

Application Attempt of Virtual Simulation in "Smoke Control and Exhaust Engineering"

Kaiqiang He¹, Simin Zhu^{1*}, Liu Yang¹, Weiwei Ge¹, Shuaijun Xie²

¹ Department of Fire Engineering, China Fire and Rescue Institute, Beijing 102200

² School of Physics and Electronic Engineering, Chongqing Normal University, Chongqing 401331

Abstract. In the context of information technology, virtual simulation technology has become an important component of university teaching. This paper presented an exploration of the application of virtual simulation technology in the course "Smoke Control and Exhaust Engineering". By assigning course projects, students were tasked with constructing a model of an educational building featuring an atrium structure. The dispersion of smoke post-fire in the above building was visually simulated. The fire simulation model can serve as a supplementary resource for the knowledge points of smoke spread patterns in atrium structures. They effectively overcame the challenges in reproducing architectural fire scenarios and addressed the teaching pain points of students' inadequate understanding of the key concepts. The deep integration of virtual simulation technology with the curriculum not only enhances the accessibility of knowledge points in the "Smoke Control and Exhaust Engineering" course but also motivates students to engage more actively in learning. The architectural fire scenarios built using virtual simulation methods are more in line with the requirements for applied talents at the fire and rescue institute.

Keywords: Virtual simulation; Smoke control and exhaust engineering; Building fires; Smoke spread

1. Introduction

To promote the application of information technology in the field of teaching, the Ministry of Education and the Beijing Municipal Government have successively issued a series of documents and notices, such as the "Guiding Opinions on Further Promoting the Application of Information Technology in Education" and "Teaching and the Action Plan for the Development of Education Informatization in Beijing". The above policy sets four the goals and measures for promoting information technology in teaching, encouraging schools to actively carry out information technology reform, and improving teaching quality and level. Many universities have actively followed up and promoted the application of virtual simulation in relevant courses^[1,2]. Han Ruigang^[3] applied virtual simulation software in the practical teaching of electric vehicles, which significantly reduced the cost of training, shortened the training time, and improved the safety of practical teaching. Zhang Yongchao et al.^[4] realized the visualization of cavitation phenomenon based on virtual simulation experiment platform, achieving the teaching goal of imparting core professional knowledge, explaining complex phenomena, and inspiring professional thinking. Zhang Ruanjing et al.^[5] introduced the teaching mode of virtual simulation experiments in the teaching of electromagnetics course and explored the motion law of charged particles in magnetic fields.

China Fire and Rescue Institute is a distinctive application-oriented university, most of the students go to the front line of fire fighting after graduation, which requires high practicality and strong application. As one of the main departments, our fire engineering major involves courses such as fire combustion, smoke control engineering, and building fire protection, etc., and the knowledge covers the characteristics of different building fire and smoke spread. This study explored the application prospects of virtual simulation technology in the context of applied talent training, aiming at the problems of difficult practice and insufficient understanding of students in fire engineering courses, especially smoke control engineering courses. Taking the law of virtual building fire smoke spread as a concrete example, students were organized and guided to analyze the example. The teaching breadth and the training program of characteristic fire personnel were investigated.

2. The Necessity Of Virtual Simulation

2.1 Meet the requirements for first-class course construction

The construction of first-class courses requires teachers to make full use of information technology, integrate online and offline teaching resources, design diversified teaching activities and tasks, and enhance the interactivity and interest of the courses. Currently, there are many softwares for the fire dynamics simulation, which are easy to operate and provide convenient conditions for the course of "smoke control and exhaust engineering"^[6]. By constructing simulation scenarios and databases, the supporting resources for courses were enriched, which helped to build first-class courses.

2.2 Address the limitations of experimental conditions

Virtual simulation can be conducted anytime and anywhere. Students can learn through fire dynamics software in their dormitories, which improves the convenience and flexibility of learning. Especially for the difficulty of building actual scenes of building fires, virtual simulation can increase operability and avoid unexpected events, ensuring the safety of students^[7].

