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The Effect of Configuration form on the Spread Speed of Fire in High-Rise Buildings

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ABSTRACT

Fire accidents in high-rise buildings pose a serious threat to the lives and property of the occupants, and safe evacuation from a fire is difficult due to the dense population and the presence of various flammable materials. Therefore, the appropriate choice of the configuration form is likely to be the main factor in controlling the fire spread and its transmission speed to the upper floors and increasing the evacuation chance. The study adopted computer modeling and fire simulation technology from Pyrosim and FDS and presented the results by Smokeview. The simulation results showed that the risk of fire spreading in high-rise buildings increases as the increase of complicated of the form, and vice versa. Therefore, the study recommends the use of simple forms for high-rise buildings. The results of the research can be adopted and generalized to other buildings to reduce the impact of fires.

1. INTRODUCTION

The increase in residence in cities by the rural population as a result of industrial growth and the increase in employment opportunities in them, as this formed a population density that led to the vertical expansion of construction by exploiting less space to secure public services, and thus the height of buildings, has become a kind of urbanization all over the world [1]. When a fire occurs, it is difficult to control it in the high-rise buildings, and it will be greater fire risk and the chance of saving lives less. Safe design lies in the employment of all measures to reduce the impact of fire hazards [2]. The fire is often caused by man-made errors, such as smoking, heating, cooking, etc., or by electrical problems such as short circuits, old wiring, and faulty fuses [3, 4]. The fire safety in buildings faces severe challenges as a result of the high dense population [5]. The studies on the fire spread in buildings have attracted more attention due to the heavy losses in property and lives as a result of these fires, and to reduce these losses, designers must take into account the design variables affecting the fire spread when preparing designs [6]. There are many design variables that affect the speed of fire spread including: The form, area, and type of the building plan, the form, height, and size of the building, building construction materials, Facade cladding materials, window design with their size, shape, and location, and balconies with their area, shape, and location. The purpose of the article is to compare the effects of different models of configuration forms on the speed of fire spread and its transmission to the upper floors, as well as its sustainability under the same conditions of the area in which the fire occurs. And by using the same thermal energy released to highlight the effect of the configuration form on the advance and vertical spread of the fire. The article consists of an introduction, a review of the literature related to the research problem, and a description of the research methodology. Then analyzing and discussing the results of the research, as well as concluding the article with conclusions and recommendations. The results showed that the risk of fire spreading in tall buildings decreases with the increase in simplicity of the form, and vice versa. Therefore, the study recommends the architectural designer use simple forms for the configuration form and avoids complex forms in high buildings, as this reduces the speed and spread of fire and may lead to a greater opportunity for evacuation in addition to reducing property losses.

