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Combustible Gas and Visible Distance by Sprinkler Head for Safety of Gymnasium Workers

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Abstract

This study analyzed the changes in carbon monoxide, carbon dioxide, oxygen and visual distance by presence of sprinkler heads and their types in the event of a fire in an indoor gymnasium. Based on carbon monoxide and visual distance that affects human bodies enormously, first, if there is no sprinkler head, carbon monoxide will reach 0.4% within five seconds and visual distance rapidly shrank within five seconds. Seconds, in the event of standard sprinkler heads, carbon monoxide gradually increased from 30 seconds onwards and visual distance rapidly shrank after five seconds. Second, Third, if there are special sprinkler heads, carbon monoxide fluctuated after opening the head and visual distance became 5m or below from 15 seconds. Finally, in the event of early response sprinkler heads, carbon monoxide fluctuated up and down at 3 seconds due to falling water drops. Visual distance shrank up to 5m or below at 6 seconds. In the future, time for operation of each sprinkler head shall be analyzed.

Keywords: *Gymnasium, Carbon Monoxide, Visual Distance, Standard Sprinkler Head, Early Response Sprinkler Head*

1. Introduction

Due to economic growth and resourcefulness in life coming from the current advanced society, the needs for leisure increase and as new gymnasiums are established, such needs are being fulfilled. Improvement of the facilities to attract customers continues ceaselessly and building of gymnasiums is increasing [1].

As the population that seeks leisure in life increases and working environments that meet and improve the needs become universal, there are more people who enjoy spare time, watch sports games and visit a gymnasium. This, in turn, increases the use of gymnasiums, meaning that the workers shall enjoy more safety and shall not be exposed to accidents [2].

In order to secure such a space and ensure that residents can use it conveniently, there are various projects to arrange sports facilities by spending budgets and workforce at the level of local governments, including

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sports parks and resident community centers in large cities so that the residents can use them more conveniently. There are continued activities for culture and physical activities so that changes occur with more residents using such facilities [3].

To catch up with these changes, it is necessary to upgrade ways to design construct to ensure that gymnasium workers may safely use the facilities while meeting users' needs at work.

The study by Sanghyeon Lee (2020) explores and analyzes the characteristics and the statuses of gymnasiums as a public space where their members can communicate and exchange while taking a rest and recovering and sums up the architectural characteristics of district resident gymnasiums as a common space [4].

The study of Jaepil Goh (2014) aimed to design and make a plan for a gymnasium for juveniles so that they can use the space for exercise, culture and education easily and their changes in needs and proper growth can be reflected with efficient usage [5].

The study of Namsook Kim (2014) aimed to provide a systemic mechanism for people to use public gymnasiums more proactively so that school exercise facilities can be used more efficiently. It provided a basic material to facilitate physical education at elementary schools through use of public facilities and improvement of them [6].

The study of Seongjin Cho (2015) aimed to explore the safety awareness of the public and provide a material to establish a safety plan for the audience of sports based on a simulation analysis [7].

The studies of Sanghyeon Lee (2020) and Jaepil Goh (2014) covered the architectural characteristics of the space of a district exercise center and the design for planning of a facility for juveniles while the studies of Namsook Kim (2014) and Seongjin Cho (2015) studiedhow to make a safety plan for the audience watching sports while providing basic materials to facilitate physical education at elementary schools.

Most of the previous studies were about space and design planning for users of physical exercise facilities involving physical activities. However, there is a lack in terms of safety of the workers at indoor gymnasiums used by nearby residents. Therefore, it is necessary to collect various materials and establish a design plan of a structure that ensures safety of the workers.

There are many cases where the workers responsible for safety and services for the visiting citizens face safety issues themselves. It is necessary to pay extra attention to safety of the workers so that their services for citizens can be improved. Therefore, this study aims to improve the design plan for such buildings. For this study, we conducted a fire simulation which resulted in the answer of 1.8m or shorter from the floor of the current building for the workers who are familiar with the structure of the building while it is also important to keep the citizens safe. The visibility range was below the allowed level and the reference values of carbon monoxide and carbon dioxide were checked to see if they exceed the limit.

2. Fire Simulation

We aim to establish plans for evacuation and fire prevention and identify properties of fires in advance. A computer program to identify loss of lives and building safety based on computer data and various experiences and improve technologies over time such as properties of fires is called fire simulation [8].

2.1 Structure of Fire Simulation

Fire simulation is a mathematical model that is based on statistical models which are risk assessment of fires in buildings, hydromechanics and thermodynamics. Such a mathematical model includes Cfast (ZoneFire Model) and FDS (Field Model) [9].

FDS (Fire Dynamics Simulator) is a representative code for field models. It was developed by Building and Fire Research Laboratory (BFRL) of National Institute of Standards and Technology (NIST). A BFRL and the architecture area established a model to identify the phenomena such as heat from fires, pyrolysis, flame spread, smoke movement and fire behaviors. It predicts the movement of heat and smoke coming from a fire and visualizes and interprets the fluidity of product of combustions through Smokeview which is a code developed by companies, laboratories and universities [10].

