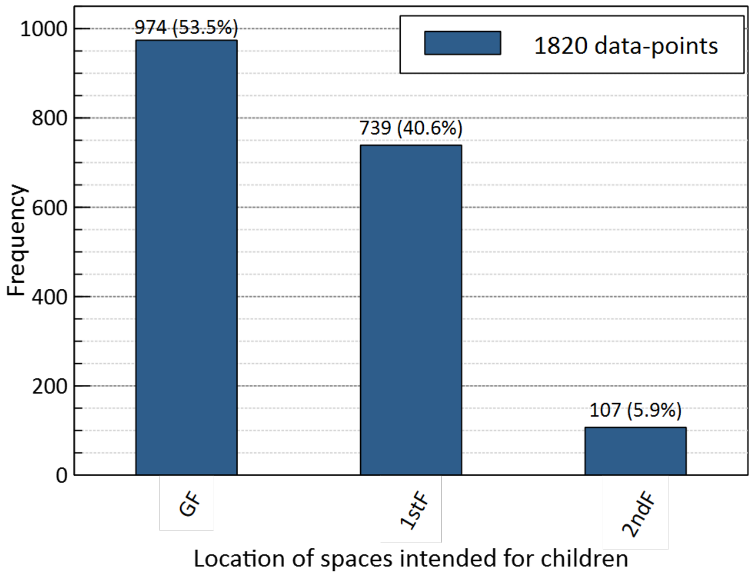


Figure 6.12: Comparison of frequency of floors where children can be present in nursery schools (GF–ground floor, 1stF–the first floor, 2ndF–the second floor)

also other occupancies than nursery schools, e.g. primary schools). In 45.2% of the replies the spaces are located simultaneously on the ground floor and on the first floor (most probably in two-storey buildings). In 5.8% of the responding nursery schools the spaces for children are located simultaneously on the ground floor, the first floor, and the second floor, it means in three-story buildings at least. Different floors than offered in the question were noted in 8 replies: 4 responses pointed out that spaces for children are located also in basement (gyms and lunchrooms were mentioned); 4 responses mentioned 4 floors intended for children (the ground floor, the first floor, the second floor, and the third floor). It can be therefore concluded that in some cases children can be present also in basements or on higher floors of the buildings. In addition, comments showed that even in the case of prevailing one-storey buildings/spaces intended for children on the ground floor staircase-free escape routes can not be automatically assumed (e.g. in the case of elevated ground floors). Considering homogeneous classes, classrooms for older children can be assumed to be located on higher floors, classrooms for younger children on ground floors. When the spaces intended for children are operationally divided in more floors (e.g. in one-class nursery schools located in a two-storey building), spaces intended for active activities (e.g. playrooms, classrooms) may be expected on ground floors, conversely resting and sleeping areas on higher floors.

Considering presence of external escape staircase/staircases in nursery schools' buildings, nursery schools replied positively in 35.3% and negatively in 64.7% (in total 1,143 responses). The acquired responses were further evaluated in relation to location of spaces intended for children in the buildings. In other words, the results were elaborated separately for the cases where children are located only on the ground floor and for the cases where spaces intended for children may be located also on higher floors (see Figure 6.13 and Figure 6.14).

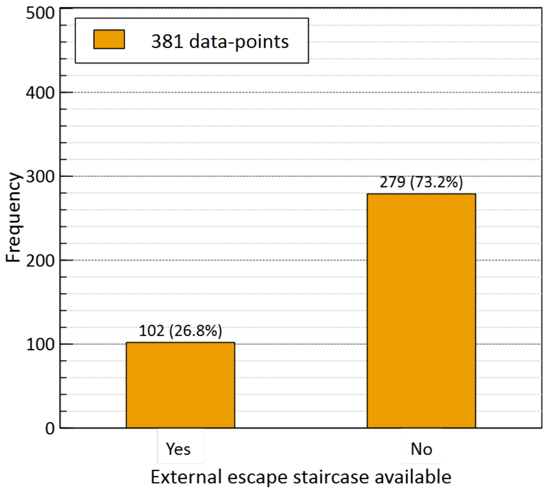


Figure 6.13: Presence of external escape staircase/staircases in nursery schools where spaces intended for children are located only on the ground floor

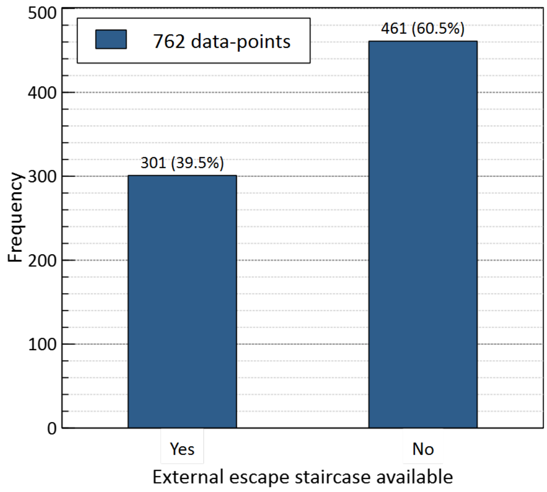


Figure 6.14: Presence of external escape staircase/staircases in nursery schools where spaces intended for children are on higher floors than on the ground floor

In nursery schools where spaces intended for children are located only on the ground floor, the presence of external escape staircase/staircases was confirmed in 26.8% of the responses. Nursery schools with spaces for children located on higher floors replies positively in 39.5%. Nevertheless, it should be mentioned that the respondents could understand the term "external escape staircase" as both external staircases intended for only emergency situations only and daily used external staircases (e.g. external staircases enabling access to the main entrance of the building) which can be certainly used in the case of evacuation (and thus understood as escape staircases). Furthermore, the comments pointed out that a response may not be applicable for all buildings or workplaces which are grouped under the responding nursery school.

Fire safety documentation and education

Two questions in the questionnaire were included at the request of the Prevention department and the Department for instruction and training services at the General directorate of Fire rescue service of the Czech Republic: ***Question 8: Is a fire safety report available for the nursery school?*** (multiple-choice: *Yes; No; I do not know*; "Other" category not available) and ***Question 9: Is the issue of personal safety included in the educational programme of the nursery school?*** (multiple-choice: *Yes; No; I do not know*; "Other" category not available). An overview of the obtained responses is provided in Figure 6.15 and Figure 6.16.

Based on the results, a fire safety report is available in the great majority of the responding nursery schools (93.3%). To provide clear interpretation of the results it should be clarified that a fire safety report represents in the Czech fire safety terminology a specific document which is a substantial part of the project for building permission made by an authorized person in fire safety design. It may be possible

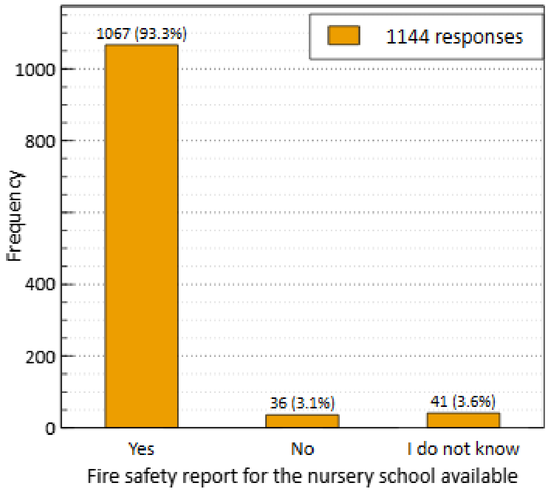


Figure 6.15: Availability of a fire safety report for the nursery school

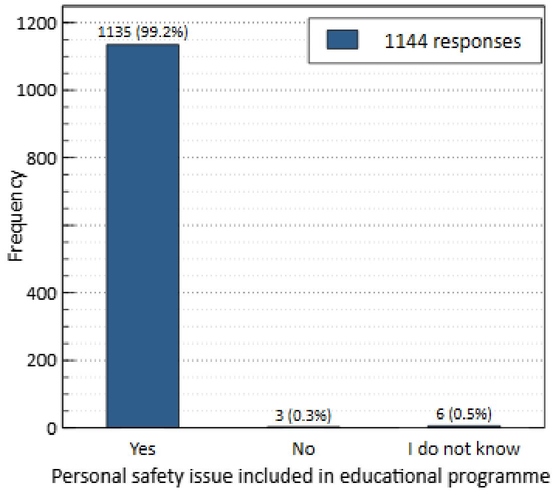


Figure 6.16: Integration of personal safety issue in the educational programme of the nursery school

that responding leaders of the nursery schools were not completely aware of this terminology and they misinterpreted this particular document for a different fire safety documentation of the building (e.g. escape plans, building fire rules). To the incorrect interpretation could further contribute the name of the questioned document (literally “a fire safety solution”) which could evoke a fire safety solution in the broad sense (e.g. that the issue of fire safety is solved in some way in the nursery school).

The results further showed that the issue of personal safety is presented to children in the vast majority of the participating nursery schools (99.2%). In addition, the comments stated that personal safety education is performed regularly and with a written record. The commenting nursery schools appreciated also welcome and well-functioning cooperation with rescue services such as open house, excursions, and common projects.

Evacuation drills

The first part of the questionnaire was closed with a general question focused on performing of evacuation drills in nursery schools (***Question 10: Are evacuation drills performed in the nursery school?*** (multiple-choice: *Yes (an evacuation drill was performed at least once in the last 5 years); No;* “Other” category available). A positive reply was obtained in 76.4% of the total 1,149 responses (“Other” category was not applied in any case). Large amount and variety of information was found in the comments (in total 163 comments received). The positively responding nursery schools commented on the season when evacuation drills are performed (the beginning vs. the end of the school year, winter season mentioned in some cases as well), on experiences with their cooperation with fire rescue service, or on the frequency and procedure of the evacuation drills. The idea to familiarise children with escape routes and evacuation signage in the building additionally to regular evacuation drills can be highlighted. Considering the comments added to the negative responses, the nursery schools explained the absence of evacuation drills as a result of lack of time and experiences, searching for suitable way, or avoiding of situation a stressful situation for children. As positive can be seen comments of 3 nursery schools which informed that the questionnaire is a good motivation for them to start with evacuation drills in the future.

6.3.3 Part 2: Evacuation drills

Based on the response on the last question in the first part, Part 2 of the questionnaire was opened only to the nursery schools performing evacuation drills, i.e. to 878 nursery schools which responded positively. This part of the questionnaire was focused on details concerning evacuation drills such as their frequency, a level of announcement, used warning signals and escape routes, organisation of children, a subsequent evaluation, and experienced complications.

Frequency

The frequency of evacuation drills performed in nursery schools was investigated in ***Question 11: How often (on average) are evacuation drills carried out in the nursery school?*** (multiple-choice: *once a year; twice a year;* “Other” category available). Based on the results (see Figure 6.17) it can be summarised that in the majority of the responding nursery schools (94.4%) evacuation drills are carried out annually (84.1%), eventually biannually (10.3%). As mentioned earlier in the introduction, in the Czech Republic, evacuation drills are not explicitly required by the legislation in nursery schools intended for children older than 2 years. Required evacuation drills (together with the prescribed or recommended frequency) may be based on the fire safety documentation of the building. Legislative requirements on regular performing of evacuation drills in early childhood education institutions differ worldwide. To provide a general insight in this issue, fire safety regulations in different countries presented by Page and Norman [160] supplemented by the requirement in the Czech Republic are summarised and reproduced in Table 6.1.

Table 6.1: Required frequency of evacuation drills in early childhood education institutions, reproduced from [160] supplemented by the requirement in the Czech Republic

1× per month	**4× per year**	**1–2× per year**	**1× per year**	**Only recommended**	**Not stipulated**
US (S), Ireland	US (M)	UK	Finland, Western Australia, Norway, Belgium	Denmark	Singapore, Sweden, Czech Republic

US = the United states, UK = the United Kingdom

S = requirement for single-storey buildings, M = requirement for multi-storey buildings

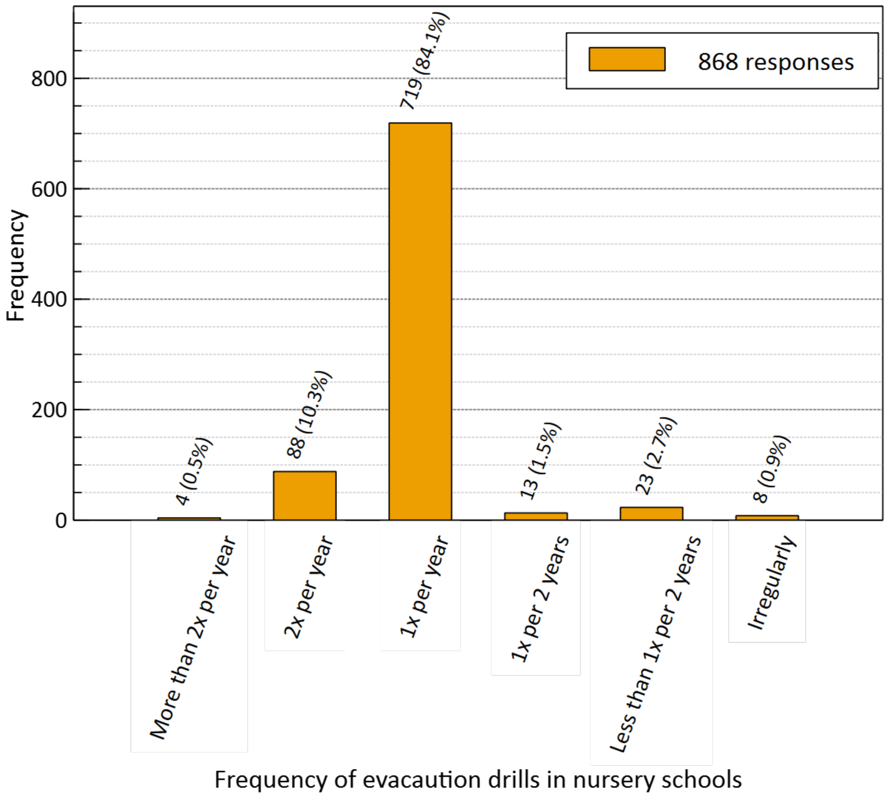


Figure 6.17: Frequency of evacuation drills in nursery schools

Information available to staff members

The level of announcement of evacuation drills provided to staff members was questioned in ***Question 12: How are evacuation drills announced to staff members?*** (multiple-choice: *All staff members know the date and the time of evacuation drills beforehand; All staff members know only the date evacuation drills beforehand; Evacuation drills are announced beforehand without the specification of the date nor the time; Evacuation drills are not announced to staff members beforehand*; "Other" category available). From the obtained results given in Figure 6.18 it can be seen that in 83.8% of the responding nursery schools evacuation drills are announced in some detail. In the most cases (42.9%), staff members are informed beforehand about both the date and the time of evacuation drills which can be therefore completely expected by them. Approximately in fifth of the responding nursery schools (20.9%) only the date of evacuation drills is announced in advance to staff members and in further fifth of the responding nursery schools (20.0%) staff members are only informed about planned evacuation drills with no further details. It can be also assumed that evacuation drills are explained beforehand also to children in some cases. A frequent argument for announced evacuation drills which occurred in the comments was prevention of stress and fear by children. Evacuation drills are performed as completely unannounced to staff members in 16.2% of the participating nursery schools. The comments also mentioned that the level of announcement

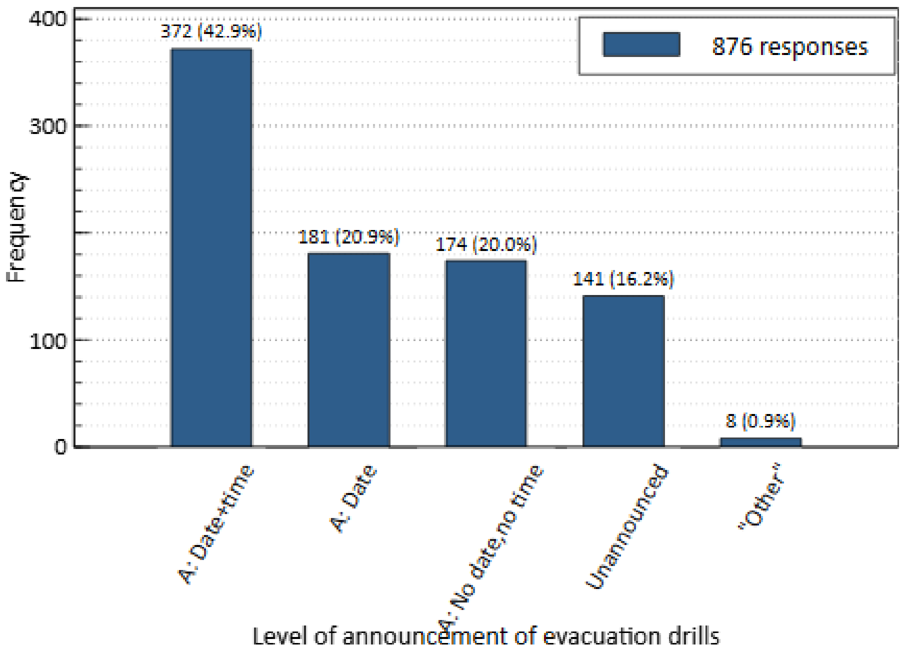


Figure 6.18: Level of announcement of evacuation drills provided to staff members in nursery schools; A–evacuation drills announced beforehand

of evacuation drills may vary within a school year (the more announced evacuation drills are performed at the beginning and the less announced evacuation drills are at the end of a school year). Furthermore, some nursery schools commented that evacuation drills are organised in the form of a game and with the motivation adjusted to the age or specifics of involved children. In such cases, children may not to know that a evacuation training is being performed.

The following question was focused on the source of information and instructions how to act during evacuation drills available to staff members: ***Question 13: Where do teaching staff members get instructions how to behave and act during evacuation drills (e.g. about evacuation routes choice, organization of children)?*** (multiple-choice, more choices possible: *Regular fire protection education given by a fire prevention officer; Internal education given by the nursery school's management (e.g. by the leader); Teaching staff members are not specially schooled (they act according to their professional experience)*; "Other" category available).

Because of the multi select option offered in the question, the results were evaluated in two ways:

- The frequency of the information source combinations was calculated, see Figure 6.19,
- The frequency of the particular information sources was evaluated separately, see Figure 6.20.

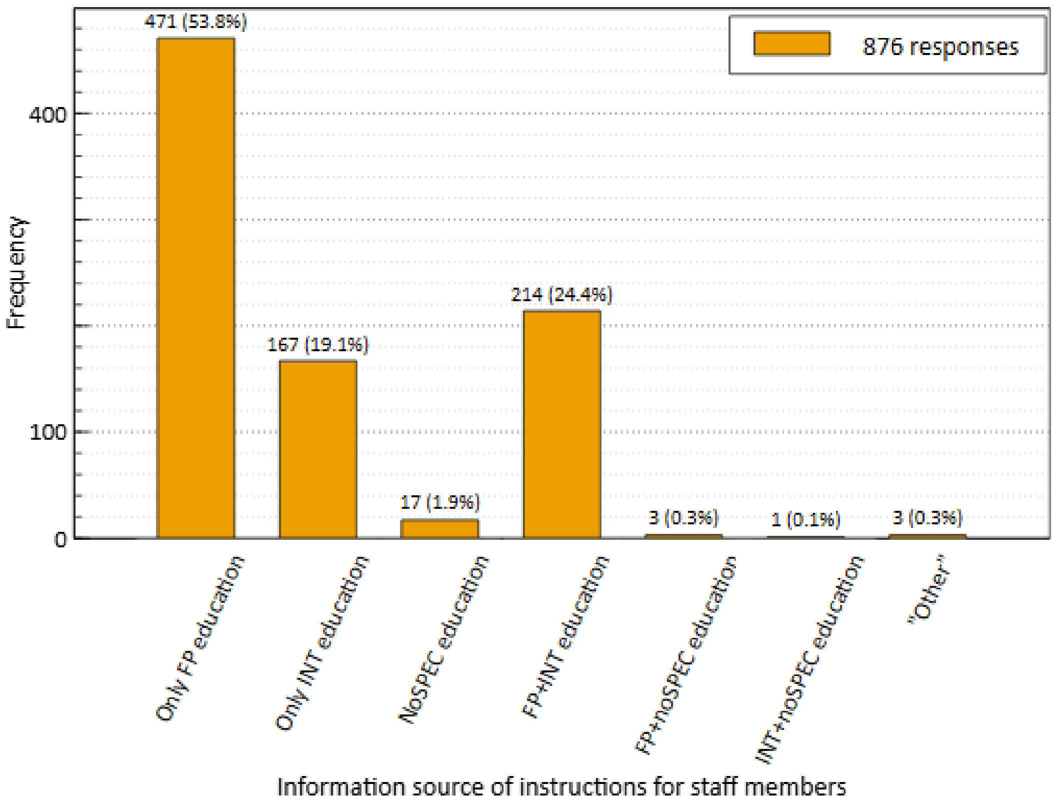


Figure 6.19: Combination of sources providing information and instructions to staff members how to act during evacuation drills in nursery schools; FP education–fire protection education, INT education–internal education, noSPEC education–no special education

The results showed that the most common source which familiarises staff members with information and instructions how to behave during evacuation drills is a regular fire protection education given by a fire prevention officer (i.e. by a professionally competent person at the fire prevention section). Only this source was mentioned by 52.8% of responding nursery schools, in the combination with other sources in 63.1% of the replies. It is obvious that the role of a professionally competent instructor is important and her/his responsible approach in fire safety education and in providing instructions and explanations to staff members may be for real evacuation process in nursery schools crucial. Internal education given by the nursery school's management (e.g. by the leader in meetings) was identified as the only source of information in 19.1% of the responses, in the combination with other sources in 35.0% of the replies. As frequent option seems to be the combination of regular fire protection education and internal education which was registered in 24.4% of the responses.

Warning signals

The following part of the questionnaire dealt with types of warning signals used in nursery schools and their dissemination in the building. The first of these issues was investigated in ***Question 14: Which warning signal to start evacuation is***

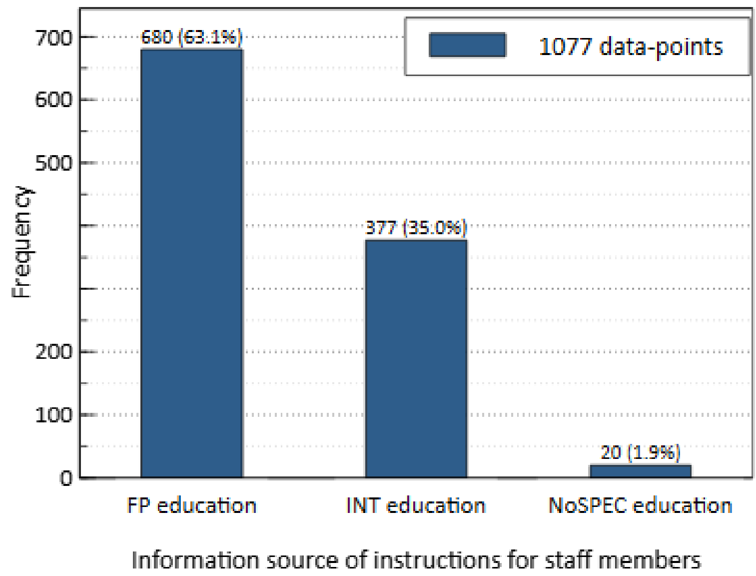


Figure 6.20: Comparison of frequency of sources providing information and instructions to staff members how to act during evacuation drills in nursery schools; FP education–fire protection education, INT education–internal education, noSPEC education–no special education

used in the nursery school? (multiple-choice: *Voice message (verbally); Manual sound signal (e.g. whistle, gong, pot banging); Combination of voice message and manual sound signal; Coded message or sound (e.g. a particular phrase or melody with the meaning known only to staff members); Activation of the fire alarm system (e.g. of a smoke detector)*; "Other" category available). The responses are summarised in Figure 6.21. 35.7% of the responses mentioned that the warning signal used to start evacuation in the nursery school was given using a verbal message (verbally); a manual sound signal was 23.3% of the replies. However, the most frequent response was the combination of those warning signals which was responded by 37.7% of the participating nursery schools. The frequency of using of fire alarm system available in the building was 2.4%; the option of a coded message or sound less than 1.0%.

The added comments further revealed which particular signals to start evacuation are used in nursery schools. Considering verbal messages phrases such as "Fire", "Fire alarm", "Fire drill", "Evacuation" were the most common. As manual sound signals banging on metal object (e.g. an anvil, a piece of a rail, cymbals, a metal hand rail), whistle, bell, siren, or gong were often mentioned. The comments further showed that two opposite approaches may occur when evacuation drills are alerted in nursery schools: "fire approach" and "cautionary approach". The former follows official fire rules in the building which usually instruct to use the phrase "Fire!" in case of fire in the building (considering occupancies with adults, it is generally recommended to mention the cause of the evacuation [178, 179]). Proponents of this approach argue that the standard evacuation procedure should be followed even the case of evacuation drills in order to children get used to and train real emergency conditions. The other approach prefer such a procedure during evacuation drills

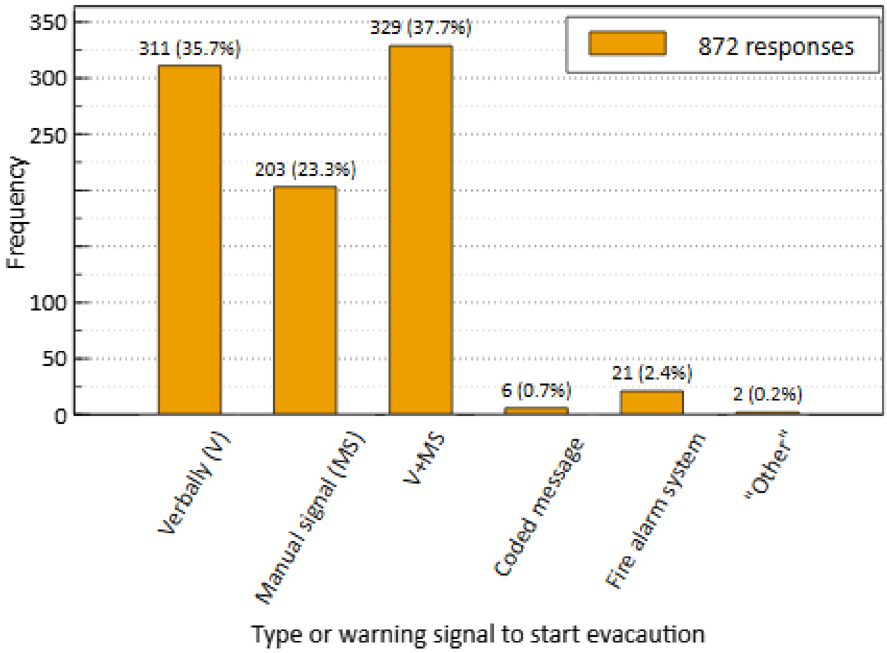


Figure 6.21: Types of warning signals used in nursery schools to start evacuation

which eliminates stress or fear experienced by children. Proponents of this approach believe that simulation of real fire conditions may cause stress which should not be put on children unless it is necessary. In those cases, evacuation drills may be processed in the form of a game or alternative motivation to leave the building to fire alarm may be presented to children. Here, a debatable question arises whether the alternative procedure used in evacuation drills would be also applied in real emergency, or not.