2. RELATED STUDIES

The fire can spread vertically very quickly and in different ways, the facades are among the fastest passages for the fire spread [7, 8]. The researchers [9] showed that buildings that have U-shaped facade designs for certain purposes such as lighting, this engineering design that increases their fire risks, as the rate of flame spread and its height increase with the engineering factor is U-shaped [10, 11], and thus engineers must be careful in the designs of the walls of this facade. The researcher emphasized in the study [12] that the architect should think about ways to protect the building from the danger of fire, starting from the planning and design stage. He stated that the greater the area exposed to fire, the greater the risk of fire spreading through the building floors. In a study of the impact of building engineering on fire safety in high-rise buildings, the two researchers showed in the paper [13] that the cavities and protrusions in the facades are considered desirable barriers in terms of protection from fire in most cases. Also, they showed that the simple facades allow the spread of fire quickly and easily vertically, and that the facades have overhangs and opening frames limit the spread of fire. The fire propagation properties of the L-shaped geometry were studied at different heights using intersection angles by the researchers [14]. It was observed that the upward flame spread rate increased with decreasing L-shaped intersection angles, while no clear trend was found for the lateral spread rate when the angle of intersection varied. The rate of flame spread also decreased with increasing height. The researchers [15] proposed using design principles to prevent the spread of fire in high-rise buildings to avoid the loss of life and property. They stated that the simple shape of the building is easier to protect from fire, as it does not trap the heat of the fire, while the complex construction, on the contrary, increases the surface area of the structure and creates shapes that trap the heat of the fire. The researcher showed [16] that the fire hazard in the dual interface is a concern where the scenario of a fire being in a flash chamber adjacent to the interface has been determined and heat and mass will be trapped in the cavity of the interface. He was simulated the hot gas diffusion in the cavity of the interface under different heat release rates with three phases identified of flame spread. The results indicated that a wider air cavity depth would be more dangerous with an increased risk of breaking the upper inner glass. As the researcher stated [17] that the architect must take into account, when starting the design phase of any engineering project, the fulfillment of all safety factors and civil protection requirements in the country in which the project is established. Where it is done by identifying the elements and materials used in the construction of the building and how they are resistant to fire and their characteristics to achieve the required protection from fire. The researchers studied [18] the effect of the presence of walls protruding from the facade at different intervals in high-rise buildings on the speed of fire spread. They showed that the height of the flame increases with the increase in the interval between the protruding walls, and the height of the flame with the increase in temperature is more evident when the protruding walls are present compared to when they are absent. The configuration form can change the behavior of the fire, and different models of the configuration form may lead to different behaviors of the fire. The available studies did not specify the effect of the configuration form on controlling the spread of fire vertically accurately, as they did not include simulations of furnished high-rise and buildings that represented different models of the configuration form.

3. METHODOLOGY

For the purpose of comparing the effects of different models of the configuration form on the speed of fire propagation, computer simulation techniques such as Fire Dynamics Simulator (FDS) were used to solve the models, draw the models by PyroSim, and display the results by McGrattan et al. [19, 20]. Fire simulations are powerful computer modeling tools that can be used to provide answers to questions that traditional analysis methods may not provide [21, 22] without incurring high costs of experimental testing [8]. PyroSim can visually simulate different parameters of a fire, where the visibility around the fire ground and the temperature can be known based on the simulation data [23]. Simulations can be used to make recommendations for improving safety preparedness and to teach people what to do in the event of a fire [21].

3.1 Building design and configuration form models

In this research, a high-rise apartment building is taken as an example. The building consists of 12 floors, and the height of each floor is 3.0 meters. Each floor contains four apartments. Computer simulation of the development of fire in the building is a very time-consuming process due to the size of the large building, so it was limited to one apartment consisting of five rooms, which are a living room, two bedrooms, a kitchen, and a bathroom on each floor. The building surrounding the apartment is located on both sides of it. In the middle of each floor, there is a staircase and an elevator for the residents. Figure 1 presents the floor plan of an apartment building. The computer simulation of the development of the fire was followed for six models of the configuration form. Figure 2 presents the different models of the three-dimensional configuration form for all floors [A, B, C, D, E, F]. And Figure 3 shows the horizontal plans of these models.

