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COMPARISON OF BUILDING SMOKE SIMULATION RESULTS: FDS, PATHFINDER VS. SPREADSHEETS

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Purpose: The purpose of this study is to compare the results of smoke simulations in buildings obtained using the FDS (Fire Dynamics Simulator) program with those obtained using calculation sheets. The study aims to assess the effectiveness of different methods for smoke and evacuation analysis in the context of fire safety.
Design/methodology/approach: The study employed a comparison of smoke simulation results obtained from the FDS program and simple calculation sheets. Various evacuation scenarios and parameters, such as visibility through smoke and smoke temperature, were analyzed. Data from the literature were utilized, and simulations were conducted to evaluate the accuracy and effectiveness of each method.
Findings: The results showed that FDS offers more advanced and accurate simulations, while calculation sheets are faster and cheaper but have limited analytical capabilities. The simulations indicated that changes in the size of the simulation grid had little effect on visibility results, suggesting stability and reliability of the simulations.
Research limitations/implications: The limitations of the study include the need for appropriate skills to operate FDS and the constraints arising from simplifications in calculation sheets. Further research is suggested to better understand the dynamics of fire phenomena and to develop more advanced analytical tools.
Practical implications: The study has significant practical implications for fire safety engineers who can use the results to better plan evacuations and smoke management systems in buildings.
Social implications: The findings of the study may influence public policy regarding fire safety and social responsibility, contributing to improved quality of life by enhancing safety in buildings.
Originality/value: The article adds new value to the field of fire safety engineering by comparing different methods of smoke and evacuation analysis, which can be useful for engineers, architects, and institutions involved in building safety.
Keywords: safety engineering, software, fire safety.
Article category: model tests.

1. Introduction

Contemporary fire safety engineering increasingly relies on modern computational technologies due to growing requirements for ensuring an adequate level of fire protection. This, in turn, has contributed to the intensive development of tools for predicting fire development and assessing the effectiveness of the protective measures used.

The choice of the appropriate method of smoke analysis and evacuation depends on the type of facility, the technical capabilities available, and how accurately we want to assess the fire risk. For simple buildings, where there are no crowds of people or complex structures, it is often sufficient to use simple spreadsheets—they are quick and inexpensive. However, it should be remembered that their accuracy in reproducing real physical phenomena is limited.

For more complex buildings with a high degree of architectural complexity, a large number of users, and special requirements for evacuation and smoke extraction, it is recommended to use advanced simulation tools such as FDS and Pathfinder. They allow for a more accurate analysis of hazards, evacuation planning, and the adaptation of technical solutions to specific needs. However, it is important to ensure that the results are interpreted correctly and that the people operating these programs are properly trained.

Today, when designing modern and safe buildings, it is important to skillfully combine simple methods with computer simulations in order to achieve the best results without unnecessary costs.

2. Characteristics of methods for smoke analysis and evacuation

2.1. FDS (Fire Dynamics Simulator)

Fire Dynamics Simulator (FDS) is a computer model that simulates fire-driven fluid flow. It is a computational fluid dynamics (CFD) model that numerically solves the Navier-Stokes equations for low-velocity flows, with an emphasis on smoke and heat transport from fires. Together with the Smokeview program, they form a single package. It is open-source software, which makes it a free tool. The creators of this software are the National Institute of Standards and Technology (NIST) of the United States Department of Commerce (McGrattan et al., 2007). FDS is based on entering object parameters in a text file and through the CMD command line (for DOS-based systems), the program performs flow simulations.

Smokeview is a separate visualization program that is used to display the results of FDS simulations. It allows the results to be animated on a computer screen and has a simple menu-based interface.