The possibilities of warning signal dissemination in the building were explored in ***Question 15: How is the warning signal to start evacuation disseminated in the building?*** (multiple-choice: *Personally by a responsible person in corridors or in classrooms; Using a building broadcast; By activation of the fire alarm system (e.g. of a smoke detector)*; “Other” category available). The obtained responses graphically summarised in Figure 6.22 showed that in the majority of the participating nursery schools the warning signal to start evacuation is given personally by a responsible person (90.3%). The comments further reported that a common means of communication was the intercom. It can be assumed that this communication means is not ordinarily designed to be capable to be operational during a fire. Therefore in a real fire situation when an intercom may be out of action dissemination of warning signal could be more difficult and untrained.

Organisation of children

The questionnaire also aimed to obtain experiences of nursery schools with specific organisation of children during evacuation drills. The organization strategy taken

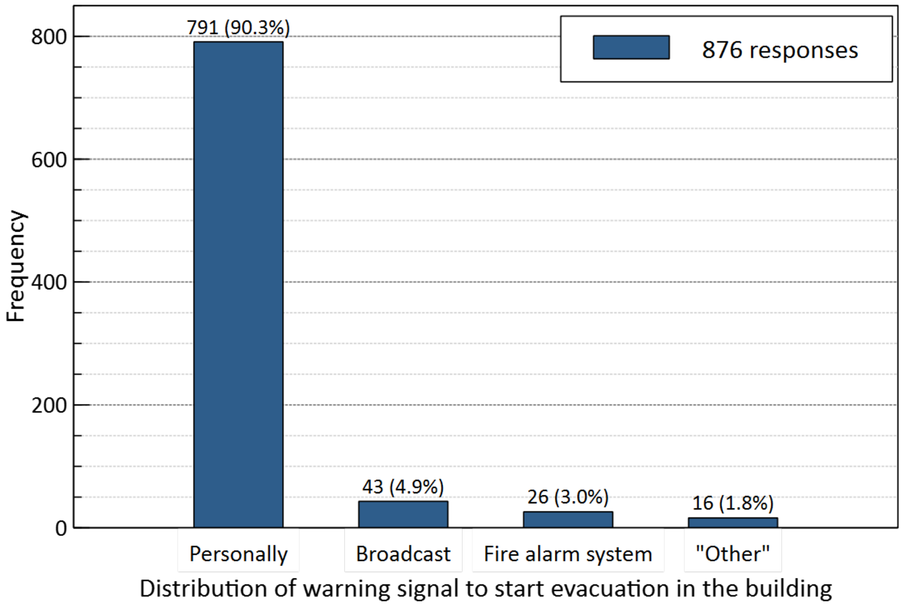


Figure 6.22: Dissemination of warning signals in the building of nursery schools

by staff members when leaving a classroom during the pre-movement phase was questioned in ***Question 16: How are children organised before leaving a classroom after the signal to evacuate is given?*** (multiple-choice: *Children are asked to form pairs and wait until the signal to leave a classroom is given (leaving in pairs as a group); Children are asked to form a group and wait until the signal to leave a classroom is given (leaving as a group); Children are asked to wait until the signal to leave a classroom is given (without a given formation); Children can leave a classroom individually*; "Other" category available). The results are provided in Figure 6.23. More than half of the participating nursery schools (52.7%) responded that before leaving a classroom children are asked to form pairs in a compact group and wait until the instruction to leave is given. The correspondent comments also clarified that such leaving strategy may be efficient since children are commonly used to form pairs in daily routine, pairs can be easily counted, and children in pairs can help each other. On the other hand, the forming of pairs may be time-consuming and inefficient, especially in the case of younger children. According to 30.1% of the responses, children are asked to form a group (pairs are not required) during the pre-movement phase. In 15.0% of the cases children are asked to wait until the signal to leave a classroom is given but they are formed neither in pairs nor in a group. Only in less than 1.0% of the responding nursery schools children can leave a classroom individually.

The organisation of children during the movement phase through the building to a place of safety was investigated in ***Question 17: How are children organised when moving through the building to the place of safety?*** (multiple-choice: *Children move in pairs in a compact group (each class forms a separate group); Children move in a group but not in pairs (each class forms a separate group); Children can move individually instructed to wait at a specific place*; "Other" category available). As can be seen from Figure 6.24 in the great majority of the responding

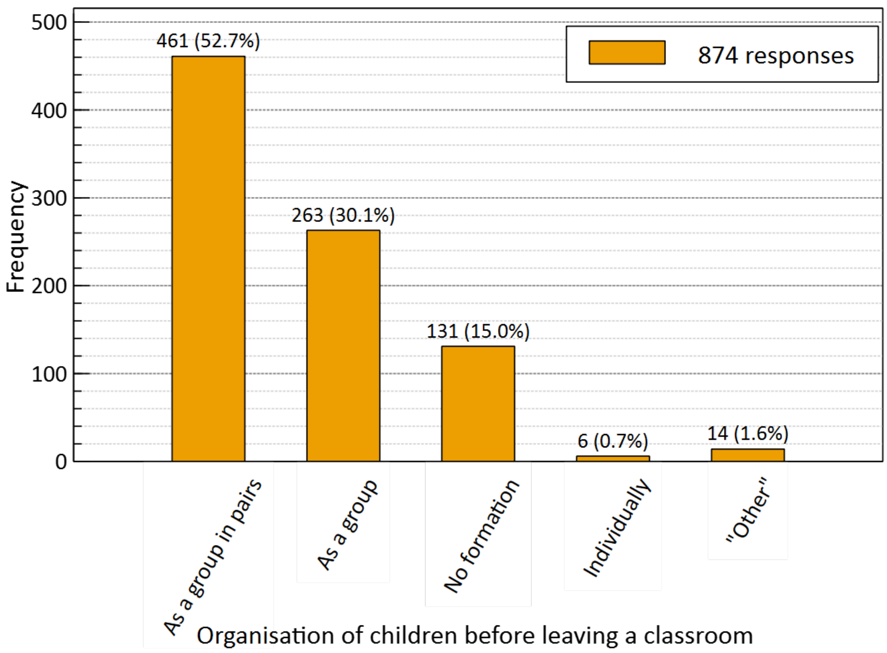


Figure 6.23: Leaving strategy employed during the pre-movement phase

nursery schools (in total 89.0%) movement of children through the building is organised in groups formed by classes. In more than half of those cases (in total in 49.9%) children are asked to form pairs (eventually triples) and to hold each other's hand. Based on the added comments, movement in organised single file is also commonly used strategy. Similarly to leaving strategies during pre-movement phase, the pairs or single line formation may be facilitate supervision over children and their counting. However, such organisation may also result in time delays, especially by children who are not used to follow those instructions in daily routine or by younger children. A specific issue is movement on staircases where walking in pairs and hand holding may be uncomfortable for children who because of such formation can not reach a handrail.

Usage of escape routes

As a part of the questionnaire, usage of various escape routes during evacuation drills in nursery schools was studied in a separate question: ***Question 18: Are the escape routes and exits, which are not daily used (e.g. external escape staircases), used during evacuation drills in the nursery school?*** (multiple-choice: *Yes; No, children move only on well-known and daily used routes; No, there is only one escape route in the building which is also daily used*; "Other" category available). The results graphically represented in Figure 6.25 indicated that during evacuation drills in over half of the participating nursery schools (in total in 56.9%) the escape routes are used which are daily used and well-known to the involving population. Either the used escape routes are simultaneously the only circulation routes in the building (18.5%), or there are other escape routes than the

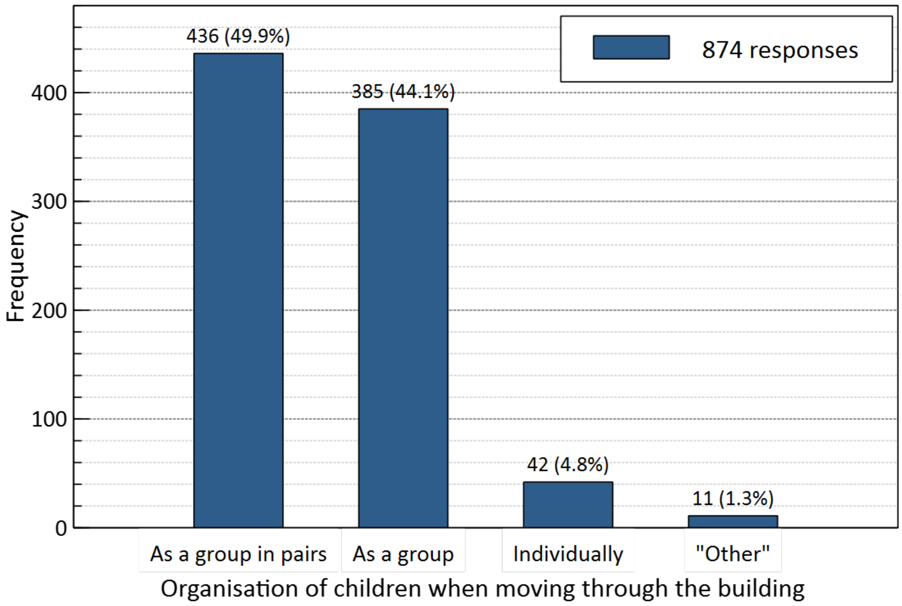


Figure 6.24: Organisation of children during the movement phase until the place of safety is reached

daily used available in the building but they are not used during the evacuation training (38.4%). On contrary, 41.2% of the responding nursery schools replied that the not daily used escape routes are used during evacuation drills. Since evacuation drills generally represent a useful means of improving staff members' and occupants' preparedness to emergency situations, the latter approach may seem as more appropriate. In this case, children are regularly familiarised with all escape routes in present the building which may streamline the evacuation procedure in a real fire incident when the route availability is potentially limited.

Evaluation of evacuation drills

As an important part of constructive evacuation drills, a subsequent evaluation of employed evacuation procedure can be recommended to prevent and limit potential weaknesses of the evacuation strategy in the future. To find out common practice of this issue in nursery schools, the following question was included: ***Question 19: Are evacuation drills evaluated after they are finished?*** (multiple-choice: *Yes, spoken and written evaluation of evacuation drills is performed; Yes, spoken evaluation of evacuation drills is performed; No*; "Other" category available). The obtained results can be found in Figure 6.26. Based on the results (see Figure 6.26) evacuation drills are verbally evaluated in 96.9% of the responding nursery schools, in 61.1% of the cases even in written (notably in class books and fire books). The comments further added that measuring of total evacuation time can be a part of the evaluation as well. However, it should be noticed that the obtained results did not investigate to what extent the evaluations of evacuations drills are performed. It is obvious that those evaluations can vary from a short record in the book or comment without further implications to useful findings beneficial for improving of

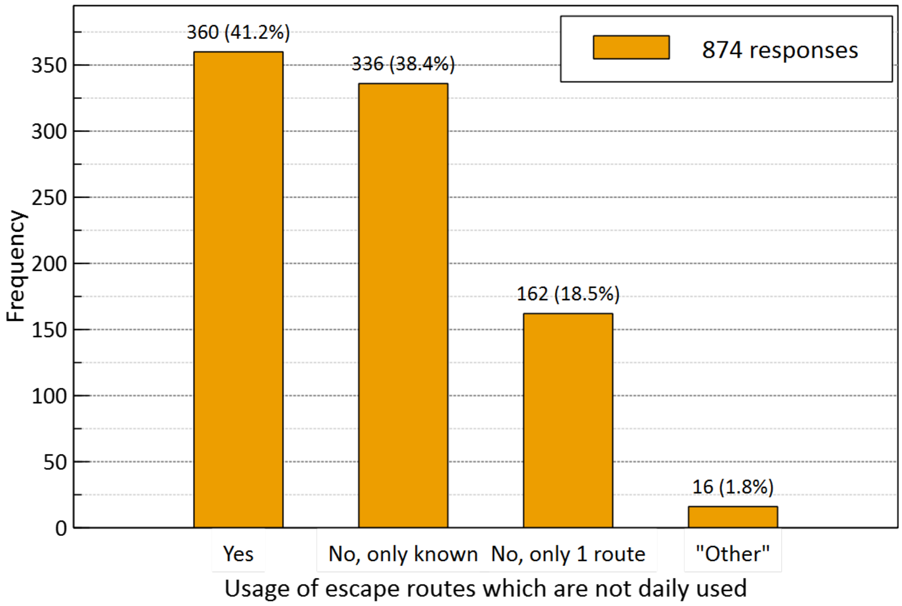


Figure 6.25: Usage of escape routes which are not daily used (e.g. external escape staircases) during evacuation drills in nursery schools

the evacuation strategy. In other words, not every evaluation of evacuation drills can be automatically assumed as worthy.

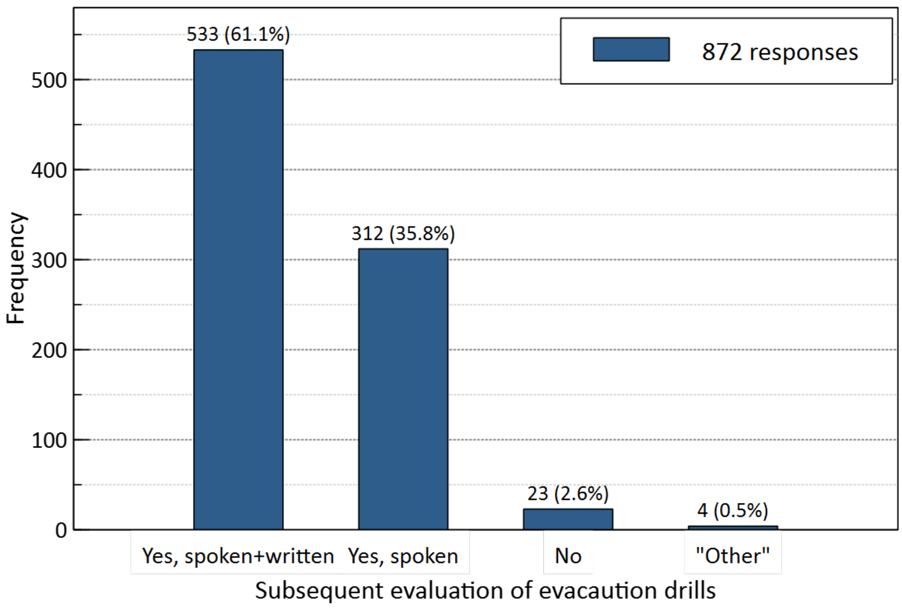


Figure 6.26: Evaluation of evacuation drills after they are finished in nursery schools

Issues identified in the evacuation drills

The presented questionnaire was closed with the question regarding issues occurring during evacuation drills in nursery schools: ***Question 20: What are the***

most common issues you must solve during evacuation drills in the nursery school? (multiple-choice, more choices possible: *Blocked escape routes (e.g. locked/blocked exits, forgotten keys); Delays caused by waiting for an empty staircase used by more classes; Escape route choice; Delays caused by poor knowledge of evacuation procedure by staff members; Slow movement caused by assistance required by children; Insufficient number of present staff members who could effectively help to all children requiring assistance; Children are not willing to leave a classroom (e.g. hiding, running away); Children do not follow instructions given by staff members; Children are scared or frightened*; “Other” category available). The question was completed (i.e. at least one of the offered options was chosen) by 803 respondents. Moreover, in further 53 responses the comment was added informing that the nursery school do not have to solve any issue. Therefore, a separate category labeled “No issues” was additionally created and included into the evaluation (i.e. in total 856 replies were evaluated).

In 640 responses at least one of the options was selected. Only the “Other” category was used in 163 replies whereas in 145 cases it mentioned that evacuation drills are carried out without any issues (in different wording and with different amount of additional information). Those replies were assumed in the separate category “No issues”. From the remaining 18 replies in “Other” category, 8 nursery schools notified slight issues, 7 nursery mentioned a particular issue different from the offered options, and 3 responses provided neutral information. On the whole, the obtained responses can be summarised as follows (see also Figure 6.27), from 856 completed replies:

- 647 nursery schools mentioned at least one issue,
- 8 nursery schools referred a slight issue,
- 198 nursery schools informed that they do not solve any issues,
- 3 nursery schools provided other information.

In the responses where an issue was indicated, one issue in one reply was mentioned in the most cases (68.0%). Less often were referred two issues (21.3%) and not more than 6 issues were identified by the responding nursery schools in one reply. An overview providing frequency of number of issues mentioned in one reply is given in Figure 6.28. A summary of particular issues responded by the participating nursery schools can be found in Figure 6.29.

It can be summarised that approximately three quarters of the responding nursery schools indicated an issue occurring during evacuation drills. Most frequently one (68.0%) or two (21.3%) issues from 9 offered options (and available “Other” category) were mentioned one reply. Among the responded issues, the issue that children required individual assistance given by staff members which slows down the movement was the most frequent (38.5%). In the second place was ranked the issue that children are scared or frightened (22.5%), followed by the issue related to the insufficient number of present staff members who could effectively help to all children requiring assistance. Based on the comments, more assistance is required by young

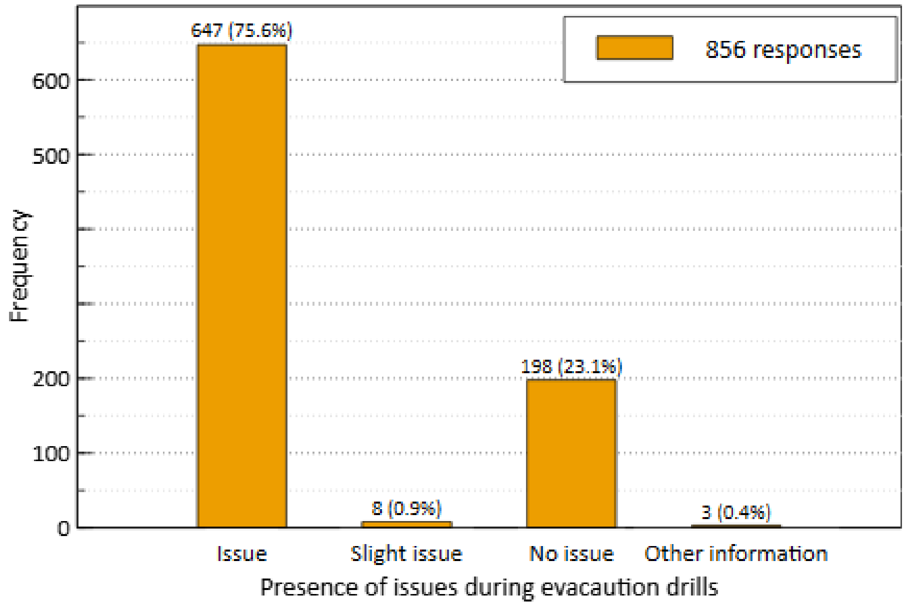


Figure 6.27: Occurrence of issues during evacuation drills in nursery schools according to the questionnaire respondents

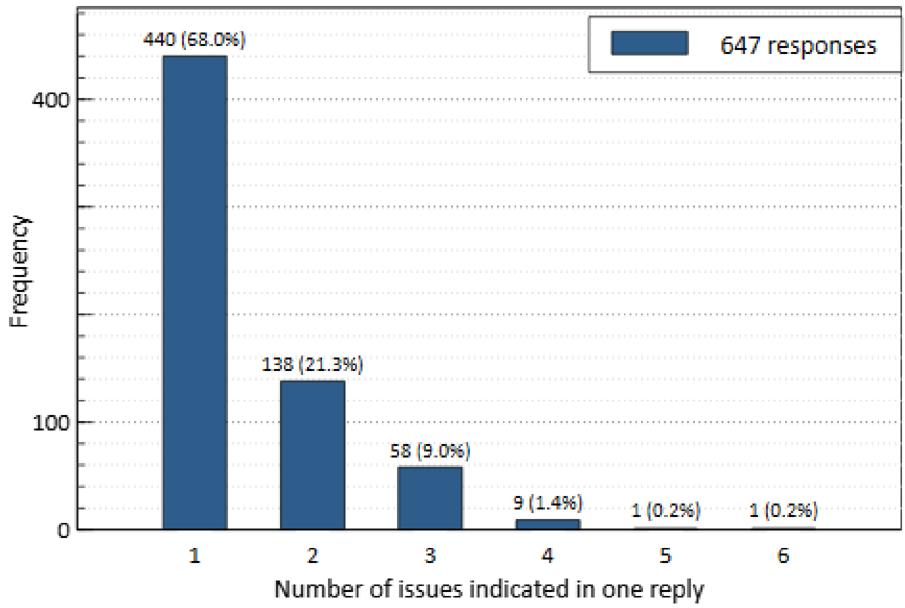


Figure 6.28: Number of issues occurring during evacuation drills in nursery schools mentioned in one reply

children (especially 2-year-olds) and notably movement on staircases may represent a complicating factor. On the contrary, almost a quarter of the responding nursery schools mentioned that evacuation drills are performed without any issues. The corresponding comments noted that evacuation drills are carried out in the form of a game. Moreover, frequent and regular performing of evacuation drills, appropriate preparedness of children and staff members, effective coordination of staff members, sufficient number of exits and their construction (such as panic exit devices) were

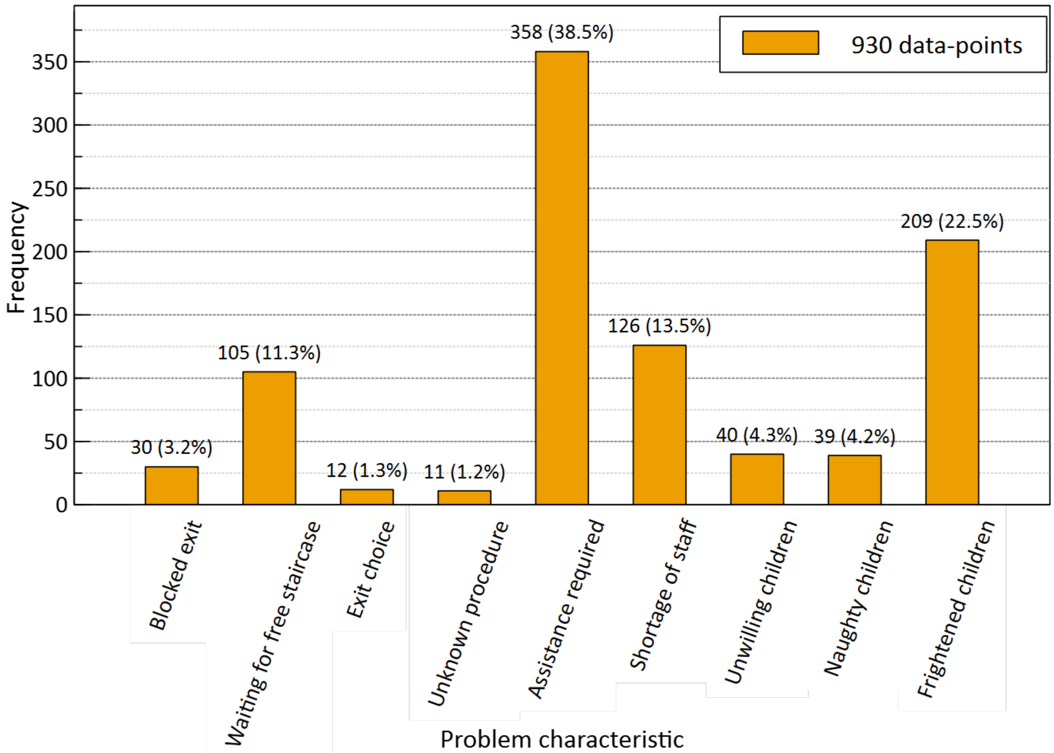


Figure 6.29: Occurrence of particular issues during evacuation drills in nursery schools

positively evaluated. A frequent topic in the comments were scared and frightened children. The comments revealed that this issue involves primarily younger children. Furthermore, several comments indicated that although they appear to be confused and scared children usually respond well to instructions given by staff members and thanks to provided help they coping well. In this context, notably appropriate and timely preparations and explanations provided to children were assessed very positively. However, opposite opinions also occurred stating that any preparations can not eliminate potential discomfort resulting from such stressful situations. In general, it can be believed that regular and frequent training resulting in a routine procedure may be a useful means to mitigate or avoid stress and discomfort experienced by children during evacuation drills.

