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INVESTIGATION OF EFFECTS OF ENCLOSURE OPENING ON INERT GAS SUPPRESSION SYSTEM

IKENNA EUGENE ATUKPAWU

WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES

Master Thesis in Fire Safety Engineering

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Investigation of Effects of Enclosure Opening on Inert Gas Suppression System

Master thesis in Fire Safety Engineering

Author: Ikenna Eugene Atukpawu	Author sign. 
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Tutor: Xiaoqin Hu Arjen Kraaijeveld External tutor: No external Tutor	
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This thesis is a part of the master's program in Fire Safety Engineering at Western Norway University of Applied Sciences. The author(s) is responsible for the methods used, the results that are presented, the conclusion and the assessments done in the thesis.

Preface

This thesis is the final academic requirement in the Master's degree program in the Fire Safety Department at Western Norway University of Applied Sciences. This study is credited with 60 ETC points.

This work is part of the BUILDER project (building design for at-risk groups) at the Western Norway University of Applied Science, funded by the Norwegian Research Centre. The idea for this work came from my supervisors Dr. Xiaoqin Hu and Dr. Arjen Kraaijeveld. The combination of experimental and numerical study is something I had longed to do for a long time and I am glad this study granted me the opportunity to achieve my desire. This work has been both educational and challenging.

Acknowledgments

I want to express my profound gratitude to my supervisors Dr. Xiaoqin Hu and Dr. Arjen Kraaijeveld for their commitment, support, and guidance throughout the duration of the study. I would also want to thank my fellow students Jishan Mahmud Rumi, Sebastian, Hågen, and Erik, for our collaborations and great discussions during this work. I wish to thank HH Fire Eater AS for their collaboration, construction of the apartment, and installation of the fire suppression system. Finally, I want to thank Thunderhead Engineering for providing the software used in performing the simulations in this study.

Abstract

A fire suppression system is very important for securing lives, property, and businesses. There are different kinds of fire suppression systems. The occupancy type is a major determinant of the type of fire suppression system suitable for use. In homes whose occupants are majorly those in the risk group, the use of an inert gas fire extinguishing system seems reasonable since it leaves no residue or damage property after discharge. However, the effectiveness of an inert gas fire suppression system may be affected by some factors such as openings in buildings they protect. The fire suppression system extinguishes fire by reducing the level of oxygen in the apartment below 15.0% which is the design concentration of oxygen to extinguish a fire. This study investigates the effects of openings on the inert gas system. Previous studies have been done for closed enclosures where fire suppression was achieved. The effect of enclosure opening on inert gas systems was investigated by conducting a full-scale experiment using a compartment of volume 83.5 m^3. The oxygen level was measured at locations close to the doors and the windows. A similar arrangement was simulated in Pyrosim/FDS to get a clear view of the filling process and more data/information, which help to analyse the opening effect. From the investigation, the opening size and height affected the inert gas fire suppression system by increasing the oxygen level in the enclosure when IG-541 was discharged into the room. However, for locations far from the opening, the oxygen level decreased to a concentration that will enable the inert gas agent to extinguish fire (below15.0%). Also, the concentration of oxygen increased rapidly after the discharge time when there was an opening in the building which implied that the openings reduced the holding time of the inert gas system. The increase in oxygen concentration was because of the loss of the fire extinguishing agent through the lower part of the opening and the inflow of oxygen from the surrounding through the upper layer of the opening. In conclusion, openings under investigation affected the inert gas system by reducing the holding time, however, fire extinguishment was achieved. Therefore, to increase the holding time, extended discharge is required.

Sammendrag

(Sammendrag må være bade på norsk og engelsk)

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Definitions

Symbol	Name	Unit
A	Pressure relief open area	[m^2]
A_o	Area of opening	[m^2]
A_t	Total surface area of the enclosure	[m^2]
A_u	Area of upper layer vent	[m^2]
A_i	Area of lower layer vent	[m^2]
C	Design concentration	[%]
C_1	The resistance figure of the pressure relief opening	[-]
D_0	Oxygen measuring device	[-]
E_m	Ventilation mass rate	[-]
F	External force	[N]
g	Acceleration due to gravity	[ms^{-2}]
g_a	Inside gas density	[kg/m^3]
h	Height of room	m]
h_s	Sensible enthalpy	[-]
H_o	Height of opening	[m]
K_1	Constant	[-]
K_2	Constant	[-]
M	Maximum flow of extinguishing gas to time	[kg/s]
$\dot{M}_g$	Mass flow rate through the opening to outside	[kg/s]
$\dot{M}_a$	Mass flow rate through the opening into the enclosure	[kg/s]
$\dot{M}_b''$	Room pressure	[Pa]
P_a	Air pressure	[Pa]
P_g	Gas pressure	[Pa]
$\bar{P}$	Background pressure	[Pa]
$\Delta \cdot P$	Change in pressure	[Pa]

