PROCEEDINGS, Fire and Evacuation Modeling Technical Conference (FEMTC) 2018
Gaithersburg, Maryland, October 1-3, 2018

EVACUATION ANALYSIS IN NURSERY SCHOOLS – CHALLENGES OF PARAMETERIZING THE BEHAVIOR OF CHILDREN

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ABSTRACT

In this study evacuation exercises in various nursery schools in Germany were carried out. The evacuation organization and behavioral patterns were examined in case of an alarm. Additionally, the walking speed and pre-movement times were measured.
In general, the educators, a short moment after they themselves have interpreted the alarm, assemble the children in order to initiate an in a body evacuation. The children react differently to this call - also depending on the distance to the educators. The collective escape movement does not begin until all children have assembled. Consequently, the individual pre-movement times of the children as well as their individual mobility until reaching their group significantly influence the group-related pre-movement time.

INTRODUCTION

Ensuring the life safety in a building is a priority aspect of structural, technical and organizational fire protection measures. The lack of uniform rules and guidelines for fire protection in nursery schools in Germany leads to a different level of safety between the buildings. Currently, fire protection in nursery schools is mainly ensured with structural and increasingly with technical measures. The trend is to enroll children at a younger age into nursery schools for longer times during the day. Especially the increasing number of infants, which, in the case of a hazard, are usually not able to orient themselves independently, is problematic.
The lack of knowledge about escape behavior of children and infants as well as their interaction with the environment complicates the assessment of life safety in nursery schools in case of fire. Fire protection measures - structural or technical - might be ineffective and in the worst case even have a negative impact on the children's safety. There are also controversies between educational concepts and fire safety requirements. For example, locked exit doors could prevent an unnoticed escape of the children, but also, according to the building code, might cumber an unobstructed evacuation of the occupants. Furthermore, alarm systems can induce anxiety in the children that cause irrational behaviors and lead to critical situations.
Nursery schools are eager to create a safe, familiar and comfortable environment for the children in which they can unfold freely. An important aspect is not to obstruct the children's urge to explore by closed doors. However, the open design in buildings can lead to a risk with regard to fire and smoke propagation.
This implies the question of whether through targeted organizational measures, missing structural or technical fire protection measures can be compensated.
There exist already some fire safety guidelines in Germany with standard solutions for nursery schools. However, mostly these guidelines only contemplate the structural fire protection and do

not at all or only peripherally take into account the specific characteristics of the population in nursery schools. Although in general evacuation exercises are always recommended in these guidelines, the specific problems and efficiency of an evacuation is not depicted sufficiently.
From the point of view of fire protection, nursery schools encounter an extraordinarily high risk, because not all children can independently flee from the danger area and are dependent on guidance by the educators. Furthermore, children might tend to unpredictable, irrational behavior. Therefore, in nursery schools, performance-based life safety concepts with regard to organizational fire protection measures or evacuation simulation models are currently regarded as inappropriate option. Instead, structural and technical fire protection measures are used to ensure the safety goals.

TERMINOLOGY

According to § 1 of the German Youth Protection Law, children are persons below the age of 14 years and adolescents are persons as of 14 but below the age of 18 years (Jugendschutzgesetz, 2002). Similar definitions exist on an international level. In Germany, one needs to distinguish between the terms crèche (German: Kinderkrippe), nursery school in combination with kindergarten (German: Kindertagesstaette) and after-school center (German: Hort).
Following an excerpt of the law on day-care facilities for children in Lower Saxony, Germany (KiTaG, 2002), is translated to clarify terminology:
General regulations
(1) This law applies to day-care centers where children are staying regularly, but at least be cared for ten hours a week.
(2) Day-care centers are facilities, which serve the care of children
a) until the age of three (Kinderkrippe),
b) from the age of three until school enrollment (Kindergarten) and
c) from school enrollment to the age of 14 (Hort).

Thus, in Germany, Kindertagesstaette can be considered as a generic term describing the three different day-care facilities.

CONSTITUTION OF THE EVACUATION TIME

In order to ensure a performance-based life safety concept in case of fire, it has to be proven that the available safe egress time is greater than the required safe egress time (ASET > RSET). In addition, it must be ensured that, due to the evacuation process, a risk of the occupants, e.g. due to critical densities (persons/m^2), can be excluded. The available safe egress time can be determined for an individual case using a fire simulation, whereby reasonable boundary conditions (low smoke-layer, CO_2 concentration, etc.) must be specified. Alternatively, the available safe egress time can be defined by prescription. Referring to Proulx, Figure 1 illustrates the composition of the evacuation time. According to the *Guideline for Microscopic Evacuation Analysis* (RiMEA, 2016), the required safe egress time of an occupant consists of the sum of the detection time, the alerting time, the individual pre-movement time and the individual movement time. These four summands constitute the individual required safe egress time. It should be mentioned that the alerting time can sometimes also differ for individuals. This is the case if the individuals are alarmed at different times, for example by other individuals, of a dangerous situation. The individual pre-movement and movement times of the occupants in turn lead to a scattering of the individual required safe egress times.

