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## Proposal of utilized to the lift for evacuation of persons

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# Proposal of utilized to the lift for evacuation of persons

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**Abstract.** In 2010 Averill defined in his work five challenges for the solution of evacuation of persons in buildings to 2020. One of the challenges is to implement helpfull technologies during evacuations from buildings – lifts. The aim of the work was to find the ideals of the design of the necessary type and number of lifts. The numerical calculation method was used using simulation software. A model of a fifteen-storey building with multiple versions of the lifts was created. The results showed what type and number of lifts brought the desired shortening of the evacuation time. Conclusion is the recommendation of an ideal lift design.

## 1. Introduction

Potential of passenger lifts is not sufficiently used as it could be. Passenger lifts are not allowed for evacuation of people in the world and in the Slovak Republic except for lifts directly intended for evacuation. Lifts directly designed for evacuation are fire and evacuation lifts that also operate during a fire or power failure. However, the legal regulation of the Slovak Republic [1] commands the design of these lifts only in exceptional cases. In most cases related to buildings, people are forced to use staircases for evacuation. For example, in a building with more than two stories high with up to ten person of limited movability, evacuation lifts may not be proposed [2]. In this way many buildings (not only in Slovak Republic) represent a series of challenges for safe evacuation, mainly based on 2 reasons - limitations of movement from the point of view of physical handicaps of people [3], [4], or fatigue during movement downstairs [5]. Within the framework of the legal regulation of the Slovak Republic [6], three movement properties of people are considered. The first group includes persons able to move alone. Each person, whose movement is not limited from the health point of view, can be categorized to this group. The ‘persons of limited movability’ belong to the second group. Persons, whose evacuation is more demanding than in the case of other persons, belong to this group. Old people, children, disabled persons of limited movability are an example of this group. The third, last group includes ‘immobile persons’. Persons, whose evacuation is possible only with help of other persons, are categorized to this group. For example, mentally affected persons, in-patients at clinics with serious health states, infants, toddlers and the like belong to this group. According to the Statistical Office [7], almost 20% of inhabitants are persons in the old pension age (62 years and more), and 12% of inhabitants are persons of the school age (4 to 15 years) in Slovakia in 2017. Altogether at least one third of inhabitants of the Slovak Republic can be considered persons of limited movability in the case of the proposal of escape routes. Moreover, since 2002 the legal regulation states that all public building in the Slovak Republic must be accessible for persons of limited movability and orientation. For that reason, lifts are inevitable for evacuation of persons of limited movability.

In 2010, Averil [8] defined several necessary steps to cope with large challenges presented by the solution of evacuation in buildings. The quantification of missing data dealing with evacuation of persons using lifts is one of these steps. Up to the present day, several papers and studies on evacuation of persons using lifts were carried out based on simulated calculations or in-situ experiments. Study by



Ding Y. et al [10] can serve as another example in this field, where simulation software was used to ascertain, besides others, which ratio of persons using the lift and staircase has the most favorable effect on the course of evacuation. Therefore, they modeled in their work 28-storey building with the staircase and 2 lifts. Their work also included different age groups of people. They said that the simulation results show that the optimal percentages of the occupants evacuated by the lifts, when achieving the shortest evacuation time, is almost not related to the number of evacuated persons and floors. Further, when focusing on age groups, it was ascertained that if older persons used the lift, the staircase will not be significantly overloaded. At the same time, if the lift is used by children, the rate of its use will be improved. Therefore, the selection of portion of persons by age categories, who should be evacuated by the lift can reduce congestions on staircase, and effectively speed up the evacuation process. For example, in the next study using the simulation tool, Andrée et al. [11] focused on the high-rise building, selection of exits and waiting time for evacuation lifts. Their objective was to examine, inter alia, effect of the lighting system on the selection of exits and to quantify waiting time for lifts. The study resulted into the fact that the well and simply designed system of marking escape routes will affect the selection of an exit. This system can also be used for increasing the portion of people, who will decide for the evacuation lift as the first choice of escape. Further, their results have demonstrated that people were willing to wait for the lift up to 5 minutes, but if they decided to wait, their waiting is usually extended to 20 minutes and more.