2.2 Fire Scenario

2.1.1 Setup of Building Structure and Experimental Model

The structure to be modeled via fire simulation is XX Gymnasium approved in 2004. It is a convenient facility equipped with exercise and meeting facilities. The area of the building is 2,657.82 m^2 and has a basement, 1st and 2nd floors and its total floor area is 3,028.71 ㎡. The basement consists of an electricity room and a machine room and its floor area is326.67 m^2. The 1st floor is equipped with exercise, meeting and other facilities and its floor is as large as 2,373 m^2. The 2nd floor consists of a stand, a projection room and a lighting room and its floor area is 1,021.26 m^2. At the center of the 1st floor, there is a stage and a basketball facility. Right next to it, there are health machines. The center of the 2nd floor is open and about 1,000 audience seats are laid in the shape of '□' and the ceiling height is 10m.

As for fire-fighting facilities, there are sprinkler facilities on the health machine area while there is no sprinkler in other areas. If there is a fire, the smoke will move to the corridor and then, to the exit.

Figure 1 shows that heat, smoke, carbon monoxide and carbon dioxide will move towards a passage from the health machines area if there is a fire on the 1st floor so that people can get out.

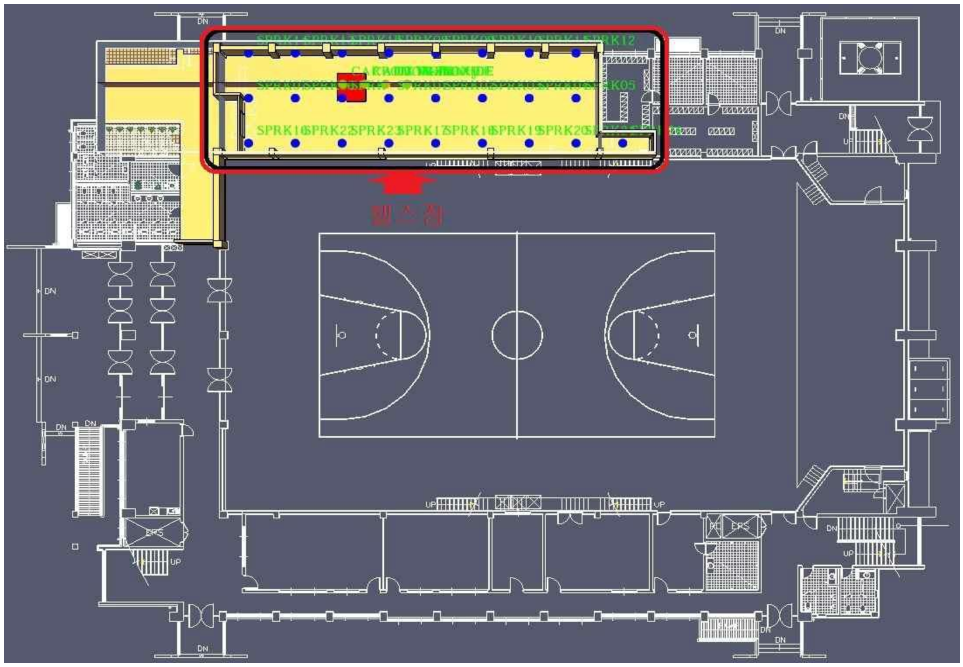


Figure 1. The Status of Architectural Modeling of OO Indoor Gymnasium

2.1.2 Structure of the Scenario

We assumed that a fire occurred in the health machines area on the 1st floor due to overheated electric facilities and aimed to measure heat, visibility range, and density of carbon monoxide, carbon dioxide and O2. The scenario was divided into several cases as shown in Table 1: without sprinkler heads, and with sprinkler heads of different levels of sensitivities.

Table 1. Scenario

Scenario	Status of Sprinkler Head
Scenario 1	No sprinkler head
Scenario 2	Standard sprinkler head installed [11]
Scenario 3	Special sprinkler head installed [12]
Scenari o4	Early response sprinkler head installed [13]

2.1.3 Scenario Application and Standards for Assessment

Table 2 summarizes the contents of [Annexed Table 1] covering performance-based design methods and standards of fire-fighting facilities. An indoor gymnasium is a meeting place. The standards of toxicity and visibility range are as follows [14].