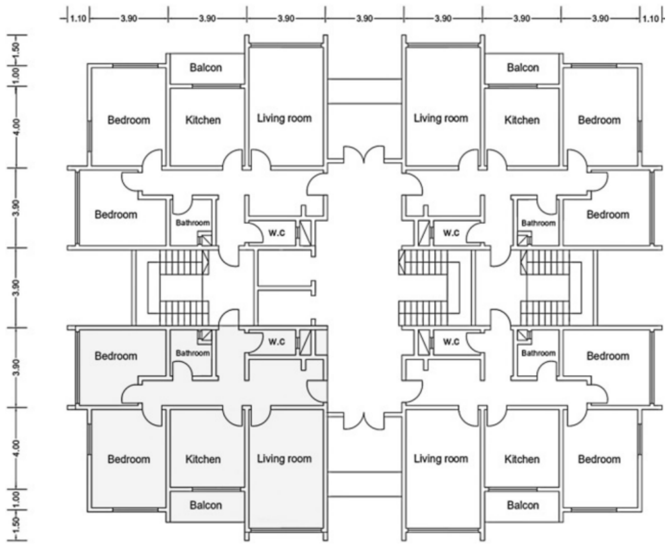


Figure 1. Floor plan of apartment building

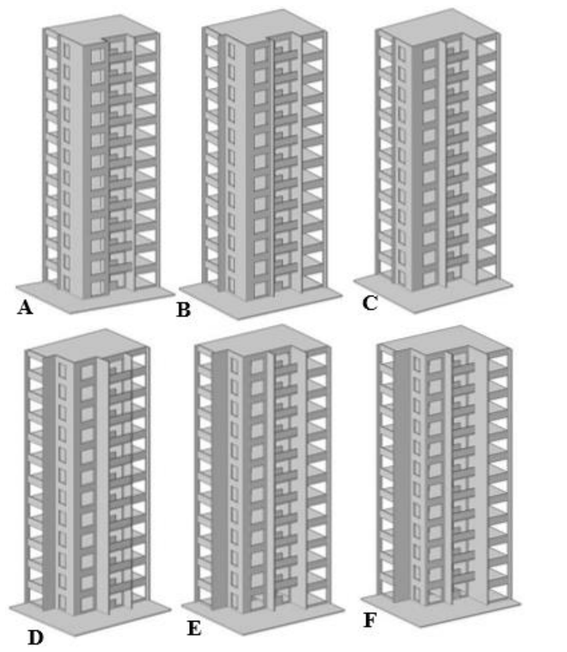


Figure 2. The different models of the three-dimensional configuration form for all floors [A, B, C, D, E, F]

The fixed building area in all models is 117 square meters, and the ratio of the building area to the area of the smallest rectangular shape that contains the building (BAR) for the different models has been found and used as an engineering factor to distinguish some characteristics of the models. Figure 4 shows the definition of the building area ratio and its values for the different models of the configuration form [A, B, C, D, E, F].

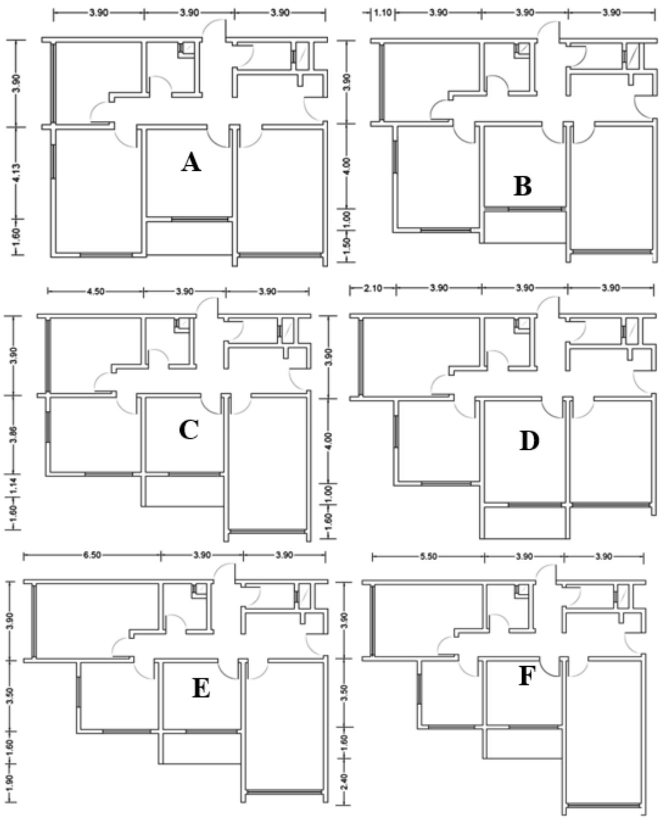
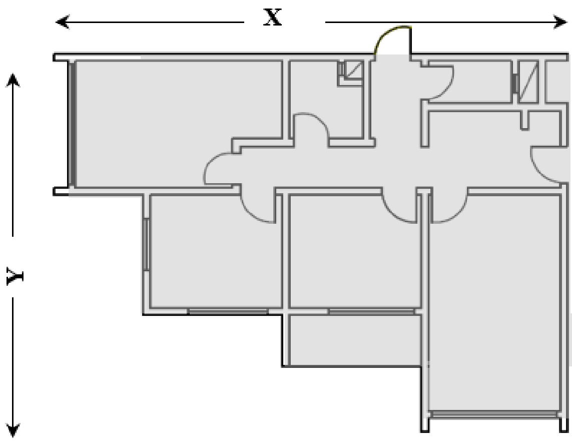