Results of previous examinations have demonstrated potential of lifts for evacuation of persons. However, in all aforementioned papers they call attention to the need of quantification of other movement parameters and description of the entire process using a suitable algorithm that could be used for simple, but also complex calculation models. Therefore, the work was focused on the design of an ideal solution for the use of the lift for evacuation. The calculation method was used with building Exodus simulation software in which the example of the building was modelled. By various variations of input quantities, combinations that represent a model of evacuation lift are subsequently obtained. As a result, the ideal combinations were subsequently selected to reduce the total evacuation time.

## 2. Method

For ease of reference, some terms have been simplified as follows:

- $t_u$  – total / final evacuation time
- $t_{u,I}$  – total / final evacuation time without the use of the lift
- $t_{u,II}$  – total / final evacuation time with using the lift
- $t_{u,V}$  – the time of evacuation of the last person who used the lift
- $t_{u,S}$  – the time of evacuation of the last person who used the stairway

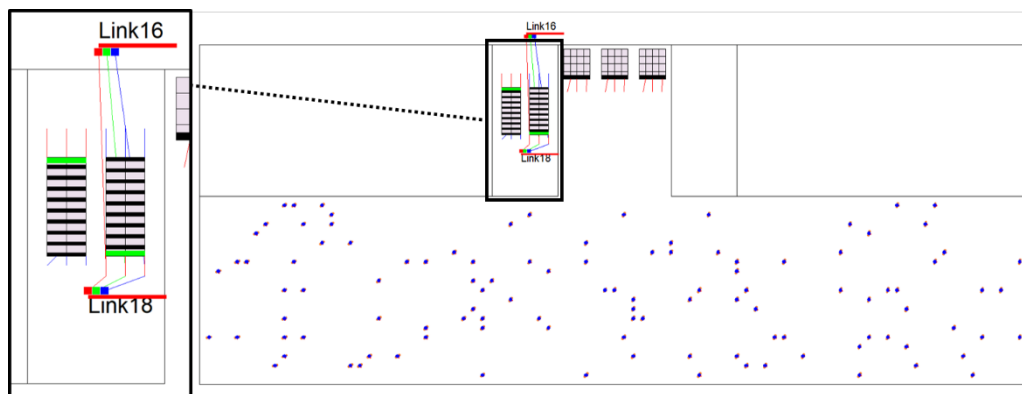
### Model of building

In simulation calculations, a building with a occupancy of no less than  $4 \text{ m}^2 \cdot \text{p}^{-1}$  was used. An example of this may be an office building with open offices (Figure 1). In this case, 110 people were placed on each floor. The number of floors was varied in the range from one to fifteen. The ground floor of the model does not contain any person. The building always contained one staircase with the same capacity parameters (1 m width) and one, two or three lifts with varying maximum capacity and speed.

The assumption of the use of the lift was chosen so that the same number of persons used the lift on each floor. The basic alternative is the following number of  $E_{PXX}$  people who use the elevator:

- 20% of the floor – 22 persons
- 40% of the floor – 44 persons
- 60% of the floor – 66 persons

The percentage of persons on the  $E_{PXX}$  floor was based on a logical proposal. It is thus possible to argue that there will never be situations where 80% and 100% of persons throughout the building will use the lift. For this reason, these alternatives were not used. On the contrary, EP20 proposals were based on the likely occurrence of persons of limited movability in the building. According to the Slovak law [1, 2], one escape route can be used only if less than 10% of persons with movement restrictions are on it.