6.4 Summary of the questionnaire on nursery schools in the Czech Republic and their implementation of evacuation drills

The presented questionnaire aimed to acquire knowledge on real conditions in nursery schools in the Czech Republic and their daily practise with evacuation drills. Thanks to the relatively satisfactory response rate (23.5%, 1,151 responding nursery schools) and willingness of the respondents to add their own comments containing many details, a large amount of data including interesting ideas, opinions, and remarks was gathered. The key findings obtained via the questionnaire can be summarised as follows:

- Considering overall capacity, most frequent are one-class nursery schools (28.7%) followed by nursery schools with 2 to 4 classes (56.8%). Nursery schools with more than 4 classes are less common (9.4%); however, it can be assumed that a nursery school with 5 to 10 classes can be still located in one building (8.5%).
- On average, the most frequent number of children in one class ranges between 20 and 28 children (80.1%) with the median value of 24 children. A class is most commonly supervised by 2 staff members (66.4%) or by 3 staff members (20.7%). The most frequent staff-to-child ratio is 1:10 to 1:14 (59.2%), followed by staff-to-child ratio 1:5 to 1:9 (31.3%). Higher values of staff-to-child ratio (i.e. more than 1:14) occurred only in 4.8% of the cases. In 56.8% of the responding nursery schools, children are organised in heterogeneous classes, homogeneous classes were identified by 37.4% of the respondents. In the latter case, there are usually 2 or 3 different homogeneous classes based on children's age (87.7%), whereas the age range in homogeneous classes is most frequently 2 years (64.6%), eventually 3 years (29.0%).
- In nursery schools, spaces intended for children are most often located on the ground floor (53.5%) or on the first floor (40.6%). In 33.6% of the responses these spaces are located only on the ground floor (i.e. in one-storey buildings), in 45.2% simultaneously on the ground floor and on the first floor (most probably in two-storey buildings). In the case the spaces intended for children are located on higher floors than on the ground floor, external escape staircase/s are present in 39.5%.
- A fire safety report (potentially in the meaning of fire safety documentation of the building) is available in 93.3% of the nursery schools. The issue of personal safety is presented to children in the vast majority of the participating nursery schools (99.2%).
- Evacuation drills are performed (at least once in the last 5 years) in 76.4% of the nursery schools. In the majority of these nursery schools (94.4%) evacuation drills are carried out annually (84.1%), eventually biannually (10.3%).
- Evacuation drills are announced (date and time) to staff members in 42.9%, partially announced (only (indicative) date or the general intention) to staff members in 40.9%, and completely unannounced to staff members in 16.2% of the nursery schools.
- The most common source which familiarises staff members with information and instructions how to behave during evacuation drills is a regular fire protection education given by a fire prevention officer, i.e. by a professionally competent person at the fire prevention section (63.1%).
- The warning signal used to start evacuation is usually given using a verbal message (verbally; "Fire", "Fire alarm", "Fire drill", "Evacuation") in 35.7% and using a manual sound signal (banging on metal object, whistle, bell, siren, or gong) in 23.3% of the nursery schools. Nevertheless, the combination of a

verbal message and manual signal sound is the most frequent (37.7%) warning signal. In the majority of the participating nursery schools the warning signal to start evacuation is given personally by a responsible person in corridors or in classrooms (90.3%).

– Before leaving a classroom, children are asked to wait until the instruction to leave is given in 97.8% of the responding nursery schools. In 52.7% of the cases, children form pairs in a compact group, in 30.1% children are asked to form a group (pairs are not required), and in 15.0% children form neither pairs nor a group. Only in less than 1.0% of the responding nursery schools children can leave a classroom individually. When travelling through a building, movement of children is organised in groups formed by classes in 89.0% of the nursery schools. In more than half of those cases (in total in 49.9%) children are asked to form pairs (eventually triples) and to hold each other's hand.
– During evacuation drills only the daily traveled routes which are well-known to the participants are used as escape routes in 56.9% of the responding nursery schools. These escape routes are either the only circulation routes in the building (18.5%), or there are other escape routes available than the daily used in the building but they are not used during the evacuation training (38.4%). The not daily used escape routes are used during evacuation drills in 41.2% of the responding nursery schools.
– Evacuation drills are verbally evaluated in 96.9% of the nursery schools, in 61.1% of the cases even in written form. In 75.6% of the participating nursery schools, at least one issue (from out of 9 offered options) occurred during the past evacuation drills; most frequently one issue (68.0%) or two issues (21.3%). The most frequently responded issue (38.5%) was individual assistance required by children slowing down the evacuation process, followed by scared or frightened children (22.5%), and insufficient number of present staff members who could effectively help to all children requiring assistance (13.5%).

The findings and gained understanding are further applied in the application part of this work (Chapter 7) when used as a worth background for further engineering application in fire safety design and for providing information and explanations for educational institutions attended by pre-school children as well. The obtained results were also provided to the Prevention department and the Department for instruction and training services at the General directorate of Fire rescue service of the Czech Republic for their further use such as supportive material in both theoretical and practical area. Despite its limitations addressed in depth in Section 6.2, the questionnaire and answers obtained could be a useful starting point for the design of future investigations concerning fire safety design and educational programs in early childhood education institutions.

Part III

Application

Chapter 7

Discussion

This chapter presents practical applications of the current research findings and outcomes, while reflecting the key research-related aspects. Following the objectives of the study described in the introduction part, the acquired knowledge and outputs are separately interpreted with the focus on their engineering application in fire safety design (Section 7.1) and application in educational institutions attended by children at the pre-school age (Section 7.2).

7.1 Engineering application in fire safety design

7.1.1 Application in egress calculation and modelling

According to the main principle of performance-based fire safety design, safe egress from a fire can be proved when the available safe egress time (ASET) is sufficiently longer than the time that people require to reach a place of safety (RSET). When estimating the required safe egress time (RSET) different methods (starting from hand calculations to sophisticated computer evacuation models) can be used for prediction of an evacuation process in an engineering analysis. In any case, fire safety engineers face challenges in the selection and use of input data representing egress performance of the population under consideration. Furthermore, various assumptions concerning characteristics of the involved occupants and specifics of evacuation procedures must be weighted carefully during the process of evacuation scenarios selection [180]. The key findings resulting from the current study which should be properly considered in an evacuation assessment involving pre-school children in early childhood educational institutions are summarised in this section.

The impact of children's age

Based on the general literature background and experimental observations, it can be concluded that children's ongoing development results in their limited motor and cognitive skills compared to adults. However, even in engineering design it is important to avoid a potentially oversimplifying impact of this statement. Thus, “childhood” and “children” should not be perceived as homogeneous terms. Conversely, particular developmental stages should be always dealt carefully when different age groups of children are addressed. Moreover, from the general overview on child’s development is apparent that even considering the more specific interval of early childhood (e.g. children aged 2–6 years) is not detailed enough to properly represent the ongoing developmental changes of children. In other words, due to their different maturity and developmental stage, locomotor and behavioural patterns of a 3- and 6-year-olds related to their movement and thinking abilities may differ considerably. Therefore it does not seem to be appropriate to assume pre-schoolers as one age group with consistent movement and self-rescue capabilities. For the fire safety and evacuation perspective, where such characteristics coupled with emergency behaviour patterns are fundamental factors to be evaluated, it can be therefore suggested to distinguish at least two age subgroups within the pre-school (early childhood) age period:

- Junior pre-school age under 4 years (typically 2.5–4-year-old children),
- Senior pre-school age over 4 years (typically 4–6-year-old children).

This subdivision follows notably age differences in children’s physical growth and mastering of fundamental motor skills involving mature walking and running patterns. In this context, expected proficiency in unassisted stair climbing involving feet alternating pattern is considered as an important factor. However, the suggested categorisation is also in line with ongoing psychological changes and progresses of children’s mind including formation of independent behaviour, onset on theory of mind, and gradually increasing attainments in cognitive, intellectual, and emotional development. It is believed that such subdivisions may be more concise to cover different level of assistance required by children caused both the ongoing developmental changes in their locomotor behaviour as well as in their thinking, while respecting a certain degree of simplification required in engineering applications such as fire safety design. In this context, individual differences [181,182] as well as gender differences [183,184] potentially impacting early childhood development can be sidelined.

Considering the occupancy of early childhood educational institutions, children can be usually organised either in homogeneous classes attended by children of similar age or in heterogeneous classes with the eventual age range from 3 to 6 years (in special cases even from 2 to 7 years). In the first case, the age division of children in classes typically corresponds with the two age subgroups suggested above. In the latter case, a mix of the suggested subgroups may be assumed; otherwise, when a greater level of simplification is required, the whole group of children can be conservatively considered as the younger age subgroup.

Behavioural statements

In an engineering application, understanding and quantification of evacuation behaviour is a challenging and complicated task. For this purpose, the concept of behavioural statements seems to be a useful tool how to present and use currently available knowledge on human behaviour in fire from various research studies in egress modelling [185, 186]. Based on the literature review and current experimental results a set of the behavioural statements on pre-school children evacuation behaviour and movement in early childhood education institutions are identified in Table 7.1.

The provided behavioural statements aim to be of use when both the pre-movement phase and movement phase of the evacuation process should be understood and further quantified in engineering applications. Moreover, in line with the original concept [186], the behavioural statements may be used during the process of evacuation scenario selection and as a background for a sensitivity analysis when parameters in the assessment are varied and their impact is evaluated. In a life safety analysis and egress modelling, five elements can be determined how the behavioural statements can be use and incorporated by fire engineers: pre-movement time, physical movement characteristics, evacuation route availability, evacuation route usage, and behavioural itineraries [186]. With the exception of the aspect of evacuation route availability which is usually rather determined by the fire scenario or by environmental conditions than by the behaviour of occupants [186], the above mentioned elements in the context of the specific evacuation conditions of pre-school children and the presented experimental data-sets are further discussed in the following sections.

Pre-movement time

In a fire safety engineering application it can be assumed that the behavioural statements are combined with relevant data-sets available in the literature. It is therefore important to highlight that the appropriate application of literature data requires also a carefully consideration of the boundary conditions related to the data source such as data collection and analysis methods of the research. The current experimental observations confirmed that the different levels of announcement and preparedness of participants of the experimental evacuation drills had a non-negligible impact on the measured pre-movement times. Since during the unannounced experimental evacuation drills the participants did not have any information about the training purpose of the drills, the results obtained during the unannounced experimental evacuation drills can be seen as the most close to a real emergency situation. Following the concept of the two age subgroups suggested in the previous section, the results on pre-movement times measured in the unannounced evacuation drills are provided in Table 7.2 (the subgroup "Senior over 4 years" includes the results for both Senior and Senior+ children, Mixed classes are excluded).

When estimating pre-movement times, all the behavioural statements summarised in Table 7.1 in the part on pre-movement phase of the evacuation process (#1–6) as well as the general statements (#16–18) can considerably impact (i.e. decrease or increase) the expected pre-movement time. Thus, their positive or negative effect should be individually reflected in a specific evacuation scenario.

Table 7.1: Overview of the behavioural statements on pre-school children evacuation behaviour and movement in early childhood education institutions

#	**Behavioural statement**
Pre-movement phase of the evacuation process	
1	Pre-school children mostly do not react to a warning signal independently; additional impulse and instruction given by responsible staff members is necessary to trigger the evacuation process. Note: This assumption may vary with various educational practises employed in early childhood education institutions.
2	Reactions of children and staff members to alarm are affected by their actual location in the building and activities currently performed.
3	Actions and instructions given by staff members are dependent on the age of children.
4	Evacuation behaviour of both pre-school children and staff members reflects to a large extent daily routines and rules. Pre-school children tend to follow a sequence of memorised daily activities. Staff members are influenced by ordinary practise established in the institution (e.g. how to organise children when leaving a classroom)
5	Level of assistance required by children is age-dependent and highly affected by actual staff-to child ratio.
6	During the pre-movement phase, pre-school children tend to use familiar exits; however, the final exit choice is usually in competence of staff members.
Movement phase of the evacuation process	
7	Movement abilities of children differ from those of adults and are age-dependent.
8	Climbing downstairs on a staircase is for pre-school children the most challenging part when travelling through a building. Notably, the movement of Junior children under 4 years of age may be considerably impeded by their limited motor abilities which are compensated by using of handrails and marking time pattern.
9	When moving on staircases, handrails are frequently used by pre-school children. Presence/absence of handrails may to a large extent influence children's travel path on staircases.
10	When travelling through a building, close physical contact (such as touching, pushing, hand holding) between each other is common among pre-school children. Under higher density conditions children can form a very compact crowd with a minimal body buffer zone.
11	In comparison to adults, pre-school children can perceive the movement more as a game which results in using of various movement patterns such as racing, jumping, and hopping.
12	When unexpected barriers occurred on evacuation routes (e.g. opened door reducing the effective width of the route, a chair located in the middle of a walkway), pre-school children prefer to squeeze through the narrow space forming a bottleneck to remove the obstacle.
13	Pre-school children travelling through a building without permanent supervision of staff members tend to use familiar escape routes.
14	Before leaving a building, pre-school children tend to follow daily practised routines and rules (e.g. putting on shoes and clothing).
15	Children's movement behaviour such as hand-holding, moving in pairs, moving in compacted groups, using of handrails, independently using of doors (i.e. their opening, unlocking), can be strongly influenced by instructions given by staff members as well as by daily routine, rules, and educational practises employed in the early childhood education institution.
General statements	
16	Evacuation of pre-school children in early childhood educational institutions may be highly organised and strongly dependent on reactions, decisions, actions, and preparedness of responsible staff members.
17	Familiarity with evacuation routes and evacuation procedure plays an important role in evacuation efficiency.
18	Evacuation procedure including both pre-movement and movement phase can be improved by regular training.

Table 7.2: Pre-movement times measured in the unannounced experimental evacuation drills in children divided into to the two age subgroups (Mixed classes excluded)

	Pre-movement time (mean/min/max/SD) [s] (data points)	
	Junior under 4 years	**Senior over 4 years**
First child	35 / 10 / 59 / 15 (9 classes)	32 / 15 / 54 / 13 (8 classes)
Last child	49 / 27 / 77 / 16 (9 classes)	45 / 27 / 62 / 14 (8 classes)

Physical movement characteristics

In order to calculate RSET, movement characteristics including travel speed, pedestrian flow, and their dependency on density conditions are the key inputs for assessing and simulating of human movement in both pre-movement phase (purposive movement) and movement phase (travelling through a building) of the evacuation process. The experimental research and the related theoretical background showed that movement abilities and characteristics of pre-school children are age-dependent and differ from those of other populations. Therefore, in an engineering application, different movement characteristics should be assumed for various age groups of children. In line with the suggested concept of the two age subgroups (Junior pre-school children under 4 years of age, Senior pre-school children over 4 years of age) the results on travel speed measured under the same low density conditions (0.00–0.05 $m^2\,m^{-2}$) during the presented experimental evacuation drills are summarised in Table 7.3 (the subgroup "Senior over 4 years" includes the results for both Senior and Senior+ children, Mixed classes are excluded). The differences in the comparison of the experimental results obtained for the two age subgroups emphasises the importance of using the appropriate values when different age groups of children are under consideration.

Table 7.3: Travel speeds measured in the experimental evacuation drills under low density conditions in children divided into to the two age subgroups (Mixed classes excluded)

Evacuation route	**Travel speed (mean/min/max/SD) [$m{\cdot}s^{-1}$] (data points)**	
	Junior under 4 years	**Senior over 4 years**
Corridors: walking	1.06 / 0.42 / 1.85 / 0.26 (139)	1.43 / 0.54 / 3.00 / 0.59 (147)
Corridors: running	1.82 / 1.12 / 2.78 / 0.42 (47)	2.98 / 1.03 / 5.25 / 0.84 (177)
Straight staircases: flights	0.71 / 0.28 / 1.21 / 0.21 (132)	0.94 / 0.33 / 1.74 / 0.26 (412)
Straight staircases: landings	0.94 / 0.17 / 1.86 / 0.38 (49)	1.24 / 0.36 / 2.55 / 0.53 (82)
Straight staircases: whole	0.77 / 0.34 / 1.11 / 0.17 (49)	1.03 / 0.37 / 1.66 / 0.27 (108)
Doorways: walking	0.92 / 0.40 / 1.59 / 0.12 (35)	1.09 / 0.67 / 1.35 / 0.19 (25)
Doorways: running	1.70 / 1.03 / 2.78 / 0.48 (13)	1.64 / 0.83 / 3.45 / 0.52 (29)

Moreover, movement characteristics of pre-school children may be to a large extent influenced by various behavioural aspects, summarised and presented as the behavioural statements (#7–18) in Table 7.1. Amongst the most important factors which should be properly reflected when specific values of movement characteristics of children are selected for further engineering application are the following: children's motivation, supervision and instructions given by responsible staff members, daily practise and routines known by children, educational practises employed in the early childhood education institution. All these aspects may impact the evacuation process and procedure. For example, if children move through a building independently without a supervision (children could easily take an unexpected direction on evacuation routes or missed an exit) or if they move in pairs holding each other's hand (travel speed of a pair may be impeded by the slower child, movement of one child in a pair may be influenced when handrails are not available on both sides or the flight width is too large).

Movement characteristics of children at the pre-school age differ from those of older children and adult population also due to different physical dimensions and personal space required. In this study, the occupied area (horizontal projection of body) of children in different age groups was determined based on the results of the 6th Nationwide anthropological survey of children and adolescents in the Czech Republic [91] (see Section 3.1 for more details on the survey and the calculation method employed). A summary of the main characteristics (shoulder width, chest depth, occupied area) provided for the two suggested age subgroups of children can be found in Table 7.4. Although the difference in values given for the age subgroups is not large, a greater contrast can be identified when these values are compared with those commonly accepted for adults [4]. This comparison confirmed the importance of using relevant density units ($m^2\,m^{-2}$) when movement of children and adults are further compared as the expressions of density in units of pers·m^{-2} might cause a misleading interpretation.

Table 7.4: Physical dimensions and assumed occupied area of pre-school children in the two age subgroups based on the 6th Nationwide anthropological survey of children and adolescents in the Czech Republic [91] compared to those generally accepted for adults [4]

Characteristic	**Junior under 4 years** range of means (average value)	**Senior over 4 years** range of means (average value)	**Adults** [4]
Shoulder width [cm]	22.0–22.8 (22.4)	23.8–25.1 (24.5)	48
Chest depth [cm]	13.7–13.9 (13.8)	14.3–14.7 (14.5)	30
Occupied area [m^2]	0.024–0.025 (0.025)	0.027–0.029 (0.028)	0.113

Evacuation route usage

As the experimental observations showed, the decision on evacuation route choice during the experimental evacuation drills in nursery schools was in competence of responsible staff members. It can be assumed that decision-making processes of staff members in early childhood educational institutions are influenced by training (receiving regular fire protection education), knowledge of the evacuation procedure, and good familiarity with the building enclosure and evacuation routes available. On the other hand, other situations may occur when children are not fully under the supervision of staff members or they receive ambiguous or incomplete instructions. Subsequently, children may choose an escape route (e.g. an exit from a classroom, a direction in a corridor) independently. In such cases, it can be assumed that children prefer to use familiar exits and escape routes (see the behavioural statements provided in Table 7.1 #6 and #13). If their choice is not to liking of responsible staff members, additional delays in the evacuation process may emerge when the escaping children are caught up and redirected to other exit or searched in a building.

Behavioural itineraries

In order to represent evacuation behaviour more specifically, delays and activities which are not directly associated with movement to a place of safety can be assigned to evacuees in more advanced evacuation models [186]. Considering the specific conditions of evacuation in early childhood educational institutions accommodating children at the pre-school age, several behavioural itineraries can be highlighted.

During the pre-movement phase of the evacuation process, the interpretation of a warning signal is mostly in competence of staff members; children's reactions typically follow the explanations or instructions given by adults (#1 in Table 7.1). Any performance during the stage of risk identification and risk assessment (i.e. searching for more information) can be therefore expected by present staff members. After the decision to escape a building is made, a sequence of activities performed by staff members may arise including asking children to form pairs holding each other's hand or to form a compact group/line, counting children, taking a name list, taking belongings, or opening/unlocking an exit door. The type of taken actions may be impacted by age of children, currently performing activities, location in the building, or daily routine in the institution (see also #2, #3, and #4 in Table 7.1). Additional tasks carried out by staff members may be necessary when children required a special physical or verbal support to start the evacuation process. Based on the observations during the experimental evacuation drills, 25% of children received some kind of physical assistance in the pre-movement phase. The level of assistance provided to children is age-dependent and highly affected by actual staff-to child ratio (#5 in Table 7.1). All the above-mentioned factors can considerably affect the pre-movement time and they should be therefore kept in mind when detailed evaluation of evacuation behaviour is assessed.

Considering the movement phase of the evacuation process, several further challenges related to evacuation specifics of pre-school children may emerge in an evacuation assessment and prediction. Based on the results obtained in the experimental part of this study, the movement of children through a building is frequently organised in compact or supervised groups. The form and shape of a group may differ (e.g. movement in a single-file, in a group with a rigid organisation, in a group as a huddle) and it can to a large extent depend on daily routine as well as on actual instruction given by staff members. Furthermore, children form very often pairs holding each other's hand (see the part focused on organisation of children in Section 6.3.3). In such organised formations, the process of overtaking is highly restricted and travel speed of individuals is limited not only by density conditions but also by the movement of children in front of them. Therefore, a splitting of a group into more subgroups and a subsequent waiting for the slower part of the group may be no exception. Due to a higher level of organisation (especially in educational institution with a higher capacity), children can be frequently instructed to keep a separate group as a class and not to mixed with other children which typically results in making stops and yielding the way to other groups (notably on staircases and in doorways). Additional stops may be required when a door is opening/unlocking by a staff member or when children are waiting for further instruction, for slower children, or for a staff member delayed by providing assistance to less experienced children.

Taking into account these aspects, a detailed prediction of children's movement in early childhood educational institutions can be a challenging task. Since the majority of the factors may be very difficult to foresee for a fire engineer, using of various evacuation and movement scenarios in a combination with the methods of sensitivity analysis or a probabilistic approach can be recommended. Nevertheless, regardless of the rapid development which has experienced the area of evacuation computer modelling, the reliability and capability of current egress models to explicitly simulate the presented specifics seems to remain limited due to a lack of appropriate and credible functionality (e.g. moving in groups/pairs, yielding between groups, following behaviour of a leader, impact of the authority on movement behaviour of individuals).

7.1.2 Fire design perspective

In addition to the application in egress calculation and modelling, the knowledge obtained in the presented research is further interpreted in the view of a fire safety design perspective.

Evacuation routes

The experimental observations showed that the movement downstairs may be for pre-school children the most challenging part of evacuation routes, notably for Junior children under 4 years of age. Therefore, special attention should be given to appropriate design of staircases including their location, geometry, and equipment with handrails. When the requirements on a building, where an early childhood educational institution should be located, are not linked to a higher capacity required or to an already existing building enclosure, one-storey buildings or spaces located on the ground floor of multi-story buildings are preferable. In the case of elevated ground floors connected with the ground level via external staircases, alternative escape routes such as ramps can be recommended where applicable, which also provides a barrier-free environment for disabled persons or strollers. In the buildings, where spaces intended for children are located on higher floors, Junior classes with children under 4 years of age are recommended to be placed on ground floors or, where there do not have to use staircases when escaping the building. Furthermore, design of staircases in early childhood educational institutions should be adapted to needs of children. The observations confirmed that handrails are frequently used by pre-school children when climbing on staircases. Therefore, installation of handrails of both sides of stairs, ideally at both standard and lowered height can be highly recommended. The geometry of stairs (stairs depth and riser) should be adjusted to the physical dimensions of pre-school children. In the Czech Republic, the maximum permitted rise height in institutional and public buildings is 160 mm. This value seems to be acceptable also for early childhood educational institutions; however, a shorter rise height may be assumed as more comfortable for children. It is also important that these principles were respected also in the case of external escape staircase. Furthermore, it can be recommended that children are familiarised with all potential escape routes including not daily used external or internal staircases and that they have a opportunity to train downstairs climbing on them.

Besides staircases, a key element on evacuation routes in early childhood educational institutions represent doors. During the experimental evacuation drills was observed that the opening of door against the escape direction can adversely affect the fluency and efficiency of the evacuation process. In addition, attention should be given to conflicts resulting from a lack of space when two doors should be opened at the same time and they block each other. For example, in one experimental evacuation drill, an opened door leading from a classroom restricted the opening of another door in a corridor only to one-half of the effective door width. Consequently, children had to squeezed through the bottleneck and the movement of the flow was considerably impeded. Doors and exits on evacuation routes have to be also easy to open for the persons in charge. Several cases were seen during the experimental evacuation drills when staff members were trying to open usually closed second leave of a door in order to increase the effective width of the doorway and to speed up the leaving process from the building. Nonetheless, due to a broken or stuck locking mechanism, they failed and were only blocking the whole exit for a relatively long time period while children had to wait in front of the door. Some other complications restricting children's evacuation can be caused by self-closing doors. If a self-closing mechanism is too heavy to be comfortably opened by a child (or even by more children together), additional support provided by a staff member to open the door (or to keep the door opened) is required, which reduces the capabilities of the staff member to accomplish other activities such as supervise, instruct, or offer help to the leaving children.

Fire alarm systems

The results of the questionnaire on nursery schools in the Czech Republic and their implementation of evacuation drills supported by the observations during the experimental evacuation drills revealed that the most common warning signal used to start evacuation is a verbal message (e.g. "Fire"), a manual sound signal (e.g. banging on metal objects, whistle, bell, gong), or a combination of them. The warning signal is usually distributed personally by a responsible person (e.g. persons in charge of fire patrols) in corridors or in classrooms or the information can be delivered to staff members present in classes by an intercom. These findings are in line with the legislative requirements in the Czech Republic which do not require any mandatory installation of fire detection and alarm systems in nursery schools (only the institutions attended by more than 100 children have to be equipped with a domestic broadcast capable to be operational during a fire). It can be therefore assumed that the only fire devices expected to be installed in this type of occupancy are autonomous smoke detectors. Nevertheless, different conditions following the local standard and special fire requirements for early childhood educational institutions can be found worldwide.