Table 2. Standards of Performance for Safety of Human Lives

Combustion gas and visibility range	Standard toxicity and visibility range
carbon monoxide	1,400 ppm
carbon dioxide	5% or below
oxygen	15% or above
Allowed visibility range	10m

2.2 Fire Simulation Program Input

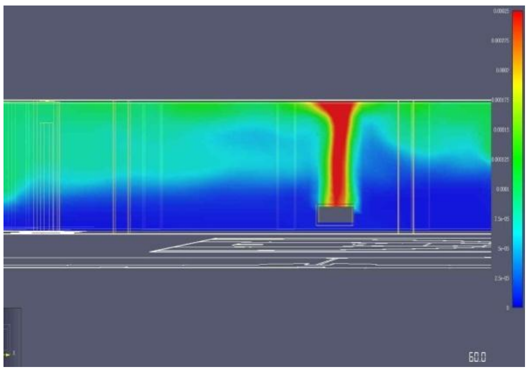
Due to evacuation in the event of a fire, cross wind is coming at 1.0m/s from the entrance door. The interval of analysis of the fire simulation is 20 seconds and changes of visibility range and toxic gases were presented as a graph. At first, we aimed to simulate the entire health site. However, due to the program error, our coverage was only a half of it. Burnt materials were wood oak in our assumption. Their sizes were 1m x 1m x 0.4 m (width x length x height) and a flame would occur on top of it. Input variables of flame and sprinkler in the fire simulation program are as shown in Table 3, all presented by simulation.

Table 3. Input variables of the simulation

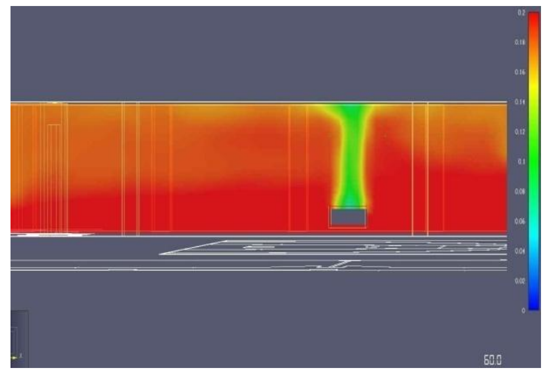
Division	Heat release rate per unit area (㎾/㎡)	Time applied (s)	Sprinkler Head			
			Working Temperature (℃)	RTI Value	Head Radius (m)	Protected Area (㎡)
Scenario1	1,000	100	-	-	-	-
Scenario2	1,000	100	72	350	2.1	10.56
Scenario3	1,000	100	70	80	2.1	10.56
Scenario4	1,000	100	68	50	2.1	10.56

2.2.1 Input Variables and Fire Phenomena of Fire Simulation of Scenario 1

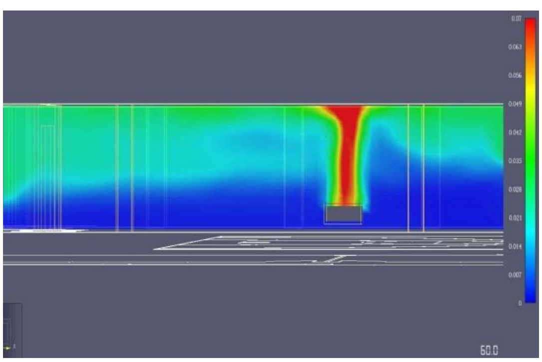
Scenario 1 assumes a case where there is no sprinkler head. Changes of toxic gases and visibility range in the fire area are as shown in Figure 2. As there is no fire-fighting facility when there is a fire, toxic gases spread quickly and visibility range shortened very fast.



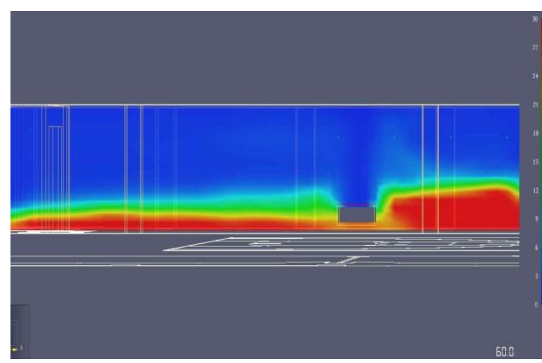
(a) Change of carbon monoxide



(b) Change of oxygen



(c) Change of carbon dioxide

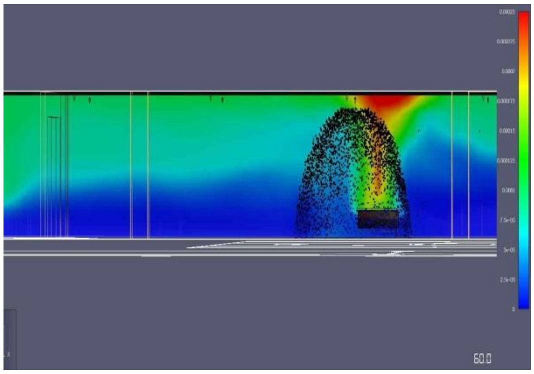


(d) Change of visibility range

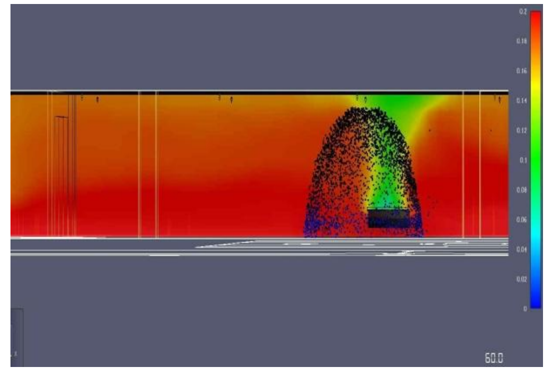
Figure 2. Statuses of Toxic Gases and Visibility Ranges under Scenario 1

