DIN 18009-2 – a New German Standard on Evacuation Simulation

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Abstract After more than eight years of intensive work, the second part of the German DIN 18009 standard on "Simulation of evacuation and personal safety" was published in August 2022. The DIN 18009 series offers a guideline for fire protection engineering in Germany. The first part "Principles and application rules" was published in 2016, with further parts describing standards for smoke simulation and safety concepts to follow. The standard lays down established procedures without claiming to incorporate the latest findings and developments. It attaches importance to simulations within the legal framework and thus marks a milestone in the application of simulation models in the safety context for Germany. This article discusses the advantages and disadvantages of prescriptive guidelines and performance-based engineering methods in the context of building evacuation. Furthermore, aspects of the application of the DIN 18009-2 are highlighted, and what challenges are still to be tackled and how. This includes in particular the choice and definition of scenarios and performance criteria.

1 Introduction

There is an ongoing discussion about the pros and cons of prescriptive methods (guidance for egress lengths and widths in Germany for example) versus performance-based methods to better represent crowd dynamics.

Building regulations use mainly experienced-based specifications of minimal egress widths and maximal route length. In many prescriptive specifications, the value for the minimum width of a bottleneck is determined by the flow rate or time needed to pass

by the occupants assigned to it. How this number of occupants is to be determined is not specified, or is very imprecise. They are widely accepted by the public and one important advantage of prescriptive methods is that they are easy to test and less prone to error. However, today's complex built environment sometimes challenges their simple implementation. It is not always possible or practical to comply with such prescriptive rules. Economic considerations must be taken into account. Thus, reconciling codes with real-world practicality remains a challenge.

One way of countering these oversimplifications is the use of the performance-based approach. It translates the level of safety into performance criteria and re-negotiates them with the authorities as representatives of the will of the society. Numerical methods are then used used for verification. Such models can calculate the spatio-temporal effects by modelling the flow of people in space. Congestion points can be identified and clearance times derived. This ensures a more detailed analysis than with prescriptive regulations. State-of-the-art models use agent based models calculating the movement of individuals. They describe when and how many people depend on which part of the building's escape routes. In addition they consider individual properties like walking speeds, pre-movement time or space requirement. However, a safe use of these tools requires a large portion of expert knowledge and the ability to abstract the system as well as implicit modelling approaches of scenarios. Even if the simulations describe how people are moving, the user has to define many initial and boundary conditions: Where to place the agents at simulation start, what type of agents to model, what escape routes are available, and much more. This is where the DIN 18009-2 comes in and offers a structure to adequately address these difficulties.

The DIN 18009-2 standardises the performance-based approach in Germany. It is derived from several pre-normative and normative approaches such as e.g. the RIMEA Guideline [1] or vfdb Guideline [2]. It is a milestone when it comes to the development of simulation models. There is progress on a national and international level when it comes to the acceptance of simulations used in the performance-based approach. Recently, laws in Germany have been updated based on the results of simulations. This marks an important milestone for the application of simulation models. Even if the DIN still shows weaknesses in some parts, it is an important step forward.

When discussing the pros and cons of prescriptive regulations versus the performance-based approach, it is important to understand that the assumption that compliance with regulations guarantees absolute safety in all possible situations is false. The supposed 100% certainty has never existed, will never exist, and is not achievable. Classical assessments are merely experience-based limits that define a certain level of safety that is accepted by society.

This paper will first introduce the application of the new standard, followed by a discussion on the challenges that still need to be addressed when using simulations.
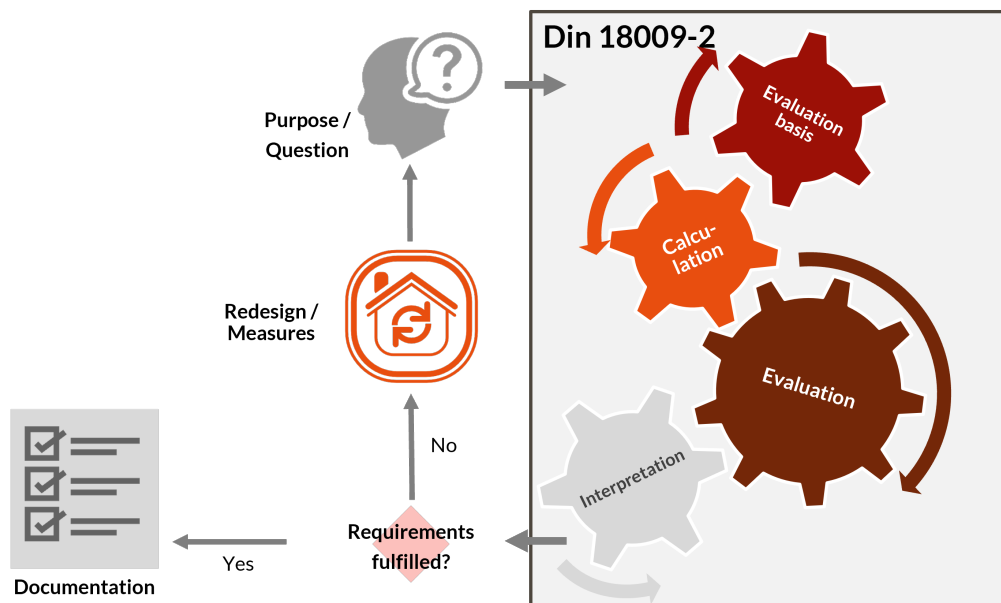
Figure 1 Overview of the process