**Figure 1.** Schematic of the geometry of the floor of the model building.

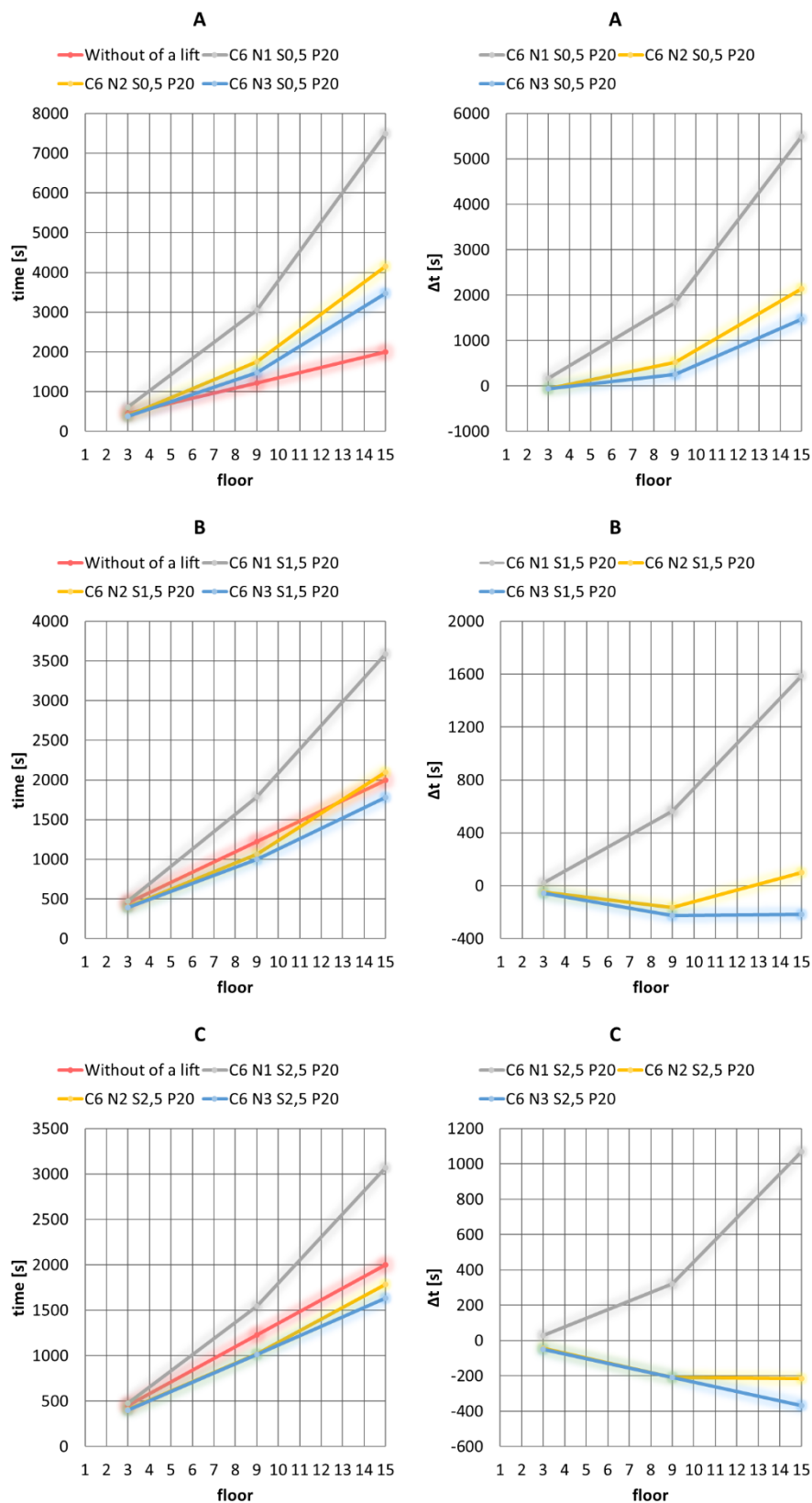
Lift(s) were in the core of the floor. The choice of elevator parameters was developed and adjusted according to market availability. The maximum capacity of the  $C_X$  cabin was 6 persons ( $C_6$  small lift), 13 people ( $C_{13}$  medium lift) and 21 people ( $C_{21}$  high capacity lift). The maximum speed of the lift  $S_X$  was  $0.5 \text{ m}\cdot\text{s}^{-1}$  ( $S_{0.5}$  low-speed lift),  $1.5 \text{ m}\cdot\text{s}^{-1}$  ( $S_{1.5}$  medium-speed lift) and  $2.5 \text{ m}\cdot\text{s}^{-1}$  ( $S_{2.5}$  high speed lift). Situation of the number of lifts is shown in Figure 1. The model was thus divided into different combinations according to the following key:

- Lift capacity "C"
- Number of lifts "N"
- Lift speed "S"
- Percentage of people on floor " $E_P$ "

