The safe evacuation of persons from a building operating within COVID-19 restrictions

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Abstract
Buildings’ environmental conditions were changed drastically around the world due to the COVID-19 pandemic hazards and restrictions. New social distance rules and organizational changes in the buildings appeared to require a modified fire safety evacuation analysis. The total number of building users under the revised requirements was often limited. Some additional restrictions, such as the reduction of evacuation exit availability, could cause escape problems in the case of fire. In order to determine how the pandemic restrictions could influence the evacuation conditions, a sports hall building was used to assess the impact of the restrictions on evacuation strategies. The research covered test evacuation simulations using the ‘Pathfinder’ modelling software, as well as manual calculations of the expected evacuation time. It was found that the pandemic social distance requirements could cause adverse evacuation conditions in the case of fire. The research helped formulate a simple mathematical algorithm for determining safety evacuation parameters under pandemic restrictions.

Practical application: The surrounding conditions for new buildings are driven by the reduction of social distances imposed by the COVID-19 pandemic. It has been found that pandemic social distancing can significantly extend the time of the evacuation of people. This article proposes a new simple mathematical algorithm for determining the evacuation parameters under pandemic restrictions, which allows the estimation of the required minimum width of emergency exits. This is a practical tool for those responsible for ensuring safety in buildings.

Keywords
Comfort and well-being, COVID-19, evacuation, fire safety health, modelling and simulation, pathfinder, social, distance

Received 15 September 2021; Revised 27 December 2021; Accepted 2 January 2022

Introduction
At the beginning of the 2020s, the whole world faced a devastating Sars-Cov-2 virus pandemic, causing the COVID-19 disease. This required the implementation of global preventive actions in a short time.¹

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The spreading virus (sars-CoV-2) has caused many global constraints and preventive measures. In many countries around the world, the obligation to use personal protective equipment and to maintain social distance has been introduced. It was necessary to introduce appropriate safety rules, especially for public buildings users, to impose required distances between people in rooms and access routes, health control stations etc. The observations had a big impact on the level of safety in buildings related to fire safety and protection.\(^2\)

Research into the spread of Sars-Cov-2 has identified social distancing as an essential preventive measure against virus spread.\(^3,4\) The new social distance rules required maintaining a distance of 1.5 m or 2.0 m between people.\(^5\) In public buildings, limitations of occupancy numbers and the introduction of procedures such as temperature testing at entrances had become commonplace. This led to limitations in the number of entrances allowed for users.\(^6\) Due to the limited number of people, the number of evacuation exits was also limited. Observations of the revised conditions in buildings have shown that they could significantly impact evacuation success.\(^7,8\)

Building managers are obliged to ensure appropriate internal safety conditions. The government administration in an emergency introduces short-term legal regulations. Due to the time and conditions of their introduction, they do not comprehensively cover all issues related to security. This does not exempt building managers from ensuring an adequate level of security. The introduction of new legal provisions in an emergency may, in some cases, lead to the disregard of the existing provisions. Organizational changes due to regulatory changes can also occur in emergency situations other than COVID-19. It is necessary to provide building managers with tools to verify new organizational conditions quickly.

**Time of evacuation**

The safe evacuation of people from a building is paramount in the event of fire. Evacuation tenability must consider the spread of hot gases, reduced visibility due to smoke, concentrations of toxic and irritating smoke constituents in the fire environment.\(^9\) The time required to cover the evacuation route from the building by all persons is referred to in the literature as the required safe escape time (RSET) (Figure 1). The time between fire detection and the onset of conditions that are hazardous to people is called available safe escape (egress) time (ASET).\(^10\) The RSET is based on the time of detection of a fire and the systems employed to maintain tenable evacuation routes for the identified number of people. The ASET is calculated on the basis of worst-case fire scenario consequences. But of these parameters can be evaluated manually or with the use of CFD simulations. The concept of available and required safe egress time was initially introduced by Cooper and reviewed by Ng and Chow in Refs. 11 and 12.