Figure 3. The horizontal plans of different models of the configuration form [A, B, C, D, E, F]



$$BAR\% = \frac{Building\ Area}{Rectangular\ Area\ (X*Y)} * 100\%$$

PLAN	A	B	C	D	E	F
BAR%	100	93	87	82	79	74

Figure 4. The definition of the building area ratio and its values for the different models of the configuration form [A, B, C, D, E, F]

3.2 Fire scene design

The choice of the location of the fire must be the most dangerous as it leads to a larger fire, and the effect of the fire that breaks out in the middle and lower floors of high residential buildings is of greater danger to the whole building. [6]. So the location of the fire was chosen in the kitchen of the apartment on the second floor. The area of the fire source is 0.5 m * 0.5 m, and the heat release rate of the fire source is 1000 kW/m2. The arithmetic domain of the simulation object grid is divided into 66*56*144, and Figure 5 shows the arithmetic domain. The cell size is 0.25m*0.25m*0.25m, and the total number of cells is 532224. The combustion reaction material is polyurethane foam, and the simulation time is 300 seconds. The furniture and furnishings in each residential apartment differ from each other. For the purpose of simplification in the computer simulation, the same furniture was used in the entire building. A general description of the computer model is given below: ● 20 cm thick concrete wall as default material for building construction walls. ● Upholstery material (2 mm fabric and 10 cm foam) was used as the default material for all sofas in this research. ● the initial temperature was 44°C, and the relative humidity was 24%. ● No consideration was given to external wind conditions.

Figure 5. The computational domain

4. ANALYSIS AND DISCUSSION OF THE RESULTS

The simulation process lasted an average of 72 hours for each of the different configuration form models [A, B, C, D, E, F] at a simulation time of 300 seconds.

4.1 Temperature distribution pattern at a simulated time of 90 seconds

Figure 6 presents the vertical temperature distribution pattern at a simulated time of 90 seconds in the front view for the different models of the configuration form [A, B, C, D, E, F]. The figure showed that the progress of the fire spread covered the eighth floor in the case of model F, the sixth floor in the case of model E, the fifth floor in the case of model D, and the fourth floor in the cases of models C, B, and A. Also, it was shown that there was a clear rise in temperature in the fifth and sixth floors for model C, and a rise in temperature in the fifth floor for model B.