2.3 Improve teaching quality and students' ability

Virtual simulation technology can help teachers better adjust teaching content and methods through real-time interaction and personalized customization. Virtual simulation provides an exploratory learning platform. Different building fire characteristics and smoke spread characteristics are diverse. Students can construct different building models according to their own pace and interests, such as tunnels, high-rise buildings, subways, etc. These choices can effectively improve students' learning enthusiasm, and cultivate their independent thinking abilities. Furthermore, contact with virtual simulation can make students familiar with the software operation process in advance. It can improve their professional ability and lay a foundation for the completion of undergraduate graduation design.

3. Analysis Of Curriculum And Learning Situation

The enrollment of fire engineering majors is divided into two channels: Young students(College Entrance Examination Candidate) and Team students (from provincial fire stations). Young students are admitted through the early batch of the college entrance examination, while team members are admitted through the examination for the fire rescue team. The ratio of current youth students to team students is about 1:1.5, and the overall quality of students is relatively high. They have completed courses in chemistry, physics, fluid mechanics, and other subjects in the early stages, and have basic knowledge reserves.

Smoke Control and Exhaust Engineering aims to teach the design of smoke control systems within buildings to achieve safe evacuation of building occupants. The main content includes chapters on the flow of fire smoke, specifications for smoke control systems, operation and control of smoke control systems, and smoke control technology for special buildings. It covers knowledge of multiple scenarios such as high-rise building smoke control technology, atrium building smoke control technology, tunnel smoke control technology, and subway smoke control technology. The course is a spring semester course in the third year of college, facing the dilemma of less class hours, rich content, strong theory and poor practice. Due to the difficulty in establishing and reproducing building fire scenarios, students generally reported a low acceptance of knowledge about the spread of smoke in buildings during learning, and were unable to provide positive feedback on practical applications after course. Meanwhile, most students will be engaged in fire rescue work after graduation, their lack of in-depth knowledge can easily lead to confusion in the actual fire disposal, resulting in more casualties. Therefore, it is urgent to increase the accessibility and understanding of knowledge points in smoke control and exhaust engineering.

4. Teaching Process And Experimental Design

4.1 Teaching process

The smoke spread pattern after a fire in the atrium building is highly representative. Due to the surrounding building structures, the air circulation in the atrium is restricted to a certain extent, and smoke may be trapped in the atrium. If the atrium building is a multi-storey structure, the smoke may be affected by the height difference between floors in the short term, causing the smoke to rise or fall. Therefore, this study attempts to take the atrium building as an example to enhance students' understanding of the smoke propagation mode in the atrium building through virtual simulation scenarios. The overall teaching process is as follows:

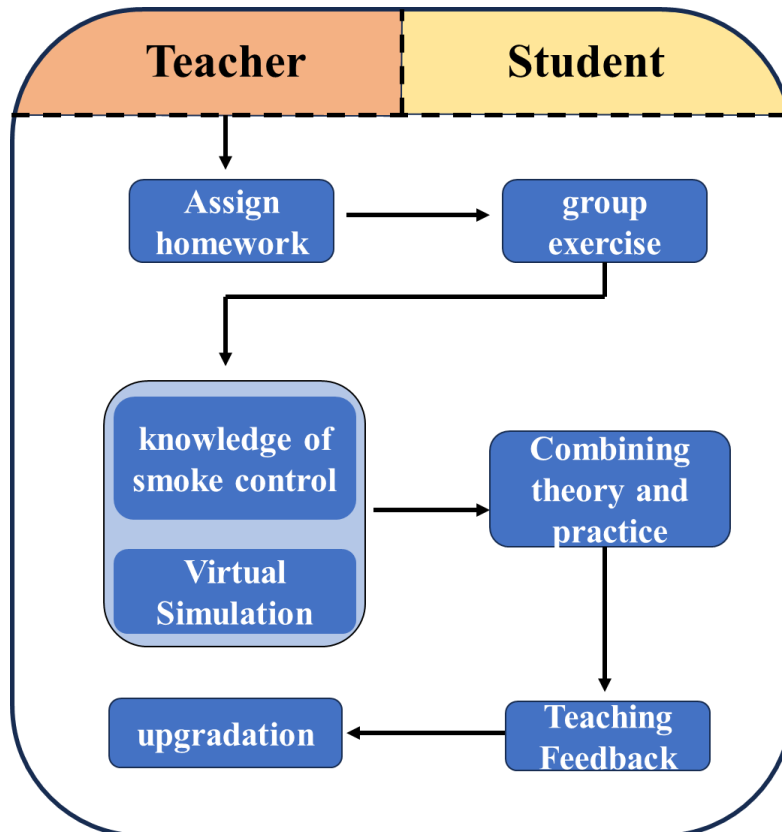


Figure 1 The process of teaching implementation

4.2 Experiment Design and Knowledge Feedback

4.2.1 Experiment Design

Taking a building with an atrium as an example, the teacher provided the CAD drawings of the building, including dimensions, evacuation routes, fire-fighting facilities, and other basic parameters. Students were assigned PyroSim modeling tasks and were asked to consider the positions for sampling parameters such as smoke concentration, temperature, CO concentration, and visibility. The architectural model drawing is shown below.

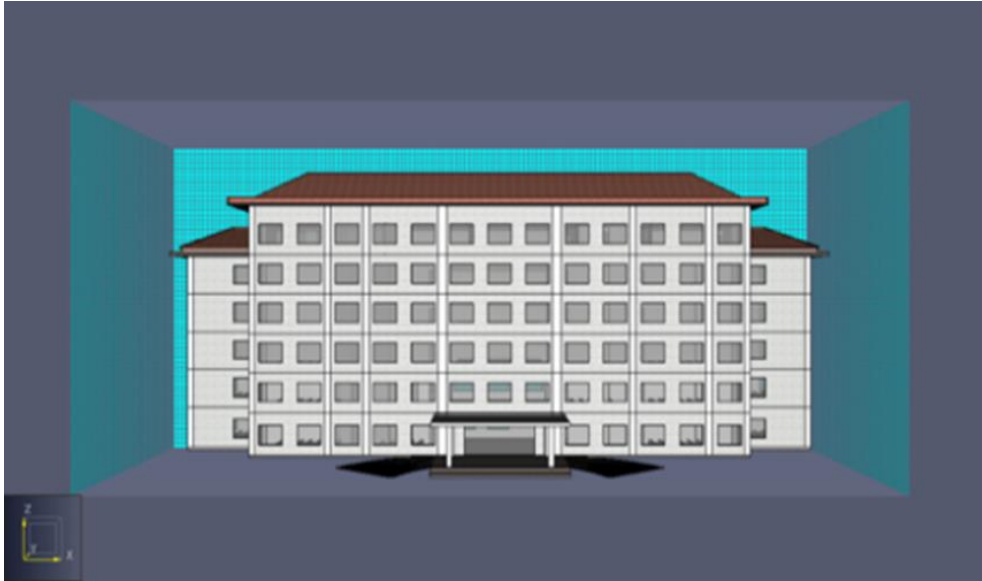


Figure 2 The drawing of architectural model

The teaching objective is to help students to understand the spreading rules of smoke near the atrium structure and the relevant knowledge of smoke control system layout. The main influencing factors of the building fire spread include ventilation conditions, location of the ignition source, and operation conditions of fire-fighting facilities. As the atrium structure is located in the middle of the first and second floors of the building, the ignition point is set on the east side of the first floor. The focus is on observing the influence of the atrium structure on the smoke spread trend in the event of a fire on the first floor. Additionally, ventilation conditions affect the supply of air, leading to changes in smoke diffusion. This task also considered the opening and closing of windows and smoke exhaust systems. By altering the fire scenarios, students can observe the changes in CO levels, temperature, and visibility during different stages of fire development processes.