The time of evacuation consists of several components presented in Figure 1.\(^10\) It includes time for fire detection, alarm announcement, people’s recognition and response and the time required to travel through escape routes to a place of safety (equation (1)). The number of building occupants affects only the time of passage through the escape routes \(t_{\text{trav}}\), while the other components stay unchanged:

\[
RSET = t_{\text{det}} + t_a + t_{\text{pre}} + t_{\text{trav}} \quad (1)
\]

A general assumption in the fire safety strategy for buildings is that the required safe evacuation time for the maximum number of persons projected at the design stage of the building should not be exceeded. This assumption was a basis for the research and the methodology for evacuation time evaluation presented in this article. This article aims to assess the impact of the organizational changes imposed impacting on evacuation safety.

**Evacuation routes**

Evacuation strategies are a fundamental aspect of fire safety in buildings. Escape routes, evacuation exits, and their parameters require a detailed design process. The Polish regulations\(^13\) provide requirements for escape routes which vary depending on the purpose of the building and its height. Similar rules are in many other countries.\(^14,15\) The fundamental
requirement for evacuation is the length of escape routes. In public facilities, this should not exceed 70 m in the case of evacuation in one direction only. If there are two evacuation routes, the travel distance could be extended to 100 m. The next significant parameter is evacuation exit width. The total width of the exits from a building should not be less than 0.6 m for every 100 persons, with total minimum availability of 0.9 m. The travel distance length of evacuation routes depends on the building type, while the width of the exits is limited by the occupancy number. The flow of people in the evacuation process is often governed by the laws of hydraulics, on the basis of which local legislation for the design of evacuation routes is introduced.16

**Evacuation time estimation**

A detailed design for escape routes in a building requires the use of fire engineering tools.17,18 One of the most accurate tools for calculating the expected evacuation time from buildings are specialized modelling programmes, like Pathfinder, PedGo or FDS+Evac.19 The computer models use advanced techniques to predict the course of the evacuation process. They use cellular automaton theory, social force models, agent systems, and even graph theory and artificial intelligence.19,20 Nevertheless, due to the complexity of the evacuation process and the changing building designs, it is necessary to constantly develop models and evaluate them using real-world scenarios.21 Despite the limitations, these models make it possible to predict the time of movement through escape routes during an orderly evacuation process.

As well as sophisticated computer models, simple calculation tools are available in standards and design guidance.22–24 These are based on new requirements and knowledge resulting from changing architectural practices around the world.

On site evacuation experimentation studies is another approach. This can provide important data for the analysis and improvement of the safety level of the building or other form of infrastructure. This method could be useful to assess non-standard conditions as found as a result of COVID-19 pandemic.25

The Academic Sports and Teaching Centre of the Lodz University of Technology was used as a test case. The authors made use of the evaluation tools described above, and developed general guidelines for creating safe evacuation rules for people under COVID-19 conditions.
COVID-19 restrictions in the Academic Sports and Teaching Centre and their influence evacuation conditions

The Academic Sports and Teaching Centre of the ‘Lodz University of Technology in Poland’ is a multifunctional public building. It features a 50-metre indoor swimming pool, a sports hall, a complex of climbing walls, badminton courts, a restaurant, a conference centre, numerous meeting rooms and a sports museum (Figure 2). The swimming pool section covers an area of more than 7000 m². The sports hall, designed for facilitating competitions, covers an area of more than 4500 m². The building was created for occupancy of around 10,000 people.

Organization of evacuation of the facility

The structure of several floors of the building is presented in Figure 3. The building is divided into nine fire zones. The largest fire zones are the swimming pool section (FZ1) and the sports hall section (FZ2). Additionally, several smaller fire zones (FZ3–FZ9) have been introduced, including training rooms, technical rooms, conference rooms and social and office areas.