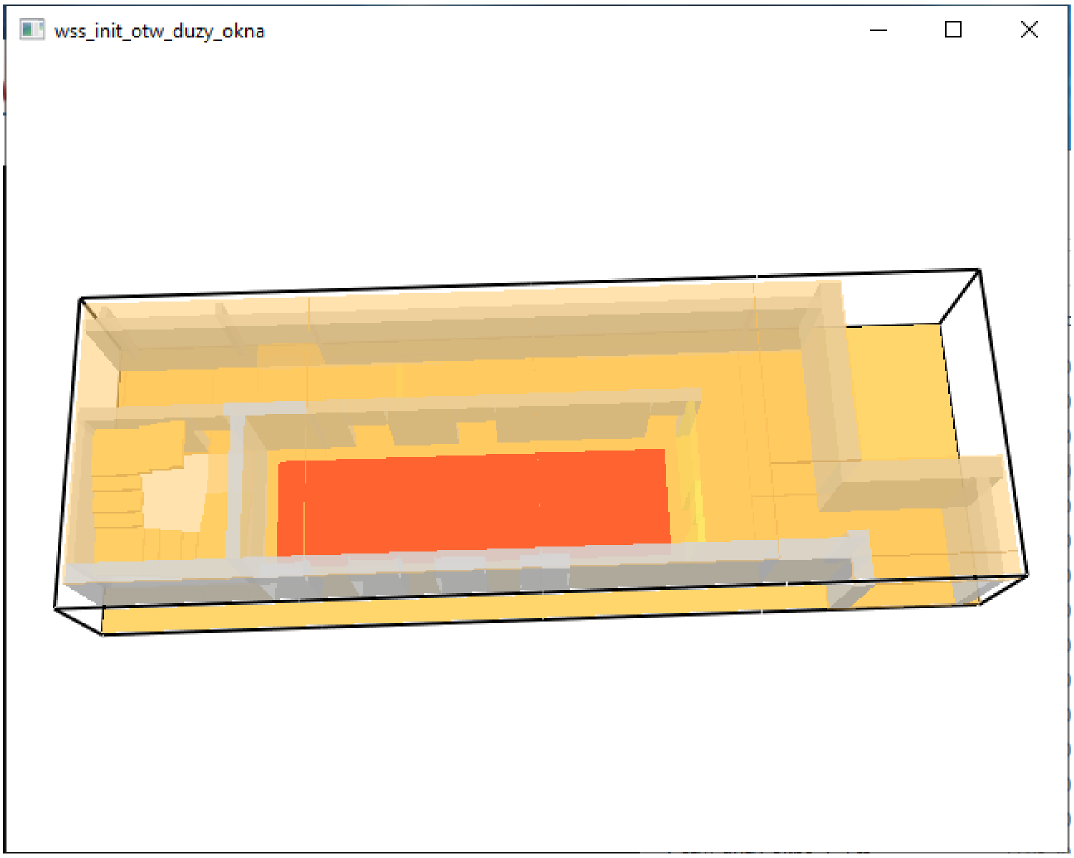

Figure 1. Smokeview window.

FDS is used to design smoke management systems, study sprinkler and detector activation, and reconstruct fires in residential and industrial environments. It is a tool for solving practical fire protection problems and for studying the basic phenomena associated with fire dynamics and combustion.

FDS and Smokeview can be used in practice to simulate and analyze fire scenarios, which is useful in the design of fire protection systems and in research on fire dynamics. Users can create input files for FDS, run simulations, and analyze the results using Smokeview, which allows for a better understanding of the behavior of fire and smoke under various conditions.

2.2. Pathfinder

Pathfinder is a program developed by Stigo that is used to simulate the evacuation of people from buildings. It works on the basis of an agent model – each person in the simulation is a separate agent who reacts to the environment and other people (Thunderhead Engineering, 2023). This allows you to analyze various evacuation scenarios, e.g., during a fire, panic, or poor visibility. The program also allows you to load building plans from CAD, PyroSim, and other files.