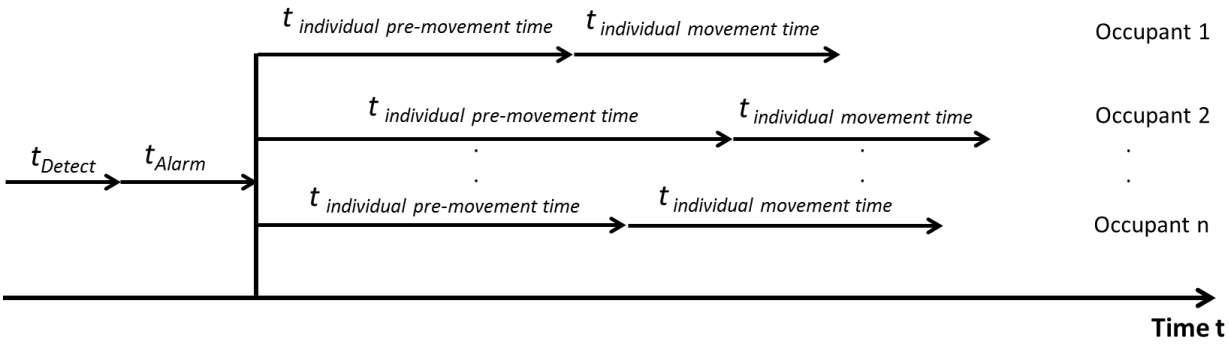

Figure 1: Composition of the individual evacuation times, based on Proulx (2002).

Evacuation organization in nursery schools

Evacuation exercises are not obligatory in every nursery school in Germany. A fire or a necessary evacuation required for other emergencies is a new and dramatic event for almost every child. Hazardous situations can cause irrational behavior in children which is difficult to predict. Here, intuitive hiding of the children from the fire, e.g. in a closet or under tables should be mentioned, as can be sometimes observed for those who are frightened. In nursery schools, the irrational behavior of one child can endanger the entire group. For example, if a child does not respond to the educator's instructions because of anxiety, or if it is curious and does not join the group, it will increase the pre-movement time and delay the evacuation. The special attachment and dependence of the children on their educators and the high sense of responsibility of the educators towards their group of children has a significant influence on the pre-movement time. Thus, the individual evacuation time according to Figure 1 does not apply to the occupants in nursery schools. Figure 2 illustrates the organized evacuation process in nursery schools.

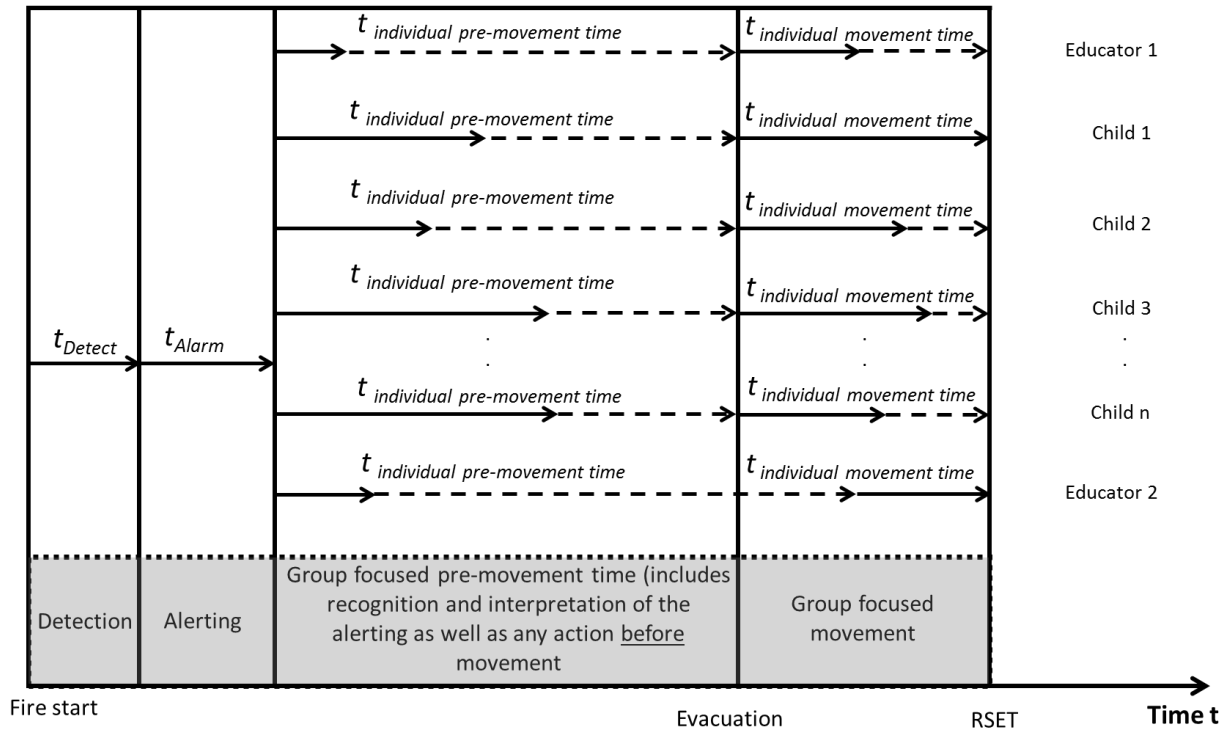

Figure 2: Individual evacuation times in nursery schools.

In general, educators, a short moment after they themselves have interpreted the alarm, assemble the children in order to initiate an in a body evacuation. The children react differently to this call - also depending on their distance to the educators. The collective escape movement does not begin until all children have assembled. Consequently, the individual pre-movement times of the children as well as their individual mobility until reaching their group have a significant influence on the group-related pre-movement time. Children who are already in the immediate vicinity of the educator have shorter pre-movement times than those who have to converge first.
In case of an immediate hazard, it has to be assumed that a collective escape movement will not occur and smaller groups of children or individual children - self-initialized or instructed by the educators - independently start the escape movement. In general, in Germany, at least two adults care for one group of children in nursery schools. The longer pre-movement time by educator 2 shown in Figure 2 takes the final checking of secondary rooms or toilets into account, after the children have assembled. At this moment, educator 1 should initiate the evacuation with the - assumed - complete group. The walking speed of the educators and the children are approximately equal, since the individual walking speed is determined by the pedestrian flow characteristics of the group. The second educator does not have to adopt the own walking speed to the group-related walking speed at the beginning. Subsequently, the educator can achieve the same individual evacuation time as the group. In summary, it can be stated that the maximum individual pre-movement time has a decisive influence on the evacuation of the group. Such circumstances are initially only applicable to kindergarten groups (children aged 3 to 6 years).
In crèche groups (up to 3 years) such circumstances cannot be expected. In crèche groups the ratio of child to adult is smaller than in kindergarten groups. In case of a hazard, this advantage is offset by several disadvantages when comparing the crèche groups to the kindergarten groups. The limited mobility of the infants makes a rapid assembling after the alert almost impossible. In addition, due to their level of development, some younger children may not yet be able to respond promptly or adequately to instructions, and may need to be collected by an adult and then carried or held by the hand. Each educator can be assigned a maximum of two completely dependent infants. The other infants of the group have to be able to escape on their own and to respond appropriately to instructions. If this is not the case, these conditions can lead to critical situations.