There are nine staircases in the building (S1, S2, S3, S4, S5, S6, S7, S8 and S9), which create vertical escape routes. In addition, there are two internal staircases in the central part of the property (with atrium), but they are not included in the evacuation scenario because they are not enclosed. The total width of the stairways intended for evacuation is 21.3 m. The staircases in the building are equipped with smoke control systems and are enclosed with fire doors and fire walls.

The building has seventeen evacuation exit doors located on the ground floor (Figure 3(a)). Nine of them are exits for people from the higher levels of the building and lead to staircases (W1, W2, W3, W4, W5, W6, W7, W8 and W9), while the other eight are located directly in the main space of the ground floor of the object (W10, W11, W12, W13, W14, W15, W16 and W17).

According to the intended purpose and the space of individual rooms in the building, a designed maximum occupancy of 9190 people was allowed.

Figure 2. The Academic Sports and Teaching Centre of the Lodz University of Technology.

Staircases were provided around the four corners of the building to ensure two evacuation directions from any point within the building. The length of the escape routes to the nearest staircase did not exceed 90 m, and to a secondary staircase did not exceed 120 m. These figures are in accordance with the Polish regulations.13

The COVID-19 restrictions for the sports hall building

Actions carried out in Poland, aimed at limiting the spread of the COVID-19 pandemic, have led to the adoption of numerous legal acts, of which the current legislation is set by the Council of Ministers on the 21st of December 2020. This established a range of restrictions, orders and prohibitions in connection with the control of the epidemic.26 The provisions of the Regulation have become the basis for internal legislative acts adopted within public bodies. Based on this legislation, the Rector of the Lodz University of Technology introduced the following internal regulations for the University:

1. Statute 21/2020 of the Rector of the Lodz University of Technology of 9th of March 2020 on specific arrangements for the prevention, counteracting and eradication of COVID-19 at the Lodz University of Technology,27 and
2. Statute 52/2020 of the Rector of the Lodz University of Technology of 9th October 2020 on the introduction of an obligation to measure the body temperature of persons entering buildings located in the Lodz University of Technology, in connection with the prevention, counteracting and eradication of the COVID-19 epidemic. 

**Figure 3.** Layout of escape routes in the building (a) ground level, (b) first floor, (c) second floor and (d) third floor.
The number of people\textsuperscript{26} allowed to participate in the University entertainment events in sports halls, concert halls, music clubs, etc., was limited to 50\% of the originally designed max occupancy for buildings. Furthermore, a minimum distance of 1.5 m between building occupants was introduced. Additionally, following Statute 52/2020,\textsuperscript{29} an obligation to measure the body temperature of all persons entering buildings located on the premises of the Lodz University of Technology was introduced.

Due to the restrictions described above, the main entrance/exit point for the building (W14+W15) was divided onto an entrance-only door (W14), where the entering person’s temperature was tested, and the exit-only door (W15) (Figure 3(a)). All persons entering and leaving the building were counted. All the other exits were closed and not available for people, even in the case of evacuation (Figure 4(a) and (b)).

**Evacuation experiment under COVID-19 restrictions**

As mentioned above, the implementation of the restrictions may affect the evacuation conditions from a building. For verification of the evacuation conditions under COVID-19 restrictions in the analyzed sports hall building, its administrators decided to undertake the evacuation experiment on the 15\textsuperscript{th} of October 2020. After the manual fire alarm activation (Figure 5(a)) the voice alarm in the fire zones FZ2, FZ3 and FZ 8 was activated. At this moment, the building occupancy was about 100 persons who could exit through only one door – W15 (Figures 3(a) and 5(b) and (c)). The evacuation of all persons was completed within 420 s. The conclusions after the experiment raised doubts over the efficacy of the evacuation process. These were due to the relatively small number of people in the test and their relatively long evacuation time.

