Research on the Influence of Smoke Vents on the Smoke Temperature in the Dormitory Corridor

Yujin Zhang*
Sichuan Vocational and Technical College, Suining Sichuan 629000 China

*Corresponding author: 547993823@qq.com

Abstract. A simplified dormitory corridor model was established in this paper to simulate the fire in the dormitory and its corridor with Fire Dynamics Simulator (FDS). By exploring the distribution and change law of temperature and smoke in the dormitory and corridor, the author found out the development characteristics of dormitory fire and the influence of different natural smoke vent heights on the change of smoke temperature, which can provide a certain theoretical basis for dormitory construction design, effective control of dormitory fire smoke, personnel evacuation and fire suppression.

Keywords: corridor model; FDS; fire simulation; evacuation

1. Introduction
Student dormitories have long been a key target of fire safety. They are the main place for students to rest, live and study, and they spend nearly half of their time there every day. On the one hand, dormitory is characterized by high population density, high fire load and many hidden dangers, and on the other hand, the students’ awareness of fire safety is weak; once a fire accident occurs, the life and property safety of students will be severely threatened [1]. In this paper, FDS is used to conduct large-scale fire numerical simulation experiments on the dormitory corridor, so as to study the distribution and change of smoke temperature in the corridor after a fire in the dormitory room. The National Institute of Standards and Technology (NIST) has built a huge fire field test database and the results got from FDS can be compared with these test data, so the accuracy and reliability of the program is beyond doubt. In addition, this model whose program is open has been verified by large-scale and full-scale fire experiments, and its accuracy has been verified by a large number of experiments. Therefore, it has been widely used in building fire research [2]. The comparative test is mainly based on three models, including corridors without natural ventilation and those with natural ventilation. Among them, the corridors with natural ventilation were divided into two kinds of opening areas, namely, the opening height was 2.0m-2.6m and 2.4m-3.0m. The study of the movement law of smoke in the corridors and the influence of ventilation conditions on the smoke movement is established on this basis, with the purpose to put forward some guiding opinions for the evacuation of people in the dormitory fire and the structure optimization of the university dormitory.
2. Simulation experiment

2.1 Overview of the simulated dormitory

As shown in Figure 1, the dormitory is divided into two sides by the corridor. On the left (each room is numbered with an odd number), there are 17 room and 2 fire exits. Fire exit 1 is located between room 107 and room 109; and fire exit 2 is located between room 125 and room 127. Each room is 3m in width, 7.6m in depth and 3m in height. On the right (each room is numbered with an even number), there are 17 rooms, 2 stairwells and annex rooms. The rooms on the right is omitted for simplicity. In the experiment, the most unfavorable room was selected as the fired room, that is, room 101 in the floor plan.

![Figure 1](https://example.com/floor-plan.png)

**Figure 1** Floor plan of the student dormitory

Every room is divided into two parts: the balcony and the main body. The length of the balcony along the X-axis direction is 2.3m, the width along the Y-axis direction is 3.0m, and the height is 3.0m. The main body along the X-axis direction is 5.3m, the width along the Y-axis direction is 3.0m, and the height is 3.0m. There is a 0.2m thick partition wall between the main body and the balcony, and a 0.9×1.9m door opening is in the partition wall. There are four multi-purpose beds in every room, with beds on the top and desk below. There generally are school things like books and stationery on the desk, and a wooden wardrobe and utility cabinet is between two desks. There is also a small cabinet placed between the main body of the bedroom and the partition wall of the balcony, which is shared by everyone. There is a 1.3m×1.7m window hole on the outer wall of the balcony. The window hole is connected by iron windows and is mainly used for ventilation and natural lighting. The size of the room door (the door set at the junction of the room and the corridor) is 1.0m×1.9m. The thickness of the outer wall of the dormitory, the partition wall between rooms, and the connecting wall between rooms and the corridor are all 0.3m. In this study, it is assumed that the door of the room on fire is open, while the doors of other rooms are closed. The specific dimensions of rooms are shown in Table 1.

| Name    | X (m) | Y (m) | Z (m) |
|---------|-------|-------|-------|
| Corridor| 2.0   | 57.0  | 3.0   |
| Bedroom | 7.6   | 3.0   | 3.0   |
| Balcony | 2.3   | 3.0   | 3.0   |
| Main body| 5.3  | 3.0   | 3.0   |