EVACUATION EXERCISES

Evacuation exercises serve building users to test dangerous or emergency situations. Only through exercises, wrong behavior can be avoided in the future and an evacuation can be conducted smoothly. As part of a master's thesis in 2014 (Lyzwa), evacuation exercises were carried out in various nursery schools. Here, the evacuation organization and behavioral patterns were examined during an alarm in nursery schools and the walking speed and pre-movement times were measured. The primary goal of the evacuation exercises was to measure the group-related pre-movement time in nursery schools. Video cameras were used, that recorded the behavior of the children and educators after an alarm, in order to allow an assessment and measurement of the pre-movement times. Furthermore, the evacuation duration of the entire respective nursery school was determined. An evacuation was considered complete, once all occupants had reached the appropriate assembly areas. The empirical data collected in the nursery schools were evaluated and compared with each other.
For this purpose, different types of nursery schools were selected, in order to cover a broad spectrum and to be able to derive general statements from them. The differences result from inequalities between structural, technical and organizational fire protection measures of the nursery schools. In addition, the benefit of a repeated exercise was examined.
For reasons of data protection, the examined nursery schools are designated with the capital letters A to D. Some fire technical relevant features of the nursery schools – with a focus on their impact on the pre-movement time - are summarized in the following.

Nursery school A

• This nursery school offers care place for 117 children (from the age of 3 to school enrollment). Composition: Four groups of 25 children, and one group with 17 children. There are 4 places for children with disabilities in this group.
• The nursery school has an alarm system with manual devices, which should warn all building users at the same time in case of danger.
• In the building there is a gymnasium where two children from each group, after consultation with the responsible educator, can play without supervision.
• Evacuation exercises have taken place, but they were done several years ago. Thus, this exercise was the first one for all children and also for most of the educators.
• Two exercises were carried out in this nursery school. The first exercise was unannounced. The second exercise was "half-announced" by informing the educators after the first meeting that a second exercise is scheduled in order to apply the knowledge gained in the first exercise. However, the educators were not told the day of the second exercise. There was a month between the two exercises.
• The head of the nursery school triggered the alarm by pressing a manual call point.

Nursery school B

• This nursery school offers childcare for 107 children (including 15 places for 1 to 2-year-old children).
• The nursery school is equipped with smoke detectors. The detectors do not cover all areas (e.g. library). Manual call points are not available.
• In the preliminary discussion, the head, the educators and parents were informed about the evacuation exercise, but with the request that the children should not be prepared for the exercise by prior information.
• The triggering time of the alert was unknown to the children and the educators.
• For this nursery school it was the first evacuation exercise since its opening in the 1980s.
• A smoke detector was triggered by real smoke generated in a remote corridor area.

Nursery school C

• This nursery school is a bilingual care facility for children from one year of age until they enter school. English is the colloquial language in this nursery school.
• The facility has two groups (1 to 2 years, each 15 children) and one group (3 to 6 years) with 25 children.
• The exercise was completely unannounced.
• From a fire safety point of view, this nursery school is equipped best compared to the other facilities. In addition to structural advantages, this nursery school has a modern fire alarm system, which, in addition to the internal alarm, transmits the fire alarm to the control center of the local fire brigade. Every year, evacuation exercises are conducted.
• The alarm was triggered by a manual call point.

Nursery school D

• The nursery school currently offers day care places for 68 children at the age from 3 to 6 years and 15 places for children at the age from 1 to 2 years. The care offer includes 4 places for children with disabilities.
• The main focus of the pedagogical work is on the integration of children with disabilities and the promotion of language skills. In comparison to the other examined nursery schools, the number of children with a migrant background is higher.
• This nursery school does not have a multi-room alerting system. Only in the bedroom and in the immediate hall area in front are two smoke detectors. These are not connected with each other. It is

highly doubtful that any potential alarm will ever reach the three relatively distant group areas, given the high noise level caused by playing children.
• The building management prescribes an annual evacuation exercise in this nursery school.
• The alarm was verbally communicated by the head who alarmed the groups with "Fire in my office - evacuation". Starting in the crèche, the head run through each of the group rooms and notified the educators.
• The exercise was completely unannounced.

The main challenge of the experiments results from the influence of the natural behavior of the children and educators with a shortening (by the preparedness) or prolongation (by ignoring the alarm) of the escape time. During the exercises, the weather conditions were always taken into account in order to be able to avoid having to dress the children, because of cold temperatures or rain.
The measurement of pre-movement times was divided into two time periods: the time it takes the educators to communicate decisions and instructions to the children (= pre_m_instruction) and the duration that takes into account the assembling and preparing for the upcoming evacuation (= pre_m_child). The sum to of these time periods constitutes the group-related pre-movement time (see Figure 3).