$\dot{q}'''$	Heat release rate per unit volume	[KW/m^3]
$\dot{q}''$	Heat flux	[W/m^2]
R_m	Discharge mass rate	[kg/s]
S	Specific volume of IG-541	[m^3]
T	Minimum ambient temperature of the protected area	[°C]
T_g	Ambient gas Temperature	[°C]
T_a	Inside air Temperature	[°C]
U	Velocity of fluids	[m/s^2]
V	Net volume of the protected area	[m^3]
V_s	Specific volume	[m^3]
V_{mix}	Mixture's specific volume	[m^3/kg]
V_{air}	Specific volume of air	[m^3/kg]
V_g	Volume of the extinguishing gas	[m^3/kg]
W	Weight of discharge gas needed	
X	Inert gas volume	
x	Extinguishing gas concentration of the agent	[m^3 gas/m^3]
ρ	Density of fluid	[kg/m^3]
ρ_a	ambient density	[kg/m^3]
τ	Tensor stress	

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1. INTRODUCTION

1.1. Background

Studies have indicated that people in the risk group are more likely to die in fires due to their inability to escape. Some of the causes of death in home fires are smoke, burns, traumas, and asphyxiation. According to [1], asphyxiation is the major cause of death in fires followed by skin burns. During a fire in an enclosure, breathing becomes difficult for the occupants, resulting in delay or inability to evacuate. For enclosures protected with inert gas suppression systems, the discharge of fire extinguishing agent leads to a decrease in oxygen concentration because of the increase in the concentration of inert gas. The increase in nitrogen gas concentration in a closed space leads to nitrogen asphyxiation. For people within the risk- group, without assistance, evacuation during a fire becomes difficult, placing them at risk of being exposed to nitrogen asphyxiation which may eventually lead to a more severe consequence. The fire protection community is working on new ways to provide safer and more reliable apartments by designing, fabricating, and installing gas fire suppression systems for the risk group occupancies to reduce the consequences of fire accidents.

Inert gas agents are one of the alternative fire suppression agents developed to replace the banned halogenated fire extinguishing agents (halons), the replacement became necessary due to the adverse impact halons have on the environment and the depletion of the ozone layer [2]. Gas extinguishing systems were invented to protect areas such as server rooms, where the use of water-based fire protection systems is not acceptable due to the damages associated with it [2]. Inert gas extinguishing systems are cleaner and safer alternative due to their ability to leave no residue in the protected area after discharge. They comprise different components which include: a cylinder, a pressure gauge fitted to the cylinder, the actuator, the manifold, the distribution pipes, and nozzles. Gas fire suppression systems are activated through electrical or mechanical trigger mechanisms. Inert gas agents are classified into five different categories: IG-01, IG-55, IG-100, IG-541 (Inergen), and IG-901. Nitrogen and Argon make up inert gas agents, except IG-541 which contains a blend of carbon dioxide. At present, the fire safety community has included the use of inert gas suppression systems in residential homes. The inert gas agents are available in the market although very costly. The positive attributes of the inert gas agents make them a good fit for use as fire suppression agents in risk-group residential houses. The risk-group in most cases is vulnerable persons with very limited ability to escape from fires. They include but are not limited to people with; impaired cognitive ability, reduced mobility, mental illness, mental disorder, known substance abuse, smoking habits, and elderly persons. The gas fire suppression agent which suppresses fire is stored in the cylinder under a predefined pressure, usually between 200 and 300 bars.