2.2.2 Input Variables and Fire Phenomena of Fire Simulation of Scenario 2

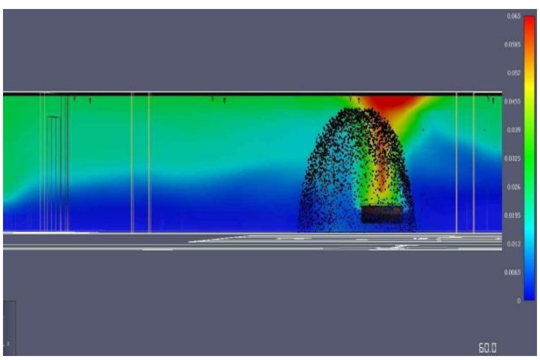
Scenario 2 applies the situation where there is a standard sprinkler head and the changes of toxic gases and visibility range are as shown in Figure 3. As shown in the picture, the first head was open at 48 seconds and as time exceeds 60 seconds, density of carbon monoxide and carbon dioxide increased while oxygen decreased as water is sprinkled when the head opens. Visibility range is below the allowed level within 60 seconds.



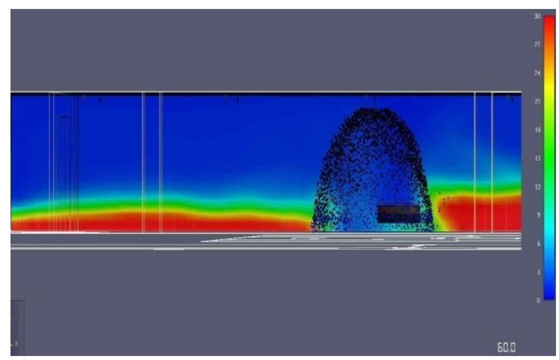
(a) Change of carbon monoxide



(b) Change of oxygen



(c) Change of carbon dioxide

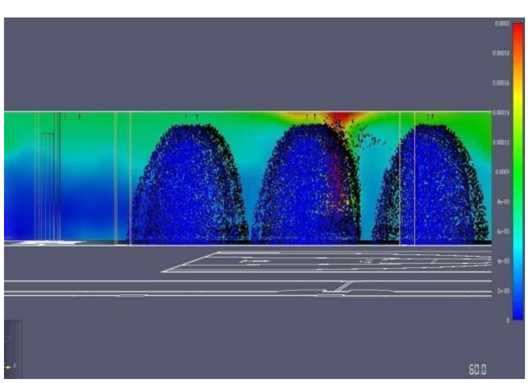


(d) Change of visibility range

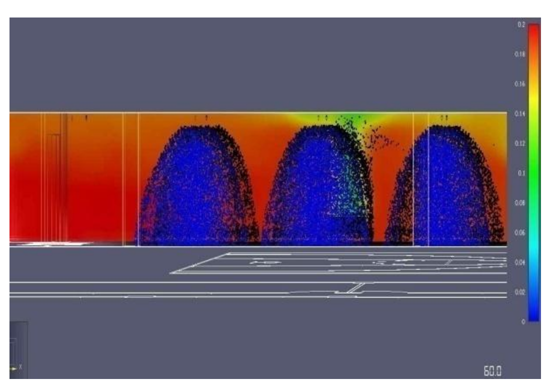
Figure 3. Statuses of Toxic Gases and Visibility Ranges under Scenario 2

2.2.3 Assignment of personnel

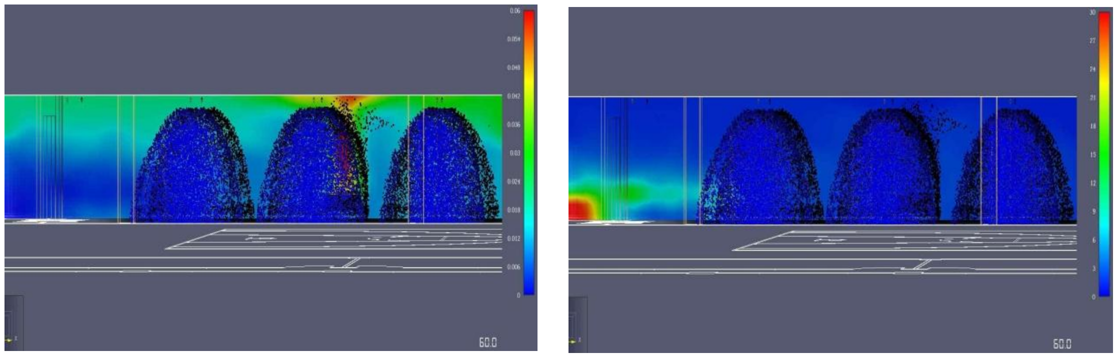
Scenario 3 is the situation where a special sprinkler head is installed. The changes of toxic gases and visibility range are as shown in Figure 4. As shown in the picture, the first head opened at 13 seconds and the second head opened at 23 seconds. Due to the water coming from open heads, density of carbon monoxide and carbon dioxide increased over a short time while density of oxygen fell only in the areas affected by water from open heads. Visibility range fell below the allowed limit within 60 seconds.