2 Application of the DIN 18009-2

The application of the new standard follows a structured process as shown in Fig. 1. It consists of four main steps that will be explained in the following.

In general, the standard is applied when the prescriptive codes cannot be met. When this is the case, the process begins with the definition of the deviation and the formulation of a as precise as possible question that should be answered using the performance-based approach.

Proof that the current design still provides the same level of safety can be given by argument, by simulation, or by a combination of both.

In this paper, We focus on the proof by simulation.

First Step: Evaluation basis First, we need to define the evaluation basis. The basis consists of a performance criteria and a set of design scenarios where we test the performance criteria.

Possible performance criteria could be:
- Evacuation time for all occupants to reach a safe area (including pre-movement times, excluding detection and alarms)
- ASET (Available Safe Egress Time) larger than RSET (Required Safe Egress Time).
- Congestion characteristics
- ... or any other quantifiable criteria that characterizes the Level of Safety.

Selecting and defining a meaningful set of scenarios is the most difficult step. Many factors come into play, which are only explained in the following as examples and do not claim to be complete. It should be scenarios whose occurrence are within a certain

probability range. Everyday use should be represented but also different usage patterns should be considered. The scenarios should not be trivial (two visitors in an airport standing close to an exit) but still feasible. Here, the term 'feasible' refers to the scope of application of the methods and procedures addressed in the standard. This is essentially the calculation of evacuation times and characteristics of congestions caused by regular pedestrian streams. It is e.g. not useful for scenarios like the impact of an explosion in which large parts of the building are destroyed or in the event of a terrorist attack with heavy weapons. Even if these scenarios do not fall within the scope of the models and methods addressed by the standard, this does not mean that these scenarios should not need to be considered and evaluated in general. Scenarios where one escape route is blocked are also commonly used in other standards and might be a feasible option for the scenario choice. The DIN standard nevertheless does not imply to choose any explicit scenario but leaves their development and selection to the user. Again, we would like to emphasise that the uncertainty and problems outlined above also apply to prescriptive procedures.

We need to be aware that there are many uncertainties and inaccuracies during the scenario selection process. It is also unknown which set of scenarios is suitable to demonstrate adequately safe evacuation (Under the premise that there is no such thing as absolute safety). But the standard provides a structured process to guide us through the selection process and consider different aspects for the selection process.

It introduces four categories, that can be systematically checked:

- Building: Describes the number and layout of egress routes and the characteristics of a building. (e.g. number of floors, layout of the floors, number, location and characteristics of egress routes etc.)
- Usage patterns: How is the building used? Are there people who are familiar with the building? Is it a workplace? A station? A public building? What kind of people use the space?
- Cause of Evacuation: Why is the building being evacuated? What is the reason? Is there a fire / Where is the fire?
- Safety and fire protection measures: What organisational and/or technical measures are in place to warn and guide people during an evacuation?

When selecting the scenario, it has to be checked what characteristics are present in each case, always keeping in mind that the goal is to find one ore more scenarios that is an as unfavourable as possible scenario (as far as we can judge this) that is still feasible.

Looking at international standards, the SFPE Handbook [3] provides in Chapter 5 approaches and background information for fire risk analysis for different types of buildings, exceeding the approach given in the DIN standard.

Second Step: Calculation   A variety of different models with different capabilities can be used to evaluate the scenario derived in the first step. Fig. 2 shows an overview of different models and their modelling properties.

While macroscopic models are much easier to use and do not require any software, microscopic models are more accurate but require more effort to create the scenarios and

	Macroscopic		Microscopic	
	Capacity Analysis	Dynamic flow models	Discrete space models	Space-continuous models
Escape and emergency routes	constant width for each way element	constant width for each way element	A multitude of the cell size	exact
Individual properties	averaged	averaged	individual	individual
Alarm and response times	section-wise	section-wise	individual	individual
Merging flows	limited	yes	yes	yes

Figure 2 Different models and their properties

to calculate. The choice of which model to use thus depends on the purpose and the need to emphasise different aspects. For example, if it is necessary to vary individual properties, an agent-based model shall be chosen, whereas the emphasis lies on an escape routing properties variation, macroscopic serve well.