The evacuation of people from the fire zones FZ2, FZ3 and FZ8 without COVID-19 restrictions should be carried out by emergency exits W3, W4, W5, W6, W11, W12, W13, W14 and W15 and staircases S3, S4, S5 and S6. The introduced organizational changes influenced the extension of the escape route length and the reduction of the total width of the emergency exits from 12.1 m to 1.7 m. The length of the escape route increased from approx. 90 m to approx. 120 m. (Figure 6)
The question, therefore, arises whether the assumed number of available evacuation exits would ensure an adequate level of evacuation safety in the event of pandemic restrictions? To help understanding of this issue, appropriate evacuation scenarios have been developed, and the movement of people has been modelled using Pathfinder programme, which is described below. It has been found that a real fire may cause building occupants to disregard the orders to ensure adequate social distancing. The fear for their own lives in immediate danger would be greater than the prospect of being infected with COVID-19. The remaining people might not be exposed to the fire factors. They might

**Figure 5.** Evacuation drills at the facility (a) starting the fire alarm, (b) service directs evacuation and (c) evacuation through the main exit of the building.

**Figure 6.** Number of people in the building taking into account Scenarios 1, 2 and 2a.
obey the orders. Such behaviour may extend the evacuation time.

**Evacuation modelling**

During the evacuation test drill demonstrated above, the evacuation time was measured from when the fire alarm was announced and people started to move. It was achieved as 120 s, when the last person left the building. This test was verified by the Pathfinder simulation what estimated it on 115 s. The similar real and simulated evacuation times confirmed that the Pathfinder simulations presented further could be reliable.

For the evaluation of the calculation method presented later, the two theoretical scenarios have been simulated, allowing testing of the evacuation time of people from the building under normal and restricted conditions. They were based upon the building’s design documentation and pandemic organizational solutions and are described below:

- **Scenario 1:** Evacuation of the maximum number of people from the building under normal conditions, assuming all evacuation exits are available. In this scenario, 9190 people were assumed to occupy the building, and the total effective width of exits was equal to 24.2 m (W1–W17 in Figure 3(a)).
- **Scenario 2:** Evacuation under pandemic conditions, with limited people and only one evacuation exit due to the COVID-19 restrictions. In this scenario 4, 110 people were assumed to occupy in the building. The number of people was calculated by assuming a distance of at least 1.5 m between persons. The total effective width of exits (where only the main of the building exit, W15 in Figure 3(a), was known to the users) was equal to 1.7 m.

Pathfinder evacuation simulation software was used for the simulations, which is developed by Thunderhead Engineering. Pathfinder modelling software uses two basic methods of human movement: an SFPE mode and a variable-control mode. The steering system in Pathfinder moves occupants so they accomplish their current movement goal and can respond to changing environments. SFPE mode calculations are made on models specified by manufacturers for moving and walking through stairs and corridors.

The evacuation space was divided into triangles. At the beginning of the assessment, a path was generated for each person, which would lead the procedure to the emergency exit. For this purpose, the software used the A* (A-star) algorithm.

The model of the variable-control mode of human movement assumed the speed of movement of the people within this environment as 1.19 m/s. Pathfinder uses a unique parameter to input the pre-movement time, the delay time parameter. Uniform and standard normal distributions can be inserted in Pathfinder. Pathfinder permits us to assign a specific exit or the nearest one to every occupant. This means a deterministic approach is used to model the problem.

Computer evacuation models are validated and verified. Pathfinder allows modelling the evacuation process for large groups of people. It is not always possible to carry out evacuation tests with a large number of people. Then computer models such as Pathfinder are used.

According to the calculations, the evacuation time for Scenario 1 was 810 s (13.5 min). This time was taken as a maximum evacuation time, which should not be exceeded in any conditions, including the special COVID-19 restrictions. The Scenario 2 evacuation time appeared to be almost twice longer, and it was equal to 1773 s (29.6 min). Detailed analyses of the evacuation time achieved in Scenario 2 suggested that the main problem for rapid evacuation was the exit width limitation, which caused a long waiting time. The simulations results at the initial and final stages of the evacuation are presented in Figure 7.