Exercise Results

The studies were carried out between the 5th February and 7th March 2014. If both exercises in nursery school A are considered separately, a total of 426 people were involved in the exercises. With the exception of the second exercise in nursery school A and the exercise in nursery school B, the exercises were completely unannounced for the employees.
Figure 3 summarizes the measured pre-movement times of the nursery schools as a bar chart. The individual bars represent the measured pre-movement time of individual groups in a nursery school. The green areas of the bars represent the pre-movement times of the educators (= pre_m_instruction), the red areas the pre-movement times of the children (= pre_m_children). Each bar represents one group consisting of children and educators. The orange points above the pre-movement times (bars) represent the total escape time for the exercise. Here, the total escape time is the time between alerting and assembling of the groups at the declared assembly areas outside the nursery schools.
Figure 3 shows that the composition of the pre-movement time can differ. Our research has shown that, besides the type of alarm system, the actions and instructions of the educators decisively determine the pre-movement times. From the author's point of view, these two components possess the greatest optimization potential in order to increase and systematically adapt the safety level of nursery schools.
During the exercises different behavioral patterns were observed.
In nursery school A, the relatively long duration of the pre-movement times of the educators (pre_m_instruction) is mainly due to the unsatisfactory alarm system. Through a repetition of the exercise, the evacuation organization in this nursery school was significantly improved, as confirmed by the results. The one short pre-movement time during the second exercise in Figure 3 is attributed to two children, who were alone in the gymnasium. After the alarm sounded, they independently started the escape movement and chose the shortest escape route out of the building. A few seconds later, an educator made sure that the gymnasium was vacated. It could be observed that educators initially did not respond to the alarm and continued their activities. During the first exercise, the children became very dependent on their educators. Children who had heard the alarm always kept their eyes on the educators. Since the educators in the group rooms often seemed irritated themselves by the alarm (a continuous tone), the instructions to the children were not always clear enough, which led to hesitant behavior of the children. Without exception, the

children followed the instructions and carried out their activities quickly. The dressing of the children was completely omitted.

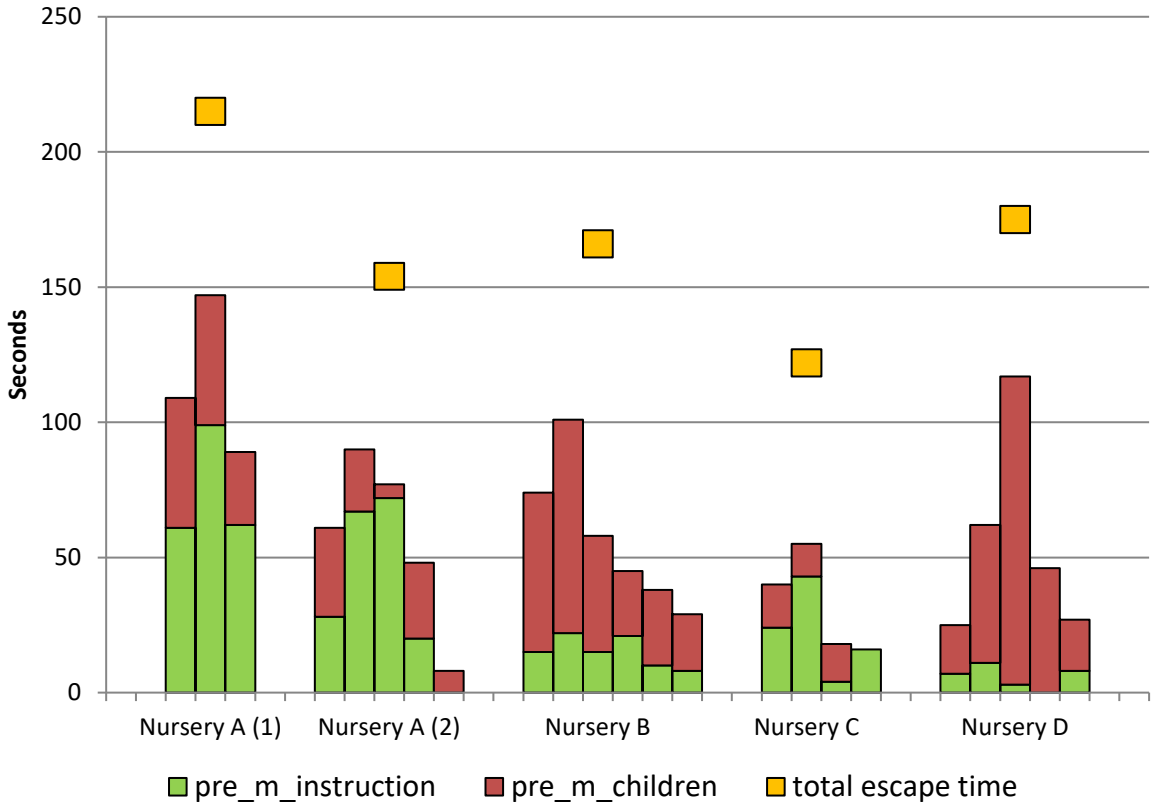

Figure 3: Measured reaction times in the analyzed nursery schools.

Unfortunately, due to the pedagogical concept, two children have been forgotten in the gymnasium in the first exercise. They had hidden in a ball pool and responded neither to the alarm nor to calls of an educator.
During the second exercise, a clear improvement in the evacuation behavior of the educators, but also of the children, was observed. For example, a child drew the attention of the educator to the fire alarm, which was hard to hear in the group rooms. An insight was also observed among the children playing in the gymnasium. The exercises illustrate the significant discrepancy between trained and untrained practices in nursery school.