Inert gas fire suppression agents suppress fire in an enclosure by reducing the flame temperature below the required value needed to sustain combustion. That is achieved by reducing the oxygen concentration in the room [2]. The effectiveness of a gas suppression system may depend on a lot of factors. They may include but are not limited to; the quantity of inert gas discharged, discharge time, leakage in the enclosure, opening location and opening size. Therefore, it is important to study how these factors may affect gas fire suppression systems with more emphasis on enclosure opening. Enclosure openings can be instrumental in fire development. They serve as a pathway for oxygen to re-enter the protected area creating an agent-air mixture, thereby increasing the oxygen concentration of the enclosure above the oxygen design level, making fire suppression and extinguishment more difficult. An enclosure opening could also act as a channel through which discharged inert gas is lost to the environment, thereby decreasing the holding time.

In this work, the effects of open doors and windows on inert gas fire suppression system will be studied.

1.2. Openings in Areas Protected with Inert Gas Fire Suppression System

Openings in building structures in form of doors and windows are designed for the entrance and exit of occupants and for adequate ventilation inside the apartments. They serve as egress paths in times of fire emergencies, therefore more emphasis is given to the openings. However, for a building protected with a gas fire suppression system such as the inert gas system, enclosure openings are given special consideration because of the effects they may have on the effectiveness of the fire suppression system. Usually, the inert gas system is very effective when the space under its protection is secluded from the immediate environmental condition such as air.

Furthermore, unclosed openings readily affect the inert gas system's ability to extinguish fire due to the loss of the extinguishing agent through the opening during discharge. The loss of the extinguishing agents to the environment may delay/hinder the reduction of oxygen concentration to the minimum concentration required to extinguish the fire completely.

1.3. Research Objectives

Presently, gas fire suppression systems are designed to extinguish compartment fires when the enclosure opening is secured to prevent agent loss and limit excessive air-agent mixture loss after discharge [2]. It is a general practice that all the openings in the protected area must be closed before the discharge of the extinguishing agent, in conjunction with fire detection and alarm. There is no test data available for protected spaces with unclosed openings to ensure adequate concentrations that will readily extinguish fires.

This study is intended to provide experiment and simulation data for a gas fire suppression system for enclosures with openings. This is especially important for worst-case scenarios where the occupants may lack the ability to close their doors and windows during evacuation or cases where the system may fail for self-closing doors and windows. Therefore, it is important to design gas fire suppression systems for compartments such that they will effectively suppress fires even when the enclosure is open.

The purpose of the current work is to investigate how a gas fire suppression system can be designed to gas extinguish fires while the enclosure opening is open.

The objective of this study is as follows:

- To investigate how small openings will affect gas fire suppression systems
- To investigate the effectiveness of a gas fire extinguishing system when the opening size is medium (when the door or window is slightly open)
- To study how large openings will affect the fire suppressions system (When a door or window is widely open)

In this study, different scenarios were considered to achieve the objectives listed above.

They include:

Scenario 1 – No opening

Scenario 2 – 1 Door completely open with other openings closed

Scenario 3 – 25 cm width opening at 2 windows with other openings closed

Scenario 4 – 1 window fully opening with other openings closed

Scenario 5 – 14 cm width opening at one door

The investigation in this project will be based on an initial literature review, studies of existing analysis, and preparing a series of full-scale experiments in cooperation with the company HH Fire Eater AS.

2. THEORETICAL BACKGROUND

In this chapter, the literature on inert gas suppression systems is reviewed. The brief history of halons, the introduction of halon replacements, computer fluid dynamics (CFD) and Pyrosim model are discussed.

2.1 Clean Agents

Before the invention of clean agents, fire suppression and extinguishments were widely done using halogenated fire suppression agents (halons). However, the use of halons in fire extinguishment was banned due to the negative effect it has on the environment because it plays a key role in the stratospheric depletion of the ozone layer [2]. Halocarbon agents and inert gas agents otherwise called the clean agents are electrically and nonconducting clean fire suppression agents that vaporize readily after discharge leaving no residue within the enclosure area [3]. Clean agents are classified into two categories which include (1) halocarbon clean agents and (2) inert gas clean agents. The table below gives a summary of the list of clean agents currently in use.

Table 1:: A summary of the list of clean agents currently in use [2].