In any case, it can be concluded that regardless of the type of used warning signal, its sound and meaning should be known to all persons in a building. In this context, it is important that children are familiarised with the sound and meaning of a warning signal as well. An example was repeated experimental evacuation drills in one nursery school where children who did not know the meaning of the word “alarm” did not react to the verbal warning announcement given by a responsible staff member (“alarm, alarm”) which resulted in considerable delays in the evacuation process. In the following experimental evacuation drill, the reaction of children who already knew the warning signal and its meaning was prompt and without any complications.

Fire protection education

In the Czech Republic, staff members in early childhood educational institutions are obligated to receive regular education in fire protection (at least every two years), staff members in charge of fire patrols must be specially trained [173]. Since the evacuation process in this type of occupancies is to a considerable extent dependent on decisions and actions taken by responsible staff members, the form and content of regular fire protection education should be taken seriously. In the majority of cases, staff members are schooled by a fire prevention officer (a professionally competent person at the fire prevention section). It is therefore necessary to appeal to these experts whose responsible approach in fire safety education and in providing instructions and explanations to staff members may be crucial. Furthermore, a joint cooperation of psychologists, fire rescue service, and fire safety experts should result into a general framework of fire safety education. This framework needs to comply to the fire safety and evacuation specifics of the early childhood education institutions.

7.2 Application in educational institutions attended by children at the pre-school age

In this section, practical application of the current findings in educational institutions attended by children at the pre-school age is presented. Based on the results of the questionnaire on nursery schools in the Czech Republic and their implementation of evacuation drills and on the observations made during experimental evacuation drills, suggestions for effective evacuation procedure and performing of evacuation drills in early childhood education institution are provided and discussed. The suggestions and recommendations provided in this part of the study were also used for preparation of the “Guide for providing evacuation drills in nursery schools in the Czech Republic” (in Czech). This brief and simply structured document aims to offer easily accessible information and clear explanations to interested educational institutions in order to provide them motivation and help for effective performing and organisation of evacuation drills. After a review process realised by cooperating leaders of nursery schools and fire prevention officers, the document will be publicly available and distributed in the cooperation with the Department for instruction and training services at the General directorate of Fire rescue service of the Czech Republic.

7.2.1 Introductory notes

Evacuation drills (fire drills) are generally recommended as a useful tool for both direct and indirect improving of the occupant performance in emergency situations [159]. They offer an opportunity how to train non-standard situations under safe conditions, help to practise and enhance evacuation procedure, and give an important experience to the participants and observers. It is therefore fundamental that evacuation drills are viewed rather in a positive light, as something beneficial which may help the occupants be prepared and trained, than a duty conducted out of necessity or only on paper. In this context, early childhood educational institutions can represent occupancies where the benefits of regular and effective conducting of evacuation drills can be maximise and over-weight potential disadvantages (e.g. disruption costs, productivity losses) which may be inconvenient in other types of facilities. Nevertheless an evacuation drill is a relatively straightforward issue, several aspects can be pointed out and discussed to carry out it as effective and as useful as it possibly can be. The general suggestions concerning effective conducting of evacuation drills in early childhood educational institutions are summarised in the following sections.

7.2.2 Frequency and timing of evacuation drills

Since only practise makes perfect, regular performing of evacuation drills seems highly recommended. Legislative requirements on regular performing of evacuation drills in early childhood education institutions differ worldwide. Based on the literature review, evacuation drills are commonly required annually, eventually more frequently [160] (see Table 6.1 for more details). Nevertheless evacuation drills in nursery schools are not explicitly required by the legislation in the Czech Republic, the results of the questionnaire conducted in the experimental part of this study showed that annually evacuation drills are a common practise (84.1% of the responding nursery schools which performed evacuation drills regularly).

It can be however assumed that more frequent performing of evacuation drills may be needed to ensure an appropriate emergency preparedness of both staff members and children, for instance, they should be preferably done on a monthly or quarterly basis. Since the former scenario may not be always organisationally feasible, a model considering the minimum number of two evacuation drills in each school year complemented by additional evacuation drills (in any number as desired) can be suggested. Following this model, the first evacuation drill (referred to as “the first evacuation drill" below) should be conducted at the start of each new school and the other evacuation drill (referred to as "the last evacuation drill" below) some time near the end of the school year. In addition, performing of several other evacuation drills (referred to as "additional evacuation drills" below) can be recommended during the school year according to the ability and desire of the educational institutions. In this concept, the first evacuation drill can be viewed as a familiarisation evacuation drill, the additional evacuation drills during the school year as exercise drills, and the last drills as a control drill. This categorisation is also closely linked to and reflected in different level of announcement of the evacuation drills, selection of evacuation scenarios, and other aspects discussed in the following sections.

Considering timing of evacuation drills, in temperate climate zones, early autumn or late spring season are typically chosen for performing evacuation drills due to the favourable climatic conditions. On the other hand, more challenging conditions of winter or adverse weather can be very valuable experience for all participants. For example, alternative evacuation procedures which include preparing children for cold outdoor conditions in a non-standard situation (such as dressing winter clothes or putting on shoes) can be tested and evaluated. The experience gained in such training may be helpful for future decisions how to proceed when a real emergency occurs in adverse conditions (e.g. if a higher level or different type of organisation is required). In any case, the evacuation training must be suitably adjusted that any health risks caused by cold weather can arise.

Another timing issue represents the scheduling of evacuation drills during the day. The experimental research revealed that reactions of staff members and children may considerably differ with the location in the building, actual staff-to-child ratio, and activities performed when the evacuation drills is started. Due to different level of attention of children, their potentially limited willingness to evacuate, and number of present staff members various evacuation procedures may be required. Therefore it can be recommended to choice for the beginning of evacuation drills different parts of the day which cover also different staff-to-child ratio, activities of children, and their location in the building (e.g. free play, small group activity, exercising, moving through a building, having a snack). In this context, a special case would represent the after lunch napping time as the most challenging evacuation situation when children can be most likely half asleep, confused, or disoriented. The evacuation training under these conditions must be always well considered thorough and thoughtful in order to avoid any discomfort or stress for children. Therefore, preparations of this training (e.g. the beforehand education and explanation for children) should be always in line with the professional and educational experience of the responsible leader and staff members.

7.2.3 Level of announcement of evacuation drills

When planning evacuation drills in early childhood educational institutions, there are many possibilities how, when, and to which extent they can be announce to the participants. For instance, different type of information (such as date, time, or evacuation scenario) can be provided to staff members and to children. In general, the level of announcement should be selected to achieve the expected goals of the evacuation drill. Following the concept suggested in the previous section, the first evacuation drill at the start of the school year should primarily aim to familiarise all participants with the importance and goals of the training and with the employed evacuation procedure (e.g. evacuation routes in the building, meeting place (place of safety), used warning signal etc.). Therefore, this evacuation drill is supposed to be completely announced to all staff members as well as well explained to children in advance. As the participants get more experienced, the level of announcement may be gradually decreased in the additional evacuation drills during the school year, eventually entirely minimised in the final evacuation drill at the end of the school year. It can be assumed that getting used to unexpected evacuation situation step by step together with a clear motivation and effective education can considerably help to prevent undesirable effects such as stress or fear by children in both training and real emergency. It should be also highlighted that the considered level of announcement must always reflect the characteristics, needs, and possible limitations of the involved persons and thus be in line with the professional, moral, and pedagogical beliefs of the responsible staff members. Moreover, an attention should be also paid to information provided to parents of the children.

7.2.4 Fire safety education for children

Although the evacuation process in early childhood educational institutions is to a large extent dependent on actions and preparedness of responsible staff members (supposed to be regularly educated in fire protection), the importance of fire protection education for children should not be underestimated as well. Conversely, it can be believed that familiarising children with the emergency evacuation plan and procedure may considerably limit stress and streamline the evacuation process in case of emergency. For this purpose, appropriate and effective methods how to explain evacuation procedure and meaning of evacuation drills to children should be carefully selected and adapted to the needs and age of children. It can be recommended to introduce the evacuation process to children as a part of usual educational activities at the start of each school year. Children should understand the main principles of the emergency evacuation plan, i.e. why, when, how, and where they are required to quickly leave the building. They should be aware especially of the type of the warning signal and its meaning, type of instructions which they can subsequently expected, and the location of the place of safety. In addition, it can be suggested that children have an opportunity to get familiarised with not daily used evacuation routes (e.g. external escape routes, emergency exits) or evacuation signs in the building by use of a fun and educational activity (i.e. not necessary only during evacuation drills). It is believed that there are many pedagogical methods in hands of responsible staff members which can contribute to an effective learning process for children in this matter as well as to increase children's positive motivation for a regular evacuation training.

7.2.5 Evacuation procedure during evacuation drills

As outlined in the previous sections, one of the main purposes of evacuation drills can be viewed as systematic training for real emergency. It can be therefore recommended that the evacuation procedure during evacuation drills (e.g. the warning signal and its delivering in the building, organisation of children) does not differ from the evacuation procedure provided for a real emergency situation. As the questionnaire performed in the experimental research of this study revealed, evacuation drills in early childhood education institutions can be organised also in the form of a game with a special motivation adjusted to the age or specifics of involved children. In general, this approach may be considered as appropriate and bringing certain advantages; however, only as long as the same evacuation procedure would be employed also in a real emergency situation. Otherwise, the training effect of evacuation drills and their contribution to emergency preparedness of the participants would be greatly reduced.

7.2.6 Selection of evacuation scenarios

In order to increase the efficiency of evacuation drills, it can be recommended that the diversity of evacuation scenarios selected for evacuation drills is maximised. This approach can include a various choice of cause and place of origin of fire in the building (e.g. electricity, rubbish and waste material, heating appliances, cooking) resulting in different availability of evacuation routes. The selection of simulated cause and location of fire should be based on real risks and potential fire hazards in the occupancy, in line with fire safety documentation of the building, and ideally in cooperation with with responsible professionally competent person at the fire prevention section. When an evacuation scenario includes using of escape routes which are not daily used and may be unfamiliar to children, it is highly recommended that children are acquainted with these evacuation routes in advance, for instance during a play or educational activity. Furthermore, different day of the week and time of the day should be selected to practise and train the evacuation process during the most diverse daily life situations. It should be also noted that the training of safety evacuation from the building may be motivated also by other emergency situation than those caused by fire (e.g. natural disasters, structural failure, attacks).

7.2.7 Evaluation of evacuation drills

After finishing, evacuation drills should be reviewed and evaluated to identify any shortcomings in the evacuation procedure which is supposed to be revised if necessary. For this purpose, it can be suggested to complete a written documentation of the evacuation drill in the format of a brief form including the following specifics:

- Date and time of the evacuation drill,
- Evacuation scenario (cause and location of fire (eventually other reason for the building evacuation), evacuation routes available, used place of safety),

- Number and specification of the participants,
- Length of time required to vacate the building (total evacuation time),
- Potential gaps in the evacuation procedure and suggested improvements.

Besides the written record, the carried out evacuation drill should be also discussed with the participating staff members as well as with children (e.g. during circle time activity). The recent active experience of the evacuation drill can be very helpful for encouraging the children to understand the main principles of the emergency evacuation plan and safety evacuation from the building. In addition, the evacuation drill should be communicate also with parents of children to ensure further feedback and discussion in their home environment.

Chapter 8

Conclusions

Children under 6 years of age represent a vulnerable part of our population whose potentially limited self-rescue capabilities may result in very specific requirements and procedures during emergency evacuation processes. The main goal of this thesis was to overview and expand our current knowledge and understanding on evacuation behaviour and movement of pre-school children aged 3–6 years and to present the acquired knowledge in the manner appropriate for further practical application, notably in fire safety engineering.

In the first part of the thesis (**Part I**), the general literature background was provided focused on our current knowledge of evacuation behaviour and movement characteristics of pre-school children (Chapter 2) and related developmental aspects (Chapter 3). Based on the literature review on previous research studies dealing with evacuation behaviour and dynamics of children accommodated in early childhood educational institutions, the available findings and data-sets were summarised and tabulated. It was found that, despite the increasing scientific interest in this research issue in the last decade, the current level of knowledge is incomplete and relevant engineering data remains limited. A special attention was further paid to developmental changes in children during the pre-school age which may considerably influence their evacuation and therefore should be considered properly in evacuation and fire safety analysis. In general, it can be concluded that all domains of child development (physical, motor, cognitive, and socioemotional) and their mutual interaction can substantially distinguish adults' and children's behaviour, thinking, and movement abilities. Furthermore, even the age interval covering the entire pre-school life period (early childhood, 2–6 years) seems to be insufficiently detailed to properly represent the ongoing developmental changes in children. Therefore, the concept distinguishing two age subgroups within the pre-school age period (Junior pre-school age under 4 years and Senior pre-school age over 4 years) was suggested in this study for engineering application in fire safety design.

New experimental data-sets and information on children's movement, behaviour, and specific evacuation conditions in nursery schools in the Czech Republic were presented in the experimental part of the thesis (**Part II**). In the first part of the experimental research (Chapter 4 and Chapter 5), children's evacuation behaviour, movement characteristics, and evacuation procedure were observed and analysed during 15 experimental evacuation drills involving 970 children aged 3–7 years and 87 staff members conducted in 10 participating nursery schools within the experimental period from May to June 2019. The level of announcement of the experimental evacuation drills differed including announced, semi-announced, and unannounced experimental evacuation drills. For purposes of the subsequent analysis, the experimental evacuation drills were video recorded. Ethical aspects of the conducted experimental research were discussed in detail in Chapter 4. Based on the analysis of video recordings, over 24,800 data-points describing evacuation behaviour of children and staff members in both the pre-movement and movement phase of the evacuation process as well as movement characteristics of children (travel speed, specific flow, density, and their relationships) on different parts of evacuation routes (in corridors, on staircases, and in doorways) were gathered and interpreted (Section 5.3). The findings which could be compared to results of previous research studies focused on evacuation behaviour and movement characteristics of pre-school children were further explored and discussed (Section 5.4). The key findings and outcomes of the experimental evacuation drills were summarised and can be found in Section 5.5. Nevertheless, the following conclusions of the experimental research can be highlighted:

– Evacuation of pre-school children in the participating early childhood educational institutions was strongly dependent on decisions and actions of responsible staff members impacted by the age of children. Evacuation behaviour of both children and staff members can to a large extent reflect daily routines, rules, and educational practises employed.

– During the evacuation process, pre-school children require both verbal and physical help provided by responsible staff members. The level of assistance required is age-dependent and is affected by actual staff-to-child ratio and daily routines in the early childhood educational institution.

– Pre-school children tend to use familiar exits and escape routes; however, the final exit choice is usually in competence of staff members.

– Movement characteristics of pre-school children are age-dependent. Different movement abilities of pre-school children should be expected on horizontal paths of evacuation routes (including landings of straight staircases) and on staircases. Climbing downstairs on staircases is for pre-school children the most challenging part when travelling through a building. Appropriate design of staircase geometry and handrails which are frequently used may be a crucial factor impacting evacuation efficiency.

– When moving through a building, a close physical contact between each other is not unusual among pre-school children. Under higher density conditions they can form a very compact crowd with a minimal body buffer zone.

– Familiarity with evacuation routes and evacuation procedure is an important factor in evacuation efficiency. Evacuation procedure including both premovement and movement phase can be improved by regular training.

In the other part of the experimental research (Chapter 6), real-life operational conditions in nursery schools and their daily practice with evacuation drills were investigated through an anonymous online questionnaire. The questionnaire included 20 questions focused on gathering basic information describing construction and operational conditions in nursery schools (Part 1) and actual practice and experiences of nursery schools when performing evacuation drills (Part 2). The questionnaire was delivered to 4,903 nursery schools in the Czech Republic and its response rate was 23.5%. The key outputs of the questionnaire were summed up and can be found in Section 6.4. Furthermore, the main conclusions of the questionnaire can be emphasised as follows:

- In 90.6%, the capacity of the nursery schools is 1–5 classes. The most frequent number of children in a class ranges between 20 and 28 children (80.1%) with the median value of 24 children. In more than half of the nursery schools, the staff-to-child ratio is 1:10 to 1:14 (59.2%). Children are organised more often in heterogeneous classes (56.8%) than in homogeneous classes (37.4%).
- In the nursery schools, spaces intended for children are most often located on the ground floor (53.5%) or on the first floor (40.6%). When spaces intended for children are located on higher floors than on the ground floor, an external escape staircase/s is present in 39.5% of the nursery schools.
- Evacuation drills are performed at least once in the last 5 years in 76.4% of the nursery schools. In the majority of these nursery schools (94.4%) evacuation drills are carried out annually (84.1%), eventually biannually (10.3%).
- The warning signal used to start evacuation is usually given using a verbal message (35.7%), a manual sound signal (23.3%), or combination of both (37.7%). In the majority of the nursery schools (90.3%), the warning signal is given personally by a responsible person in corridors or in classrooms.
- In 42.9%, evacuation drills are completely announced to staff members. The most common source of fire safety education for staff members is a regular fire protection education given by a fire prevention officer (63.1%).
- Only the daily travelled routes are used as escape routes during evacuation drills in 56.9% of the nursery schools (in 18.5% there are the only circulation routes in the building, in 38.4% using of alternative escape routes is omitted). The not daily used escape routes are used during evacuation drills in 41.2% of the nursery schools.
- Evacuation of children is organised and controlled by staff members during both pre-movement phase (97.8%) and movement phase (89.0%) of the evacuation process.
- During evacuation drills, 75.5% of nursery schools register some issue/s; on contrary, in 23.1% of nursery schools evacuation drills run smoothly without any issues.

The findings resulting from the general theoretical background (Part I) and the conducted experimental research (Part II) were further presented in the context of their application in fire safety engineering and in educational institutions attended by children at the pre-school age (**Part III**, Section 7). For the interpretation of the presented knowledge for the purpose of engineering application, the concept of behavioural statements [185, 186] was used. In order to facilitate understanding and quantification of the evacuation process in egress calculation and modelling, a set of 18 behavioural statements on pre-school children evacuation behaviour and movement in early childhood education institutions was identified. Furthermore, four elements allowing a direct incorporation of the behavioural statements in a life safety analysis and egress modelling (namely pre-movement time, physical movement characteristics, evacuation route usage, and behavioral itineraries) were clarified in the context of the specific evacuation conditions of pre-school children. In addition, the knowledge obtained in the presented research was interpreted in the view of a fire safety design perspective including design of evacuation routes, fire alarms systems, and fire protection education in early childhood education institutions.

For application of the research outputs in educational institutions attended by children at the pre-school age, suggestions for effective performing of evacuation drills were established. It can be believed that any complications during evacuation drills and real emergency situations may be minimized through a regular and effective training as well as easy access to practical, simple, and understandable information. Following this perspective the main recommendations for providing evacuation drills in early childhood education institutions can be underlined:

- Evacuation drills should be conducted regularly. The model considering the minimum number of two evacuation drills every school year complemented by additional evacuation drills (in any number as desired) can be suggested.
- The level of announcement of evacuation drills to staff members and to children should correspond to the purpose of evacuation drills as well as to characteristics, needs, and possible limitations of the involved persons. A gradually decreasing level of announcement of evacuation drills during the school year together with a clear motivation and effective education can be suggested as a useful tool to prevent undesirable effects such as stress or fear by children in both training and real emergency.
- Evacuation scenarios for evacuation drills should be selected as alternating as possible including different day time, activities, staff-to-child ratio, cause and place of origin of fire, evacuation routes available etc.
- Fire protection education for children should not be underestimated. Conversely, familiarising children with the emergency evacuation plan and procedure may considerably limit stress and streamline the evacuation process in case of emergency. Appropriate methods how to explain evacuation procedure and meaning of evacuation drills to children should be carefully selected and adapted to the needs and age of children, as much as possible by use of fun and educational activity (i.e. not necessary only during evacuation drills).
- Evacuation drills should be recorded, evaluated, and the results archived.

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Appendix A

Ethical approval of the experimental research issued by the Ethical review board at Czech Technical University in Prague

Odbor pro vědeckou a výzkumnou činnost
Rektorát ČVUT v Praze
Jugoslávských partyzánů 1580/3
160 00 Praha 6-Dejvice

Vyjádření Komise pro etiku ve výzkumu na Českém vysokém učení v Praze

Složení komise:	Předseda	prof. Ing. František Wald, CSc.
	Členové:	prof. Ing. Jan Holub, Ph.D.
		doc. Ing. Václav Jirovský, CSc.
		prof. RNDr. Bohumil Kratochvíl, DSc.
		prof. RNDr. Ivo Kraus, DrSc.
		doc. RNDr. Pavla Poučková, CSc.
		prof. Ing. Olga Štěpánková, CSc.

Projekt: **Evakuace předškolních dětí ve věku od 3 do 6 let.**

Řešitele: **Ing. Hana Najmanová**

byl schválen Komisí pro etiku ve výzkumu na Českém vysokém učení v Praze pod jednacím číslem: 0000-01/19/51902/EKČVUT

dne: 12.4.2019

Komise pro etiku ve výzkumu na Českém vysokém učení v Praze zhodnotila předložený projekt a neshledala žádné rozpory s platnými zásadami, předpisy a mezinárodní směrnicemi pro provádění výzkumu zahrnujícího lidské účastníky.

Řešitel projektu splnil podmínky nutné k získání souhlasu Komise pro etiku ve výzkumu na Českém vysokém učení v Praze.

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
REKTORÁT
JUGOSLÁVSKÝCH PARTYZÁNŮ 1580/3
160 00 PRAHA 6 – DEJVICE
(7/1)

Razítko ČVUT v Praze

podpis předsedy Komise pro etiku ve výzkumu na ČVUT v Praze

Appendix B

Written statement on the experimental research given by the Department for instruction and training services at the General directorate of fire rescue service of the Czech Republic

MINISTERSTVO VNITRA
generální ředitelství HZS ČR
plk. Ing. Pavel Nepovím
ředitel odboru ochrany obyvatelstva
a krizového řízení

Praha 2. dubna 2019
Počet listů: 1

Vážená paní inženýrko,

na základě Vaší žádosti jsme posoudili návrh Vaší disertační práce „Evakuace dětí ve věku od 3 do 6 let".

S přihlédnutím k cílům a předpokládaným výsledkům práce a vzhledem ke skutečnosti, že této skupině nebylo doposud věnováno tolik pozornosti, konstatujeme, že pro Hasičský záchranný sbor ČR budou výsledky této práce prakticky využitelné a mohou přispět k rozvoji této oblasti v budoucnu.