In nursery school B, the short pre_m_instruction duration indicates that the educators had a certain anticipation and were able to give instructions accordingly. However, the lack of experience in the evacuation organization led to the extension of the pre_m_children time.
After the alarm, a wide variety of behaviors of the educators was observed in the group rooms. While some of the educators were very well prepared for the imminent evacuation, others were overtaxed and unable to formulate clear instructions to the children. Due to the loud alarm, for example, one educator asked the children to cover their ears with their hands. Then, she tried to give instructions to the children. The children behaved in an exemplary way and followed the instructions, even supporting each other. The educators searched the restrooms. Existing plateaus, which offer a particularly attractive refuge for children, were not fully controlled. In a debriefing with the educators, the alarm system was criticized. Thus, due to the local installation of the detectors, the volume of the alarm differed across the building.

The educators in nursery school C initially had difficulties in interpreting the signal, but were subsequently able to achieve short pre-movement times due to training and regulated responsibilities.
The evacuation was very structured and swift. Surprisingly, the shortest pre-movement times on average were needed compared to the other nursery schools, although the number of crèche children in this nursery school outweighs those of the other nursery schools. In the course of this exercise, it became clear once again that the limited mobility of the crèche children has an impact on the pre-movement time. The educators in crèche groups had to collect and carry the children or wait for the children to come and take them by the hand.

In nursery school D, especially the preparation of the children had a decisive impact on the entire pre-movement duration. This is the logical consequence of the verbal alert by the nursery school head; the signal did not need to be interpreted and was unmistakable: “Fire in my office - evacuation." The long pre-movement time of one group results from a thorough attendance control of the children within the group rooms.
After the alarm, almost all children remained motionless; they did not try to find an escape route on their own, but waited for instructions. One child wanted to follow the nursery school’s head after her verbal alarm, but was called back by the educator. The shortest pre-movement time was reached in the crèche. Irritated crèche children who did not respond immediately to the instructions of the educators were carried or hands were hold. Within a group, the pre-movement time was extended by a thorough attendance control within the group rooms. In each group, additional rooms and sanitary facilities were searched for any children who remained behind, before the escape movement of the group started. In the crèche group, this was not necessary because the educators had a good overview of the number of children, all of whom were in one room. Since the smallest children do not go to the toilet by themselves, the additional control of the sanitary facilities was not necessary.

The alarm system was criticized by the heads of each nursery school: In nursery school A, the signal in the group rooms was “clearly too quiet”, in nursery school C, according to the head a “bit too quiet”. In nursery school B it was "irritating" and partly "too loud". In nursery school D there was no alarm system at all.
A missing alarm system can lead to dangerous situations, especially in nursery schools with numerous children, due to a delayed perception of a hazard. In this context, it should be noted that in nursery school D, in addition to the pre-movement time, the time to alarm the groups has to be taken into account, as well, in order to assess the evacuation time.
In the nursery schools A and B, many educators were unfamiliar with the existing alarm system in the building; this extended the pre-movement time. The research conducted in the context of this work demonstrates that in "untrained" nursery schools there is a clear potential for optimization regarding the pre-movement time.
The familiarity of educators with the alarm is of paramount importance and depends on the type of alarm system. Although the pre-movement time, pre_m_instruction and pre_m_children can differ across nursery schools and also across groups, in general, taking into account the results of the present study, the following key statement applies*: The evacuation of the group is controlled by the educators. They have a decisive influence on the duration of the pre-movement time and direct all actions to be performed during the pre-movement time. During evacuation movements, educators must provide a variety of assistance, such as holding hands or carrying children and determine the walking speed of the group.*
The analysis of the relationship between the number of children and the pre-movement time did not yield conclusive results. It can be assumed that the group size, if all other factors are identical, has an influence on the pre-movement time. Within the present study, the number of children within a group had no significant influence on the group related pre-movement time. In principle,

after an alert - whether it was an alarm tone or verbal communication- a similar behavior could always be observed: the children waited for instructions. Thus, the children have behaved dependently, but not irrationally.

MICROSCOPIC EVACUATION ANALYSIS

In general, an evacuation simulation enables the dimensioning of escape routes and, as a result, the determination of evacuation times. Furthermore, it serves to identify critical densities, which can arise from congestion of pedestrian flows in front of bottlenecks and exits or on stairs. Achieving the safety goals is mainly demonstrated by mathematical methods that range from simplified approximation equations to complex simulation models. The complex models nevertheless encounter application limits, especially with respect to human behavior. The behavior of the occupants, especially possible irrational human behavior, is generally unpredictable and therefore very difficult or impossible to represent.

Microscopic models describe the movement of individuals in a pedestrian flow. The development of computer programs for microscopic models has increased significantly in recent years. The market now offers a variety of software packages. However, these are based on fundamentally different approaches. With regard to agent configuration, established microscopic models differ in some cases considerably. Here, main parameters are the pre-movement time, which includes behavioral patterns, and the walking speed of the individuals. The programs allow setting these parameters. Alternatively, stored default parameters can be selected. A problem is that these were not necessarily generated based on the same empirical data. This leads to different results and implies the question which models can actually represent the reality.

Complex behavior of humans, for example, the cohesion of families in the event of danger or adults providing assistance to children are not fully included in many models yet. The level of detail in terms of agent configuration differs for each model. However, such complex behaviors correspond to reality and can have a significant impact on the evacuation process.

An overview of current evacuation models is given by Kuligowski (2016). Here, 26 models are differentiated with regard to the validation, the availability of the models, the modeling method, the refinement of the population, the refinement of the building structure, the refinement of the behavior (deterministic or stochastic) of the agents and the output of the simulation results. An in-depth presentation regarding the configuration possibilities of the agents in the respective model does not take place.

