Fire Characteristics of Light Steel Structure Building and Suggestions for Fire Alarm System

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Abstract. This study is a small residential factory with a lightweight steel structure for fire characteristics analysis and alarm equipment analysis. This kind of factory fire grows very quickly, and there is no perfect fire protection zone, the temperature rises rapidly when the fire occurs, and it is difficult for the fire brigade to rescue. Use FDS for fire simulation and discuss the activation time of fire alarms with different functions, when the people in the building are awake, the thermocouple distribution position is combined with the heating curve to analyze the critical value of the human body's dangerous temperature, and the building is partitioned and the allowable evacuation time includes: 13 minutes in the factory area, 11 minutes in the corridor, and office area there are 12 minutes and the room has 15 minutes. In addition, the difference in the action time of the two detectors, the smoke detection type and the fixed temperature type, is discussed. In the simulation results, the smoke alarm device can detect the fire 137 seconds earlier.

1. Introduction
Lightweight steel structure buildings are a type of building that can be seen everywhere in Taiwan. Because of their simple structure and rapid construction, they become factories, warehouses or general temporary buildings. The common forms are own factories, roof tops, and temporary factories. (Chen 2001), this type of building has a higher risk of fire, because the structure is not strong and the temperature is likely to rise quickly during fire; the fire grows quickly; there is no building fire protection inside. (Chen 2019), the human body is exposed to high temperature and heat during a fire. When the average temperature reaches 200°C, serious injuries will occur after five minutes. About the evacuation time of personnel put forward the content of Formula 1 according to the sequence of fire and refuge action, using the concept of time.

\[
\frac{T_p + T_r + T_a}{T_f} \leq 1
\]  

(1)

This research simulates a lightweight steel structure factory building, and uses the FDS fire simulation program to conduct fire simulation and disaster prevention research. Fire simulation items include changes in the internal temperature of the iron sheet, comparison of detector types and operating time, fire heat release rate, etc.

In the fire alarm equipment, the driving principle of the fire detector is divided into: temperature, ion type, photoelectric type, etc. (Peng 2018) Temperature detector: When the surrounding temperature rises above a certain temperature, it will immediately sound an alarm. Smoke Detector: After the smoke concentration increases, an alarm will be issued immediately when the smoke concentration in the
detection protection area reaches a certain level. The biggest factor affecting the opening of the building caused by fire is glass and combustible materials. Skelly (1991) measured the temperature and time of glass rupture in a fire environment by experiment. According to the experimental results, it is easier to break when the edge of the glass is covered than the edge of the glass without covering. The data and results indicate that glass breakage is mainly caused by the temperature difference between the center point and the edge of the glass when heated, and the temperature difference is about 90°C.

This study compares these fire parameters with the types of fire alarm detectors, hoping to find the most suitable detector types for lightweight steel structures, and reduce the fire hazards to personnel.

2. Research Methods

2.1. Fire Dynamics Simulator

The fire simulation software (FDS) used in this study is a calculation developed by the Building and Fire Research Laboratory (BFRL) under the National Institute of Standards and Technology (NIST). The Fire Dynamics Simulator (FDS) developed by Computational Fluid Dynamics (CFD) can simulate a three-dimensional fire scene. Use the Large Eddy Simulation (LES) in the Field Model to simulate the fire scene, divide the indoor space into many small grids, and then use mass, momentum, energy, and combustion. The governing equations, such as the conservation of heat transfer, are solved by Navier-Stokes Equation, which can accurately predict the pressure, temperature, velocity, and physical data of smoke flow during a fire. According to Piotr Smardz (2006), "Validation of Fire Dynamics Simulator (FDS) for forced and natural convection flows" master degree, through FDS simulation and small size comparison, it is verified that FDS is correct for forced natural convection flows. Through experiments, it is found that FDS predicts gas flow rate and temperature with an error of 5-20% (related to mass and heat conduction). After calculation, the pressure, Temperature, flow rate, carbon monoxide, carbon dioxide, smoke particles and other important parameters and distribution conditions, using these data can analyze and discuss the situation of the fire scene, suitable for fire simulation of large buildings.