4.2.2 Knowledge Feedback

(1) Understanding of the Atrium Structure

The atrium structure has a significant impact on the spread of smoke during a fire. Simulation images showed that if a fire occurs inside the atrium building, the generated smoke spread along the evacuation routes, ultimately accumulating mostly in the atrium (see Figure 3). This module highlights two key points regarding the smoke spread patterns in the atrium structure. Firstly, the atrium can provide a certain space for smoke accumulation, delaying the spread of fire smoke towards the other side of the building. Secondly, the fire hazard near the atrium, especially at the top of the atrium, will be greatly increased. When selecting evacuation pathways and routes, consideration should be given to staying away from the atrium area. Furthermore, the driving force behind the smoke spread between the atrium and the surrounding floors comes from the pressure difference between the atrium and the surrounding floors, which prompting students to think deeply about the positioning of smoke control facilities.

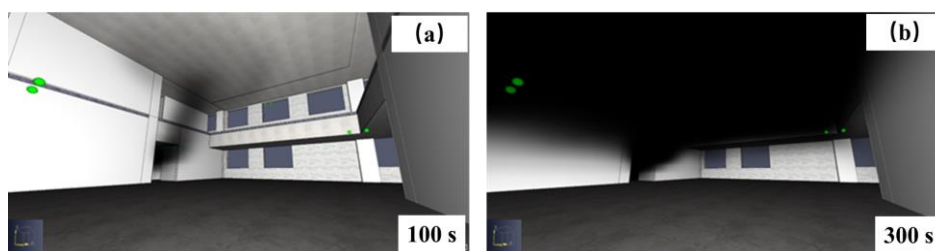


Figure 3 Distribution of smoke in the atrium at 100 s and 300 s

(2) Understanding of Smoke Control Facilities

Through virtual simulation, students can gain a deeper understanding of smoke control facilities, focusing on the selection of smoke control facilities and the advantages of natural ventilation. Smoke control design requires students to master the application of natural ventilation and mechanical pressurized air supply in an atrium structure building. How to control the spread of smoke and reduce its harm through design is a basic requirement of the course. According to the "Technical Standard for Building Smoke Control and Exhaust Systems (GB51251-2017)" section 3.1.3, "For public buildings and industrial buildings with a height less than or equal to 50 m, and residential buildings with a height less than or equal to 100 m, natural ventilation systems should be used in smoke-proof stairwells, independent anterooms, shared anterooms, and fire elevator anterooms (except for shared anterooms combined with fire elevator anterooms)." Considering this building's height is less than 50 m, window opening should be the preferred smoke control technique for students.

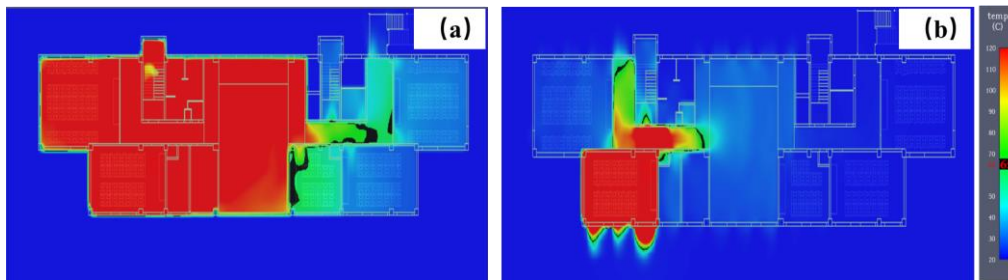


Figure 4: Temperature distribution on the fire floor
 (a) Windows closed; (b) Windows opened

The simulation experiment intuitively explains the advantages of natural smoke exhaust. Taking smoke temperature as an example, virtual simulation results also demonstrated that natural ventilation (Figure 4b) effectively improved the extent of smoke spread within the building compared to windows being closed (Figure 4a). Furthermore, compared to the scenario with closed windows, both CO concentration and visibility significantly decreased when windows were open. A substantial amount of smoke was directly expelled through the windows, without entering the evacuation corridors. This part of the simulation can greatly enhance students' understanding of smoke control through natural ventilation.

(3) Understanding of Smoke Exhaust Facilities

Mechanical smoke exhaust is an important design element in smoke exhaust systems, as it can prevent fire spread, improve air quality, and provide escape routes. Take the example of CO concentration, which can easily cause human poisoning. The virtual simulation results showed that when the fire was at the same ignition point, the CO concentration was lower in the case of combined natural ventilation and mechanical smoke exhaust (Figure 5b) compared to natural ventilation alone (Figure 5a). Mechanical smoke exhaust further controlled the spread of toxic smoke within the building. The virtual simulation visualizes various fire parameters, deepening students' understanding of the necessity and functioning of mechanical smoke exhaust systems through visual means.