Type of Agent	Trade name	Chemical name	ASHRAE name	Chemical formula
Inert Gas Agents				
	Inergen	$N_2/Ar/CO_2$	IG-541	N_2(52%), Ar (40%), CO_2 (8%)
	Argonite	N_2/Ar	IG-55	N_2(50%), Ar (50%)
	Argon	Argon	IG-01	Ar (100%)
	Nitrogen	Nitrogen	IG-100	N_2
Halocarbons				
	FE-13	Trifluoromethane	HFC-23	CHF_3
	FE-24	Chlorotetrafluoroethane	HCFC-124	$CHClFCF_3$
	FE-25	Pentafluoroethane	HCFC-125	CHF_2CF_3
	FE-36	Hexafluoropropane	HFC-236fa	$CF_3CH_2CF_3$
	FM - 200	Heptafluoropropane	HFC-227ea	CF_3CHFCF_3
	Novec-12330	Dodecaflouro-2-methylpentan-3-one	FK-5-1-12mmy2	$CF_3CF_2C(O)(CF(CF_3))_2$
	Triodide	Trifouroiodie	FIC-1311	CF_3I

2.1.1 Halocarbon Clean Agents

Halocarbon clean agents comprise of compounds of halogen consisting of iodine, fluorine, chlorine, bromine, hydrogen, and carbon. Halocarbon clean agents are further categorized into sub-categories which include fluoroiodocarbons (FIC), perfluorocarbons (PFC), and hydro fluoro chlorocarbons (HCFC), hydrofluorocarbons (HFhydro Bromo fluorocarbonsbons (HBFC). They are characterized by the following attributes [2].

1. Halocarbon agents have a very negligible ozone depletion potential (ODP)
2. They vaporize after discharge leaving no residue in the environment.
3. Halocarbon clean agents produce decomposition products compared to Halon 1301, all halocarbons have greenhouse characteristics except FK-5-1-12, mmy2, and FIC-1311.
4. Halocarbon agents are total flooding gases after discharge, that require special care relative to nozzle design and mixing.
5. All halocarbons use nitrogen super pressurization in most applications for discharge purposes except HFC-23.
6. Halon 1301 has more fire suppression efficiency compared to halocarbons in terms of weight and storage volume.
7. All halocarbons usually undergo evaluation with regards to safety and health concerns before installation.
8. They are stored and discharged from a Halon 1301 hardware.

In terms of fire extinguishing principles, halocarbon clean agents use both physical and chemical mechanisms to extinguish a fire depending on the compound. The chemical mechanism involves the interruption of chemical reactions while physical mechanism involves extracting heat from the flame reaction zone [2]. Upon heat extraction, flame temperature decreases below the required threshold to support the reaction by combining energy absorbed by decomposition, heat capacity, and heat of vaporization [2].
The toxicity problem associated with halocarbon agents is cardiac sensitization [2]. Cardiac sensitization has the potential of developing into cardiac arrhythmia when an occupant is exposed to halocarbon agents. Cardiac arrhythmia (heartbeat irregularities), in the worst case, could lead to a heart attack [2]. Naturally, the body produces adrenaline with an increased production rate when the body is stressed. Adrenaline concentration associated with the onset of cardiac arrhythmia is minimized by cardiac sensitization upon exposure to a halocarbon agent [2].

Cardiotoxicity is described in two allowable exposure levels, (a) no observable adverse effect level (NOAEL), and (b) lowest observable adverse effect level (LOAEL). The highest concentration an individual is exposed to which no marked adverse effect occurs is NOAEL, while the lowest concentration that can cause adverse effects is LOAEL [2]. |The table below summarizes the NOAEL and LOAEL values for halocarbon agents.

Table 2: Toxicity data for halocarbon clean agent fire suppressants [3]

Trade name	Agent	NOAEL (%)	LOAEL (%)
Triodide	FIC-1311	0.2	0.4
Novec 1230	FK-5-1-12	10	>10
NAFS-III	HCFC Blend A	10	>10
FE-24	HCFC-124	1	2.5
FE-25	HCFC-125	7.5	10.0
FM-200	HFC-227ea	9	10.5
FE-13	HFC-23	30	>30
FE-36	HFC-236fa	10	15
Halontron II	HFC Blend B	5.0[a]	7.5[a]

Table 3: Environmental factors for halocarbon clean agents [23]

Name	ODP	GWP (100 years)	Atmospheric lifetime (years)
Halon 1301	12.000	7030	65
HFC-227ea	0.000	2900	34.2
HFC-23	0.000	14,310	270
HFC-125	0.000	3450	29
FK-5-1-12	0.000	1	0.038
Inert gases	0.000	0	NA

In [3] it is stated that halocarbon clean agent fire suppressants are a cause for concern in issues related to ozone depletion and global warming. Environmental factors are considered when using clean agent fire suppression systems. The key environmental factor considered is the ozone depletion potential (ODP) [2]. The work in [24] indicates that halocarbon clean agents contribute less than 0.01%of the impact of all greenhouse gases. Table 03 shows the environmental impact data for all halocarbon agents.