2.2. Initial conditions and boundary conditions

| Item                | Initial conditions and boundary conditions |
|---------------------|--------------------------------------------|
| Building size       | 2000cm(L):600cm(W):600cm(H)                |
| Grid Distribution   | 2000*600*600 (uniform grid point), refer to Bounagui et al. (2003) mentioned that the optimal calculation grid point for house fire is set to 0.2m*0.2m*0.2m in the area outside the fire source. |
| Initial Temperature | 20℃                                        |
| Space configuration | 1F (Front) : factory operation area        |
|                     | 1F (Back) : office area                    |
|                     | 2F : night accommodation                   |
| Ventilation state   | 1F workshop area 1m*1m: 10 locations,      |
|                     | 1F office area 1m*1m: 2 locations,         |
|                     | Entrance and exit 1m*2m on both sides of 1F: 2 places |
|                     | 2F room 1m*1m: 1 place,                    |
|                     | 2F corridor 1m*1m: 1 place                 |
| Wall Material       | Exterior wall material: lightweight steel structure |
|                     | Internal wall material: wood               |
| Fire setting        | Fire point: below the stairs on the first floor |
|                     | Heat release rate: 2000 kW/m²              |
|                     | Fire source: gasoline                      |

2.3. Fire detector settings

1. Temperature detection settings (Figure 1):
1. In the 1F workshop area, a detector, stairs and office are set every 2m.
(2) 2F escape corridor and room.
2. Smoke detector settings (Figure 2):
Set according to the characteristics of the temperature detector. The setting locations include 1F office; 2F corridor; 2F room to install smoke detectors.

3. Results and Discussions

3.1. Temperature Distribution
The thermocouple in the plant area reaches the limit of human body temperature within 8 minutes (Figure 3). The burning time of the walls of the office and factory area is 260 seconds, because the burning is expanded, the temperature of the office and the aisle leading to the office is higher.

After the fire broke out, the 2F corridor reached the highest temperature in about 10 minutes, and the room reached the highest temperature in about 12 minutes. The corridor is close to the fire point, so the smoke accumulation speed and temperature are faster than the room. Therefore, you should escape as soon as possible in case of fire to avoid human body hazards due to high temperature (Figure 4).

3.2. Fire detector alarm time
This study analyzes the starting conditions of the smoke detector and temperature detector. Smoke detection alarm in this model, when the smoke coverage rate reaches 1.68%/m, the alarm device will be activated, because of the thermal buoyancy, the smoke detector in the 2F corridor will alarm at 48 seconds, and the smoke detector in the 2F room will alarm at 80 seconds. The alarm was issued, and the 1F office close to the fire location did not sound the alarm until 118 seconds (Figure 5).

A fire alarm will be issued when the temperature detector alarm time is at ambient temperature +30°C. The results of this model show that the temperature detector in the 2F corridor issued an alarm in 185 seconds, and the 2F room had an alarm in 245 seconds. The slowest alarm was issued in the 1F office in 296 seconds(Figure6).
4. Conclusion and Recommendations

4.1. Conclusion
In this study, FDS was used to simulate the fire of lightweight steel structure buildings. After obtaining the fire environment parameters, the alarm conditions were analyzed with the fire detector. The conclusions are as follows:

1. The fire environment of this building is compared with the living conditions that the human body can withstand as shown in Table 2.
2. In light-weight steel structure buildings, smoke detectors are installed to start alarms 48 seconds after the fire; the fixed-temperature live alarms operate for more than 185 seconds.
3. These factories that store a large amount of combustibles are used as accommodations and have poor evacuation capabilities when a fire breaks out late at night. With the correct fire alarm equipment, the evacuation and initial fire-fighting time can be increased by 137 seconds, and the chance of survival can be increased.

Table 2. Timetable for evacuation

| Location        | Temperature /Time | Evacuation time |
|-----------------|-------------------|-----------------|
| Workshop area   | 250 /8min         | 13min           |
| Workspace       | 250 /7min         | 12min           |
| Room            | 250 /10min        | 15min           |
| Corridor        | 250 /6min         | 11min           |

4.2. Recommendations
1. This research mainly explores the impact of the use of residential fire alarms in lightweight steel structure factories and residential buildings on the lives and property disasters of people. It only simulates two common detectors (temperature and smoke) alarm conditions on the market to estimate the evacuation time.
2. The building model in this study is a hypothetical environment, and the actual scale building can be used to simulate fire and evacuation in the future.

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