Adaptation of model parameters in nursery schools

The exercises demonstrate that the individual pre-movement times of the children as well as their individual mobility until reaching their group have a decisive influence on the group-related pre-movement time. During the escape movement, the walking speed of the pedestrian flow is determined by the slowest person, with an educator at the head of the group guiding the children and a second educator driving the children at the end of the group.

A comparable escape movement of the groups was observed in all performed exercises. The escape movement was always structured and the groups stayed together the entire time. The evacuation of the group is controlled by the educators. They have a crucial influence on the duration of the pre-movement time and direct all actions that are performed during the pre-movement time and influence the pedestrian flow to a certain extent.

With the program FDS+Evac a model was developed, which depicts the special situation in nursery schools. For this purpose, the evacuation exercises were simulated and compared with each other.

The specific interaction between children and adults will first be illustrated by defining *herding agents*. Herding agents in FDS+Evac are characterized by the fact that they look around to see what other agents are doing. When these move to an exit, the herding agents try to follow them. If there is no known exit or agent in the vicinity of the herding agent, it will stay in its initial location until the

end of its pre-movement time. If the nearest neighbor of a herding agent starts the escape movement, then the herding agent will follow the neighbor regardless of its own pre-movement time. If a herding agent is unfamiliar with the current floor and incapable of receiving information from its closest neighbors, it looks around for all visible agents and tries to find one who has started the escape. In this case, the herding agent updates this status continuously as long as there are visible agents. This behavior, described in the FDS+Evac manual (Korhonen & Hostikka, 2017), can only partially reflect the reality in nursery schools. Certainly, it can be assumed that children have the described behavior of herding agents. The high sense of responsibility of the educators towards the children, however, cannot be represented adequately by implementing herding agents. An independent escape of the children or selfish behavior of the educators can generally be excluded. Therefore, when using the program FDS+Evac, a challenge is that the group model - here - the special interaction between children and educators - has not been sufficiently developed. Here, reference is made to the open source project "evac.f90". An approach to a group model is implemented in the current version of FDS+Evac. This function is not documented and the functionality of this group model is questionable.
The special evacuation situation in nursery school is simulated using this function. This makes it possible to describe the following behavior of the agents: After the detection time (= alarm), the defined group members gather in a circle by moving towards each other with their individual walking speed. The initial positions of the individuals, depending on their walking speed, have an influence on the time needed to come together.
When all individuals have come together, the evacuation movement starts in a closed group. The walking speed of the group members are here adapted to the lowest walking speed of an agent within the group. It should be noted that the agents run towards each other immediately after the alert. An individual pre-movement time is therefore not considered. Although this contradicts reality, here, the group-related pre-movement time is crucial to the occupants' safety due to the evacuation organization in nursery schools. A short example regarding a simulation using the group model in FDS+Evac is given: If a group of agents is given a fixed value of 100 seconds for the pre-movement time (all agents have the same pre-movement time), the following can be observed. After the alert, the group members will find each other. The resulting circle of people rotates until the 100 seconds have elapsed. Then the circle disengages and the group starts the evacuation movement. This would not be considered as natural group behavior at first. However, for an evacuation in a nursery school, the group model can be considered meaningful if the individual pre-movement time is neglected. This behavior, the waiting and moving of children within a narrow staggered group, was observed regularly in the evacuation exercises.

There are only a few systematic studies on the evacuation behavior of children. After 2009, more investigations, e.g. by Larusdottir & Dederichs and Kholshevnikov et al., were carried out.
In this paper, the experimentally obtained parameter are used, in order to modify the default agent *child* in FDS+Evac. To facilitate classification of the measured results in this paper, individual measurements from comparable studies are presented.

Table 1: Unimpeded walking velocities and body dimensions in FDS+Evac (Korhonen & Hostikka, 2017).

Body Type	R_d [m]	R_t/R_d [-]	R_s/R_d [-]	d_s/R_d [-]	Speed [m/s]
Adult	0.255±0.035	0.5882	0.3752	0.6275	1.25±0.30
Child	0.210±0.015	0.5714	0.3333	0.6667	0.9±0.30

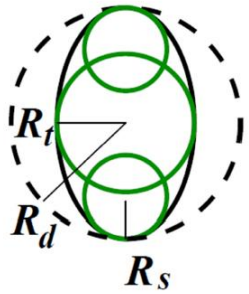

Figure 4: In FDS+Evac the shape of the human body is approximated by a combination of three overlapping circles (Korhonen & Hostikka, 2017).

The individual walking speed of children might be very different from each other and depend on the age and the state of development of the child. In case of danger, educators as well as some children may not be able to fully utilize their walking speed abilities due to the evacuation organization (keeping the group together) in nursery schools.

Larusdottir & Dederichs (2012) present horizontal walking speeds of children aged 0 to 6 years. In summary, the authors point out that the walking speeds they determined depend on the age of the children and in some cases deviate extremely from existing literature values. Their upper and lower limit of the walking speed is summarized in Table 2. The average walking speed is 0.60 m/s for children aged 0 to 2 years and 0.84 m/s for children aged 3 to 6 years.

Table 2: Horizontal walking speed of children according to Larusdottir & Dederichs (2012).

Age group	Horizontal walking speed [m/s]	
	Minimum	Maximum
Children aged 0 - 2	0.21	1.00
Children aged 3 - 6	0.41	1.40

It should be added that these measurements were obtained at a low density (< 0.5 persons/m^2) and therefore represent the free movement of the children. Our measurements have shown that due to the special escape movement, one should not focus on the individual walking speed of the children. Rather, all individuals within a group should be assigned a group-specific walking speed. Based on our investigations, the lower and upper limits of the equally distributed walking speed according to Table 3 were modified.

Table 3: Modified walking speed in FDS+Evac.