S pozdravem

Vážená paní
Ing. Hana Najmanová
K124 Katedra konstrukcí pozemních staveb (A630)
Fakulta stavební
České vysoké učení technické v Praze
Thákurova 7 Praha 6 - Dejvice 166 29

Appendix C

Complementary material to Section 5.3 (Results of the experimental evacuation drills)

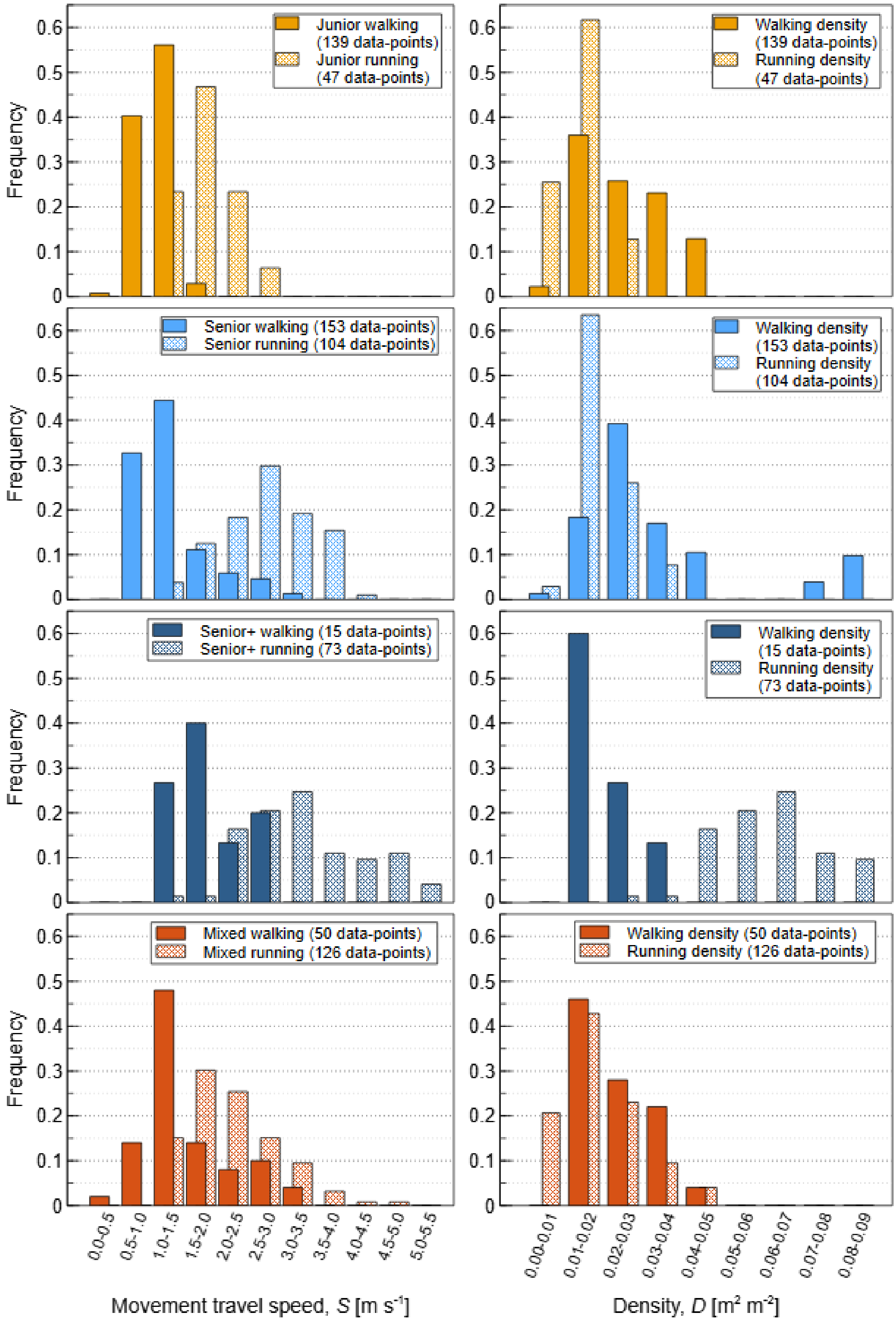

Figure C.1: Probability distribution for travel speeds (**left**) and density (**right**) measured in corridors for different age groups

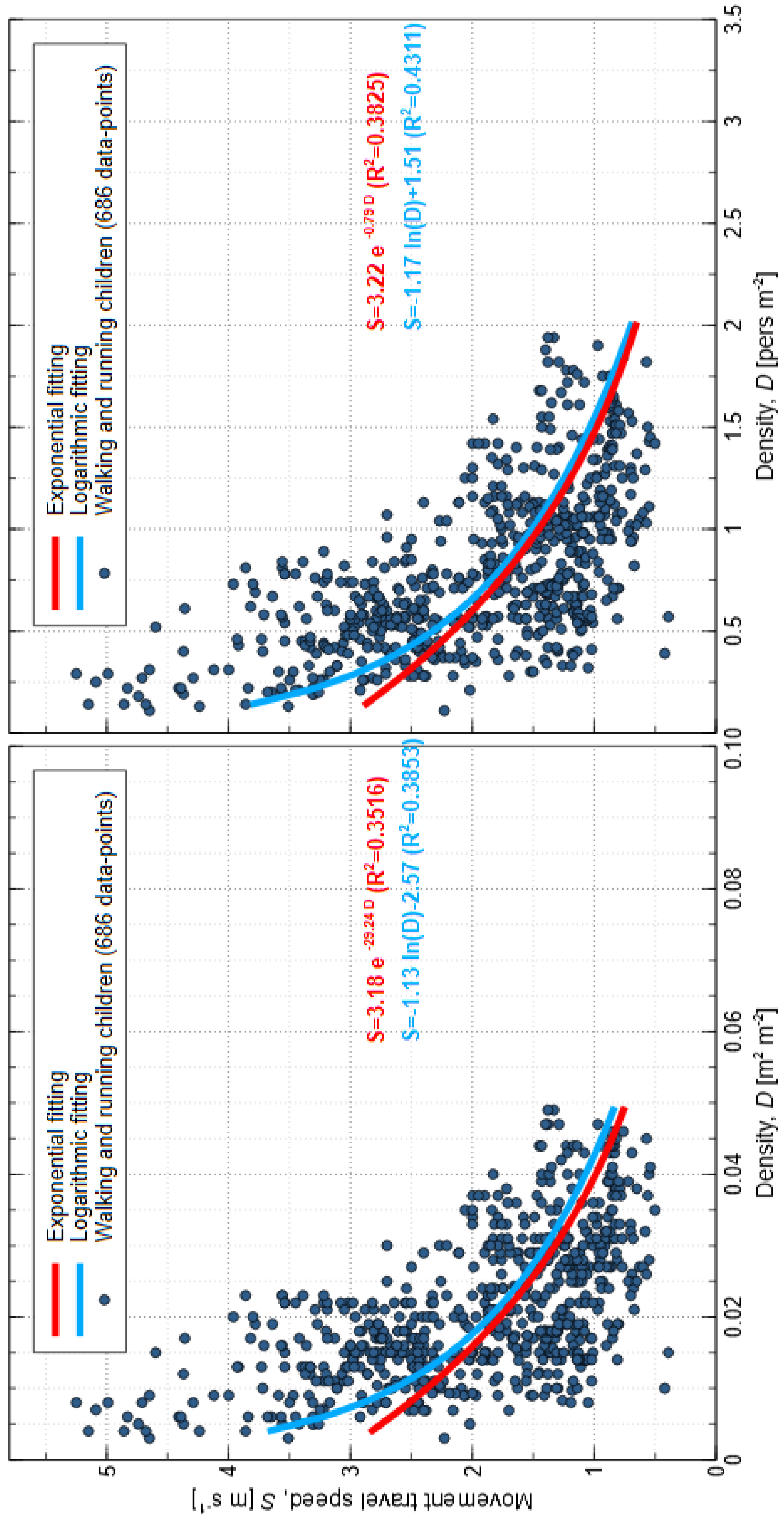

Figure C.2: Travel walking and running speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with calculated trend lines measured in corridors (the modified data-points excluded)

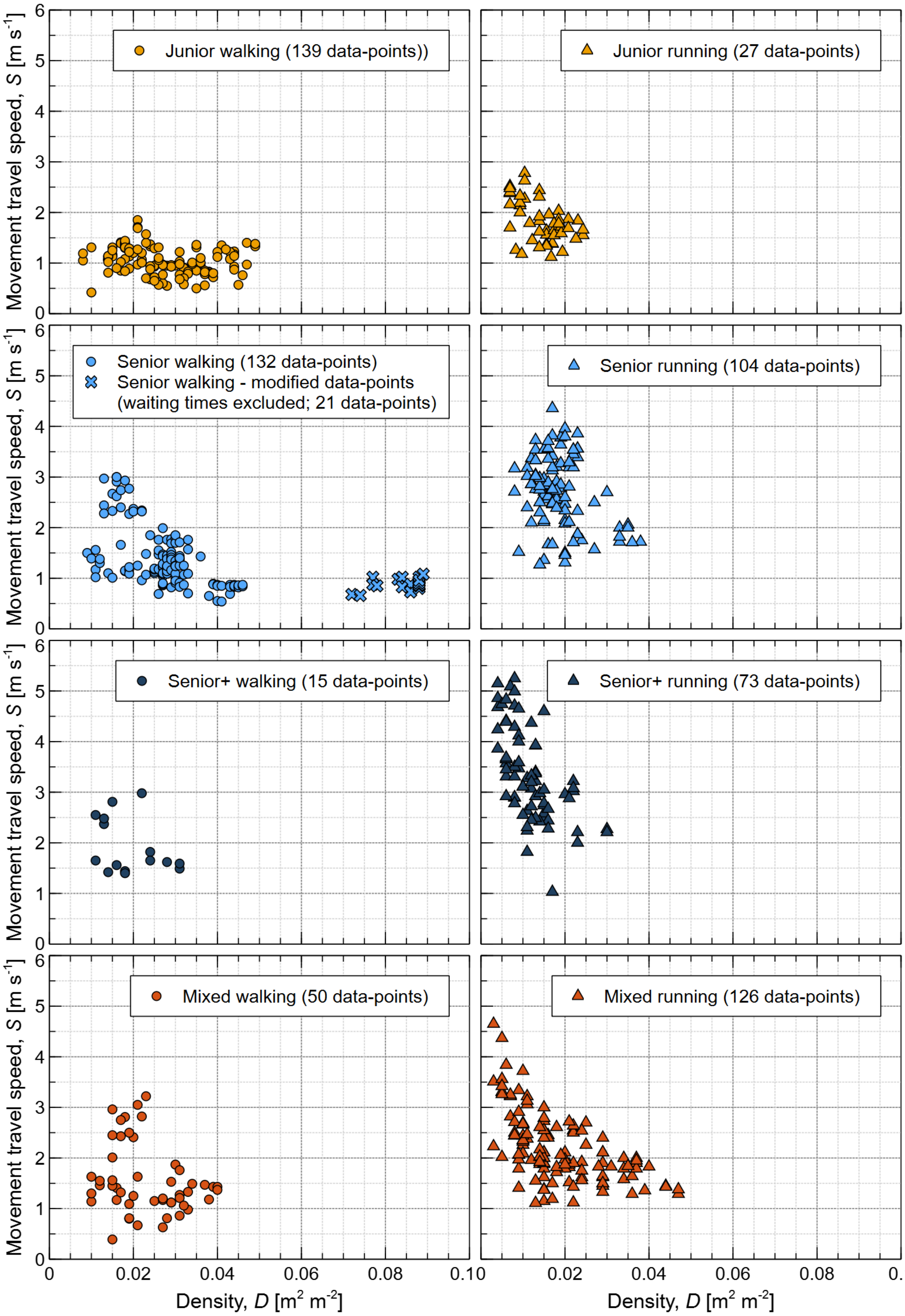

Figure C.3: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] measured in corridors for different age groups

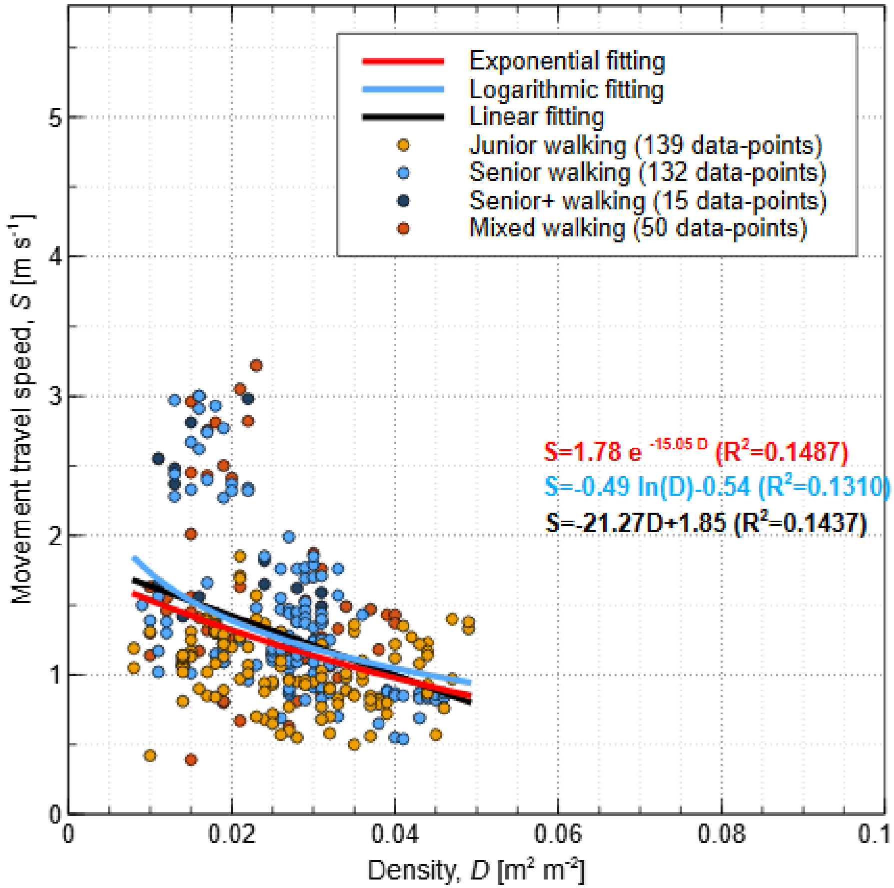

Figure C.4: Walking travel speed per density [$m^2\,m^{-2}$] with calculated trend lines measured in corridors for different age groups (the modified data-points excluded)

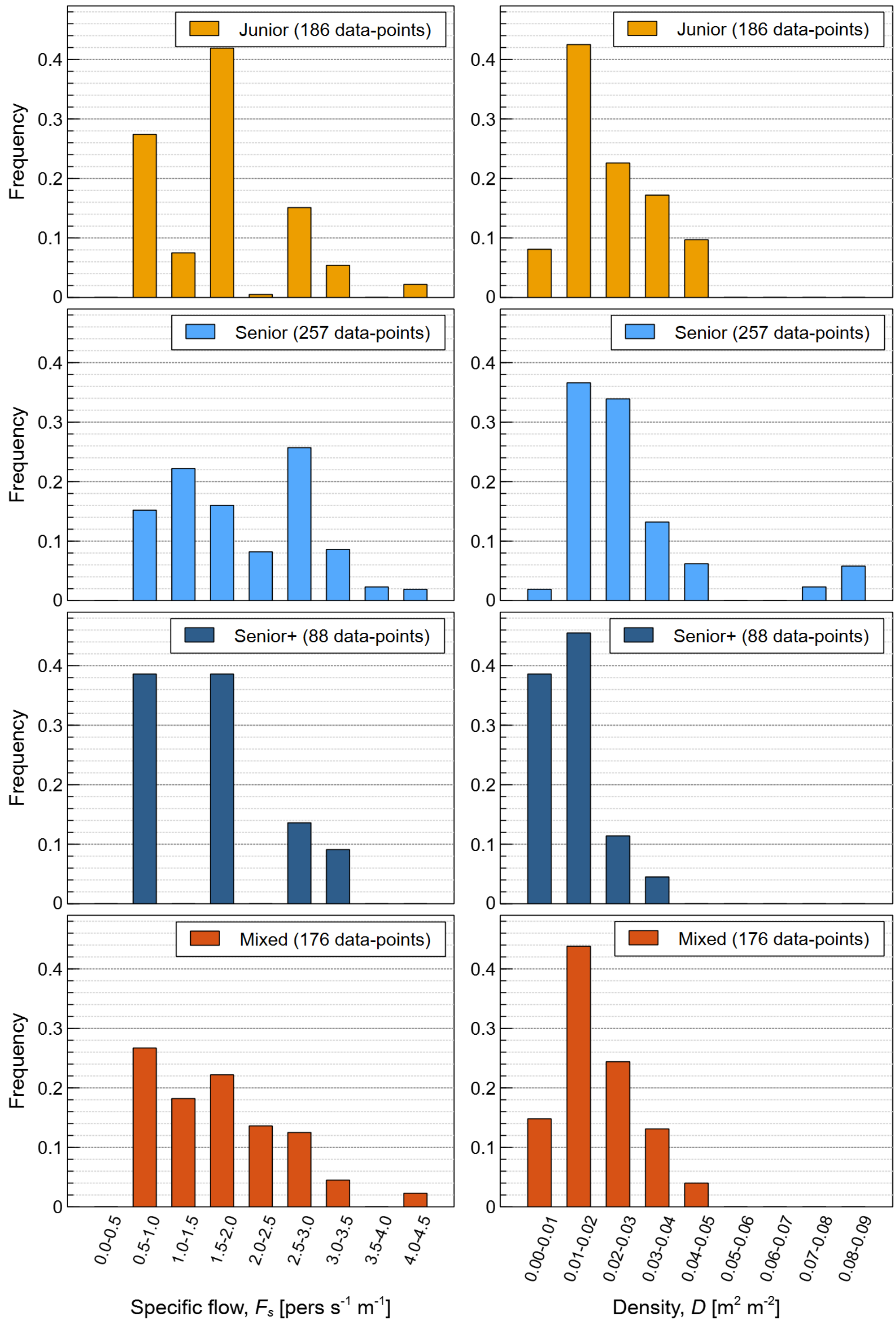

Figure C.5: Probability distribution for specific flow (**left**) and density (**right**) measured in corridors for different age groups

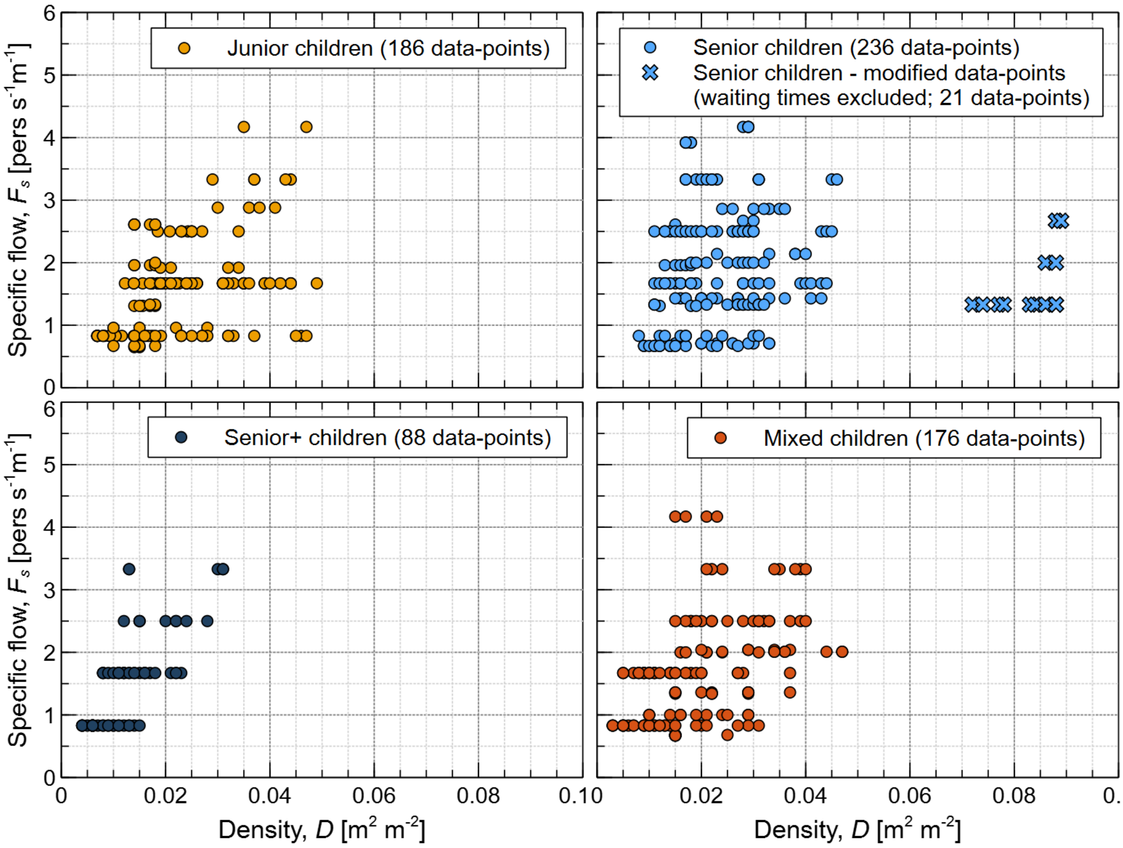

Figure C.6: Specific flow per density [$m^2\,m^{-2}$] measured in corridors for different age groups

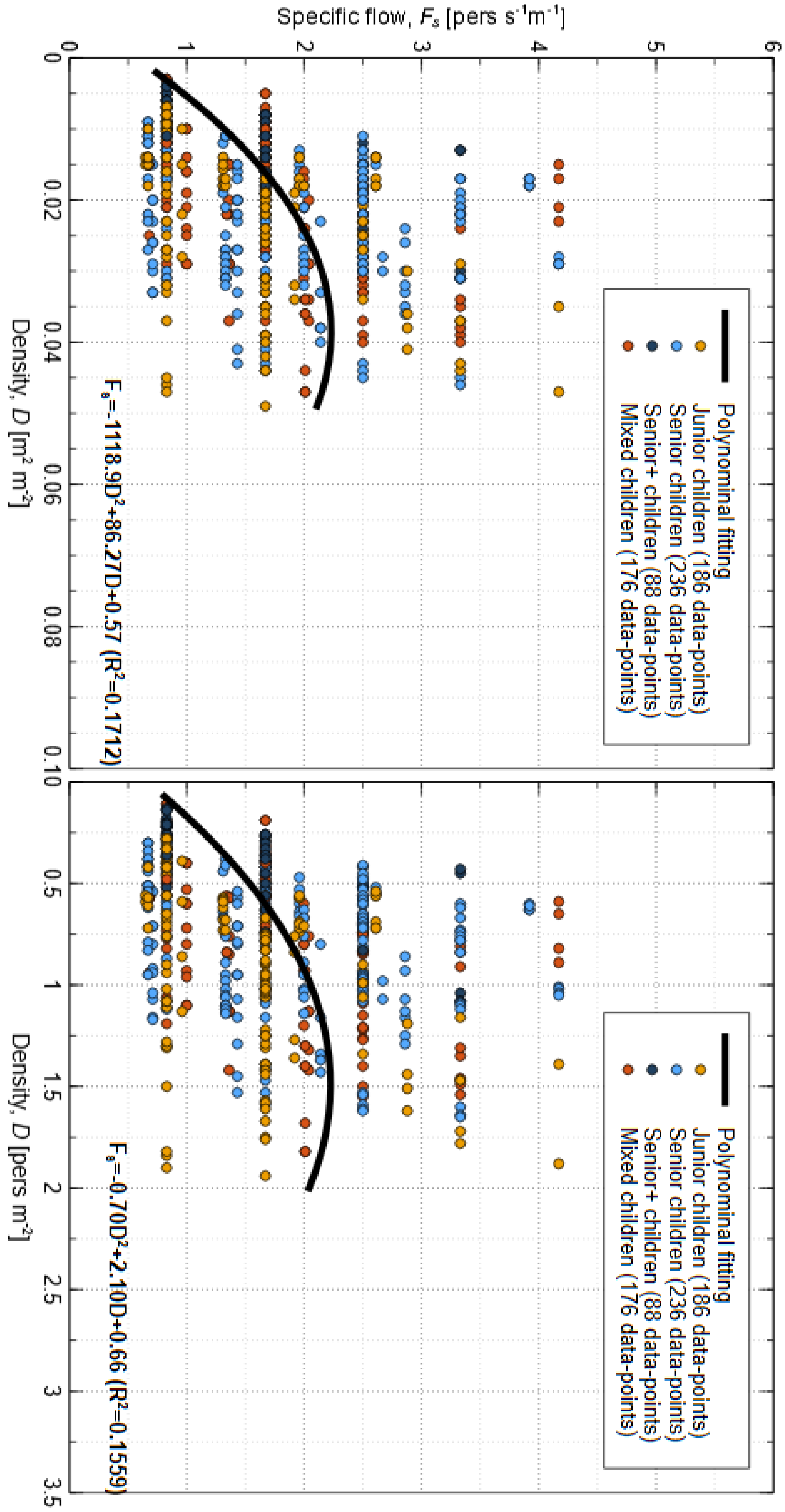

Figure C.7: Specific flow per density (**left**: [m^2 m^{-2}]; **right**: [pers·m^{-2}]) with calculated trend lines measured in corridors (the modified data-points excluded)

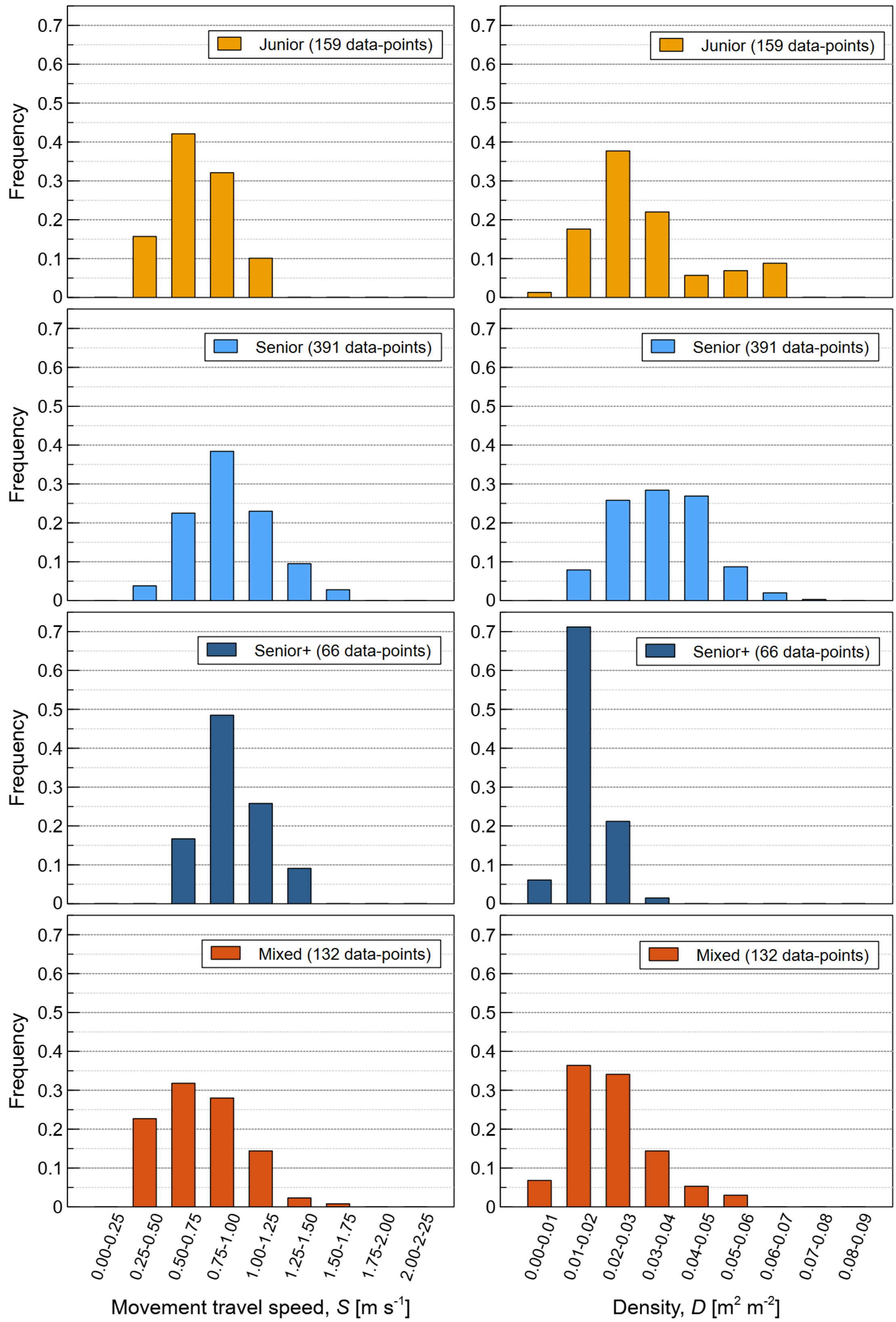

Figure C.8: Probability distribution for travel speeds (**left**) and density (**right**) measured on flights of straight staircases for different age groups