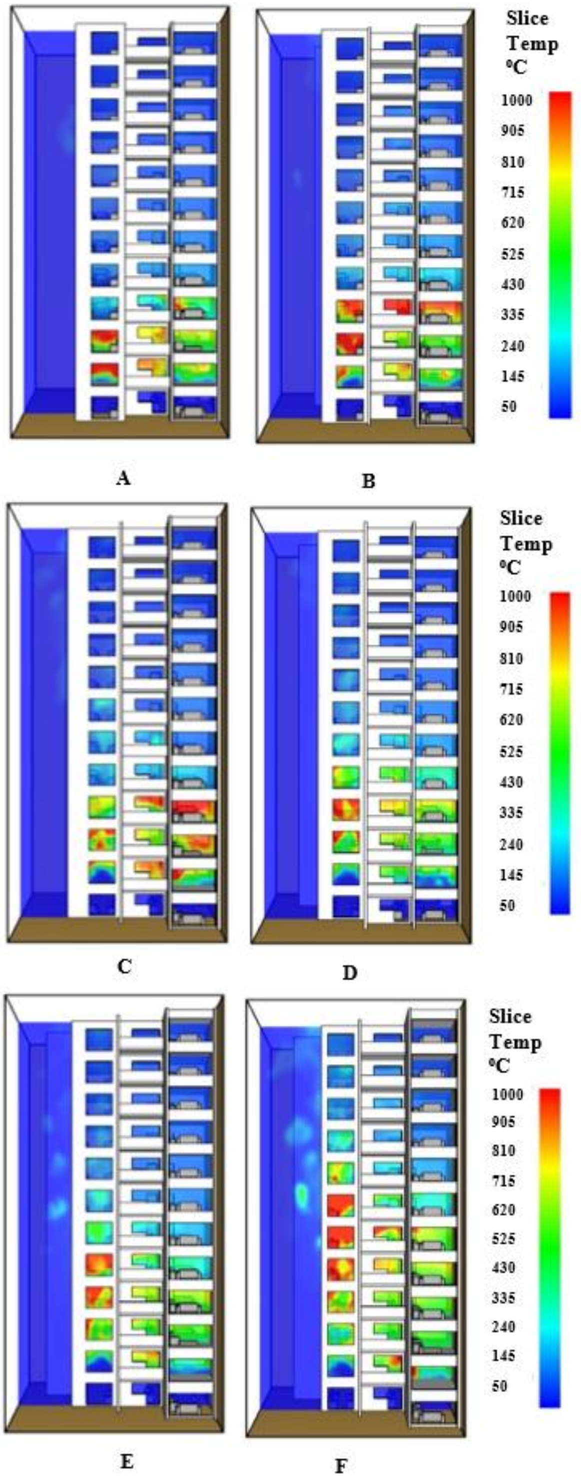


Figure 6. The vertical temperature distribution pattern at a simulated time of 90 seconds in the front view for different models of the configuration form [A, B, C, D, E, F]

4.2 Temperature distribution pattern at a simulated time of 180 seconds

Figure 7 presents the vertical temperature distribution pattern at 180 seconds of simulation time in the front view of the different models of the formation shape [A, B, C, D, E, F]. The figure showed that in the case of Model F, the fire spread to the 12th floor and disappeared from the second and third floors. In the case of Model E, the fire spread to the ninth floor and disappeared permanently from the second and third floors, with a drop in temperature on the fourth floor. In the case of Model D, the fire spread to the eighth floor, with the temperature rising on the ninth floor and disappearing from the second and third floors. Where as in the case of Model C, the fire spread to cover the seventh floor, with the temperature rising on the eighth floor and disappearing from the second and third floors. In the case of models A and B, the spread of the fire settled on the fourth floor and disappeared from the second and third floors for both of them.