### 3. Results and discussions

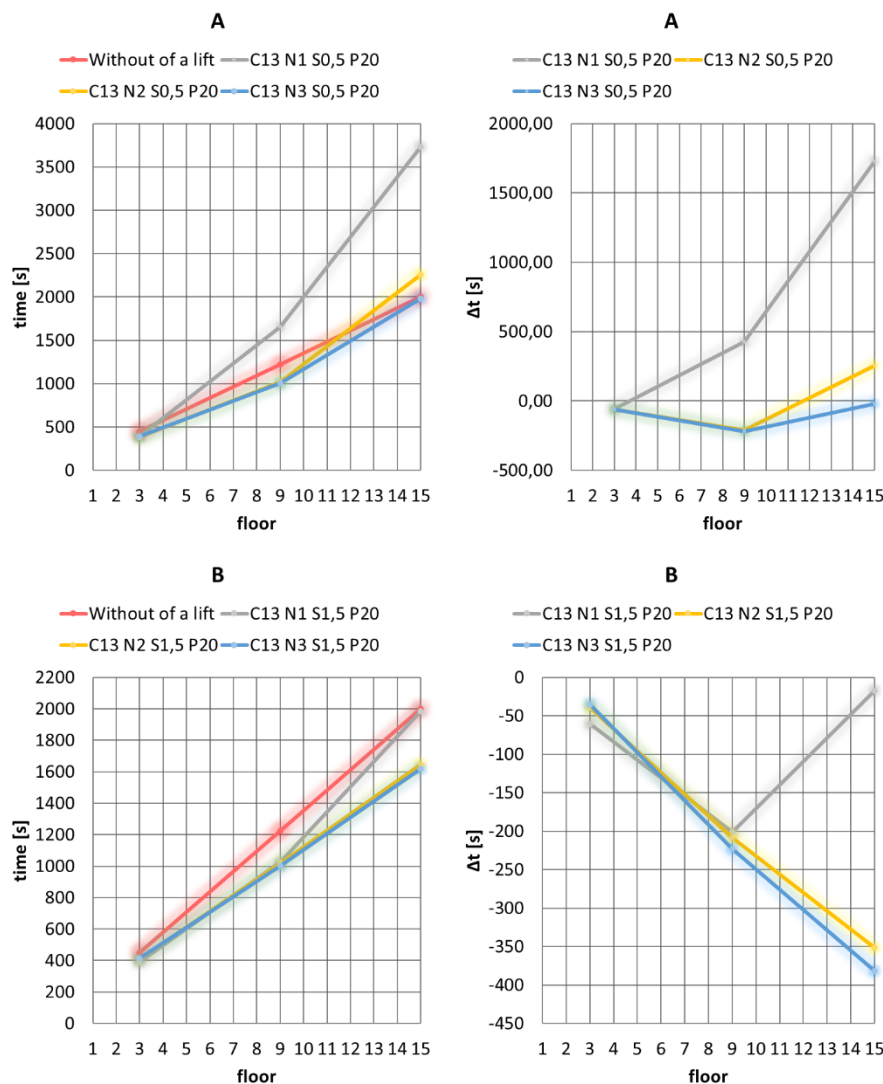
#### 3.1. Comparison of the number of lifts