(a) Change of carbon monoxide



(b) Change of oxygen

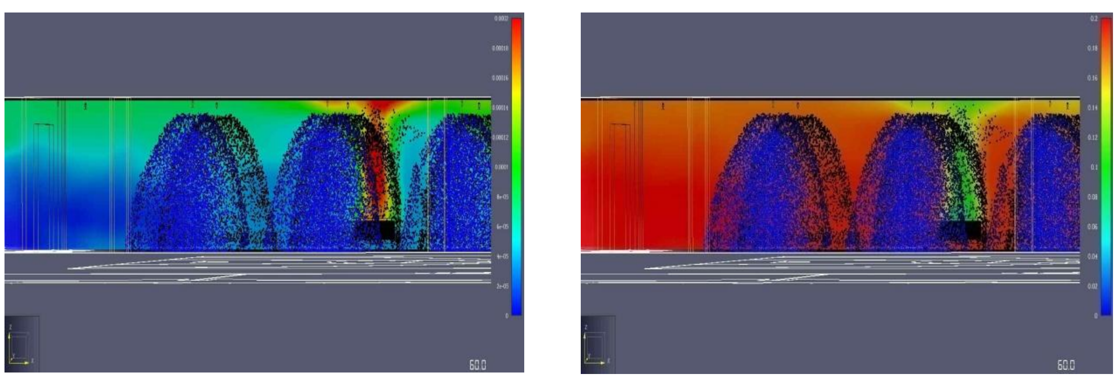


(c) Change of carbon dioxide **(d) Change of visibility range**

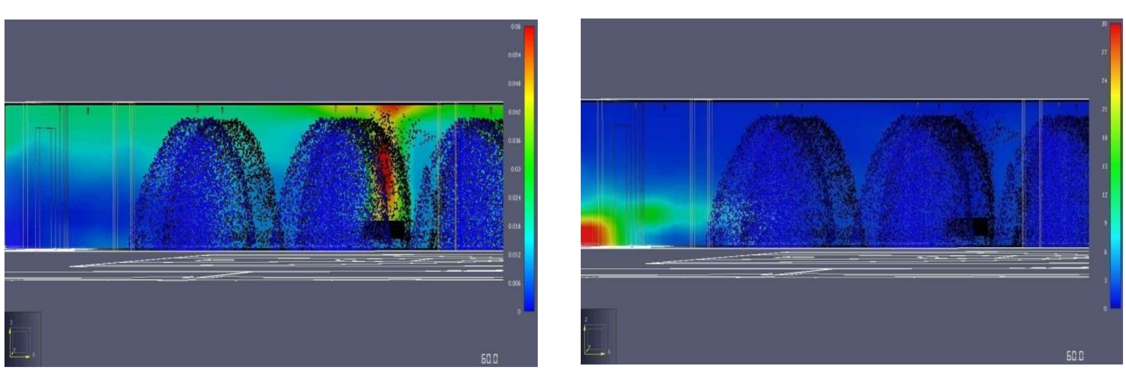
Figure 4. Statuses of Toxic Gases and Visibility Ranges under Scenario 3

2.2.4 Input Variables and Fire Phenomena of Fire Simulation of Scenario 4

Scenario 4 is the situation where an early response sprinkler head is installed. The changes of toxic gases and visibility range are as shown in Figure 5. As shown in the picture, the first head opened at 9 seconds and the second head opened at 15 seconds. At 70 seconds, all the heads were open. Due to the water, density of carbon monoxide and carbon dioxide increased while density of oxygen decreased only when the water fell from the open head. Visibility range fell below the allowed limit within 60 seconds.