2.2 Establishment of the physical model

2.2.1 Physical model of the dormitory corridor: According to the actual size of the aforementioned dormitory and its corridor plan, the physical model of the dormitory corridor established through the text file of FDS is shown in Figure 2, including the geometric dimensions of the standard-floor rooms, the size and location of the door and window openings in the dormitory, the size and placement of obstacles in the dormitory, the geometric dimensions of the corridor, and the openings for natural ventilation. The most basic core of using FDS for numerical simulation is writing text files, including: establishing grids; setting simulation time; setting boundary conditions; setting fire points; defining objects in the bedroom; defining walls, doors, windows and vents; and defining output files.
2.2.2 Determination of the grid. The division of the grid needs to consider the length of the simulation time and the accuracy of the calculation results. Based on previous researches, one of the dormitory grid programs is as follows:

- &MESH IJK=76,30,30, XB=-2.3,5.3,0.0,3.0,0.0,3.0/grid of the burning room
- &MESH IJK=16,570,30, XB=5.3,6.9,0.0,57.0,0.0,3.0/corridor grid
- &MESH IJK=76,30,30, XB=-2.3,5.3,0.0,3.0,0.0,3.0/grid of the un-burning room

2.2.3 Setting simulation time. Combining the existing literature and related researches of other scholars, the simulation time is determined as 1300s in this research.

- &TIME T_END=1300.0 /

2.2.4 Setting boundary conditions. MISC is a command used to define various input parameters, and a text file can only have one MISC line. The MISC command contains many parameters. The GVEC parameter is used to define gravity. The unit is m/s², and the default value is GVEC=0,0, -9.81 (the default value is selected in this study). The HUMIDITY parameter is used to define the relative humidity. The unit is “%”, and the default value is 40% (the default value is selected in this study). This parameter is used to track the evaporation of water and it is used when there is water in addition to fire in the simulation. ISOTHERMAL is a logical parameter, which means that the calculation does not include radiant heat and temperature changes, that is, the simulation is in an adiabatic state, and its default value is FALSE. The P_INF parameter is used to define the environmental pressure. The unit is Pa and the default value is 101325Pa (the default value is selected in this study). The TMPA parameter is used to define the ambient temperature, that is, the temperature of the object at the beginning of the simulation. SURF_DEFAULT is used to define the boundary wall. The default value is ‘INERT’, and it is applied to all boundaries through the SURF line. The procedures for writing MISC commands in this study are as follows:

- &MISC TMPA=20.0, SURF_DEFAULT='WALL'/
- &MATL ID='GYPSUM PLASTER'
  FYI = 'Quintiere, Fire Behavior'
  CONDUCTIVITY = 0.48
  SPECIFIC_HEAT = 0.84
  DENSITY = 1440. /
- &SURF ID='WALL'
  RGB = 200,200,200
  MATL_ID = 'GYPSUM PLASTER'
  THICKNESS= 0.012 /

A wall-coating mud is defined through the MATL parameter, which specifies the thermal conductivity, specific heat and density of the material, and then it is applied to other boundaries through the SURF parameter. According to the actual needs of the simulation and the environmental conditions at the time, the selected ambient temperature is 20°C.

2.2.5 Defining the fire point. The setting of the fire point should be combined with the layout and parameter setting of the fired room. In this research, Kerosene was used to simulate the ignition source, and the heat release rate of the ignition source was defined by the HRRPUA parameter of the SURF command. After the source caught fire, other combustibles in the room would be ignited. The specific
procedure is as follows:

&REAC ID = 'KEROSENE'
    FYI='Kerosene, C\(_{14}\) H\(_{30}\), Tewarson, SFPE Handbook'
    SOOT\_YIELD = 0.042
    C=14.0
    H = 30.0
    CO\_YIELD=0.012 / CO\(_2\)\_YIELD = 2.85

&SURF ID='FIRE', HRRPUA=1500, PART\_ID='smoke' /
&PART\_ID='smoke', MASSLESS=TRUE, SAMPLING\_FACTOR=1/
&VENT XB=1.6,1.7,2.6,2.7,0.8,0.8, SURF\_ID='FIRE' / (fired room)

2.2.6 Defining natural smoke vent. Two types of natural smoke vents were defined, namely the natural smoke vent 1: 2.0m to 2.6m and the natural smoke vent 2: 2.4m to 3m (the top of the corridor).