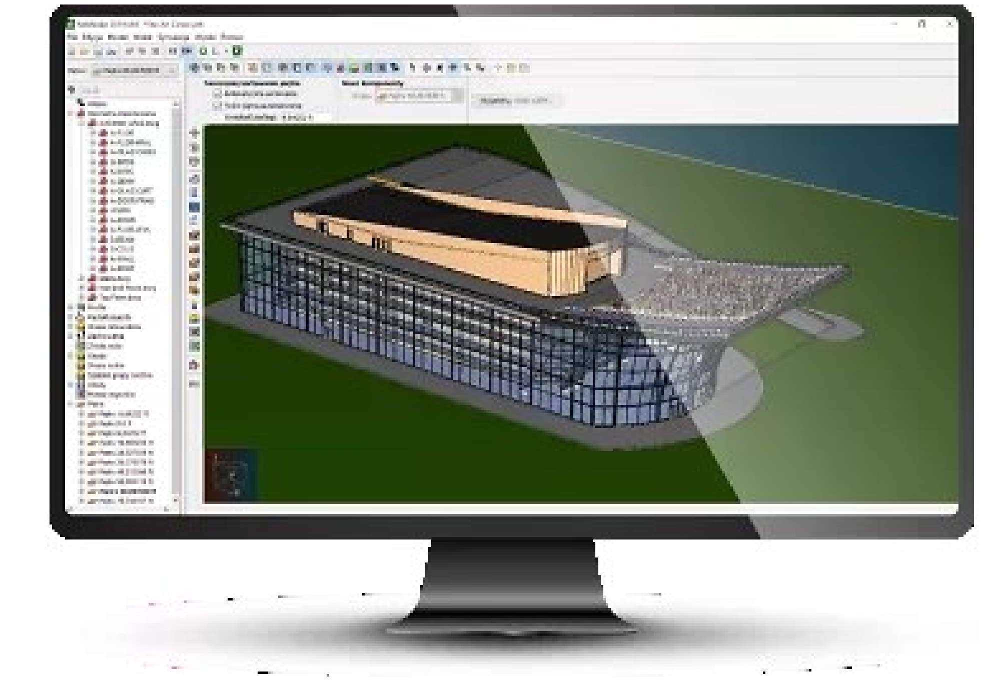

Figure 2. Pathfinder program image.

Source: https://pyrosim.pl/program-pathfinder/

The Pathfinder program, combined with high-quality animated 3D results, allows you to quickly obtain reliable answers using the software's artificial intelligence.

Such simulations are particularly valuable where it is impossible or dangerous to conduct a real experiment, and they also allow mathematical and physical models to be used in a way that produces reliable and accurate results.

What you can do with this tool:

- Independently plan various evacuation scenarios.
- Work on a drawing or building plan loaded from a graphic file (e.g., jpg).
- Record videos showing the evacuation process and save them in video format.
- Automatically recognize evacuation routes based on CAD drawings.
- Ability to independently define elements of the environment, such as rooms, doors, stairs, or slopes.
- Great freedom in creating different profiles of people participating in the simulation (e.g., age, mobility).
- Support for CAD files (dwg, dxf) and models from PyroSim (psm, fds), also in 3D.
- Creation of graphs showing how many people move through specific zones.

Advantages:

- attractive 3D visualization,
- intuitive interface,
- ability to test multiple evacuation scenarios,
- taking individual characteristics into account (age, fitness).

Disadvantages:

- no direct modeling of fire phenomena,
- license cost (from approx. USD 4500) (Prauzner, 2014),
- limited compatibility with certain European standards.

Despite its numerous advantages, the program's limitations—including the inability to model fire phenomena, high license cost, and partial incompatibility with European standards—indicate the need for careful evaluation of its applications in specific projects. Nevertheless, for entities seeking effective solutions for simulating movement in emergency conditions, investing in Pathfinder may prove justified, especially due to the possibility of testing complex evacuation scenarios taking into account individual factors. Despite certain shortcomings, this tool sets the standard in the field of digital safety analysis, integrating simulation precision with intuitive operation.