(a) Change of carbon monoxide **(b) Change of oxygen**



(c) Change of carbon dioxide **(d) Change of visibility range**

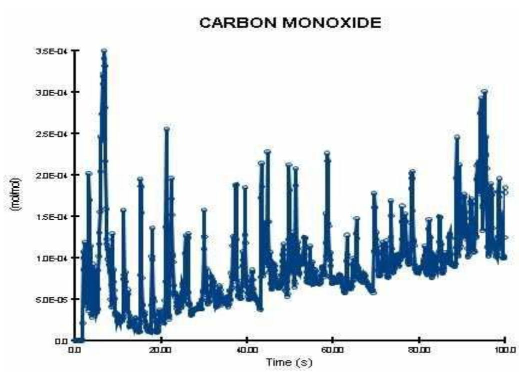
Figure 5. Statuses of Toxic Gases and Visibility Ranges under Scenario 4

3 Results and Discussions

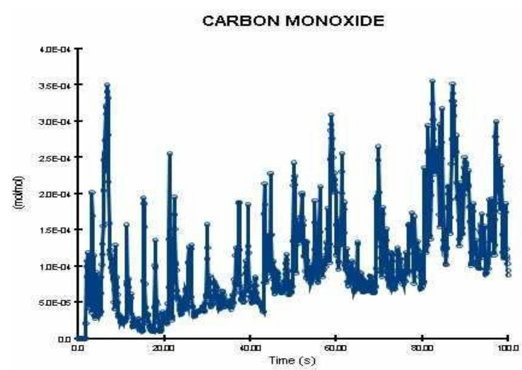
3.1 Changes of carbon monoxide in the Fire-affected Area

Figure 6 shows graphs depicting changes of density of carbon monoxide for each scenario. Density of carbon monoxide will reach 0.4% within 5 seconds if there is no sprinkler head and density of carbon monoxide changes by type of sprinkler head installed.

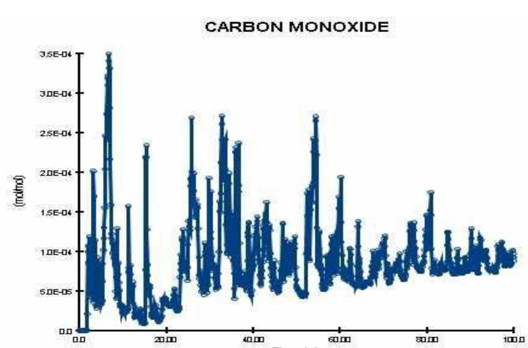
Fig 6 (a) shows that content of carbon monoxide tends to get higher with fluctuation, while Fig 6 (b) shows that carbon monoxide content is on the rise with fluctuation caused by falling water drops. Fig 6 (c) shows that carbon monoxide content is gradually on the rise, while Fig 6 (d) shows that carbon monoxide content does not change significantly.



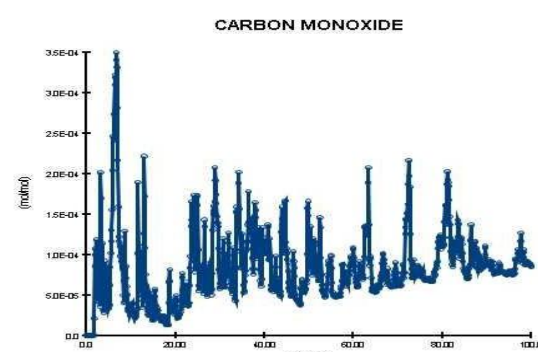
(a)Density of carbon monoxide in Scenario 1



(b) Density of carbon monoxide in Scenario 2



(c) Density of carbon monoxide in Scenario 3



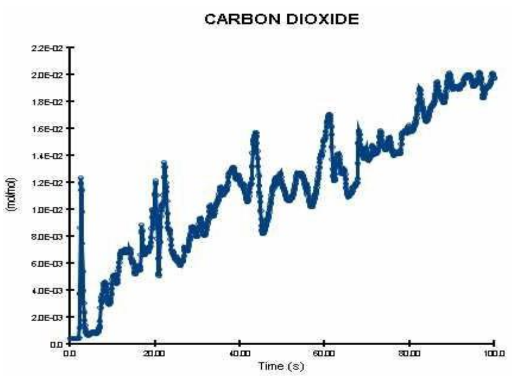
(d) Density of carbon monoxide in Scenario 4

Figure 6. Changes of carbon monoxide Density over Time per Scenario

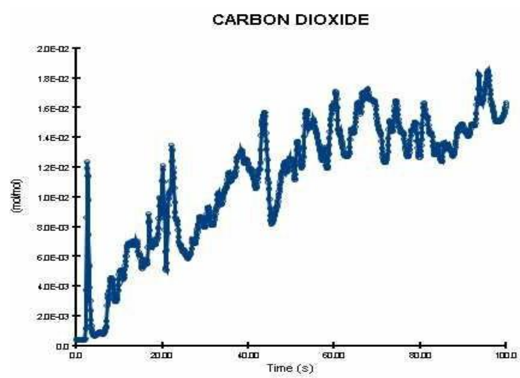
3.2 Changes of carbon dioxide in the Fire-affected Area

Figure 7 shows changes of density of carbon dioxide per scenario in the graphs. Density of carbon dioxide rapidly changes due to water falling down from the open sprinkler heads.