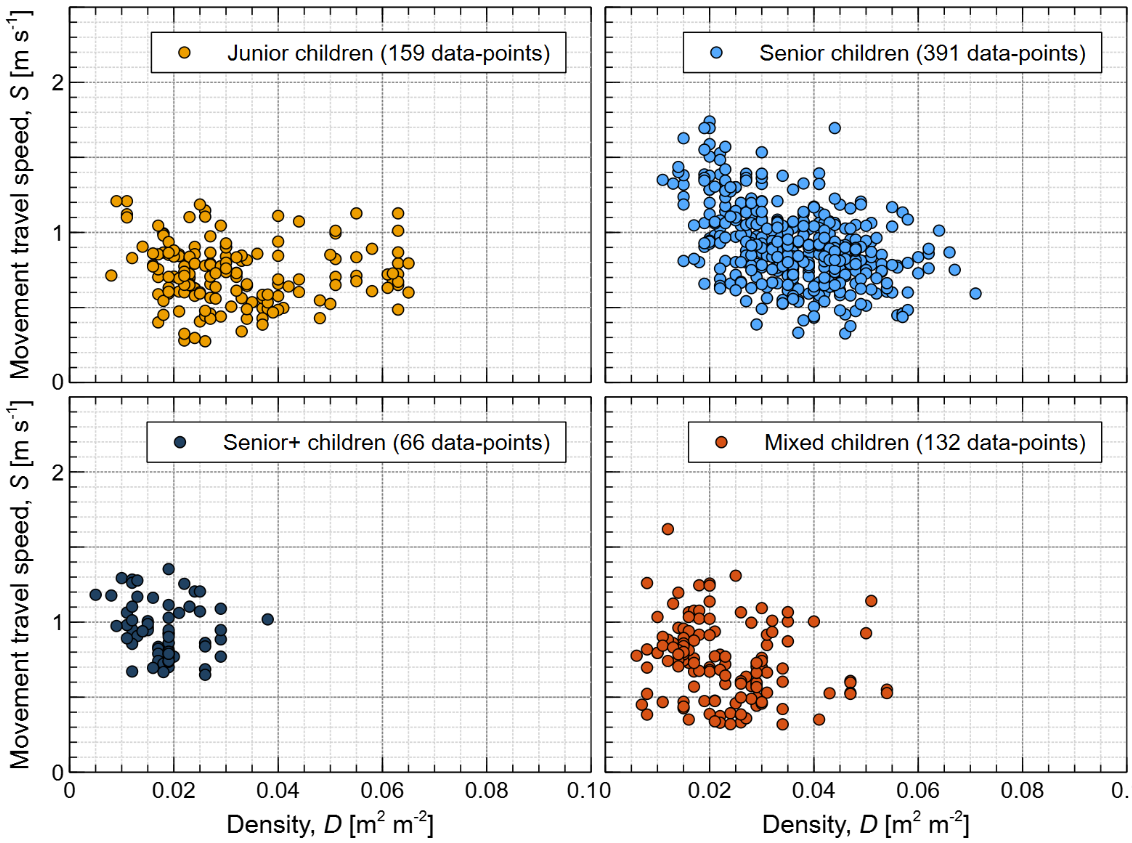

Figure C.9: Travel speed per density [$m^2\,m^{-2}$] measured on flights of straight staircases for different age groups

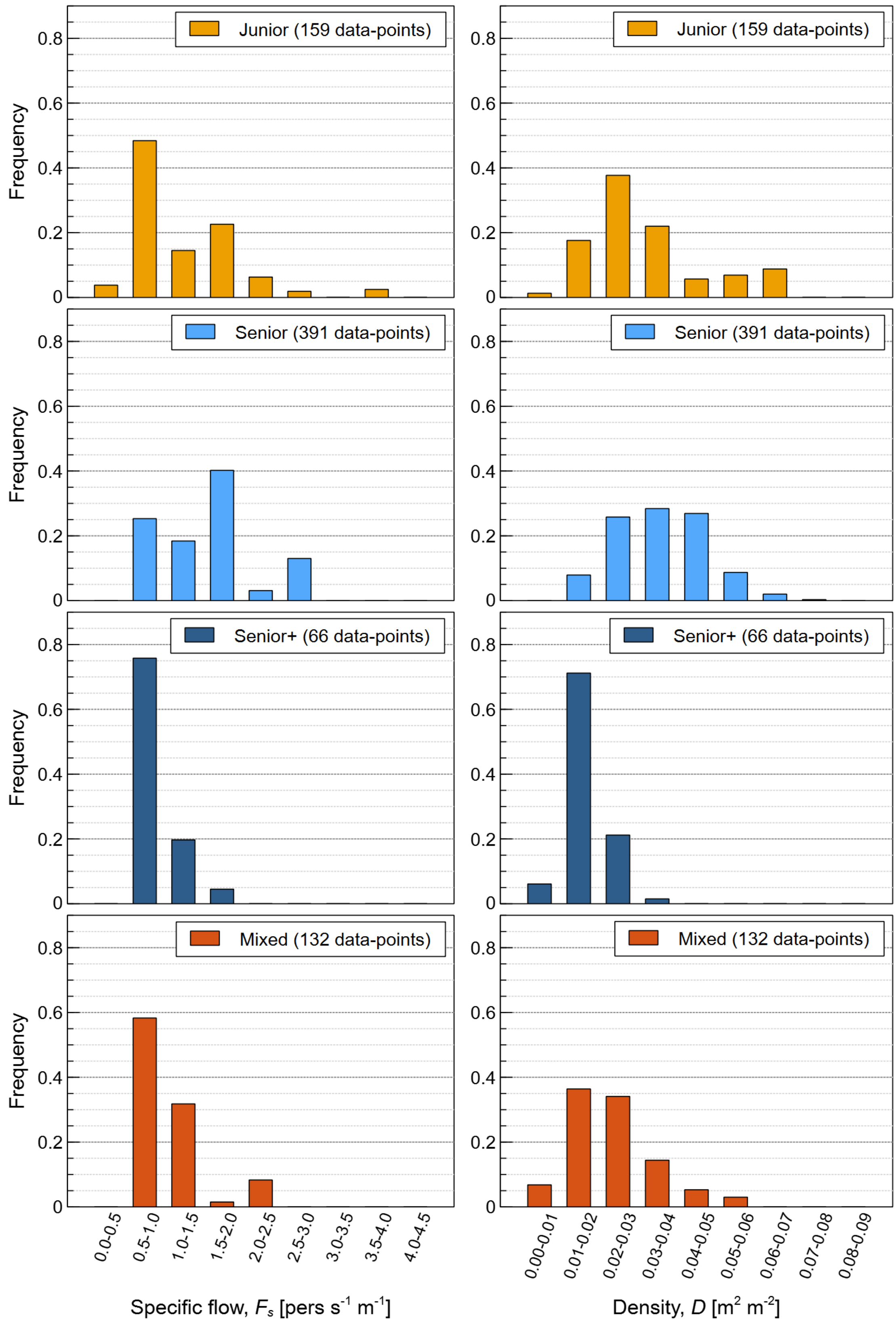

Figure C.10: Probability distribution for specific flow (**left**) and density (**right**) measured on flights of straight staircases for different age groups

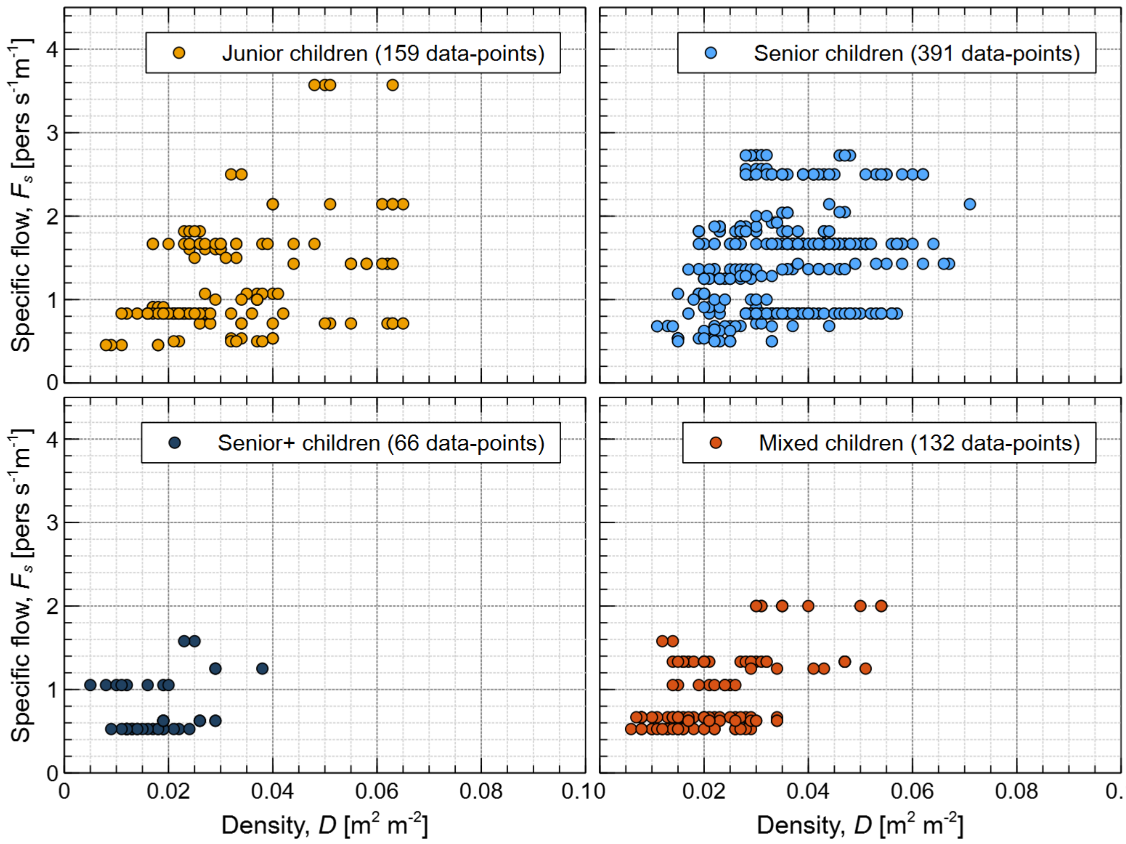

Figure C.11: Specific flow per density [m^2 m^{-2}] measured on flights of straight staircases for different age groups

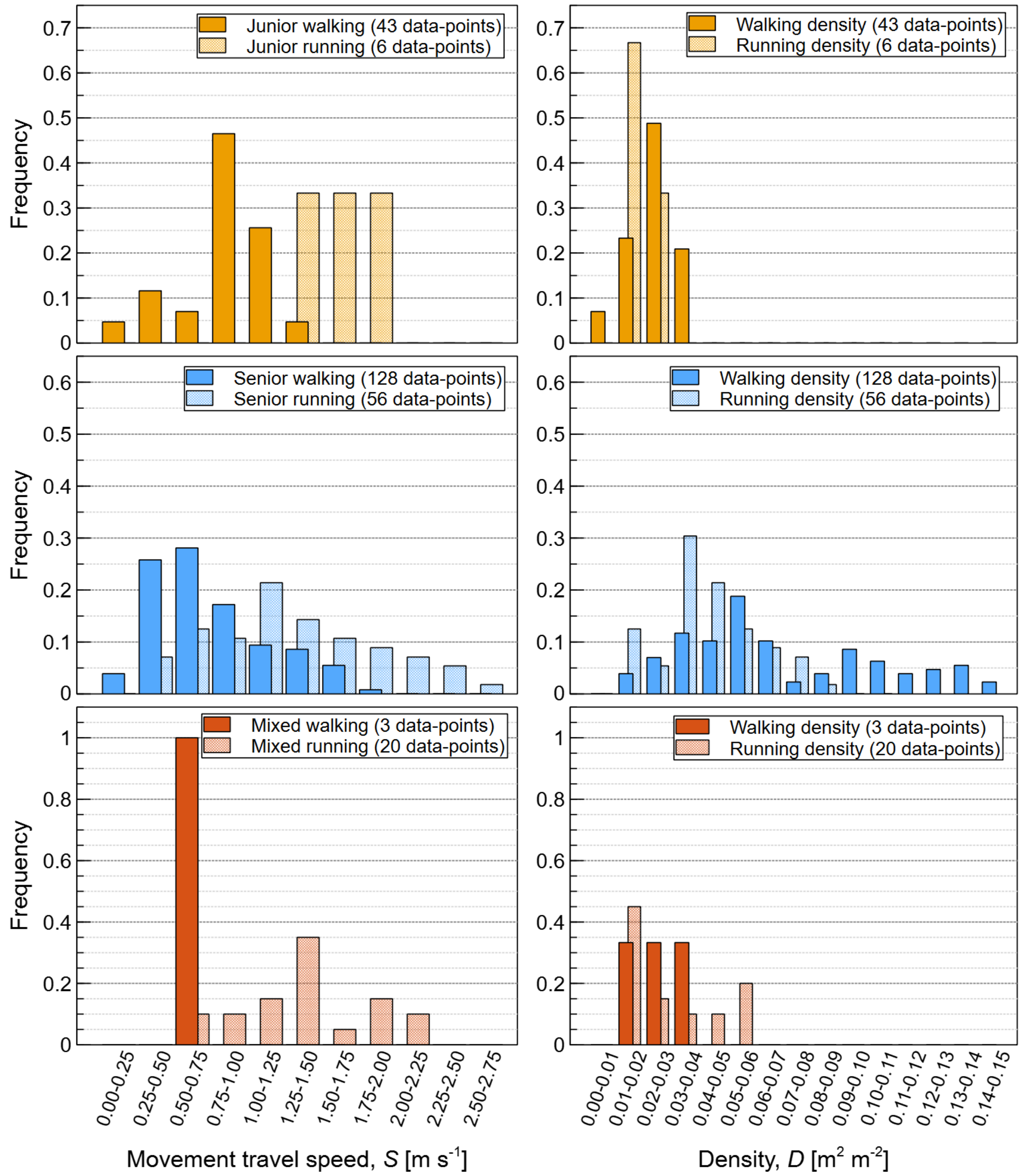

Figure C.12: Probability distribution for travel speeds (**left**) and density (**right**) measured on landings of straight staircases for different age groups

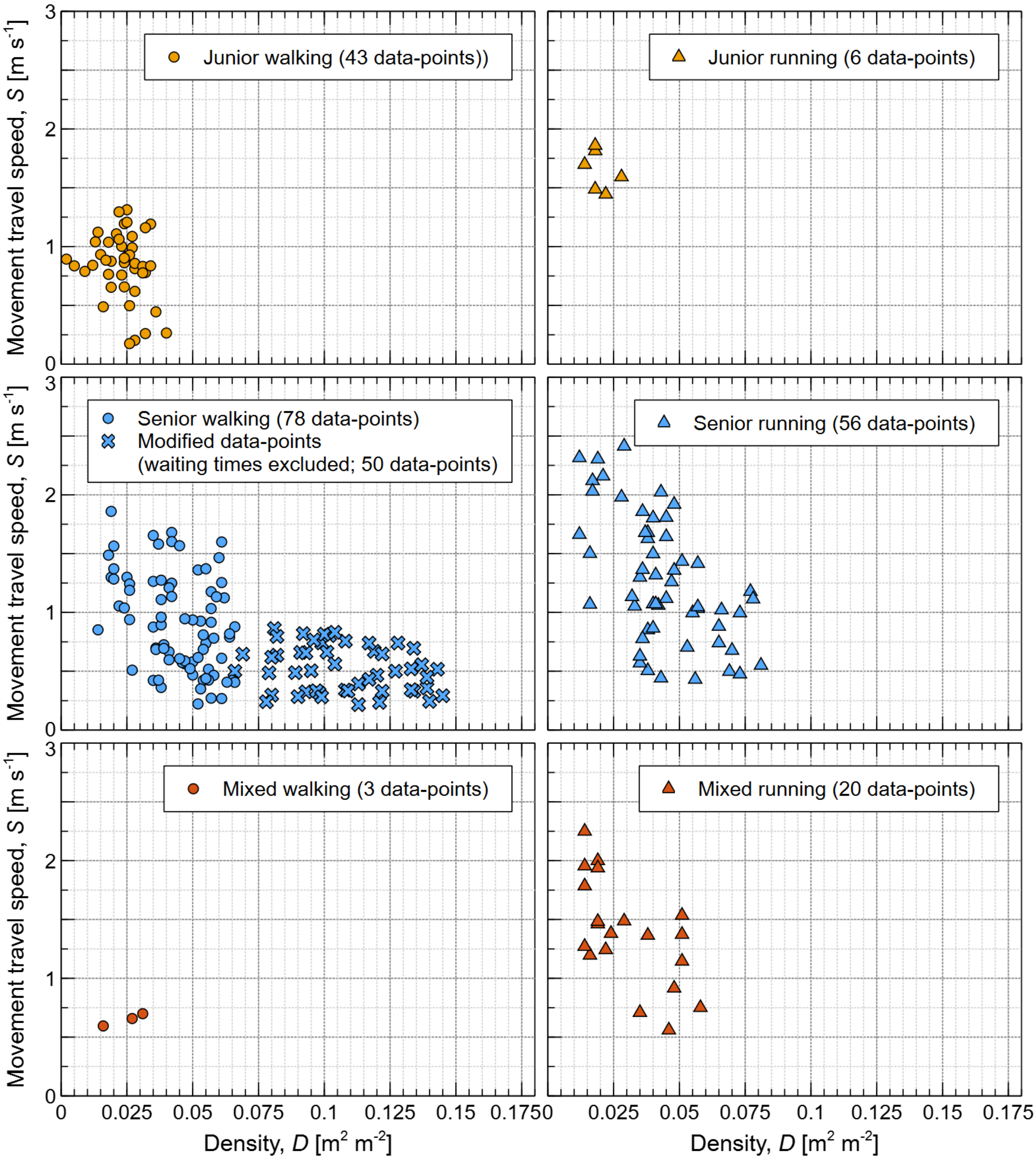

Figure C.13: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] measured on landings of straight staircases for different age groups

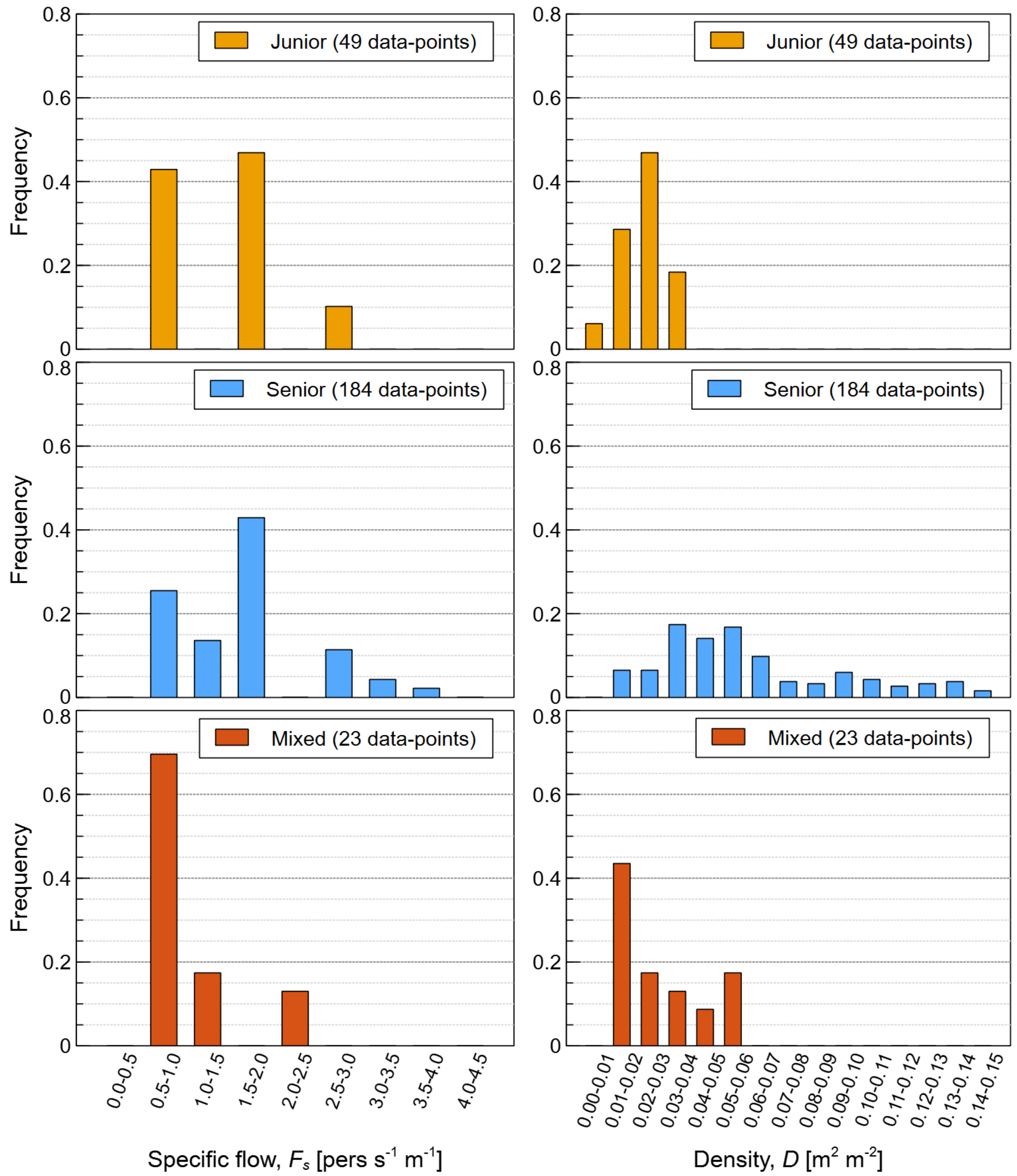

Figure C.14: Probability distribution for specific flow (**left**) and density (**right**) measured on landings of straight staircases for different age groups

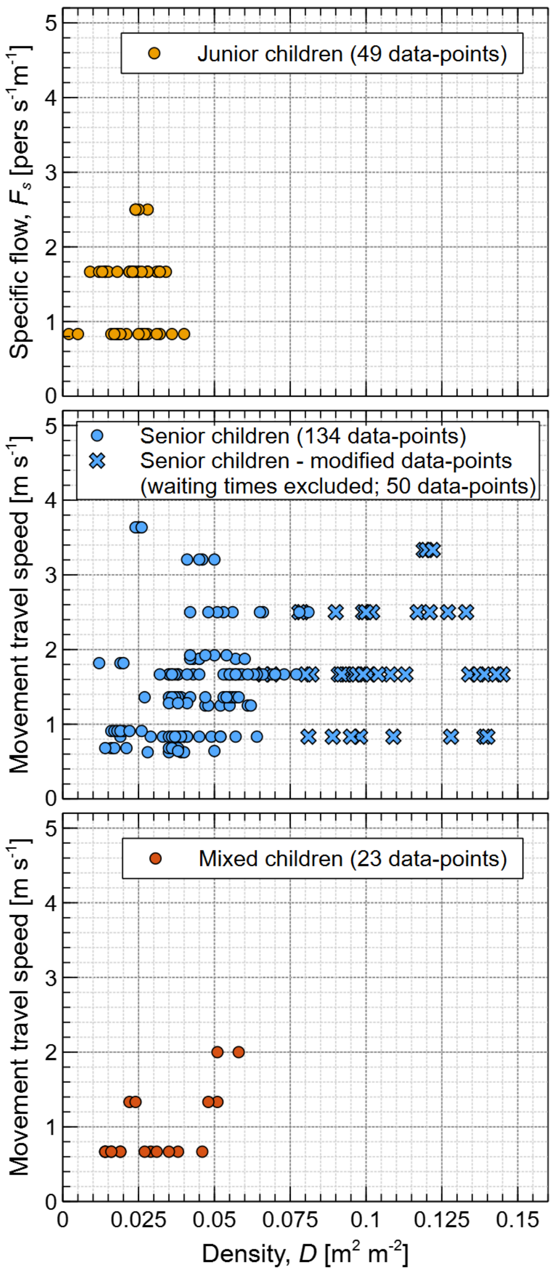

Figure C.15: Specific flow per density [m^2 m^{-2}] measured on landings of straight staircases for different age groups