**A new calculation method**

The evacuation time achieved in Scenario 2 became a motivation for developing a simple method of evacuation time verification for buildings under pandemic conditions. The estimation of the evacuation travel time could be determined by (equation (2)). The travel time depends on the length and width of the evacuation routes and exits and the
average speed of people. Literature suggests the average speed of movement on horizontal and vertical escape routes of 0.9 m/s\(^3\) and exits flow of 0.7 persons/ms, respectively.\(^{10}\) The formula for the travel time calculation is

\[
T = \frac{l}{s} + \frac{n}{f \times w}
\]

as it was mentioned before, the basic assumption for the research was to ensure the evacuation time under non-standard conditions (\(T_2\)) is not longer than the evacuation time under standard (designed) conditions (\(T_1\)) (equation (3))

\[
T_1 \geq T_2
\]

linking (equation (2)) and (equation (3)), (equation (4)) was achieved

\[
\frac{l_1}{s} + \frac{n_1}{f \times w_1} \geq \frac{l_2}{s} + \frac{n_2}{f \times w_2}
\]

from (equation (3)), the variable of the width of the exits under special conditions (\(w_2\)) was estimated (equation (5))

\[
w_2 \geq \frac{n_2 \times s}{(l_1 - l_2) \times f + \frac{n_1 \times s}{w_1}}
\]

The calculations assumed the evacuation route length of \(l_1 = 90\) m, \(l_2 = 120\) m, \(n_1 = 9190\), \(n_2 = 4110\), \(w_1 = 24.2\) m, \(s = 0.9\) m/s and \(f = 0.7\) m/s.

Substituting the assumed parameters in (equation (5)), the required minimum width of exits under non-standard conditions was achieved as \(w_2 \geq 11.5\) m. For verification of the calculations presented above, the evacuation Scenario 2 was modified, and a new model, with three evacuation exits available from the main lobby and four active staircases in the assessed part of the building, was simulated (Scenario 2a). The total width of the escape exits was taken in this case as 12.7 m. In this scenario exits W1 (1.65 m), W4 (1.70 m), W5 (1.90 m), W9 (1.85 m), W12 (2.00 m), W14 (1.80 m) and W15 (1.80 m) were available (Figure 4(a)). The total evacuation time for Scenario 2a was 681 s. Table 1 presents the results of modelling the evacuation time for all the Scenarios being analyzed.

The Pathfinder modelling confirmed that a total exit width of 11.5 m would satisfy the required
evacuation time under non-standard conditions, which appeared to be no longer than under the standard conditions. Therefore, the proposed simple calculation method made it possible to estimate the required width of escape exits with a defined level of safety, which was confirmed by the simulations. The simulation results of the three Scenarios, at the initial and final stages of the evacuation, are presented in Figure 7.

Conclusions

Organizational changes in the building due to COVID-19 pandemic restrictions required an evacuation safety analysis. The authors proved that pandemic social distancing could significantly extend the time of the evacuation of people. Extended evacuation times increase the risk of human movement in critical conditions. A series of studies using an existing sports hall building was undertaken to verify how pandemic restrictions could influence the expected evacuation time. The research included actual evacuation experiments from the building under the pandemic situation. In research also used evacuation simulation models under both normal and pandemic situations.

The authors propose a simple mathematical algorithm for determining the evacuation parameters under pandemic restrictions. The algorithm allows the estimation of the required minimum width of emergency exits. The research confirms the possibility of using a simple method to assess the safe evacuation of building users in changed organizational conditions.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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References