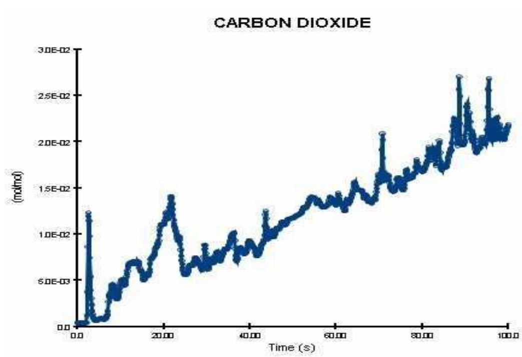
Figure 7 (a) shows that carbon dioxide content is rapidly on the rise, while Fig 7 (b) shows that carbon dioxide content tends to be rising with repeated fluctuation caused by falling water drops. Fig 7 (c), (d) shows that carbon dioxide content is rising slowly.



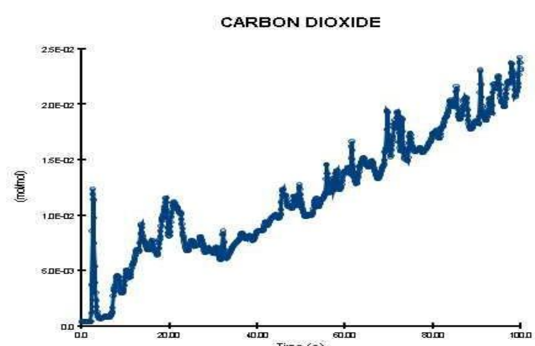
(a) Density of carbon dioxide in Scenario 1



(b) Density of carbon dioxide in Scenario 2



(c) Density of carbon dioxide in Scenario 3



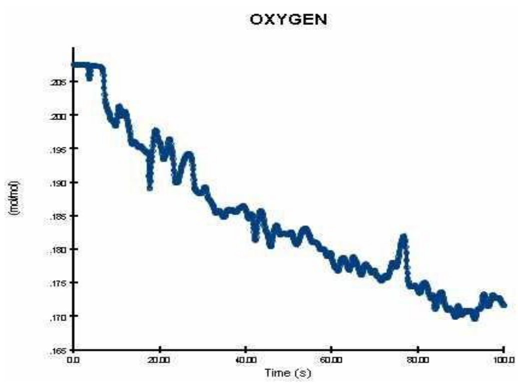
(d) Density of carbon dioxide in Scenario 4

Figure 7. Changes of carbon dioxide Density over Time per Scenario

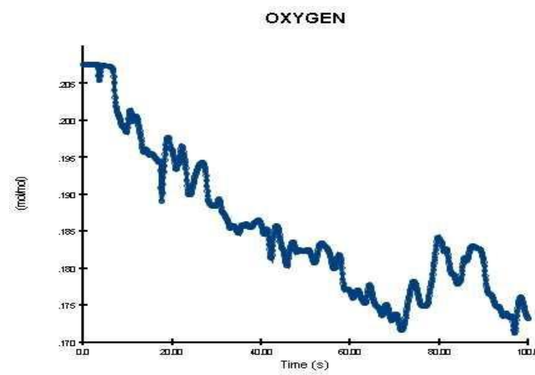
3.3 Changes of oxygen in the Fire-affected Area

Figure 8 shows the changes of density of oxygen per scenario. Density of oxygen rapidly changes as the sprinkler head opens within 5 seconds and water comes down.

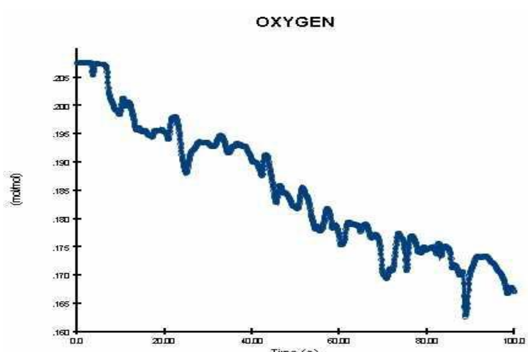
Fig 8 (a) shows that oxygen content is rapidly falling, while Fig 8(b) shows that oxygen content is fluctuating, affected by falling water drops. Fig 8 (c) shows that oxygen content is falling at some regular interval, while Fig 8 (d) shows that oxygen content is gradually falling by certain portion.