Third Step: Evaluation After calculating (macroscopic models) or simulating (microscopic models) the design scenario, the results need to be evaluated. For macroscopic models, this is mostly done by checking the evacuation times of the different variants that have been calculated.

For microscopic models, it is possible to visualise and analyse the dynamics of processes. The visualisation minimises the cognitive overhead and supports planning in many ways. It illustrates not only where, but also when and for how long congestion will occur. With the localisation in space and time, new ideas for problem solutions can also arise.

Fourth Step: Interpretation Once we have analyzed the results, we need to classify and evaluate them in terms of plausibility and uncertainty. Depending on the model used, there may be uncertainties in the choice of parameters and the sensitivity of the model. This needs to be addressed and, depending on the outcome, a higher safety margin should be introduced.

A second part is the interpretation of the protection goal: Is the protection goal being met? This is done by comparing the results with the defined thresholds of the performance criteria that have been defined in Step 1. If necessary, organisational or structural measures should be derived or additional scenarios considered to make the results more reliable with respect to the protection goal.

Finally, a thorough documentation of the results and interpretations must be written. The structure of such documentation and its content are specified by the standard.

3 Discussion

The new standard shows a viable way how to use simulation models to assess buildings in the context of fire safety in a structured and comprehensible way. Although this is a huge step forward for the recognition of simulations as verification methods, there are still some challenges that need to be solved in the future.

Definition of performance criteria The definition of performance criteria is a method to make the protection goal measurable and thus a simplification of reality. The standard proposes performance metrics but does not set criteria to assess the metrics on whether they are adequate or not. Taking congestion characteristics as an example: When is a congestion no longer feasible? There is a lack of specification of characteristic values of a congestion that need to be further examined and quantified. Another important topic is the interference between different performance criteria. Sometimes, a longer escape route leads to a faster evacuation. Is this feasible? Practical experience and further experiments as well as research studies will be needed to get a better understanding of congestions and their impact on safety.

Scenario choice Since a proof must be economical, it is not possible to consider an arbitrary number of scenarios. Rather, the selected scenarios must guarantee that the complexity of the assessment value to be investigated is well captured.

Although, the standard provides a process for developing scenarios, it does not provide a tool for selecting the relevant scenarios.

So, how can we find the relevant scenarios? In theory, this is a reverse optimisation problem that is difficult to solve and due to its complexity not practically implementable in a broader sense. There are parameter studies [4] that extensively tested the combination and variation of certain parameters and their influence on the output. RiMEA Test 8 [1] provides a good insight into the used (microscopic) model and its sensitivity with respect to different input parameters. This can be referred to when choosing certain parameters (e.g. population, space requirements). Nevertheless, from a practical point, right now we can only rely on best practices and the experience of the modeller when choosing the design scenario. Beyond that, stakeholders need to agree on appropriate scenarios, knowing that there is no such thing as absolute safety. In the future, AI might help us to create the most relevant scenarios based on a pre-assessment by using excessive data sets that vary in geometry. A first study in the context of office buildings have been performed by [5]

In summary, the DIN 18009-2 is a very important step in moving from static and descriptive regulations to dynamic evaluation of scenarios. With the help of evacuation simulations, we are able to identify deficiencies, to see the potential for optimization and to discover points that we would not have without them. The remaining challenges need to be addressed in the near future to enable a reliable and broad application of the new standard.

References

[1] RiMEA – Guideline for microscopic evacuation analysis. Guideline 4.0.1 (2023). URL http://www.rimea.de/

[2] Leitfaden Ingenieurmethoden des Brandschutzes. Guideline 4. Auflage (2020). URL https://www.vfdb.de/media/doc/technischeberichte/TB_04_01_Leitfaden_IngMethoden_4Auflage_2020-03-26.pdf

[3] DiNenno, P.J., Drysdale, D., Beyler, C.L.: SFPE handbook of fire protection engineering; 4th ed. SFPE, Quincy, MA (2008). URL https://cds.cern.ch/record/1403081

[4] Schröder, B., Arnold, L., Seyfried, A.: A map representation of the ASET-RSET concept. Fire Safety Journal **115**, 103154 (2020). doi:10.1016/j.firesaf.2020.103154. URL https://linkinghub.elsevier.com/retrieve/pii/S0379711219307209

[5] Berggold, P., Nousias, S., Dubey, R., Borrmann, A.: Towards predicting pedestrian evacuation time and density from floorplans using a vision transformer. In: Proc. of the 30th Int. Conference on Intelligent Computing in Engineering (EG-ICE) (2023)