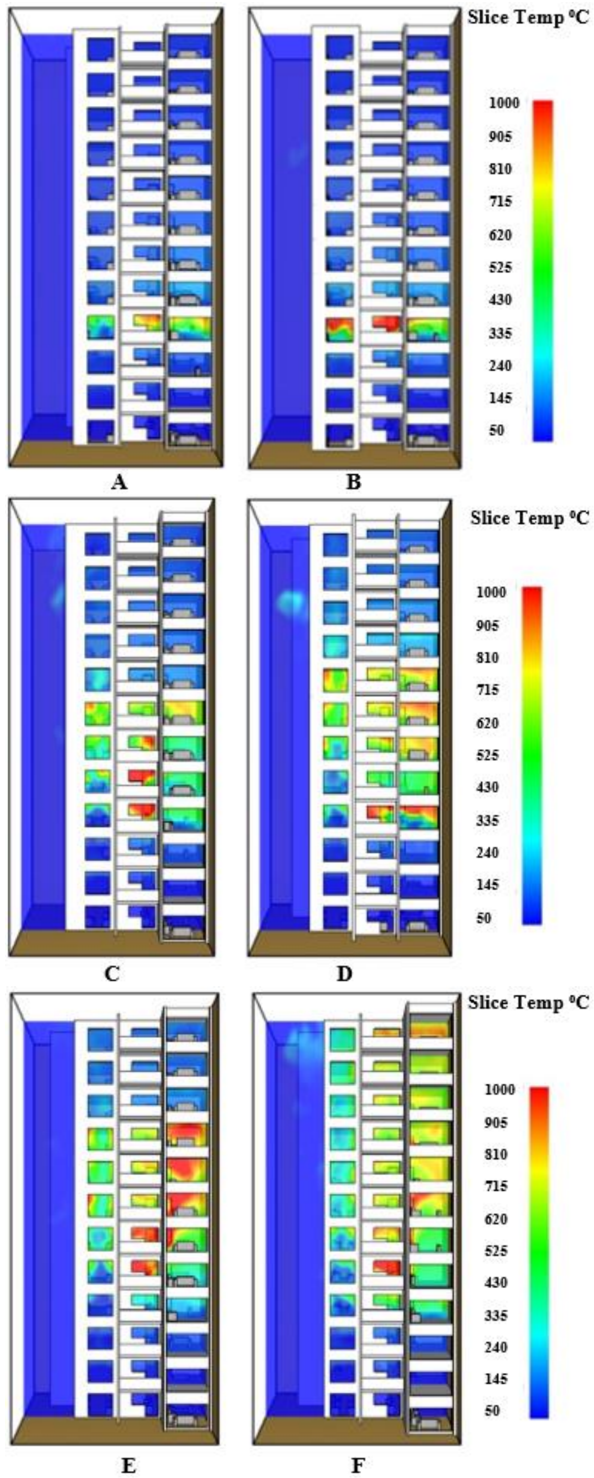


Figure 7. The vertical temperature distribution pattern at a simulated time of 180 seconds in the front view for different models of the configuration form [A, B, C, D, E, F]