2.3. Spreadsheets

Simulation of smoke in buildings using spreadsheets Excel spreadsheets are used in the assessment of evacuation conditions because they are simple and inexpensive. The well-known program from Microsoft's Office 365 suite, a popular office software package, is used for this purpose. To make good use of this tool, you need to be familiar with formulas, such as those used for calculations and formulas used by Excel. Everything is made as accessible as possible for anyone who does not use professional engineering software on a daily basis.

The calculation methods, e.g., in spreadsheets, are based on formulas from standards such as PN-B-02852:2001 or PN-EN 12101-5. To use them, you need to know the parameters of the building, the expected fire conditions, and the rules for selecting smoke extraction equipment. It all depends on which mathematical formulas we use. In this study, we will use a spreadsheet based on the book "Principles of Smoke Management" (Klote, Milke, 2002).

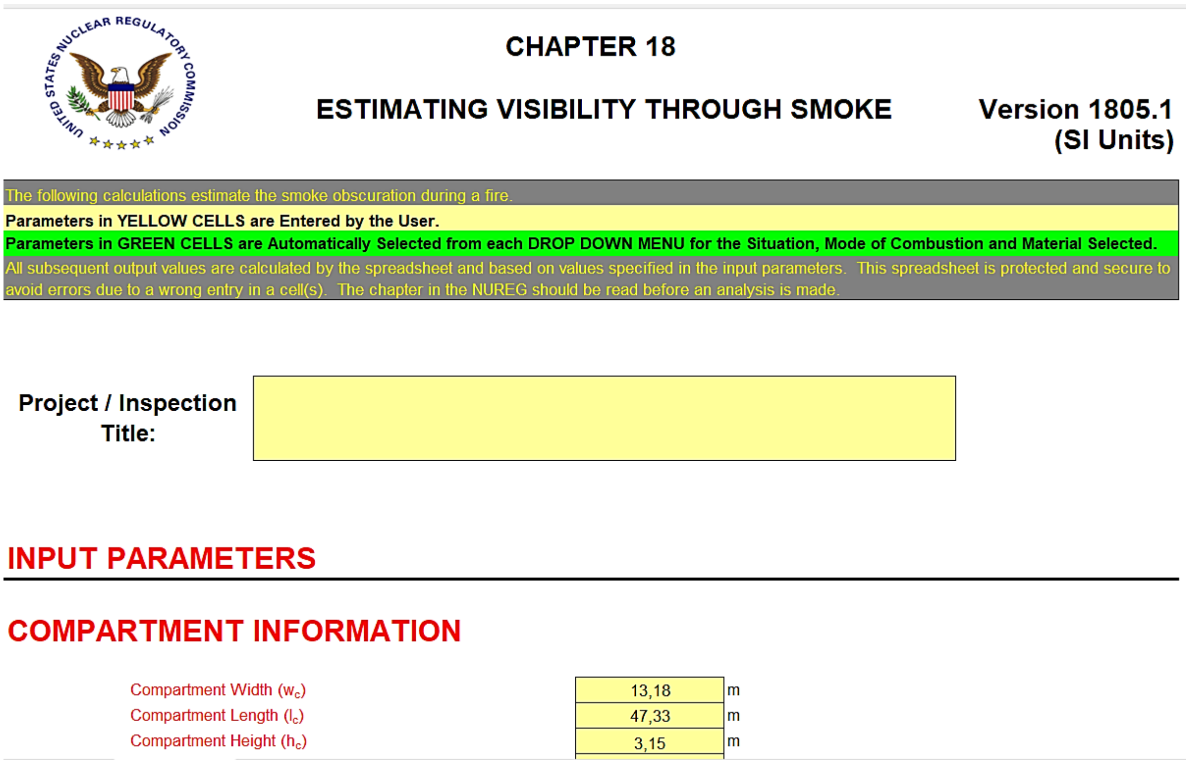

Figure 3. Estimating visibility through smoke – Excel spreadsheet.