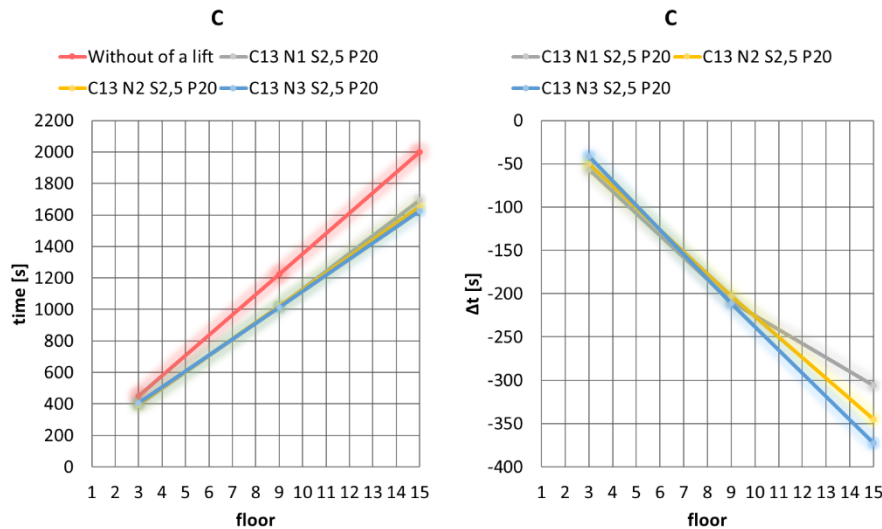
For a lift  $C_6$  and  $S_{0.5}$  (Figure 2 A), it can be seen, that with the highest number of floors, neither combination produced a shortening of the resulting time. The difference in the evacuation times (at the highest floor) between two and three lifts was up to 20% and between one and two lifts up to 50%. Two and three pieces of such lifts bring shorter time  $t_u$  only to 4-storey building. If lift speed is increased to  $1.5 \text{ m}\cdot\text{s}^{-1}$  (Figure 2 B) it can be seen that at fifteen floors the final time  $t_u$  is shortened with the use of three lifts. In this case, the difference in the evacuation times (at the most storey) between two and three lifts was 15% and between one and two lifts 40%. With two lifts, the time is shortened up to the thirteenth floor. One lift does not produce any time reduction. At lift's speed  $2.5 \text{ m}\cdot\text{s}^{-1}$  (Figure 2 B), it can be seen, that two and three lifts will always reduce the time  $t_u$ . On the other hand, even at this speed one lift does not bring any shortening of time  $t_u$ . The difference in the evacuation times (at the highest floor) was between two and three lifts up to 10% and between one and two lifts 40%. When setting  $E_{P40}$ , the total time was not shortened nor in one combination at the highest floor. For this reason, these shares of individuals were not included in the results and were not considered in other parts of the work.



**Figure 2.** Evacuation times  $t_u$  and  $\Delta t$  for combinations with the C<sub>6</sub> lift.

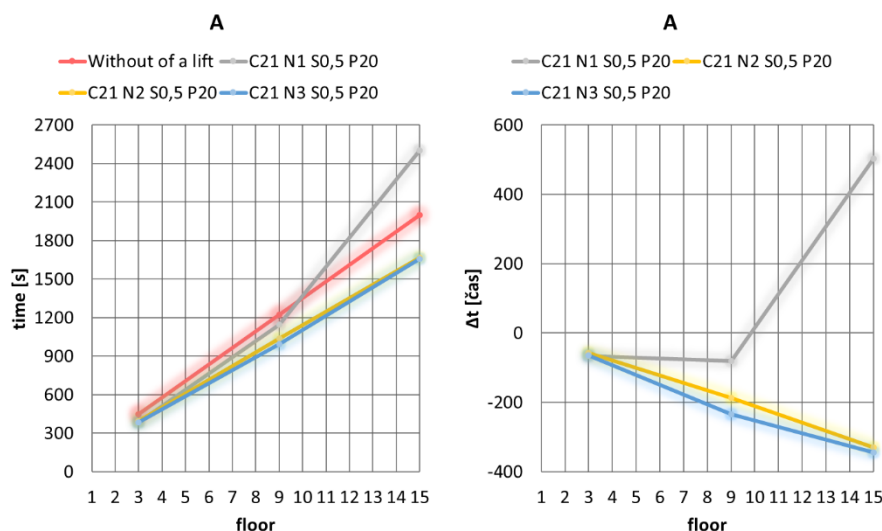
At the lift  $C_{13}$  and  $S_{0.5}$  (Figure 3 A), it can be seen, that at fifteen floors the final time  $t_u$  is shortened here only by using three lifts. The difference in evacuation times (at the highest floor) was between two and three lifts up to 12% and between one and two lifts up to 40%. Combination with two lifts brought shortening of the building time to twelve storeys and one elevator only for a building up to four floors. When changing the speed to  $1.5 \text{ m}\cdot\text{s}^{-1}$  (Figure 3 B), the resulting time is shortened even when one lift is used. The difference in evacuation times (at the highest floor) was between two and three lifts up to 2% and between one and two lifts to 17%. If the lift speed increased to  $2.5 \text{ m}\cdot\text{s}^{-1}$  (Figure 3 C), the difference in times (at the highest floor) was between two and three lifts up to 2% and between one and two lifts up to 3%. With  $E_{P40}$ , the total time  $t_u$  was shortened to the highest number of floors in combinations of two and three lifts. On the other hand, when setting the  $E_{P60}$ , the total time was shortened by using only three lifts. However, the total times  $t_u$  at  $E_{P60}$  were never shorter than with  $E_{P40}$ . On the other hand, the total time  $t_u$  of  $E_{P40}$  was shorter than  $E_{P20}$ , with a difference of 7%, which can be considered approximately the same time. Moreover, the results of the combination with  $E_{P40}$  from the eighth floor approximate the result with  $E_{P20}$ . For this reason, these shares were not included in the results and were not considered in other parts of the work.