&VENT XB=5.3,6.9,0,0,2.0,2.6, SURF\_ID='OPEN'/natural smoke vent 1 near the corridor
&VENT XB=5.3,6.9,57,57,2.0,2.6, SURF\_ID='OPEN'/natural smoke vent 1 near the corridor
&VENT XB=5.3,6.9,0,0,2.4,3, SURF\_ID='OPEN'/natural smoke vent 2 at the far end of the corridor
&VENT XB=5.3,6.9,57,57,2.4,3, SURF\_ID='OPEN'/natural smoke vent 2 at the far end of the corridor

2.2.7 Defining output file. There are two kinds of FDS output files. One is defined by the DEVC command, and the generated data is saved in an Excel file with a suffix of ‘.csv’ (such as Corridor_smoke_1_devc.csv). The other is defined by the SLCF (Slice File) command or the BNDF (Boundary File) command. What it generates is a visual two-dimensional data, which is saved in a file with the suffix ‘.smv’ (such as Corridor_smoke.smv). Since the smoke temperature is the main parameter in this study, the visualized two-dimensional data program is:

&SLCF PBX=6.3, QUANTITY='TEMPERATURE' /the smoke temperature distribution in the middle of the corridor

When measuring physical parameters of smoke temperature by DEVC command, there were three groups of measuring points respectively at the height of 1.2m, 1.9m and 2.6m in the corridor, each group has 27 measuring points, and one was arranged every 2m (the first measuring point was 0.5m from the near end of the corridor). The specific procedure is as follows (the measurement point was at the height of 1.9m):

&DEVC XYZ=6.3,0.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-0.5-1.9' /
&DEVC XYZ=6.3,2.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-2.5-1.9' /
&DEVC XYZ=6.3,4.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-4.5-1.9' /
&DEVC XYZ=6.3,6.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-6.5-1.9' /
&DEVC XYZ=6.3,8.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-8.5-1.9' /
&DEVC XYZ=6.3,10.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-10.5-1.9' /
&DEVC XYZ=6.3,12.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-12.5-1.9' /
&DEVC XYZ=6.3,14.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-14.5-1.9' /
&DEVC XYZ=6.3,16.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-16.5-1.9' /
&DEVC XYZ=6.3,18.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-18.5-1.9' /
&DEVC XYZ=6.3,20.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-20.5-1.9' /
&DEVC XYZ=6.3,22.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-22.5-1.9' /
&DEVC XYZ=6.3,24.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-24.5-1.9' /
&DEVC XYZ=6.3,26.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-26.5-1.9' /
&DEVC XYZ=6.3,28.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-28.5-1.9' /
&DEVC XYZ=6.3,30.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-30.5-1.9' /
&DEVC XYZ=6.3,32.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-32.5-1.9' /
&DEVC XYZ=6.3,34.5,1.9,QUANTITY='TEMPERATURE',ID='T-6.3-34.5-1.9' /
3. Experimental results and analysis

3.1 Harm of smoke
The solid and liquid particles suspended in the gas phase produced by combustion or pyrolysis are called smoke particles, and the gas containing smoke particles is called smoke. A large number of fire cases have proved that smoke is the main cause of casualties in the event of a fire, and more than 70% of the victims are directly or indirectly killed by the smoke in the fire [3]. The hazards of fire smoke are mainly manifested in four aspects: the chemical toxicity, the dimming, the physical high temperature and the psychological terror. This study mainly focused on the physical high temperature of smoke. Fire smoke has a very high temperature, and the temperature of the smoke is dangerous for people in the fire scene and nearby areas. The temperature of smoke can reach hundreds of degrees Celsius in fire room, and sometimes as high as thousands of degrees Celsius. Even in areas far away from the burning room, the temperature of the smoke still poses a great threat to people due to the migration and carrying effect of the smoke. The impact of high temperature environment on people is shown in Table 2.

| Temperature (℃) | Exposure time | Symptoms                                                                 |
|-----------------|---------------|---------------------------------------------------------------------------|
| 66              | ——            | When the temperature of the breathing area reaches 66℃, people will unbearable. |
| 120             | 1min          | Over 1min, people will be burned                                           |
| 140             | short time    | People will lose physiological functions in a short time                    |
| >180            | short time    | People will quickly become incapacitated and die                            |