2.3.1. How does it work in Excel?

In Excel, you can easily program relationships that show how quickly smoke builds up in a given room. All you need to do is create a table in which you enter input data such as room volume, smoke generation rate, and acceptable concentration, and then apply the appropriate mathematical formulas that use these values to calculate the time it will take for the smoke to reach a dangerous concentration. Thanks to the spreadsheet functions, we can also estimate how low the smoke layer will fall over time and how long a safe evacuation space will be maintained. A spreadsheet prepared in this way allows you to quickly analyze different scenarios by changing only a few numbers in the table. This is a great solution at the preliminary analysis stage, when we do not yet have access to specialized programs. The fire power, as a key input parameter for any simulation, can also be estimated based on available data and formulas described in the technical literature Pyrosim.pl. (2021). Fire power as the most important input parameter for CFD simulations (Fliszkiewicz et al., 2012).

Potential errors and limitations:

- Ignoring the variability of thermal and pressure conditions.
- Lack of representation of dynamic phenomena (e.g., changes in smoke volume, turbulence).
- Assumption of a constant smoke flow regardless of the fire development phase.
- No information about the smoke layer and its impact on visibility.
- Limited possibilities for validating results without a real model.

Advantages:

- simplicity and speed of calculations,
- low costs,
- acceptance by building control authorities,
- data can be quickly changed and different scenarios can be checked,
- almost every student or employee has Excel.

Disadvantages:

- significant simplifications of the model,
- Excel will not show how smoke moves,
- lack of dynamics of phenomena,
- inadequate for unusual objects (STIGO, 2025).

2.3.2. How much does it cost?

Although using Excel for such simulations does not require significant financial outlay, it is worth mentioning a few things. Many universities provide students with free access to this program under an educational license, which makes it a particularly attractive tool for learning and analysis. However, if you do not have such access, the cost of purchasing an annual license is approximately PLN 200-500, or a monthly subscription as part of Microsoft 365. Added to this is the time you need to spend learning how to use it – although most users know the basics of Excel, creating a working simulation spreadsheet requires some practice. There are also paid courses that teach more advanced use of Excel – their prices start at around PLN 500. Nevertheless, compared to specialized engineering programs, Excel remains a much cheaper and easier-to-use solution.

3. Results

For our study, we will use the two programs mentioned above: FDS and MS Excel. The parameter we will compare is visibility through smoke. We will use the data used in the article Simulation of Heat and Smoke Behavior for Wood and Subway Fires by Fire Dynamics Simulator (FDS) (Sonh et al., 2010).

3.1. FDS

The research conducted by the Koreans focused on analyzing the behavior of smoke and heat in wood and subway fires using the FDS simulator. In terms of visibility through smoke, the study found that changes in the size of the simulation grid had little effect on visibility results, meaning that the simulations were stable and reliable at smaller grid sizes.

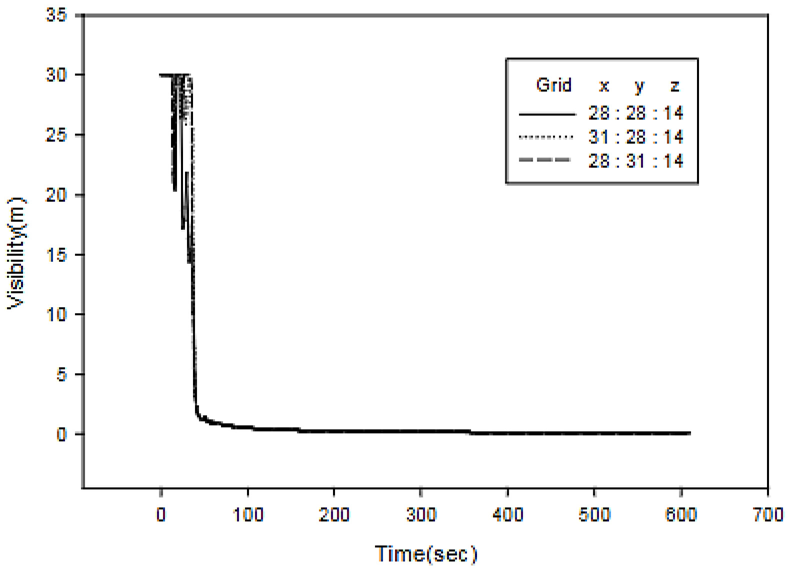

Figure 4. Changes in visibility depending on grid size at a height of 1.5 m and a distance of 7.5 m in a subway fire.