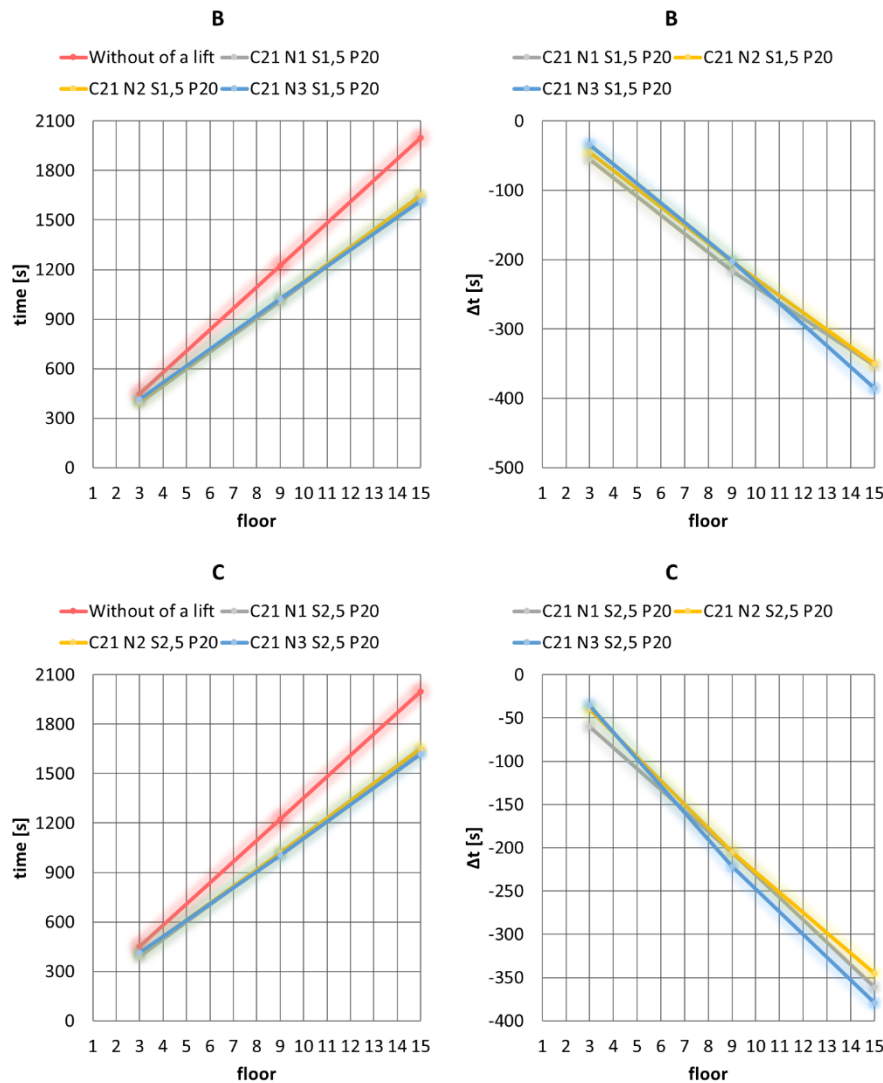




**Figure 3.** Evacuation times  $t_u$  and  $\Delta t$  for combinations with the  $C_{13}$  lift.

For the lift  $C_{21}$  and  $S_{0,5}$  (Figure 4 A) it can be observed that at fifteen floors total time  $t_u$  is shortened using two or three lifts. The difference in evacuation times (at the highest floor) was between two and three lifts up to 1% and between one and two lifts up to 34%. Combination with one lift brought shortening of the total time  $t_u$  to only tenth floor. When changing speeds to  $1.5 \text{ m}\cdot\text{s}^{-1}$  and  $2.5 \text{ m}\cdot\text{s}^{-1}$  (Figures 4 B and C), the total time  $t_u$  is shortened even when using one lift. The difference in evacuation times (at the highest floor) was 2% between two and three lifts. Total times  $t_u$  using one and two elevators were almost same (with a difference of 0.5%). With  $E_{P40}$  setting, the total time  $t_u$  was shortened to the highest number of floors in combinations of two and three lifts. In both cases, the total times at  $E_{P40}$  were always shorter than with  $E_{P20}$ . In these cases, it can be argued that with a large lift capacity it is important to increase the ratio of the number of persons using the lift to 40%. However, the design of 2 to 3 large capacity lifts in 15-storey buildings is virtually impossible in real life. For this reason, we will not consider these alternatives in the next part of the work.





**Figure 4.** Evacuation times  $t_u$  and  $\Delta t$  for combinations with the C<sub>21</sub> lift.

### 3.2. Evaluation of the ideal design

The time ratio  $t_{u,v}$  and  $t_{u,s}$  is a comparison of time values. If the ratio greater than 1.0 means that time  $t_{u,v}$  is longer than  $t_{u,s}$ . The same goes for the opposite. The most ideal use of the elevator takes place when the last person in the lift evacuates together with the last person from the staircase at the same time. If one person decides to change the path of evacuation, the ratio will no longer be 1.0. In the next procedure, it was necessary to choose the ratio of the ratio when the lift is ideally utilized. The range from 0.9 to 1.1 (90% to 110%) was selected. If the ratio less than 0.9 is elevated, the lift design is oversized and if the ratio is greater than 1.1, the design of the lift is under dimensioned (Figure 5).