4.3 Temperature distribution pattern at a simulated time of 270 seconds

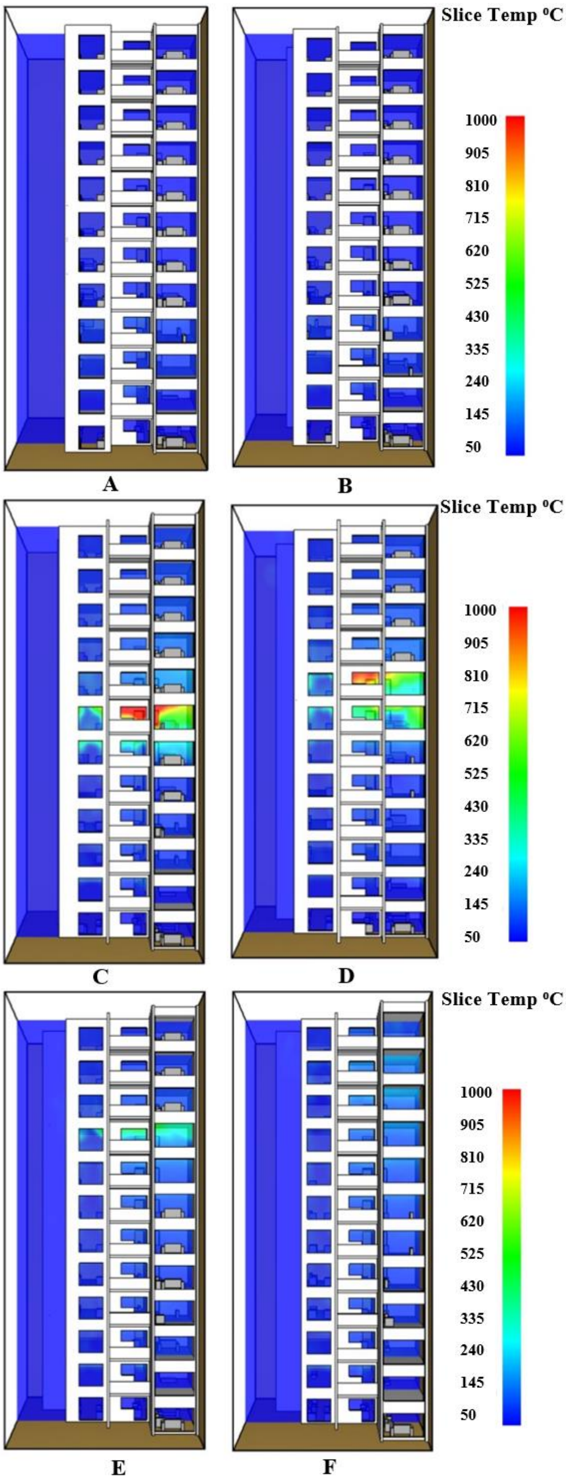
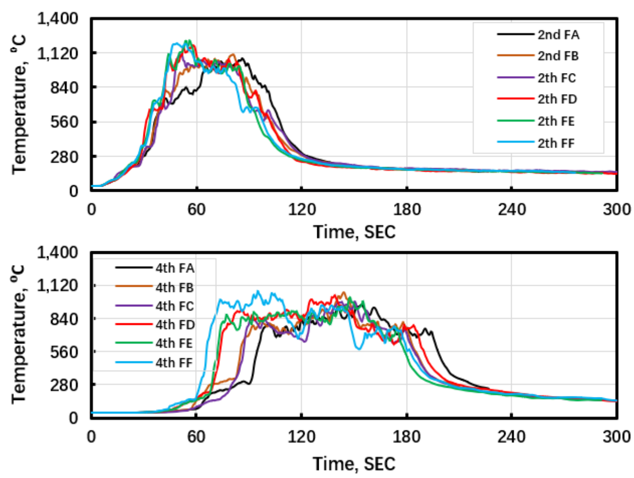


Figure 8. The vertical temperature distribution pattern at a simulated time of 270 seconds in the front view for different models of the configuration form [A, B, C, D, E, F]

Figure 8 presents the pattern of temperature distribution vertically at a simulated time of 270 seconds in the front view for the different models of the configuration form [A, B, C, D, E, F]. The figure showed that: In the case of model F, the spread of fire had completely disappeared. In the case of model E, while there was a decay of the fire in the ninth floor, with its disappearance in the other floors. In the case of model D, the fire was still in the seventh and eighth floors, with its disappearance in the lower floors. But in the case of model C, the spread of the fire was still on the seventh floor and diminished on the sixth floor while it faded on the lower floors. In the cases of models A and B, the fire completely died out for both of them. And that the number of floors completely covered by the fire was eleven in the case of model F, eight in the case of model E, seven floors in the case of model D, six floors in the case of model C, and three floors in the case of models B and A. The total time in seconds for the fire in models [A, B, C, D, E, F] is 230, 230, 300, 315, 309, and 264, respectively.

4.4 Temperature change with time

Figure 9 presents the change of temperatures with time for several floors in the different models of the configuration form [A, B, C, D, E, F]. The figure was showed that: At the level of the second floor, the pattern of temperature change with the progress of time was symmetrical for all models. At the level of the fourth floor, the pattern of temperature change was the same for all models, but it varied with the progress of time. The temperature patterns of models (F, E, D) were earlier than the temperature patterns of models (A, B, C). At the level of the sixth floor, in general, the temperature change pattern was symmetrical for models (F, E, D, C) and it varied with the progress of time. The temperature pattern of model F was earlier than the temperature pattern of model E, which in turn was earlier than the temperature pattern of model D, and this in turn was earlier than the temperature pattern of model C, and this means in this floor The fire was started and was ended faster for models F, then E, then D, then C. As for the temperature patterns of models B and A, there was a slight rise in temperature that does not reach the point of burning. At the level of the eighth floor, with regard to the temperature patterns of the F, E, and D models, their behavior was similar to what was mentioned on the sixth floor. As for the temperature pattern of the C model, there was also a slight rise in temperatures that did not reach burning, and at the level of the tenth floor, there was one clear pattern of change Temperatures with time for model F, while there was a slight rise in temperatures for model E and lower than that for model D. At the level of the twelfth floor, there was one clear pattern of temperature change with time for model F and for a period of time less than in the temperature patterns mentioned in the lowest floor for the same model.