Age group	Horizontal walking speed [m/s]	
	Minimum	Maximum
Children aged 1 - 2	0.61	0.73
Children aged 3 - 6	0.72	1.07

Space requirements for children are lower compared to those for adults. The smaller body size is a significant advantage at bottlenecks. This allows several children to easily cross a door at the same time. During the exercises, no significant congestions were observed. In the exercises, high density always occurred when an educator asked the children to gather after hearing the alarm. Here, densities of 8 to 9 persons/m^2 were measured. During the movement of the group, densities between 2 and 5 persons/m^2 were observed.
According to § 1 of the German Youth Protection Act, children are people who are not yet 14 years old and adolescents are people who are 14 but not yet 18 years old (Jugendschutzgesetz, 2002). For

the studies carried out here, for children between the age of 1 and 6 years, the information given in Table 1 therefore has to be questioned. For this purpose, parts III and IV of the 'Dortmund longitudinal growth study' (Reinken, 1980) are used. The shoulder width is compared to the average diameter ($2*R_d$ = 2*0.210 m = 0.42 m) of the agent type *child* according to Table 1. Therefore, an adjustment of body dimensions is required. For this purpose, the children are divided into two groups (1 to 2 years and 3 to 6 years). In order to represent the agent according to Figure 4, mean values for the radius R_t, as well as for the radius R_s were modified.

For the torso diameter ($2*R_t$) and shoulder diameter ($2*R_s$) only the mean value have to be defined. The scattering of these diameter values is due to the distribution of the body diameter ($2*R_d$) representing the agent (e.g., $R_{t,i} = R_{t,mean}*R_{d,i} / R_{d,mean}$).

Table 4: Modified body dimensions in FDS+Evac.

Age group		Children aged 1 - 2	Children aged 3 - 6
Body diameter ($2*R_d$); Uniform distribution	Minimum	0.175 m	0.201 m
	Maximum	0.232 m	0.297 m
Torso diameter ($2*R_t$)		0.156 m	0.176 m
Shoulder diameter ($2*R_s$)		0.050 m	0.054 m

The individual pre-movement time includes the perception of the alert, giving and receiving of instructions and all other activities before the beginning of the direct movement to a safe area. The time for non-immediate escape activities, such as the investigation of the environment, firefighting, warning or searching for people, is also assigned to the pre-movement time (Hosser, 2013).
Findings about the specific pre-movement time in nursery schools are presented by Kholshchevnikov (2012). The author cites ethical consideration as the main reason for the inadequate investigations in this field. Because of concerns of physical injuries or a psychological trauma of the children, the practice of evacuation is generally waived. For the pre-movement time of the children in pre-school education institutes, he presents four maximum values, depending on the weather conditions, s. Table 5. The weather conditions and the associated time required to get dressed leads to a stronger scattering of values around the mean value of the pre-movement time. Because of fear of hypothermia, the children were dressed adequately in the winter months. In spring and autumn this was not necessary to the same extent - in the summer it was not necessary at all. Thus, the shortest pre-movement times (and lowest scattering) were achieved in summer. As a provision, the wrapping of the children in blankets was done in order to reduce the pre-movement time in cold seasons.
The average pre-movement time including all measurements in this paper is exactly one minute. It is in the range between the "summer" and "children wrapped in blankets" pre-movement times presented by Kholshchevnikov (2012).

Table 5: Children's pre-movement times in pre-school education institutions determined by Kholshchevnikov (2012).

season / provision	Time requirement [min]
summer/ no additional clothing	0.6
spring and autumn / additional clothing	5
winter / intensive additional clothing	7.5
wrapping the children in blankets	1.1

In Figure 5, the measured group-related pre-movement times presented in this paper are displayed as a histogram. The empirical distribution is approximated with a lognormal distribution with the parameters $\mu = 4.14$ and $\sigma = 0.65$. These serve as input parameters to the simulations. The

distribution corresponds qualitatively to other studies on pre-movement times in the event of a fire or hazard (see Purser, 2003). Usually those are individual pre-movement times of occupants within a group. The results presented here, however, refer to group-related pre-movement times and implicitly take into account the interaction between child and educator.

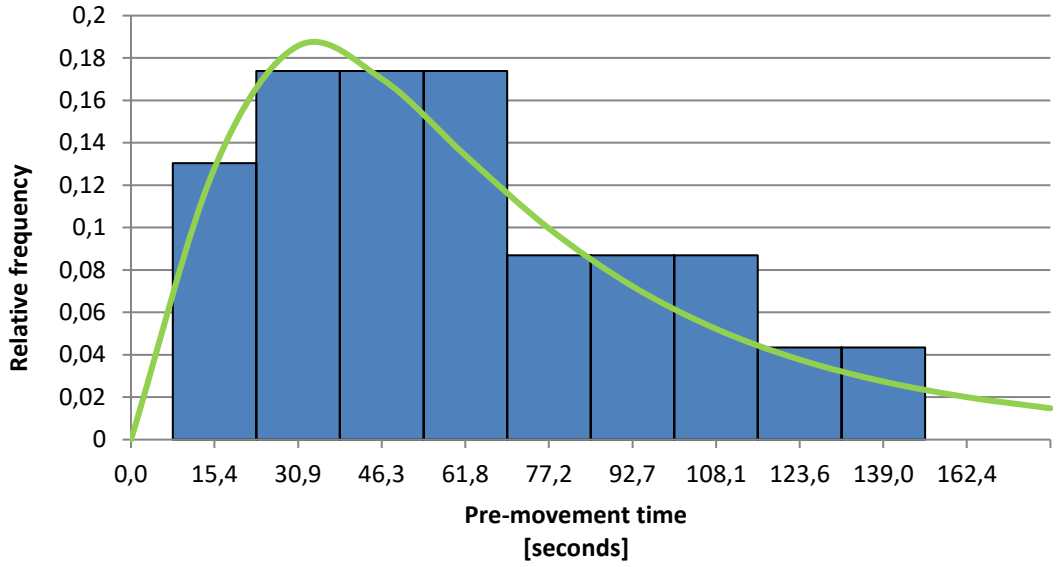

Figure 5: Distribution of measured pre-movement times.