$t_{u,v}/t_{u,s} < 0,9$ 90% or less	$0,9 \leq t_{u,v}/t_{u,s} < 1$ 90% to 100%	1 (100%)	$1 < t_{u,v}/t_{u,s} \leq 1,1$ 100% to 110%	$1 < t_{u,v}/t_{u,s}$ 110% or more
$t_{u,v} < t_{u,s}$	$t_{u,v} < t_{u,s}$	$t_{u,v} = t_{u,s}$	$t_{u,v} > t_{u,s}$	$t_{u,v} > t_{u,s}$
Oversizing proposal	Ideal proposal	The shortest evacuation time	Ideal proposal	Undersigned proposal

**Figure 5.** Schematic of the suitability of the lift design.



In Figure 6, combinations that represent the ideal use of the elevator or are close to it can be seen. It is also possible to see oversizing and underdimensional proposals. Areas highlighted in red and labelled "X" are combinations for which lifts (at first ride) were occupied on the highest floor less than 80% of their capacity. For example, 2 lifts with a capacity of 21 people can take up to 42 people on the top floor. However, for 22 persons on the floor ( $E_{P20}$ ), these lifts are only used for 52% of their capacity. This is an unnecessary oversizing of the lift capacity design in terms of the number of people on the floor, despite the significant reduction in the evacuation time. Therefore, for these combinations, the ratio of times  $t_{u,v}$  and  $t_{u,s}$  was not calculated. Therefore, these combinations are ideal if you use 44 people on the floor using the lift ( $E_{P40}$ ). Areas highlighted in blue and labelled "X" are combinations for which there has been no overall reduction in evacuation time, despite the fact that the lifts were occupied (at first ride) at the top floor over 80% of their capacity. This is a underdimensional of the lift design in terms of its total capacity for the number of persons on the floor. These combinations are ideal if the lift uses up to 11 people, representing about 10% of the floor. The remaining cells in the table are combinations for which elevators were occupied (at first ride) by more than 80% of their capacity on the top floor, and the overall evacuation time was shortened. In the next step, attention was paid to these combinations. This indicates an incorrect lift design.