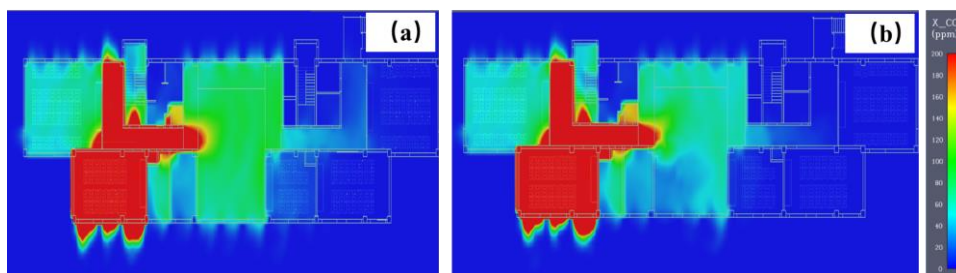


Figure 5 Distribution of CO on the fire floor

(a) Under natural smoke exhaust conditions; (b) Under combined natural and mechanical smoke exhaust conditions

5. Teaching Effect And Application Prospects

In the process of teaching the smoke spread regulations in atrium buildings, traditional textbook knowledge was presented through visual means. With the help of virtual simulation technology, the acceptability of students is greatly increased, deepening their understanding of key points and highlighting the teaching effectiveness.

(1) Firmer Knowledge Mastery

Utilizing virtual simulation technology has deepened students' understanding of atrium building smoke control systems. By leveraging virtual technology, a rich digital teaching resource library can be established. The resource includes virtual lab videos, simulated case analyses, and online interactive courses, providing students with more learning resources and tools to facilitate the digestion and absorption of knowledge.

(2) More Active Innovative Thinking

Virtual simulation provides a flexible experimental environment and exploration space, along with error tolerance and real-time feedback mechanisms. This fosters the cultivation of interdisciplinary comprehensive thinking, enhancement of overall capabilities, and teamwork skills. All of them contribute to stimulating students' innovative awareness and abilities. This is particularly evident in student competitions and graduation design processes. Typical applications include developing new smoke exhaust facilities suitable for atrium staircases by understanding the flow patterns of smoke in smoke-protected stairways.

(3) Further Enhancement of Professional Skills

Considering that students in the college will be heading directly to the frontlines of fire incidents after graduation, using simulation methods to simulate fire scenarios in virtual environments can reduce risks in actual situations. It can decrease the likelihood of injuries and accident rates for firefighting and rescue personnel. For example, by simulating a tunnel fire in Fujian Province, reconstructing the fire scene allows for a review of rescue tactics. This incident, which involved a car catching fire, using Pyrosim software to simulate critical fire speeds, CO concentrations, temperatures, and visibility. The simulation reinforces students' awareness of wearing breathing apparatus and understanding the impact of wind on rescue operations.

6. Conclusion

The study took the virtual scenario of an atrium building fire as a starting point, and used virtual simulation technology to digitally demonstrate the smoke spread rules and the effectiveness of smoke control facilities in the atrium building fire. By setting specific parameters, students visualized the process of smoke accumulation in the atrium building during a fire and observed the effectiveness of smoke control facilities (natural ventilation and mechanical smoke extraction) intuitively. The understanding of relevant knowledge was deeply understood by students. Through virtual simulation, to a certain extent, the challenges of the theoretical emphasis and practical difficulty in "smoke control and exhaust engineering" were overcome. In the future, virtual simulation technology can promote the integration and linkage of smoke control engineering at our school with other related disciplines such as the fire fighting and combustion, providing higher-dimensional learning content and practical cases to help students establish a more comprehensive knowledge system. However, regarding specific fire situations, students should be informed to make comprehensive judgments based on factors such as combustible material type and ignition source power.

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