3.2 Analysis of simulation results

3.2.1 Fire development of the burning room. Figure 3 shows the screenshots of the fired room at several time points, and they respectively are 1s, 50s, 250s, 300s, 350s, 400s, 600s, 700s, 750s, 800s, 850s, 900s, 1000s, 1050s, 1200s and 1300s.
3) Screenshot of the burning room at the 250s  
4) Screenshot of the burning room at the 300s

5) Screenshot of the burning room at the 350s  
6) Screenshot of the burning room at the 400s

7) Screenshot of the burning room at the 600s  
8) Screenshot of the burning room at the 700s

9) Screenshot of the burning room at the 750s  
10) Screenshot of the burning room at the 800s

11) Screenshot of the burning room at the 850  
12) Screenshot of the burning room at the 900s
Figure 3 Screenshot of the burning room at different time points

Figure 4 shows the temperature-time curve at a height of 1.9m in the middle of the room on fire.

Figure 4 Temperature-time curve in the room (1.9m)

As can be seen from Figure 3 and Figure 4, the period from the source ignition to the 230 seconds after the ignition belongs to the initial stage of the fire. During this stage, a large amount of combustible gas was accumulated in the dormitory. After the 230s, the flame spread from the ignition point to other combustibles, and the fire transitioned from the initial stage to the full-combustion stage. At the beginning of the fire, the average indoor temperature was low, but high temperatures existed in the combustion zone and its vicinity; at this time, the fire development speed was relatively slow, and the fire was extremely unstable during the combustion process [4]. At the 330s, a mighty bang occurred in the dormitory, marking the beginning of the full combustion phase, at which time the fire began to spread through the doorway to the corridor. This phenomenon of the transition from partial combustion to full-room combustion in the room is called “mighty bang”, which marks the beginning of the full development stage of the fire, and it is one of the most significant features of indoor fires [5]. At the 380s, the licking flame had already reached the balcony. At the 700s, the fire entered the extinguishing stage, at which time the indoor temperature had dropped to 80% of the maximum temperature. At the 890s, only some sporadic flames remained in the room. According to the previous
3.2.2 Changes and distribution of fire smoke temperature in the corridor.

It can be known from the previous analysis of physical high temperature hazards of smoke that it is unbearable for ordinary people when the temperature of the breathing area reaches 66 °C and that the maximum temperature of the human body breathing cannot exceed 130 °C.

Figure 5 shows the temperature change and distribution curve in the corridor when a fire occurs. The chart on the left shows a closed corridor. The middle chart shows the first case where there are natural vents at both ends of the corridor -- the vent are located at 2.0m-2.6m of the corridor, with an area of 1.8m², and the total area of the two vents is 3.6m². The chart on the right shows the second case where there are natural vents at both ends of the corridor -- the vent are located from 2.4m to the top of the corridor, with an area of 1.8m², and the total area of the two vents is 3.6m². According to the Technical Standards for Building Smoke Protection and Exhaust System (GB51251-2017), natural smoke exhaust vents should be set on the top or outer wall of the smoke exhaust area and should meet the following requirements: the natural smoke exhaust vent should be inside the smoke storage bin when it is installed on the external wall; however, the natural smoke exhaust vent in the area where the clear height of the walkway and indoor space is not greater than 3m can be set at more than 1/2 of the clear indoor height [6]. Therefore, the vents selected in this study are all set at the clear height of the walkway above 1.5m. It is also pointed out in the above-mentioned technical standards that the calculation of smoke exhaust rate for a smoke-proof zone in the following places except the atrium should meet the following regulations: for places where the clear height of the building space is less than or equal to 6m, the smoke exhaust rate should not less than 60m³/(h·m²), and the value is not less than 15000m³/h; or there should be a natural smoke exhaust vent with an effective area not less than 2% of the building area of the room [6]. Therefore, the area of the natural smoke vent set in this research is greater than 2% of the corridor area (3×57=171 m²).