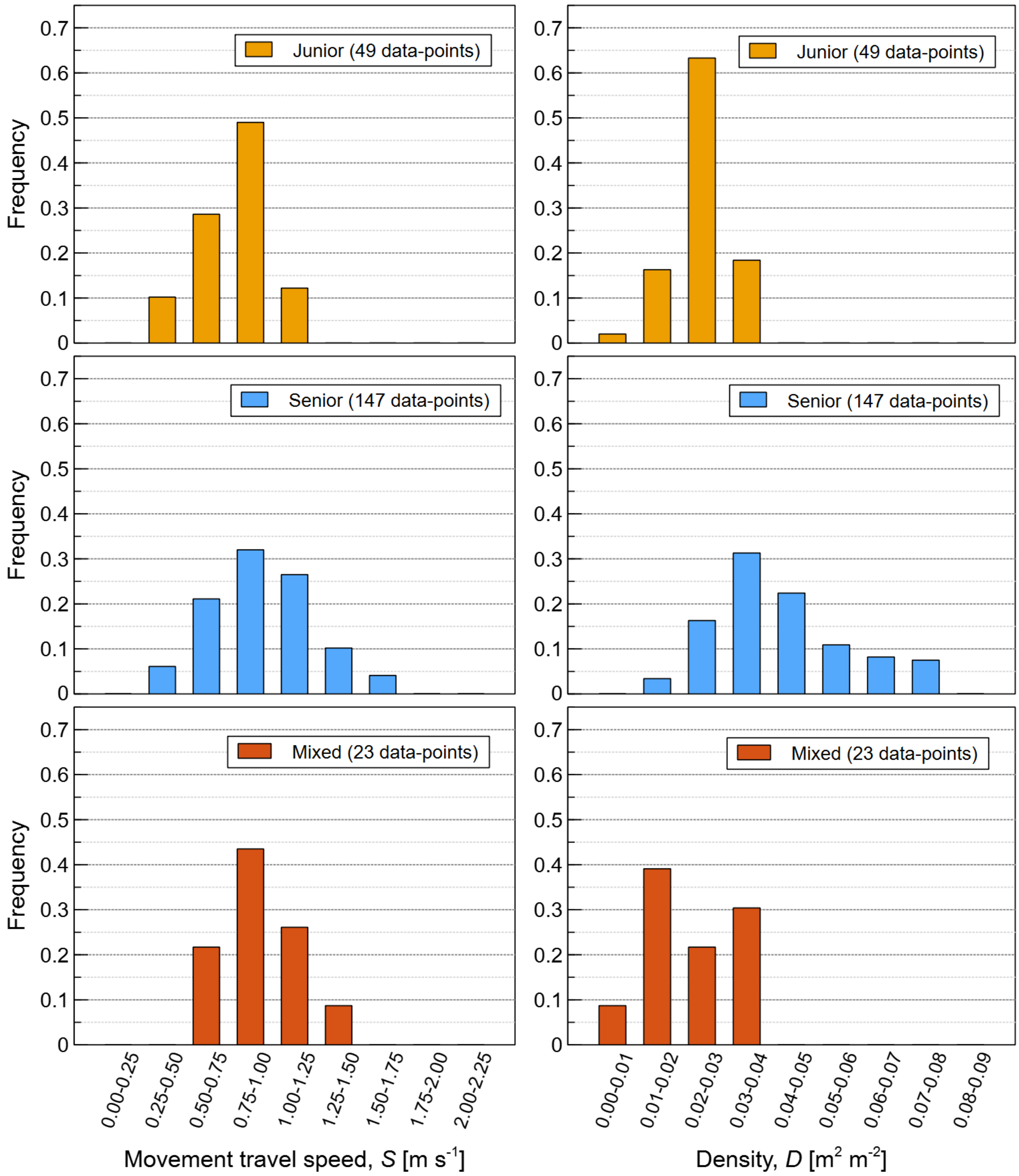

Figure C.16: Probability distribution for travel speeds (**left**) and density (**right**) measured on whole straight staircases for different age groups

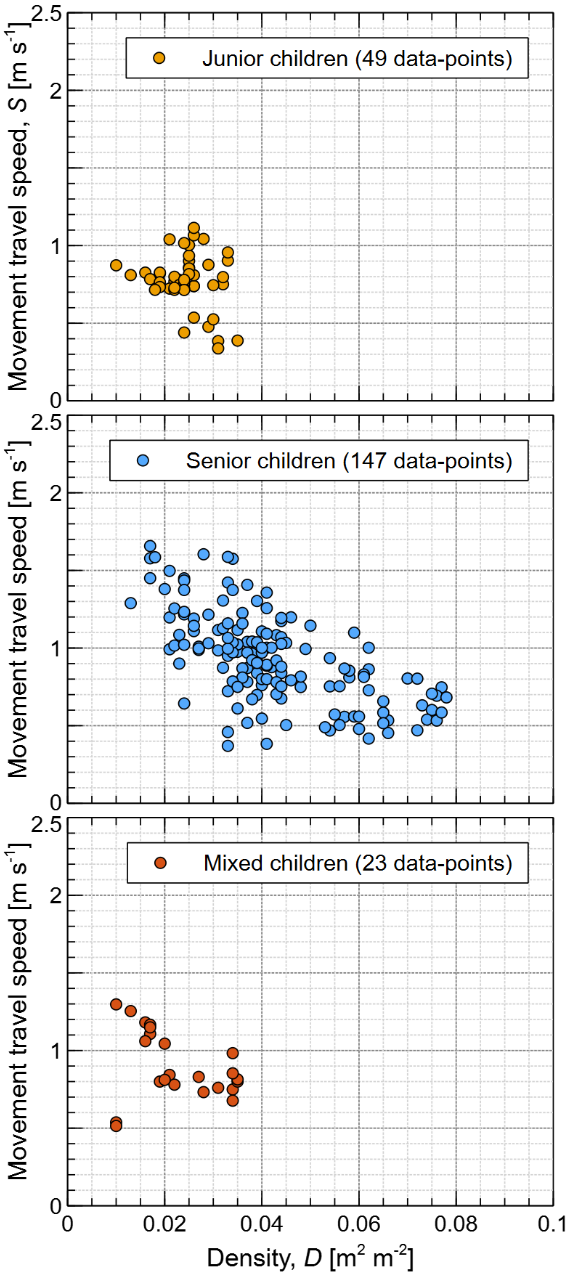

Figure C.17: Travel speed per density [$m^2\,m^{-2}$] measured on whole straight staircases for different age groups

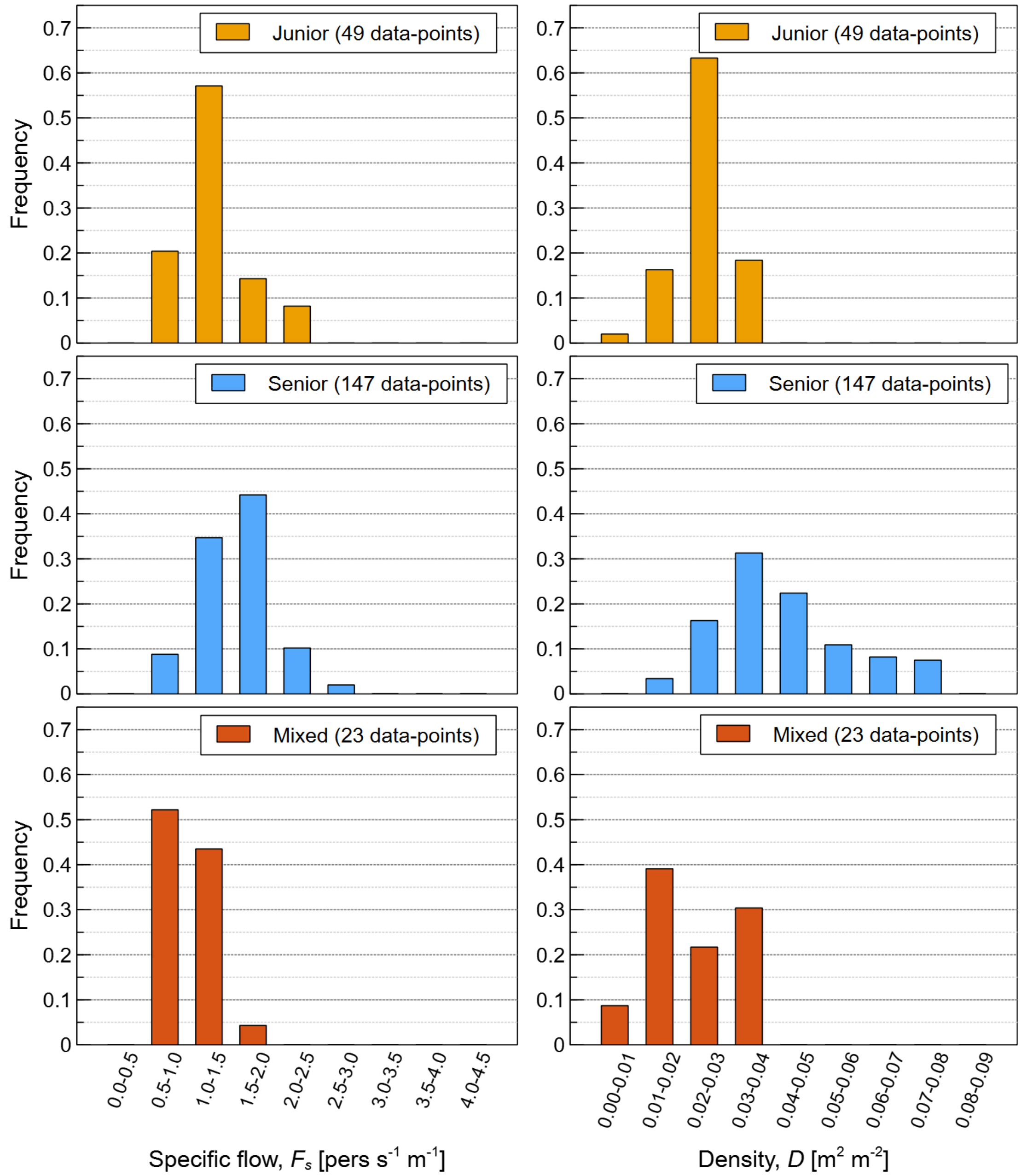

Figure C.18: Probability distribution for specific flow (**left**) and density (**right**) measured on whole straight staircases for different age groups

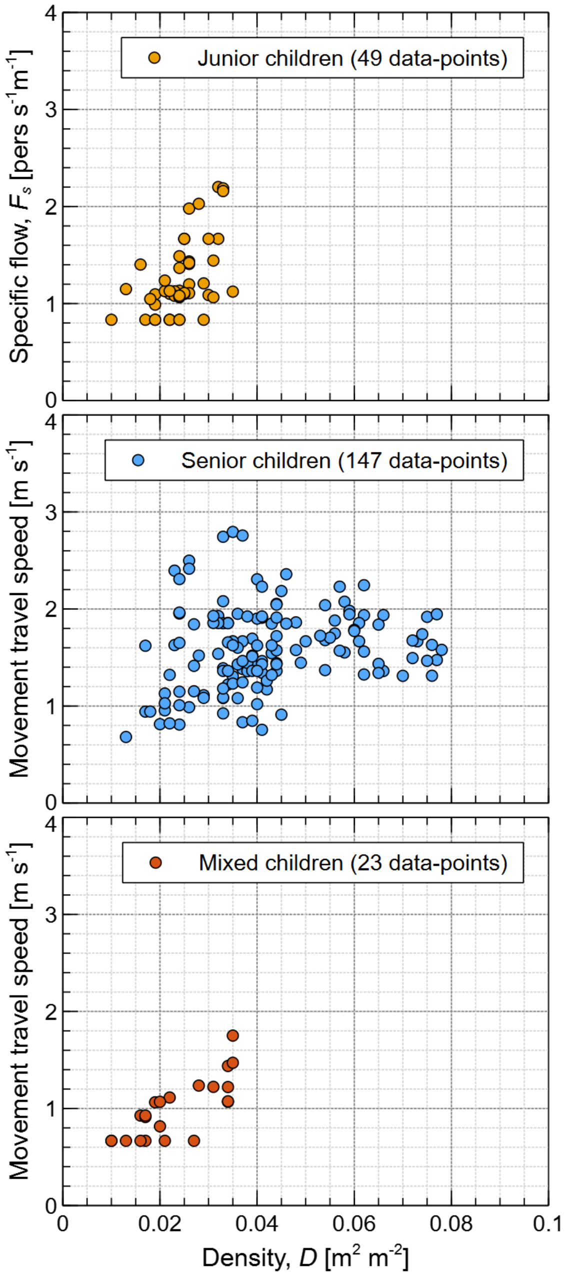

Figure C.19: Specific flow per density [$m^2 m^{-2}$] measured on whole straight staircases for different age groups

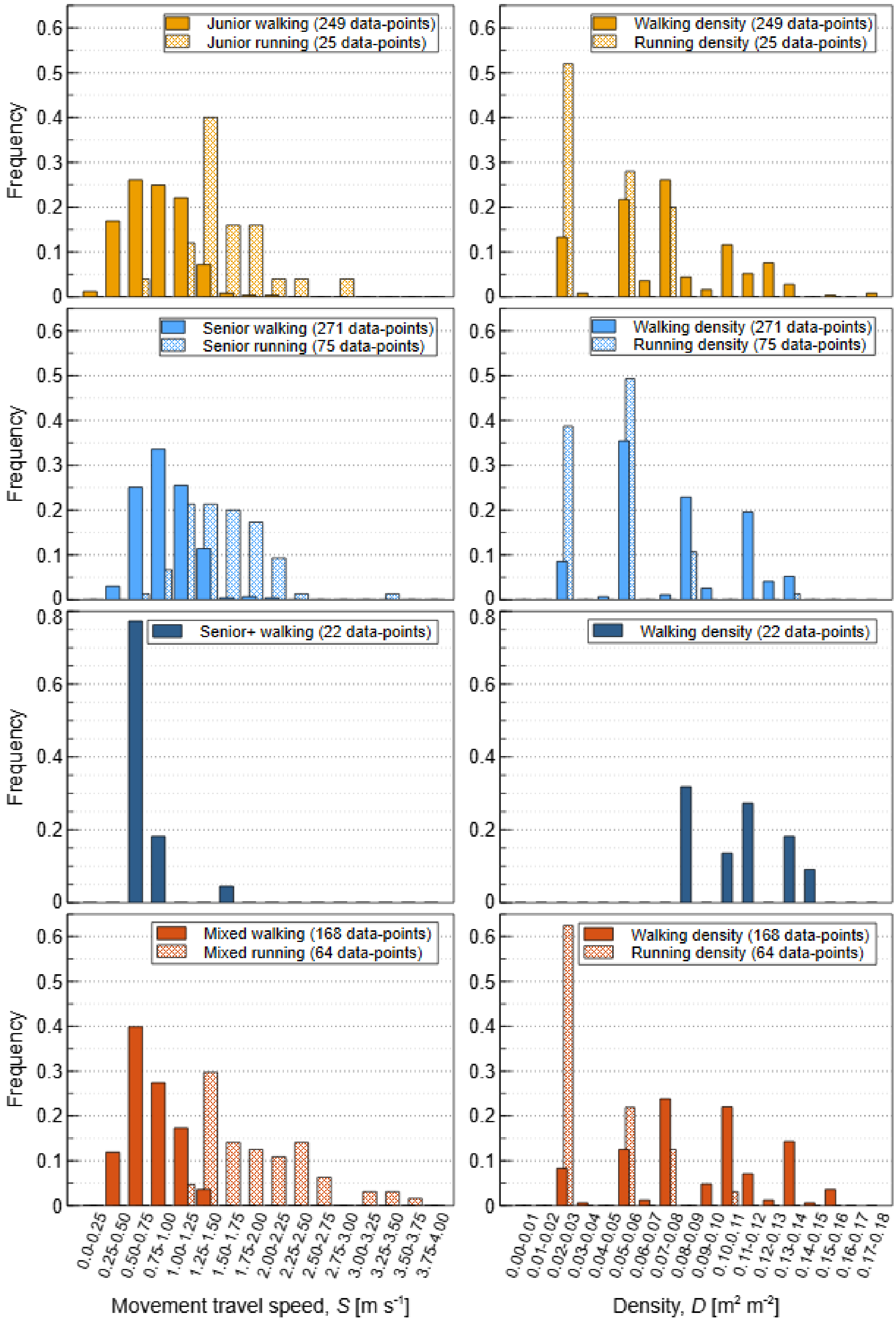

Figure C.20: Probability distribution for travel speeds (**left**) and density (**right**) measured in doorways for different age groups

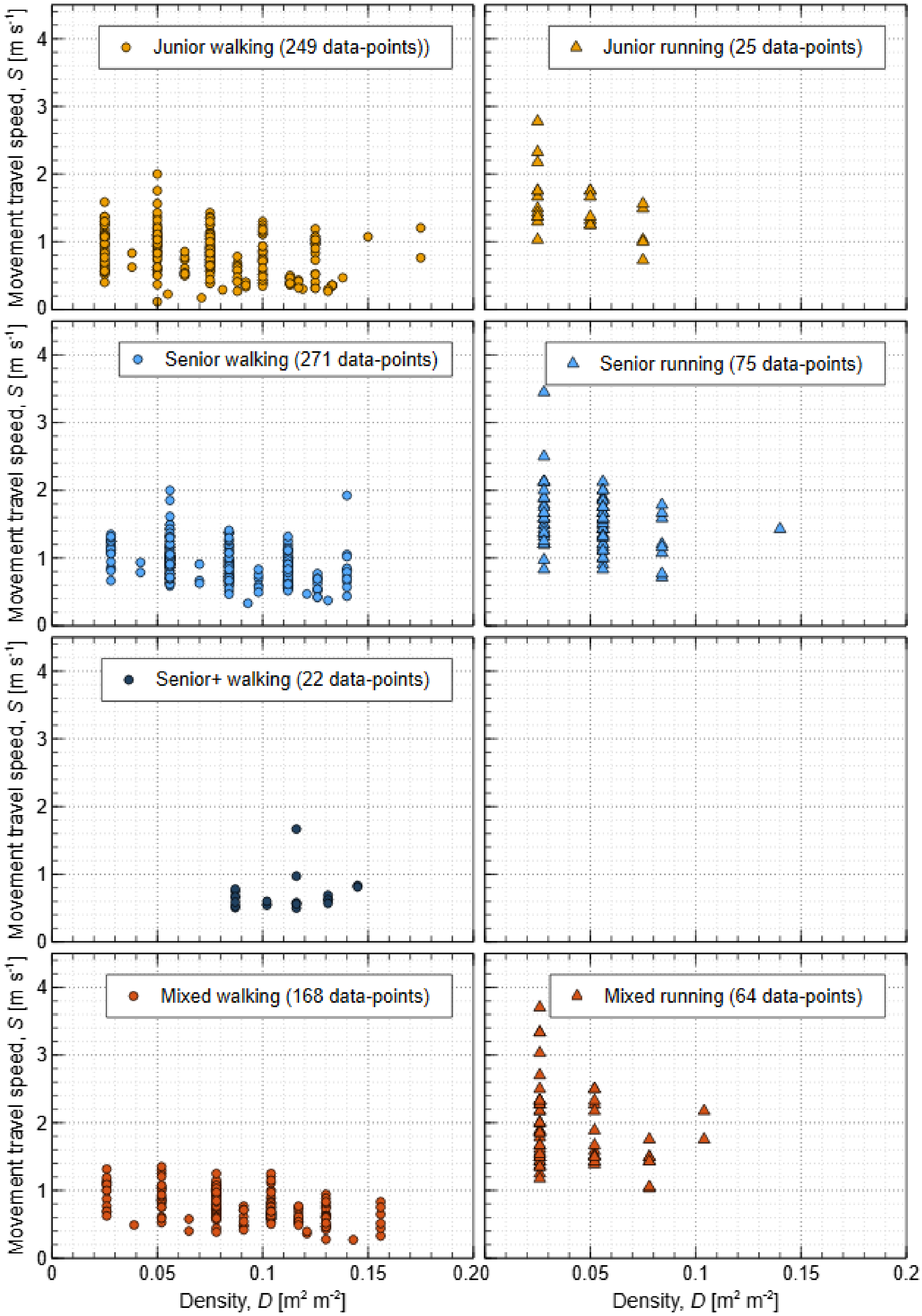

Figure C.21: Walking travel speed (**left**) and running travel speed (**right**) per density [$m^2\,m^{-2}$] measured in doorways for different age groups

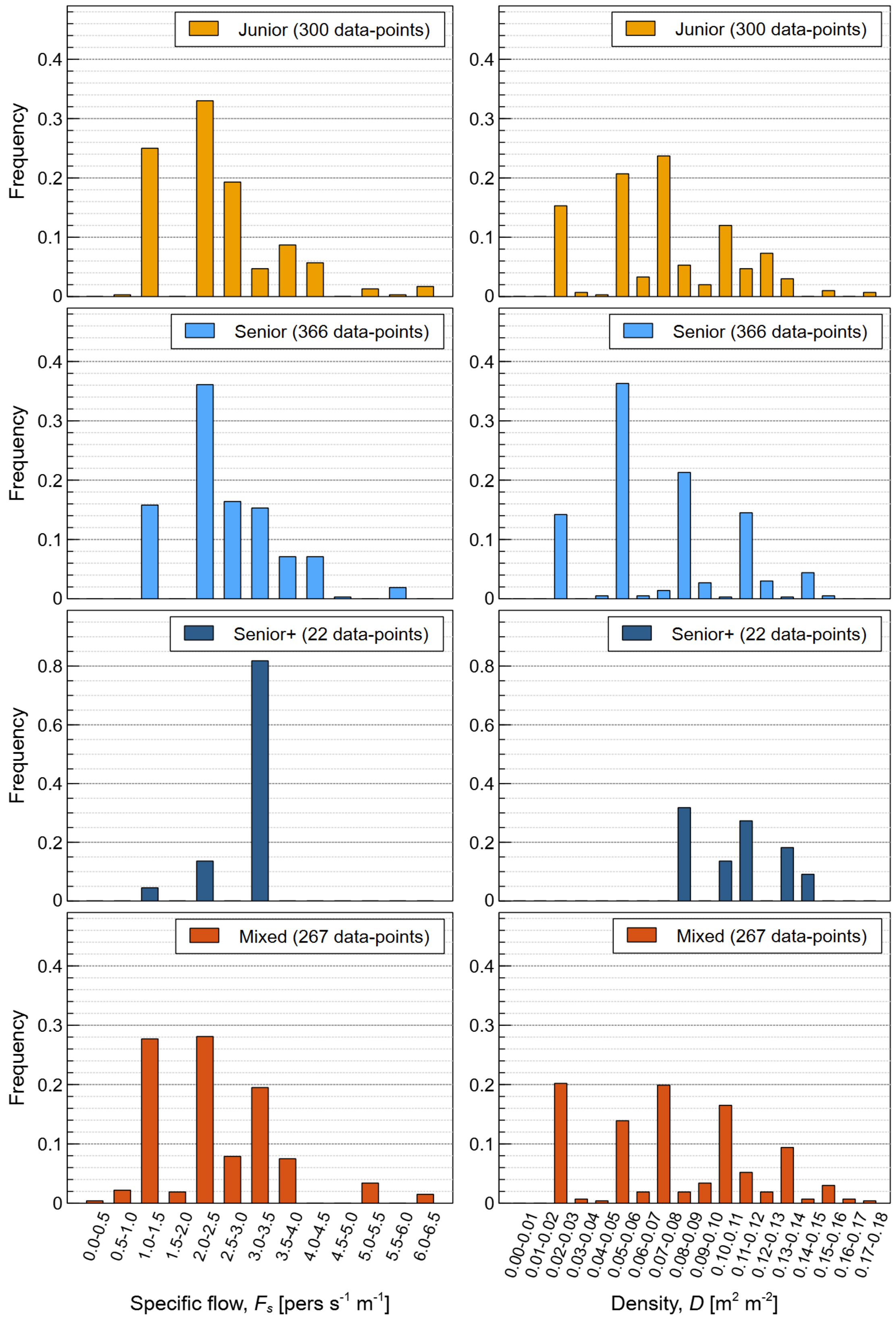

Figure C.22: Probability distribution for specific flow (**left**) and density (**right**) measured in doorways for different age groups

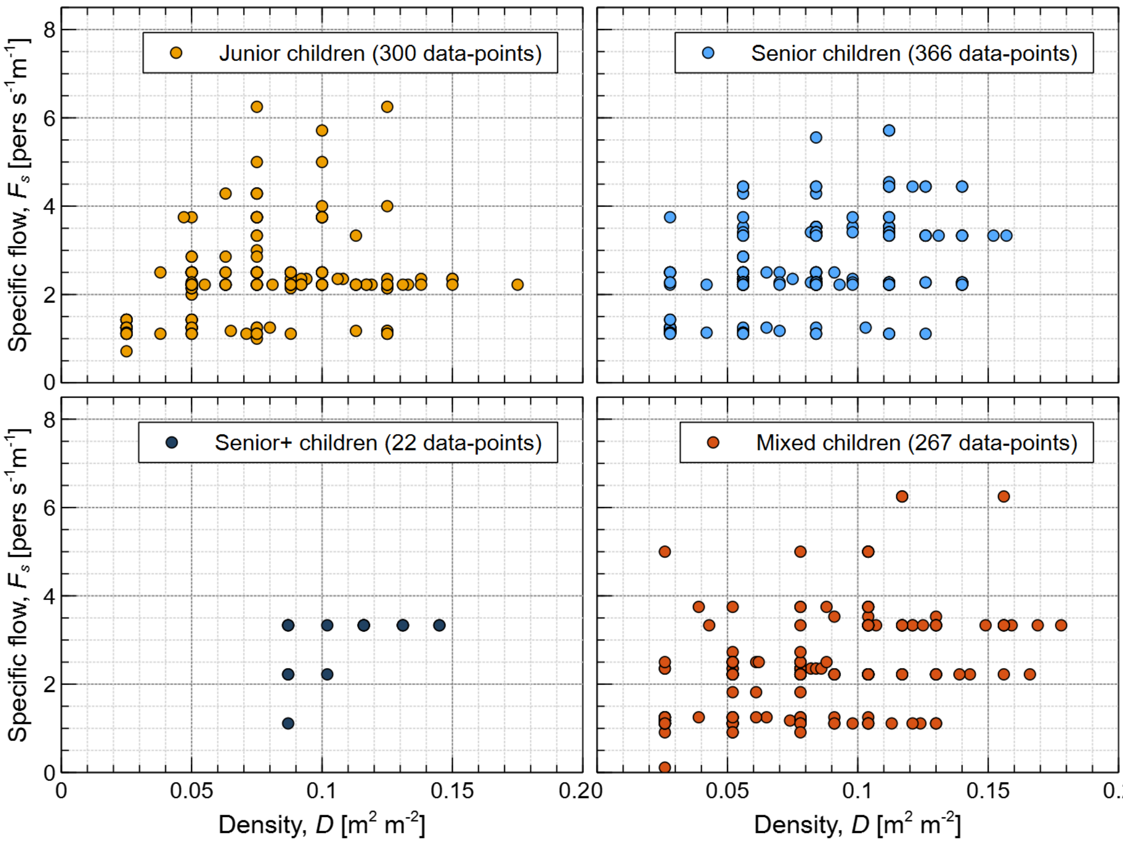

Figure C.23: Specific flow per density [$m^2\,m^{-2}$] measured in doorways for different age groups