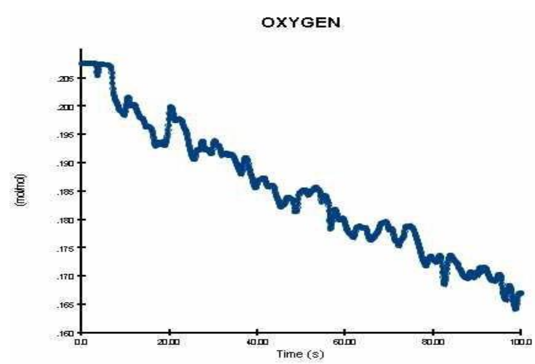
(a) Density of oxygen in Scenario 1



(b) Density of oxygen in Scenario 2



(c) Density of oxygen in Scenario 3



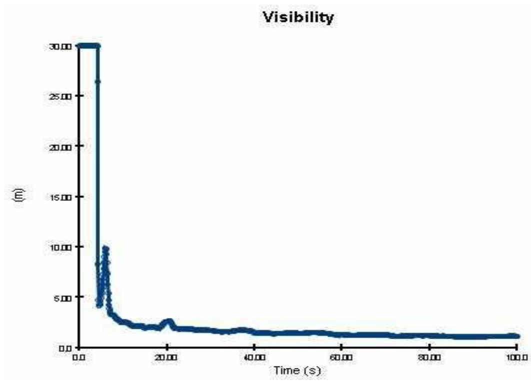
(d) Density of oxygen in Scenario 4

Figure 8. Changes of oxygen Density over Time per Scenario

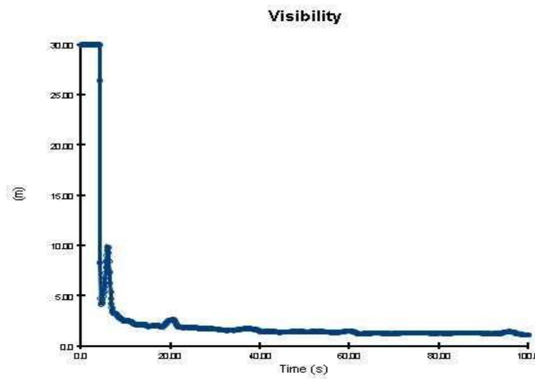
3.4 Change of Visibility Range in the Fire-affected Area

Figure 9 shows the graphs of changes of visibility range per scenario. The visibility range rapidly changes as the sprinkler head opens and water comes down.

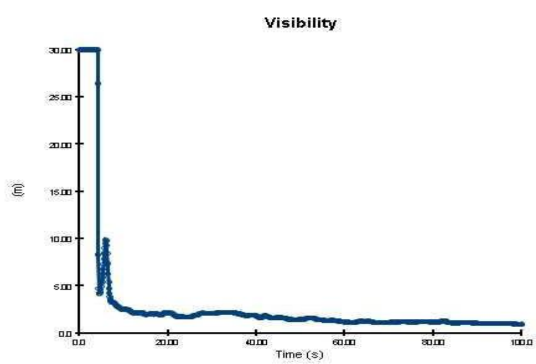
Fig 9 (a)(b)(c)(d) shows that visible distance dramatically fell to 5m in 5 seconds and rebounded to 10m again, falling again.



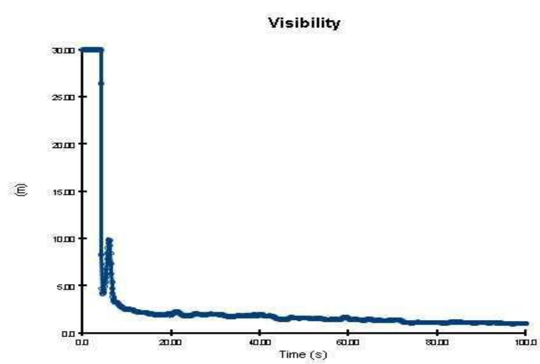
(a) Visibility range in Scenario 1



(b) Visibility range in Scenario 2



(c) Visibility range in Scenario 3



d) Visibility range in Scenario 4

Figure 9. Change of Visibility Range over Time per Scenario

4. Conclusion

Under the assumption that a fire breaks out at gymnasium frequented by residents, the study focuses on analyzing at what point toxic gas possibly leading workers familiar with inner features of the building and, as a voluntary fire-fighter, responsible for fire containment, fire alarm and evacuation to be affected by fire with change in carbon monoxide, carbon dioxide, oxygen content and visible distance is starting to be emitted above a certain level. The analysis includes the points of time when density of toxic gases generated at a place where a flame has occurred affects, which differs for each scenario.

1) density of carbon monoxide rapidly increased when there was no sprinkler head. It also increased when a sprinkler head was installed due to water coming down.
2) density of carbon dioxide rapidly increased when there was no sprinkler head. It also increased when a sprinkler head was installed due to water coming down.
3) density of oxygen rapidly decreased when there was no sprinkler head. It also decreased when a sprinkler head was installed due to water coming down.
4) visibility range rapidly fell when there was no sprinkler and when there was a sprinkler due to water coming down from the open head.

This study identified safety from fires depending on installation of sprinkler heads within a gymnasium. In the future, we aim to analyze working time of sprinkler heads through a fire simulation program.

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[11] RTI values are more than 80 and not more than 350 with registration temperature of 79℃ and draft temperature of 282℃ and draft speed of 2.4m/s.
[12] RTI values are more than 51 and not more than 80 with registration temperature of 79℃ and draft temperature of 191℃ and draft speed of 2.4m/s.
[13] RTI values are not more than 50 with registration temperature of 79℃ and draft temperature of 191℃ and draft speed of 1.65m/s.
[14] National Law Information Center, See Appendix 1 regarding performance-based design method, including fire-fighting facility, 2017