Capacity	Speed	Floor	One lift	Two Lifts	Three lifts
6 p.	0,5 m·s <sup>-1</sup>	3	X	96%	72%
		9	X	X	X
		15	X	X	X
	1,5 m·s <sup>-1</sup>	3	X	59%	59%
		9	X	103%	89%
		15	X	X	110%
	2,5 m·s <sup>-1</sup>	3	X	62%	53%
		9	X	93%	72%
		15	X	109%	91%
13 p.	0,5 m·s <sup>-1</sup>	3	93%	65%	X
		9	X	93%	X
		15	X	X	X
	1,5 m·s <sup>-1</sup>	3	72%	44%	X
		9	101%	67%	X
		15	120%	77%	X
	2,5 m·s <sup>-1</sup>	3	67%	51%	X
		9	88%	58%	X
		15	102%	66%	X
21 p.	0,5 m·s <sup>-1</sup>	3	81%	X	X
		9	113%	X	X
		15	X	X	X
	1,5 m·s <sup>-1</sup>	3	58%	X	X
		9	75%	X	X
		15	87%	X	X
	2,5 m·s <sup>-1</sup>	3	60%	X	X
		9	66%	X	X
		15	78%	X	X

**Figure 6.** Ratio values  $t_{u,v}$  and  $t_{u,s}$  for individual combinations with EP20.

#### 4. Conclusion

It can be said that the following combinations represent the ideal design of lift:

- For building up to three floors:

- two lifts with a capacity of 6 persons and a speed of  $0.5 \text{ m}\cdot\text{s}^{-1}$
- one lift with a capacity of 13 persons and a speed of  $0.5 \text{ m}\cdot\text{s}^{-1}$
- For building up to nine floors
  - two lifts with a capacity of 6 persons and a speed of  $1.5$  or  $2.5 \text{ m}\cdot\text{s}^{-1}$
  - two lifts with a capacity of 13 persons and a speed of  $0.5 \text{ m}\cdot\text{s}^{-1}$
  - one lift with a capacity of 13 persons and a speed of  $1.5 \text{ m}\cdot\text{s}^{-1}$
- For building from nine to fifteen floors
  - two or three lifts with a capacity of 6 people and a speed of  $2.5 \text{ m}\cdot\text{s}^{-1}$
  - one lift with a capacity of 13 persons and a speed of  $2.5 \text{ m}\cdot\text{s}^{-1}$

The lift (speeds of  $1.5$  and  $2.5 \text{ m}\cdot\text{s}^{-1}$ ) with a capacity of 21 people is always oversizing. However, when designing this lift at a speed of  $0.5 \text{ m}\cdot\text{s}^{-1}$ , the ideal lift design can be achieved by adjusting the number of people using the lift.

## 5. References

- [1] Ministry of Interior of the Slovak Republic 2004 *94/2004 Decree of the Ministry of Interior of the Slovak Republic laying down technical requirements for fire safety in the construction and use of buildings*
- [2] STN 92 0201-3 2000 *Fire protection of buildings, General regulations, Part 3, Escape routes and evacuation of occupants*
- [3] Dunlop K E Shields T J Real fire emergency evacuation of disabled people *Proceedings of CIB W14 International Symposium and Workshops on Engineering Fire Safety in the Process of Design Equivalency* 13-16 September 1993 Newtownabbey Northern Ireland pp 157–164
- [4] Shields T J Boyce K E McConnell N 2009 *The behavior and evacuation experience of WTC 9/11 evacuees with self-designated mobility impairments* vol 44 pp 881–893
- [5] Averill J D Mileti D Peacock R D Kuligowski E Groner N Proulx G Reneke P Nelson H E 2018 *Final report of the federal building and fire safety investigation of the World Trade Center disaster* <http://wtc.nist.gov/oct05NCSTAR1-7index.htm>
- [6] STN 92 0101 1997 *Structural fire protection, Vocabulary*
- [7] Statistical Office of the Slovak Republic 2018 <https://slovak.statistics.sk>
- [8] Averill J D *Five grand challenges in pedestrian and evacuation dynamics* 5th International Pedestrian and Evacuation Dynamics Conference 8-10 March 2010 Gaithersburg Maryland p 11
- [9] Ding N Chen T Zhang H 2017 *Experimental study of elevator loading and unloading time during evacuation in high-rise buildings* vol 53 pp 29–42
- [10] Ding Y Yang L Weng F Fu Z Rao P 2015 *Investigation of combined stairs elevators evacuation strategies for high rise buildings based on simulation* vol 53 pp 60–73
- [11] Andrée K Nilsson D Eriksson J 2015 *Evacuation experiments in a virtual reality high-rise building: Exit choice and waiting time for evacuation elevators* vol 18 pp 554–567

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