1. Bruinen de Bruin Y, Lequarre AS, McCourt J, et al. Initial impacts of global risk mitigation measures taken during the combatting of the COVID-19 pandemic. Saf Sci 2020; 128: 104773. DOI: 10.1016/j.ssci.2020.104773.
2. U.S Fire Administration. “Understanding the impact of social distancing on occupancy.” U.S. Fire Administration, https://www.usfa.fema.gov/coronavirus/planning_response/occupancy_social_distancing.html
3. Sun C and Zhai Z. The efficacy of social distance and ventilation effectiveness in preventing COVID-19 transmission. Sustain Cities Soc 2020; 62: 102390. DOI: 10.1016/j.scs.2020.102390.
4. Blocken B, Malizia F, van Druenen T, et al. Towards aerodynamically equivalent COVID19 1.5 m social distancing for walking and running. Urban Phys., 2020.
5. Hesman Saey T. Six foot social-distancing will not always be enough for COVID-19. https://www.sciencenewsforstudents.org/article/coronavirus-covid-19-6-feet-social-distancing-not-always-enough
6. Setti L, Passarini F, De Gennaro G, et al. Airborne transmission route of covid-19: why 2 meters/6 feet of inter-personal distance could not be enough. Int J Environ Res Public Health 2020; 17: 2932. DOI: 10.3390/ijerph17082932.
7. Sagun A, Anumba C and Bouchlaghem D. Designing buildings to cope with emergencies: findings from
case studies on exit preferences. Buildings 2013; 3: 442–461. DOI: 10.3390/buildings3020442.
8. Tokazhanov G, Tleuken A, Guney M, et al. How is COVID-19 experience transforming sustainability requirements of residential buildings? A review. Sustainability 2020; 12: 8732. DOI: 10.3390/su12208732.
9. ISO. ISO/TR 13571-2:2016 Life-threatening components of fire methodology and examples of tenability assessment. [Online]. Available https://www.iso.org/standard/65996.html (2016, Accessed October 31, 2020).
10. British Standard Institute. “PD 7974-6:2019 Application of fire safety engineering principles to the design of buildings. human factors. life safety strategies. occupant evacuation, behaviour and condition (Sub-system 6).” [Online]. Available: https://www.techstreet.com/standards/bs-pd-7974-6-2019?product_id=2040315 (2019, Accessed October 31, 2020).
11. Cooper LY. A concept for estimating available safe egress time in fires. Fire Saf J 1983; 5(2): 135–144. DOI: 10.1016/0379-7112(83)90006-1.
12. Ng CMY and Chow WK. A brief review on the time line concept in evacuation. [Online]. Available: http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/summary_of_output/journal/IJAS/V7/ pl1-13.pdf (2006, Accessed October 17, 2020).
13. Dz U. 75 poz. 690 z późn. zm. “Rozporządzenie ministra infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie, wraz z późniejszymi zmianami”. Min Infrastruktury 2002; 75: 1422. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20020750690 (2002, Accessed November 01, 2020).
14. NFPA101. Life safety code. [Online]. Available: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=101 (2015, Accessed: November 01, 2020).
15. Great Britain. Building regulations 2010. and Great Britain. Department for Communities and Local Government. Building regulations 2010. Approved document B. fire safety. 2010
16. Kendik E. Methods of design for means of egress: towards a quantitative comparison of national code requirements. Fire Saf Sci 1986; 1: 497–511. DOI: 10.3801/IAFSS.FSS.1-497.
17. Zheng X, Zhong T and Liu M. Modeling crowd evacuation of a building based on seven methodological approaches. Building Environ 2009; 44(3): 437–445, Mar. 2009. DOI: 10.1016/j.buildenv.2008.04.002.
18. Ronchi E, Kuligowski ED, Reneka PA, et al. The process of verification and validation of building fire evacuation models. 2013. November 2013. DOI: 10.6028/NIST.TN.1822.
19. Barański M and Maciak T. Możliwości współczesnego oprogramowania do symulacji procesu ewakuacji ludności z zagrożonych obiektów. Zesz. Nauk. SGŁódzka Główna Służby Pożarniczej, 2014.
20. Ni B, Li Z, Li X, et al. Agent-based evacuation in passenger ships using a goal-driven decision-making model. Polish Maritime Res 2017; 24: 56–67. DOI: 10.1515/pomr-2017-0050.
21. Barański M. A review of models that take into account the effects of emotional contagion during evacuation. Saf Fire Technol 2019; 53(1): 106–116. DOI: 10.12845/sft.51.3.2019.6.
22. Gwynne SMVMV and Rosenbaum ER. “Employing the hydraulic model in assessing emergency movement.” In: SFPE handbook of fire protection engineering. 5th ed. NY: Springer New York, 2016, pp. 2115–2151.
23. Kuligowski ED and Peacock RD. A review of building evacuation models. NIST, 2005.
24. Kuligowski ED, Peacock RD and Hoskins BL. A review of building evacuation models. 2nd ed. NIST, 2010.
25. KGPSP. Praktyczne sprawdzenie organizacji oraz warunków ewakuacji w czasie epidemii COVID-19. [Online]. Available: https://www.gov.pl/attachment/2380ccf0-a3e5-43fb-91f6-f663a7222f36 (2020).
26. SRP. Rozporządzenie w sprawie ustanowienia określonych ograniczeń, nakazów i zakazów w związku z wystąpieniem stanu epidemii. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20200001066 (2020, Accessed: Feb 16, 2021).
27. Rektor PL. Zarządzenia Nr 21/2020 Rektora Politechniki Łódzkiej z dnia 9 marca 2020 r. w sprawie szczegółowych rozwiązań związanych z zapobieganiem, przeciwdziałaniem i zwalczaniem COVID-19 w Politechnice Łódzkiej.
28. R. PL. Zarządzenie Nr 52/2020 Rektora Politechniki Łódzkiej z dnia 9 października 2020 r.
29. PL. “Koronawirus: informacje i zalecenia,” https://koronawirus.p.lodz.pl/zarzadzenia-komunikaty (2021, accessed 16 Feb. 2021)
30. Qin J, Liu C and Huang Q. Simulation on fire emergency evacuation in special subway station based on Pathfinder. *Case Stud Therm Eng* 2020; 21: 100677. DOI: [10.1016/J.CSITE.2020.100677](https://doi.org/10.1016/J.CSITE.2020.100677).