1) The temperature change and distribution curve of the corridor at the 350s

2) The temperature change and distribution curve of the corridor at the 400s
3) The temperature change and distribution curve of the corridor at the 600s

4) The temperature change and distribution curve of the corridor at the 700s

5) The temperature change and distribution curve of the corridor at the 750s

6) The temperature change and distribution curve of the corridor at the 800s
7) The temperature change and distribution curve of the corridor at the 1000s

**Figure 5** The temperature change and distribution curve of the corridor at different time

It can be seen from the figure that, when a fire occurs in the most unfavorable room, the smoke temperature is distributed in an “L” shape horizontally, that is, the closer to the fired room, the higher the temperature. The smoke temperature shows a gradient distribution in the longitudinal direction, that is, the higher the height, the higher the temperature. The smoke temperature rises slightly at the end of the corridor. This is because after the smoke flows out of the fired room, it forms a ceiling jet in a restricted space above the corridor. The smoke first fills the ceiling due to buoyancy and spreads rapidly below the ceiling. When the smoke flows to the end of the corridor, it will flow down the wall after being blocked by the wall, causing smoke to accumulate at the end. It can be seen from the analysis curves that the temperature in the corridor continues to rise as the combustion intensifies. And when the corridor is closed, the smoke temperature is higher than that when there are natural vents at both ends of the corridor. Through the analysis of the middle and right curves, it can be seen that the size of the vents at both ends of the corridor has a significant effect on the smoke temperature, that is, the larger the opening area of the vent, the lower the average temperature of the smoke in the corridor.

In a closed corridor, the average temperature reached the evacuation value at the 400s. In the scene where the vent is from 2.5m at the height of the corridor to the top of the corridor, the average temperature reached the evacuation value at the 700s. In the scene where the vent is from the 1.8m at the height of the corridor to the top of the corridor, the average smoke temperature does not directly harm people.

4. Conclusion

In this research, the law of fire smoke temperature change in the corridor was explored from two aspects, namely, theoretical analysis and numerical simulation. The author verified the feasibility and effectiveness of FDS in the study of smoke movement in the dormitory corridor through the temperature rise curve, and finally used FDS to numerically simulate the full-size dormitory corridor. Under the condition that the heat release rate per unit area of the ignition source is 1500kw/m² (the power of the ignition source is 15kw), the comparative analysis of whether there are natural vents at both ends of the corridor and the opening height of the natural vents, the main findings are as follows:

(1) With the development of the fire in the room, the flames are mainly transmitted at the low place and to both sides of the room. This is because the hot smoke continues to rise, causing the O₂ content in the upper air to drop sharply, while the surrounding fresh air continues to flow in from the both sides of the corridor and balcony.

(2) From the perspective of the smoke temperature change and distribution in the corridor, after the fire develops to the mighty bang stage (400s), the average temperature in the corridor without natural ventilation is higher than the limiting temperature (130°C) that the human body can bear. Therefore, if the fire has reached the full combustion stage, students should bend over or crawl forward as much as
possible when evacuating to prevent the hazards of high-temperature smoke.

(3) When there are no natural smoke vents at both ends of the corridor, high-temperature smoke is mainly concentrated at both ends of the corridor, because the entrainment phenomenon formed by the wall covering causes the temperature at both ends to be higher than the middle.

(4) When there are natural smoke vents at both ends of the corridor, high-temperature smoke is mainly concentrated near the door of the fired room. The further away from the burning room, the lower the temperature. The higher the position of the natural smoke vent, the more favorable it is for natural smoke exhaust.

Acknowledgements
The study was supported by “Natural Science Project of Sichuan Education Department (Grant No. 18ZB0536)”

References
[1] Feng Rui. Analysis on the Characteristics of Fire Disaster in Colleges and Universities and Countermeasures [J]. China Science and Technology Information, 2007(6): 172-173
[2] Jiang Ling, Liu Xiaolu, Wang Yingqi. A brief analysis in the current development of fire computer simulation technology [J]. Fire Science and Technology, 2009, 28(3): 156-158
[3] Weng Miaocheng. Toxicity Analysis of Building Fire Smoke [J]. Refrigeration & Air Conditioning, 2005: 228-231
[4] Zhao Xiaoling. Study on the Automatic Fire Fighting System in Closed Combustible Place [D]. Hefei: Hefei University of Technology, 2004
[5] Zhai Wenpeng. Research on Image-based Detection Technology of Early Fire Smoke [D]. Tianjin: Tianjin University, 2009
[6] Technical Standards for Building Smoke Protection and Exhaust System (GB51251-2017) [S]. Beijing: Standards Press of China, 2017