Source: (Sonh et al., 2010).

In addition, other parameters such as smoke temperature and CO concentration were observed in the study. The simulation results showed that the smoke temperature at a height of 2 meters initially rose rapidly, then gradually increased, and after about 500 seconds began to drop rapidly due to the smoke settling and dispersing. The CO concentration was slightly higher for larger grid sizes at certain points, but overall the values were similar for different configurations.

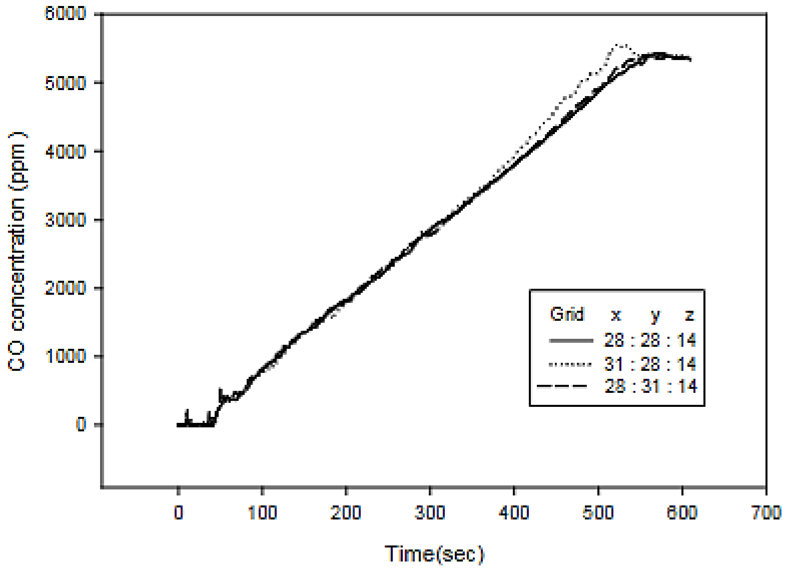

Figure 5. Changes in maximum CO concentrations depending on mesh size at a height of 1.5 m and a distance of 7.5 m during a subway fire.

Source: (Sonh et al., 2010).

3.2. Excel

For comparison, an Excel spreadsheet based on the book "Principles of Smoke Management" (Klote, Milke, 2002) will be used. The data was entered based on the Korean article and is shown in the table below.

Table 1.
Input data

Parameter	**Value**	**Unit**
Compartment Width (w_c)	3.0	m
Compartment Length (l_c)	20.00	m
Compartment Height (h_c)	2.75	m
Mass of Fuel Burn (M_f)	2.77	kg

$$S = \frac{K}{\alpha_m \times m_p} \tag{1}$$

where:
S – visibility through smoke (m),
K – proportionality constant,
α_m – secific extinction coefficient (m^2/kg),
m_p – mass concentration of particulate (kg/m^3).

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c \tag{2}$$

where:
V – volume of the compartment (m^3),
w_c – compartment width (m),
l_c – compartment length (m),
h_c – compartment height (m).

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p \times M_f \tag{3}$$

where:
M_p – mass of particulates produced (kg),
y_p – particulates yield,
M_f – mass of fuel consumed (kg).

Mass Concentration of the Particulates Calculation

$$m_p = \frac{M_p}{V} \tag{4}$$

where:
m_p – mass concentration of the particulates (kg/m^3),
M_p – mass of particulates produced (kg),
V – volume of the compartment (m^3).