31. Chu H, Yu J, Wen J, et al. Emergency evacuation simulation and management optimization in Urban residential communities. *Sustainability* 2019; 111(3): 795, Feb. DOI: [10.3390/SU11030795](https://doi.org/10.3390/SU11030795).

32. Thornton C, O’Konski R, Hardeman B, et al. Pathfinder: an agent-based egress simulator. In: *Pedestrian evacuation dyn*, 2011, pp. 889–892. DOI: [10.1007/978-1-4419-9725-8_94](https://doi.org/10.1007/978-1-4419-9725-8_94).

33. Togawa W. Study of fire escape based on the observation multitude currents. 1955.

34. Knoblauch RL, Pietrucha MT and Nitzburg M. Field studies of pedestrian walking speed and start-up time. *Transp Res Rec* 1996; 1538(1538): 27–38. DOI: [10.3141/1538-04](https://doi.org/10.3141/1538-04).

### Appendix

#### Notation

| Symbol | Description |
|--------|-------------|
| $t_{\text{det}}$ | detection time (s) |
| $t_a$ | alarm time (s) |
| $t_{\text{pre}}$ | response time of people before movement (s) |
| $t_{\text{trav}}$ | time to go through evacuation routes (s) |
| $t_{\text{reco}}$ | time to understand the alarm (s) |
| $t_{\text{resp}}$ | response time after understanding the alarm (s) |
| $T$ | travel time (s) |
| $T_n$ | travel time in case n (s) |
| $l$ | length of the escape route (m) |
| $l_n$ | length of escape route in case n (m) |
| $s$ | average speed on the escape route (m/s) |
| $n$ | number of people |
| $n_n$ | number of people in case n |
| $f$ | flow through the escape exit (persons/m·s) |
| $w$ | the effective width of the escape exit from the building (m) |
| $w_n$ | the effective width of the escape exits from the building in case n (m) |