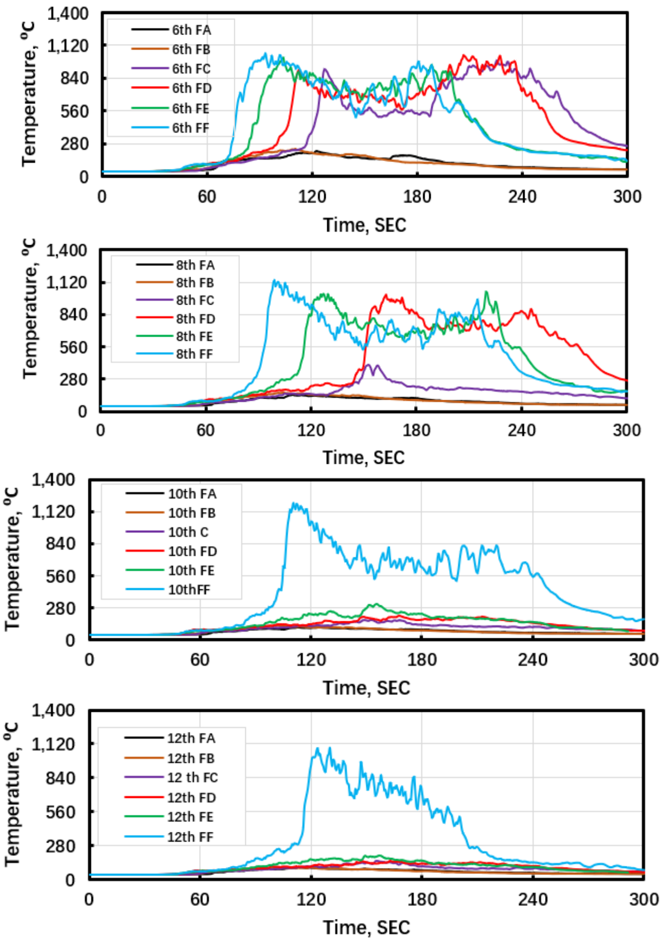


Figure 9. Presents the change of temperatures with time for several floors in the different models of the configuration form [A, B, C, D, E, F]

5. CONCLUSIONS

(1) The study showed, when comparing the performances of different models for the configuration form, that there are clear differences in the speed of fire propagation across the facade of the building.

(2) The results showed that the risk of fire spreading in high-rise buildings decreases with the increase in simplicity of form, and vice versa. Therefore, the study recommends using simple forms and avoiding complex forms in high-rise buildings.

(3) The risk of fire spreading increases with the decrease in the building area ratio for different models with equal building areas, and vice versa.

(4) The study showed that the average time taken to complete a fire on one floor was 24 seconds in the F form, 34 seconds in the E form, 45 seconds in the D form, 50 seconds in the C form, and 76 seconds in each of the forms B and A.

(5) From the foregoing, it is clear that the time required for burning an entire floor of each of models A and B is about three times the time required for burning one floor of model F, and it can also be added that the time required for burning an entire floor of each of models C and D is about twice the time required for burning a bungalow of form F.

In general, the conclusions of the research can contribute to the selection of the optimal design alternative in terms of the speed of fire spread by the architectural designer, and that is: first, by choosing the simple configuration forms without the complex; and second, by comparing the BAR values of different alternatives with equal building areas and then choosing the alternative with the smallest value.

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