Summary of Results

Visibility Through Smoke Calculation

$$S = \frac{K}{\alpha_m \times m_p} \tag{5}$$

Answer S = 2.77 m = 9.08 ft

Table 2.
Summary of results from Excel spreadsheet

Parameter	Value	Unit
Compartment Width (w_c)	3.0	m
Compartment Length (l_c)	20.00	m
Compartment Height (h_c)	2.75	m
Mass of Fuel Burn (M_f)	2.77	kg
Volume of the compartment (V)	165.00	m^3
Mass of particulates produced (Mp)	0.04	kg
Mass concentration of the particulates (mp)	2.52 x 10^{-4}	kg/m^3
Visibility through smoke (S)	2.77	m

Visibility through smoke according to the Excel sheet is 2.77 m.

4. Summary

There is no doubt that Fire Dynamics Simulator (FDS) is a more advanced fire simulation tool than a simple spreadsheet. The simulation uses the Navier-Stokes equation for low-velocity flows, which allows for more accurate prediction of fire behavior. On the other hand, the Excel spreadsheet allows for quick and inexpensive preliminary smoke analysis and enables easy testing of different scenarios by changing the input data.

In terms of accessibility, FDS is a free program, but the threshold for using it is quite high and requires at least an average knowledge of DOS-based commands (for Windows) and programming language, as FDS does not have a graphical user interface (GUI) and data for this program is entered in text files.

When it comes to Excel, its advantage is undoubtedly its simplicity of use and the vast possibilities it offers in selecting mathematical components. Although formulas can be somewhat difficult, the program offers extensive support during spreadsheet editing. The disadvantage of this solution is, of course, the author's knowledge. While FDS is a ready-made product that we know or can predict how it will behave, with a spreadsheet we are the programmers ourselves and we need to know what parameters and formulas to use. If we rely on ready-made solutions, we don't have to worry about this problem. Another issue is that the spreadsheet will give us one or several results from a given point on the timeline. It will not simulate how the object will behave throughout the entire simulation.

In the practice of fire safety engineering, the complementary use of tools such as Excel and FDS can bring significant benefits. Excel can be used to quickly test different scenarios and parameters, allowing for a preliminary understanding of smoke dynamics and evacuation. This allows engineers to quickly identify potential problems and focus on key aspects that require more detailed analysis. Here, for example, they will use FDS, which will be used for final validation or more detailed analysis of smoke physics in more advanced building structures.

In summary, FDS offers more advanced and accurate simulations, but is more complex and time-consuming to use. Excel, on the other hand, is simpler and faster, but its capabilities are limited to basic analyses and it does not reflect the dynamics of fire phenomena.

References

1. Fliszkiewicz, M., Krauze, A., Maciak, T. (2012). Study of the effectiveness of designed smoke extraction ventilation systems using CFD simulation. *Scientific Journals of the Main School of Fire Service*, *No. 43*, 13-35.
2. Klote, J.H., Milke, J.A. (2002). *Principles of smoke management*. American Society of Heating, Refrigerating and Air-Conditioning Engineers.
3. McGrattan, K.B., Klein, B., Hostikka, S., Floyd, J.E. (2007). *Fire dynamics simulator (version 5) User's Guide*. https://doi.org/10.6028/NIST.SP.1019-5
4. Prauzner, T. (2014). Modern simulation techniques for hazards in safety engineering. *Scientific Papers of the Jan Długosz University in Częstochowa. Technology, Information Technology, Safety Engineering*, *Vol. 2*, 253-265.
5. Sonh, Y.-S., Dan, S.-K., Lee, B.-W., Kwon, S.-P., Shin, D.-I., Kim, T.-O. (2010). Simulation of Heat and Smoke Behavior for Wood and Subway Fires by Fire Dynamics Simulator (FDS). *Journal of the Korean Institute of Gas (한국가스학회지), 14(*6), 31-37. https://www.sciencedirect.com/science/article/pii/S0360544218314518
6. STIGO (2025). *Fire power as the most important input parameter for CFD simulation*.
7. Thunderhead Engineering (2023). *Pathfinder - Technical Reference Manual*.