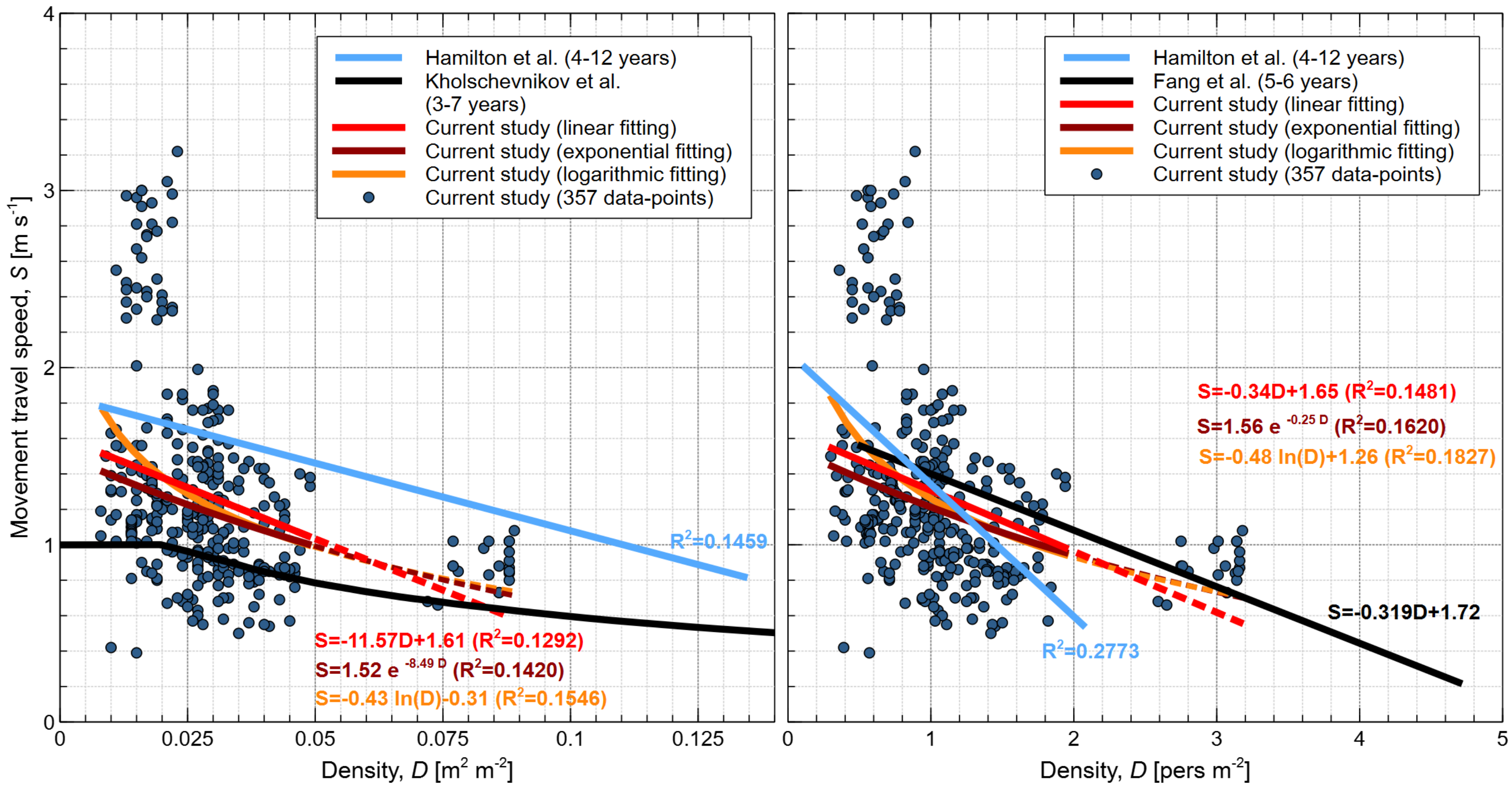

Figure C.24: Walking travel speed per density (**left**: $[m^2\,m^{-2}]$; **right**: $[pers{\cdot}m^{-2}]$) with the linear trend line measured in corridors during the experimental evacuation drills and comparisons to Kholshchevnikov et al. [16], Hamilton et al. [24], and Fang et al. [25]

Appendix D

Questionnaire distributed in nursery schools in the Czech Republic

D.1 Czech version (original)

Cvičné evakuace v mateřských školách

Vážená paní ředitelko/Vážený pane řediteli,

děkuji Vám za Váš zájem o vyplnění následujícího dotazníku. Dotazník má maximálně 20 otázek a jeho vyplnění zabere přibližně 10 minut. Pro případ, že nabízené odpovědi nejsou dostatečně výstižné či pro případ, že je z Vaší strany vhodné cokoliv doplnit, je u každé otázky možné připojit vlastní komentář.

Pod pojmem "cvičná evakuace" je vždy myšlen nácvik opuštění budovy u příležitosti cvičného požárního poplachu.

Velice si vážím Vaší spolupráce a předem děkuji za vyplnění dotazníku!

S úctou

Hana Najmanová
hana.najmanova@fsv.cvut.cz

1) Obecné informace o mateřské škole

Celkem 10 otázek.

1. Ve kterém kraji se mateřská škola nachází?

- ○ Hlavní město Praha
- ○ Středočeský kraj
- ○ Jihočeský kraj
- ○ Plzeňský kraj
- ○ Karlovarský kraj
- ○ Ústecký kraj
- ○ Liberecký kraj
- ○ Královéhradecký kraj
- ○ Pardubický kraj
- ○ Olomoucký kraj
- ○ Moravskoslezský kraj
- ○ Jihomoravský kraj
- ○ Zlínský kraj
- ○ Kraj Vysočina

2. Jaký je celkový počet tříd v mateřské škole? . . . .

   Prostor pro Váš komentář: . . . .

3. Jaký je průměrný počet dětí v jedné třídě? . . . .

   Prostor pro Váš komentář: . . . .

4. Jaký je průměrný počet osob pedagogického personálu (pedagog, asistent pedagoga, vychovatel) v jedné třídě? . . . .

   Prostor pro Váš komentář: . . . .

5. Jsou děti do tříd zařazeny podle věkových kategorií?

   - ○ Ne, třídy jsou věkově heterogenní (smíšené)
   - ○ Ano, děti jsou ve třídách podle věkových kategorií
   - ○ Jiná odpověď: . . . .

   U odpovědi "Ano" prosím uveďte, o jaké věkové kategorie se jedná.

   . . . .

6. Ve kterém podlaží (či podlažích) jsou umístěny třídy či provozy určené pro pohyb dětí?

   Je možné označit více možností. V případě, že se mateřská škola nachází ve více budovách, označte prosím všechny možnosti, které se v těchto budovách objevují.

   - ☐ Přízemí

- ☐ 1. patro
- ☐ 2. patro
- ☐ Jiná odpověď: ....

Prostor pro Váš komentář: ....

7. Nachází se v budově/budovách mateřské školy externí únikové schodiště (případně i více takových schodišť)?

   - ○ Ano
   - ○ Ne

   Prostor pro Váš komentář: ....

8. Je pro provoz mateřské školy zpracované požárně bezpečnostní řešení?

   - ○ Ano
   - ○ Ne
   - ○ Nevím

   Prostor pro Váš komentář: ....

9. Jsou děti v rámci výchovného a vzdělávacího programu seznamovány s problematikou osobního bezpečí?

   - ○ Ano
   - ○ Ne
   - ○ Nevím

   Prostor pro Váš komentář: ....

10. Jsou v mateřské škole prováděny cvičné evakuace?

    - ○ Ano (cvičná evakuace proběhla alespoň 1× za posledních 5 let)
    - ○ Ne

    Prostor pro Váš komentář: ....

2) Cvičné evakuace

Posledních 10 otázek.

11. Jak často (průměrně) v mateřské škole cvičné evakuace probíhají?

    - ○ 1× ročně
    - ○ 2× ročně

- ○ Jiná odpověď: . . . .

Prostor pro Váš komentář: . . . .

12. Jak jsou zaměstnanci o cvičné evakuaci dopředu informováni?

- ○ Všem zaměstnancům je předem známo datum a čas konání
- ○ Všem zaměstnancům je předem známo pouze datum konání
- ○ Cvičná evakuace je předem ohlášena, ale datum konání není zaměstnancům upřesněno
- ○ Cvičná evakuace není předem ohlášena
- ○ Jiná odpověď: . . . .

Prostor pro Váš komentář: . . . .

13. Kde získává pedagogický personál instrukce/informace, jak při cvičné evakuaci jednat (např. volba únikových cest, organizace dětí)?

Je možné označit více možností.

- ☐ Osobní školení od požárního specialisty v rámci preventivního školení (školení BOZP a PO)
- ☐ Osobní školení v rámci instituce mateřské školy (od nadřízeného, např. ředitelky/ředitele mateřské školy)
- ☐ Pedagogický personál není na tuto situaci speciálně školen, jedná v souladu se svou profesní zkušeností
- ☐ Jiná odpověď: . . . .

Prostor pro Váš komentář: . . . .

14. Jakým signálem je vyhlašován pokyn k zahájení cvičné evakuace?

- ○ Mluveným slovem (stanoveným slovním spojení či větou)
- ○ Domluveným signálem (např. cinkáním zvonku, boucháním o kovadlinu, sirénou z megafonu)
- ○ Kombinací mluveného slova a domluveným signálem (kombinace předchozích dvou možností)
- ○ "Šifrovanou zprávou" (např. smluvené heslo/věta/melodie, jehož význam je známý jen dospělým osobám)
- ○ Zkušební aktivací poplachového systému v budově (např. aktivací detektoru kouře)
- ○ Jiná odpověď: . . . .

Prostor pro Váš komentář: . . . .

V případě, že se jedná o domluvené slovní spojení, signál či šifrovanou zprávu, prosím uveďte jeho konkrétní podobu. . . . .

15. Jak je signál k zahájení cvičné evakuace šířen po budově?

    - ○ Osobně pověřenou osobou na chodbách či v jednotlivých třídách
    - ○ Pomocí domácího rozhlasu
    - ○ Zkušební aktivací poplachového systému v budově (např. aktivací detektoru kouře)
    - ○ Jiná odpověď: ....

    Prostor pro Váš komentář: ....

16. Jak jsou děti organizovány po zaznění signálu k zahájení cvičné evakuace před opuštěním třídy?

    - ○ Děti jsou vyzvány k vytvoření dvojic (v zástupu) a k vyčkání na pokyn k hromadnému opuštení třídy
    - ○ Děti jsou vyzvány k vytvoření skupiny a k vyčkání na pokyn k hromadnému opuštení třídy
    - ○ Děti jsou vyzvány k vyčkání na pokyn k hromadnému opuštení třídy (bez formování do skupiny či dvojic)
    - ○ Děti opouštějí třídu neorganizovaně
    - ○ Jiná odpověď: ....

    Prostor pro Váš komentář: ....

17. Jak probíhá přesun dětí po budově na venkovní shromaždiště?

    - ○ Děti se pohybují ve dvojicích a v ucelené skupině, kterou tvoří jejich třída
    - ○ Děti se pohybují v ucelené skupině, kterou tvoří jejich třída, ale nemusí tvořit dvojice
    - ○ Děti se mohou pohybovat jednotlivě, přičemž mají pokyn počkat na vybraném místě (např. u východových dveří z budovy)
    - ○ Jiná odpověď: ....

    Prostor pro Váš komentář: ....

18. Jsou při cvičných evakuacích využívány také únikové východy, které nejsou při běžném provozu používány (např. externí úniková schodiště)?

    - ○ Ano
    - ○ Ne, děti se pohybují pouze po známých trasách, které každodenně používají
    - ○ Ne, budova má jen jednu únikovou možnost a ta je zároveň každodenně používaná
    - ○ Jiná odpověď: ....

    Prostor pro Váš komentář: ....

19. Je průběh cvičné evakuace po jejím ukončení dále vyhodnocován (např. zhodnocením doby evakuace či vzniklých komplikací)?

   ◦ Ano, průběh cvičné evakuace je slovně zhodnocen a je o ní proveden záznam
   ◦ Ano, průběh cvičné evakuace je slovně zhodnocen
   ◦ Ne
   ◦ Jiná odpověď: ....

   Prostor pro Váš komentář: ....

20. S jakými nejčastějšími problémy se při cvičné evakuaci setkáváte? *Je možné označit více možností.*

   □ Neprůchozí východové dveře (např. zamčené dveře, zapomenutý klíč, zatarasené dveře jinými věcmi)
   □ Zdržení způsobené čekáním na volný prostor na schodišti, kdy se více tříd snaží použít jednu únikovou cestu (např. centrální vnitřní schodiště)
   □ Obtíže při volbě správné únikové cesty
   □ Zdržení z důvodu neznalosti evakuační procedury ze strany zodovědných zaměstnanců
   □ Děti vyžadují při pohybu individuální asistenci dospělých a dochází k častému zastavování pohybu
   □ Nedostatečný počet přítomného personálu, který by mohl efektivně pomoci všem dětem vyžadujícím asistenci
   □ Dětí jsou neochotné při opouštění třídy (např. se schovávají, utíkají)
   □ Děti nerespektují pokyny pedagogického personálu
   □ Děti jsou vzniklou situací vyděšené
   □ Jiná odpověď: ....

   Prostor pro Váš komentář: ....

Děkuji Vám za vyplnění dotazníku!

Velice si vážím Vaší ochoty a času, který jste jeho vyplňování věnovali. Pokud Vás řešené téma zaujalo, nebo máte zájem o výsledky dotazníku, budu ráda za Vaši zpětnou vazbu na emailové adrese hana.najmanova@fsv.cvut.cz.

D.2 English version (translation)

Evacuation drills in nursery schools

Dear leader of the nursery school,

I would like to thank you for your interest to respond the following Questionnaire. The questionnaire includes at most 20 questions and it takes approximately 10 minutes to be completed. If you find the offered options not representative enough or if you would like to attach additional information, you are welcome to use the space "Your comments" available for each question.

The term "evacuation drill" refers to practicing how a building would be evacuated in the event of a fire.

I truly appreciate your cooperation and I thank your for filling out the questionnaire!

Yours faithfully,

Hana Najmanová
hana.najmanova@fsv.cvut.cz

1) General information about the nursery school

In total 10 questions

1. In which region is the nursery school located?

    - ○ Prague
    - ○ Central Bohemian
    - ○ South Bohemian
    - ○ Plzen
    - ○ Karlovy Vary
    - ○ Usti nad Labem
    - ○ Liberec
    - ○ Hradec Kralove
    - ○ Pardubice
    - ○ Olomouc
    - ○ Moravian-Silesian
    - ○ South Moravian
    - ○ Zlin

- ○ Vysocina

2. How many classes are in the nursery school? ....

   Your comments: ....

3. How many children are on average in a class? ....

   Your comments: ....

4. How many teaching staff members (teacher, teacher's assistant, educator) are on average in a class? ....

   Your comments: ....

5. Are children divided into classes based on their age?

   - ○ No, classes are heterogeneous
   - ○ Yes, classes are homogeneous
   - ○ Other: ....

   If option "Yes" is selected, please, specify the age categories

   ....

6. On which floors the spaces intended for children are located in the nursery school?

   More choices are possible. In the case, the nursery school is located in more buildings, please, select all options which occur in these buildings.

   - ☐ Ground floor
   - ☐ First floor
   - ☐ Second floor
   - ☐ Other: ....

   Your comments: ....

7. Is an external escape staircase/staircases available in the building of the nursery school?

   - ○ Yes
   - ○ No

   Your comments: ....

8. Is a fire safety report available for the nursery school?

   - ○ Yes
   - ○ No
   - ○ I do not know

Your comments: ....

9. Is the issue of personal safety included in the educational programme of the nursery school?

   - Yes
   - No
   - I do not know

   Your comments: ....

10. Are evacuation drills performed in the nursery school?

    - Yes (an evacuation drill was performed at least once in the last 5 years)
    - No

    Your comments: ....

2) Evacuation drills

The last 10 questions

11. How often (on average) are evacuation drills carried out in the nursery school?

    - 1× a year
    - 2× a year
    - Other: ....

    Your comments: ....

12. How are evacuation drills announced to staff members?

    - All staff members know the date and the time of evacuation drills beforehand
    - All staff members know only the date evacuation drills beforehand twice a year
    - Evacuation drills are announced beforehand without the specification of the date nor the time
    - Evacuation drills are not announced to staff members beforehand
    - Other: ....

    Your comments: ....

13. Where do teaching staff members get instructions how to behave and act during evacuation drills (e.g. about evacuation routes choice, organization of children)?

    More choices are possible.

- ☐ Regular fire protection education given by a fire prevention officer
- ☐ Internal education given by the nursery school's management (e.g. by the leader)
- ☐ Teaching staff members are not specially schooled (they act according to their professional experience)
- ☐ Other: ....

Your comments: ....

14. Which warning signal to start evacuation is used in the nursery school?

    - ○ Voice message (verbally)
    - ○ Manual sound signal (e.g. whistle, gong, pot banging)
    - ○ Combination of voice message and manual sound signal
    - ○ "Coded message or sound" (e.g. a particular phrase or melody with the meaning known only to staff members)
    - ○ Activation of the fire alarm system (e.g. of a smoke detector)
    - ○ Other: ....

    Your comments: ....

    If a voice message, manual signal, or "Coded message or sound" is under consideration, please, specify its particular form. ....

15. How is the warning signal to start evacuation disseminated in the building?

    - ○ Personally by a responsible person in corridors or in classrooms
    - ○ Using a building broadcast
    - ○ By activation of the fire alarm system (e.g. of a smoke detector)
    - ○ Other: ....

    Your comments: ....

16. How are children organised before leaving a classroom after the signal to evacuate is given?

    - ○ Children are asked to form pairs and wait until the signal to leave a classroom is given (leaving in pairs as a group)
    - ○ Children are asked to form a group and wait until the signal to leave a classroom is given (leaving as a group)
    - ○ Children are asked to wait until the signal to leave a classroom is given (without a given formation)
    - ○ Children can leave a classroom individually
    - ○ Other: ....

Your comments: . . . .

17. How are children organised when moving through the building to the place of safety?

    ○ Children move in pairs in a compact group (each class forms a separate group)
    ○ Children move in a group but not in pairs (each class forms a separate group)
    ○ Children can move individually instructed to wait at a specific place
    ○ Other: . . . .

    Your comments: . . . .

18. Are the escape routes and exits, which are not daily used (e.g. external escape staircases), used during evacuation drills in the nursery school?

    ○ Yes
    ○ No, children move only on well-known and daily used routes
    ○ No, there is only one escape route in the building which is also daily used
    ○ Other: . . . .

    Your comments: . . . .

19. Are evacuation drills evaluated after they are finished?

    ○ Yes, spoken and written evaluation of evacuation drills is performed
    ○ Yes, spoken evaluation of evacuation drills is performed
    ○ No
    ○ Other: . . . .

    Your comments: . . . .

20. What are the most common issues you must solve during evacuation drills in the nursery school? *More choices are possible.*

    □ Blocked escape routes (e.g. locked/blocked exits, forgotten keys)
    □ Delays caused by waiting for an empty staircase used by more classes
    □ Escape route choice
    □ Delays caused by poor knowledge of evacuation procedure by staff members
    □ Slow movement caused by assistance required by children
    □ Insufficient number of present staff members who could effectively help to all children requiring assistance
    □ Children are not willing to leave a classroom (e.g. hiding, running away)

- ☐ Children do not follow instructions given by staff members
- ☐ Children are scared or frightened
- ☐ Other: . . . .

Your comments: . . . .

Thank you for filling out the questionnaire!

I really appreciate your willingness and time to respond the questions. If you are interested in the addressed issue or in the results of the questionnaire, please, do not hesitate to contact me at my email address hana.najmanova@fsv.cvut.cz.

Appendix E

Publications

E.1 Refereed publications

1. H. Najmanová and E. Ronchi, “An experimental data-set on pre-school children evacuation,” *Fire Technology*, vol. 53, July 2017.

E.2 Conference contributions

1. M. Bukáček, H. Najmanová, and V. Pešková, “Double-deck railcar egress experiment: The influence of heterogeneity, exit width and exit type on pedestrian time headways,” in *Traffic and Granular Flow 2019*, (Berlin, DE), Springer-Verlag, 2020.

2. M. Bukáček, V. Pešková, and H. Najmanová, “Quantitative analysis of the train unit evacuation,” in *Proceedings of SPMS 2019 - Stochastic and Physical Monitoring Systems*, vol. 10, (Praha, CZ), Česká technika - nakladatelství ČVUT, 2019.

3. P. Hejtmánek, H. Najmanová, and T. Váchal, “Požární zkouška slaměného domu s jílovými omítkami,” in *ZDRAVÉ DOMY 2018*, (Brno, CZ), Sdružení hliněného stavitelství z.s., 2018.

4. P. Hejtmánek, H. Najmanová, and T. Váchal, “Experimental assessment of separation distances of a load-bearing straw-bale construction,” in *Journal of Physics: Conference Series: Proceedings of the 3rd European symposium on fire safety sciences (ESFSS2018)*, vol. 1107, (Bristol, GB), Institute of Physics Publishing, 2018.

5. P. Hejtmánek, V. Flídr, and H. Najmanová, “Furnace setup for preliminary fire resistance testing,” in *Book of Abstracts Nordic Fire and Safety Days*, (Copenhagen), RISE Research Institutes of Sweden, 2017.

6. J. Holeček, M. Procházka, T. Váchal, and H. Najmanová, “Technologie výstavby experimentální budovy z nosných slaměných balíků,” in *Recenzovaný sborník Mezinárodní Masarykova konference pro doktorandy a mladé vědecké pracovníky 2017*, vol. VII, (Hradec Králové, CZ), Akademické sdružení MAGNANIMITAS, 2017.

7. H. Najmanová, P. Hejtmánek, and D. Košťák, “Simulace evakuace osob z železničního vozidla při mimořádné události,” in *Juniorstav 2017, 19. odborná konference doktorského studia*, (Brno, CZ), Vysoké učení technické v Brně, Fakulta stavební, 2017.

8. H. Najmanová, M. S. Christiansen, and A. S. Dederichs, “Staff-to-child ratios in day-care centres: a concern with respect to fire safety,” in *Proceedings of Pedestrian and Evacuation Dynamics 2016*, (Shanghai, CN), University of Science and Technology of China Press, 2016.

9. M. Bukáček, H. Najmanová, and P. Hrabák, “The effects of synchronization of pedestrian flow through multiple bottlenecks – train egress study,” in *Proceedings of Pedestrian and Evacuation Dynamics 2016*, (Shanghai, CN), University of Science and Technology of China Press, 2016.

10. M. Schultz Christiansen, H. Najmanová, and A. Dederichs, “Staff-to-child ratio in day-care centres: a concern with respect to fire safety,” in *Book of Abstracts*, (Kodaň), SP Technical Research Institute of Sweden, 2016.

11. H. Najmanová and E. Ronchi, “Pre-school children evacuation modelling,” in *Book of Abstracts*, (Kodaň), SP Technical Research Institute of Sweden, 2016.

12. H. Najmanová, P. Hejtmánek, and M. Bukáček, “Požární bezpečnost osobních kolejových vozidel: Analýza evakuace osob z dvoupodlažní jednotky cityelefant,” in *Požární ochrana 2016 - Sborník přednášek XXV. ročníku mezinárodní konference*, (Ostrava, CZ), Sdružení požárního a bezpečnostního inženýrství, 2016.

13. H. Najmanová, P. Hejtmánek, and M. Hornig, “Hodnocení evakuace osob pomocí matematického modelování: Pohyb osob na schodišti,” in *Sborník konference JUNIORSTAV 2016*, (Brno, CZ), Vysoké učení technické v Brně, Fakulta stavební, 2016.

14. V. Kupilík, P. Hejtmánek, H. Najmanová, and M. Pokorný, “Failures of residential buildings from fire point of view,” in *Central Europe towards Sustainable Building 2016 - Innovations for Sustainable Future*, 1st edition, Prague, June 2016, Complete edition - printed version + Flash disk with full paper version, (Praha, CZ), GRADA PUBLISHING, 2016.

15. M. Pokorný, P. Hejtmánek, and H. Najmanová, “Virtuální cfd model pro room corner test,” in *Sympozium Energeticky efektivní budovy 2015*, 1. vydání, (Praha, CZ), Společnost pro techniku prostředí, 2015.

16. H. Najmanová, P. Hejtmánek, and M. Pokorný, “Matematické modelování pohybu osob na schodišti,” in *Sympozium Energeticky efektivní budovy 2015*, 1. vydání, (Praha, CZ), Společnost pro techniku prostředí, 2015.

17. H. Najmanová and P. Hejtmánek, “Požárně technické charakteristiky izolačního materiálu stered,” in *Juniorstav 17. odborná konference doktorského studia, fakulta stavební*, (Brno), VUT v Brně, Fakulta stavební, 2015.

18. H. Najmanová, P. Hejtmánek, and M. Hornig, “Evakuace osob na vertikálních složkách únikových cest,” in *Požární ochrana 2015 - Sborník přednášek XXIV. ročníku mezinárodní konference*, (Ostrava, CZ), Sdružení požárního a bezpečnostního inženýrství, 2015.

19. V. Kupilík, P. Hejtmánek, and H. Najmanová, “Unsuitable mounting of wooden cladding to the base structure and its consequences,” in *Proceedings of the 17th Conference on the Rehabilitation and Reconstruction of Buildings (CRRB 2015)*, (Zurich, CH), Trans Tech Publications, 2015.

20. P. Hejtmánek, H. Najmanová, and M. Pokorný, “Vliv pozice hořlavých povrchů stěn a stropu na rychlost uvolňování tepla ve virtuálním cfd modelu room corner test,” in *Požární ochrana 2015 - Sborník přednášek XXIV. ročníku mezinárodní konference*, (Ostrava, CZ), Sdružení požárního a bezpečnostního inženýrství, 2015.

E.3 Other publications

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