Simulation Results

Table 6 summarizes the results of the simulations. The real evacuation times are shorter than the minimum value of the simulated evacuation times in 4 out of the 5 examined exercises. The remaining exercise is only 1 second longer than the minimum simulated value.

Table 6: Comparison of the evacuation times of the simulation and the real exercises.

Simulation	Evacuation time [s]				
	Nursery_A (1)	Nursery_A (2)*	Nursery_B	Nursery_C	Nursery_D
Mean Value (10 trials)	232	218	242	214	224
Min	214	200	230	203	209
Max	245	228	257	225	230
Exercise	215	154	166	122	175

* 2nd Exercise

Due to the input parameters, it is traceable. In the group model, the beginning of the escape movement as well as the subsequent walking speed of the group are equal to those of the slowest group member. This initially corresponds to reality. The difference between the respective minimum value of the simulation and the exercise ranges from ~0 to 81 seconds.

The defined pre-movement time in the simulation strongly determines the required evacuation time. Here, this is the reason for overestimating the evacuation time.
The empirical data are group-related but in FDS+Evac, because of the group model, this data is applied for individual agents. As the number of children (agents) within a created group in FDS+Evac increases, so does the likelihood that a child will be assigned a high pre-movement time or a low walking speed. This in turn means that these worst-case input parameters are decisive in several groups. The simulated evacuation time of several groups is high, whereas in reality only occasionally high pre-movement times or low walking speeds were measured in the groups.

The replication of the evacuation exercises in FDS+Evac became increasingly complex. In the exercises, questionable selections of escape routes were sometimes observed. In order to use theoretical approaches for a representation of reality, microscopic evacuation analyses in nursery schools have to be critically examined.

CONCLUSIONS

The evacuation in nursery schools should always be done in groups. In principle, an independent escape of children is unacceptable, as it is likely that children will not choose the shortest or safest escape route, but will use the most familiar way. Additional risk arises from childish curiosity or fears. If children are in a remote area without the supervision of an educator, such an evacuation strategy is not appropriate. However, the second exercise in nursery A proves that under certain circumstances a self-rescue of children can be assumed.

During an evacuation in nursery schools, it is reasonable to expect strong relationships between individuals. If the individuals are in spatial distance from each other, depending on the strength of the bond, it has to be assumed that they will try to find each other first before they start walking towards the exit. In nursery schools such behaviors are very likely.

In principle, it can be assumed that the number of children and the ratio of child to educator has an influence on the duration of the evacuation if all other conditions are identical. However, in the experiments it was also observed that very large groups can be faster than very small groups.

Rightly, there are doubts about the rational behavior of children. The reasons for this are primarily due to the children's anxiety potentials - which also vary across individuals. Rational behaviors can only be expected when children have received comprehensive fire safety education and have internalized the alarm signal, and the behavioral mechanisms derived from it. In addition, the special environment and the higher number of people in nursery schools must be taken into account. This can positively influence the behavior of the children. Therefore, with regard to the behavior of the children, nursery schools and parents' homes should be distinguished.

Statutory evacuation exercises and appropriate alarm systems can increase the level of safety in nursery schools where no voluntary evacuation exercises are performed. Due to the special evacuation organization, the pre-movement times and thus the evacuation duration can be continuously optimized. Prerequisites for this are regular exercises, which on the one hand reveal potential misconduct of the educators and on the other hand enable the children to acquire the right behavior during a fire alarm.

In general, the application of evacuation simulations offers the possibility of optimizing the evacuation process in buildings. In order to ensure the effectiveness of evacuation simulations, both the user and the building authority must correctly interpret the human behavior for the specific use of a building. Possible patterns of behavior in hazard situations must not be ignored or excessively simplified. The modeling of human behavior and pre-movement times in particular is a complex topic. The existing models cannot currently represent all conceivable behavioral patterns. The most significant uncertainty during an evacuation and its simulation lies in the irrational, possibly panicky behavior of the people involved in an alert and immediate threat.

An evacuation simulation can only be as good as the assumptions made by the engineer regarding the parameterization of human characteristics. In this paper, it has been shown that the use of evacuation analyses is complex for specific situations – here, the evacuation of nursery schools. First, appropriate agent characteristics have to be measured. Then these have to be inserted into suitable models. Appropriate literature can support the user, so that not necessarily the agent characteristics have to be determined. Nevertheless, the implementation of the agents' characteristics into the available program may be difficult. As a rule, not all models or program systems are available to the user. With regard to the configuration options, a model can be good, less good or not at all suitable for a specific case in order to be able to depict the reality

appropriately. The same applies to the available data records of the occupants' properties in order to map the agents in the respective model.
In this paper, the measured values were converted into a model and implemented into FDS+Evac. Here, the observed evacuation organization and behavioral patterns in nursery schools could only be implemented very simplified. Commercial programs such as *Pathfinder* (2018) or *PedGo* (2013) offer a more detailed configuration of the agents and group behavior. The development of a suitable calculation model with FDS+Evac is proving to be difficult and does not fully enable the implementation of the evaluation criteria. Although the physical prerequisites of the children can be precisely implemented, the representation of the organizational process of an evacuation in nursery schools is not realistic. Only through the use of a questionable algorithm, an approach to the evacuation process in a nursery school could be made in FDS+Evac. The transferability of the model to further nursery schools must be critically questioned because main aspects (building geometry, number of occupants, options for escape routes, etc.) can be different.

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