2.1.2 Inert Gas Clean Agents

Basically, the inert gas clean agents are made of nitrogen and argon, with one type having a blend of carbon dioxide. There are four (4) types available. They are IG- 541, IG-01, IG-100, and IG-55.

Inert gas agents are electrically non-conductive and leave no residue after discharge. They are stored under high-pressure cylinders, usually placed some same distance away from the protected enclosure. Inert gas extinguishing agents do not produce more decomposing products and have zero global warming potential. Just like all other halon replacements, they are usually evaluated for health and safety concerns which are usually related to nitrogen asphyxiation [2]. During fires in an enclosure, inert gas agents extinguish a fire by reducing the flame temperature below the degrees required to sustain a combustion reaction. This is achieved by reducing the oxygen concentration of the enclosure to a threshold, by raising the heat capacity of the enclosure. Flames are extinguished at 12% oxygen concentration in the room [2]. The thermophysical properties of all inert gas fire suppression agents are presented in Table 05 below.

A little percentage of carbon dioxide (CO_2) is contained in IG-541 which protects the occupants in the protected area when the extinguishing agent is discharged. The CO_2 increase by 4% when discharged in an enclosure, the increase in CO_2 concentration increases the respiration rates making breathing possible for the occupants of the building [4].

Table 4: Physical properties of clean Inert Gas agents [3]

Physical property	Units	IG-541	IG-55	IG-100	IG-01
Solubility of water in agent	NA	0.015 %	0.006 %	0.0013 %	0.006 %
Molecular weight	NA	43.0	33.95	28.0	39.9
Boiling point at 760 mmHg	℃	-196	-190.1	-195.8	-189.85
Relative dielectric strength at 1 atm at 734 mmHg, 25 ℃ (N_2 =1.0)	NA	1.03	1.01	1.0	1.01
Heat of vaporization at boiling point	kJ/kg	220	181	199	163
Freezing point	℃	-78.5	-199.7	-210.0	-189.35
Critical temperature	℃	NA	-134.7	-146.9	-122.3
Specific heat, vapor at constant pressure (I atm) and 25 ℃	kJ/kg ℃	0.574	0.782	1.04	0.519
Critical pressure	kPa	NA	4150	3399	4903

The table above indicates that all inert gas fire extinguishing agents except IG-100 do not have a similar molecular weight as air. IG-541 has the highest molecular weight at 43.0 compared to other inert gas agents. Air is less dense than IG-541, which explains why upon discharge, the IG-541 gas descends downward towards the floor of the enclosure. The density of gas agent is the inverse of specific volume. The specific volume of IG-541 is given by the formular, $S = k1 + k2 * T$, where k is a constant and it is given in **Table *5***. T is the minimum ambient temperature of the protected area.

Table 5:Specific volume of inert gas agents

Generic name	Trade name	K_1 (°F)	K_2 (°F)	K_1 (°C)	K_2 (°C)
Inert gases					
IG-01	Argon	8.40299	0.018281	0.5612	0.002054
IG-55	Argonite	9.8809	0.0214956	0.65979	0.0024134
IG-100	Nitrogen	11.976	0.02606	0.7997	0.002927
IG-541	Inergen	9.858	0.02143	0.659	0.00241

2.2 Clean Agent System Design

Basic processes involved in the design of the inert gas system have been listed in the following steps [2].

1. Selection of the extinguishing agent
2. Find the design concentration of the extinguishing agent
3. Determine the total quantity of the agent
4. Choose the discharge time of the agent
5. Selection of piping materials and specification of the thickness
6. Selection of the nozzles
7. Check enclosure pressure to determine under/overpressure to know if the compartment needs venting
8. Establishment of the holding time of the agent.

The figure below shows a workflow of a clean agent system design.

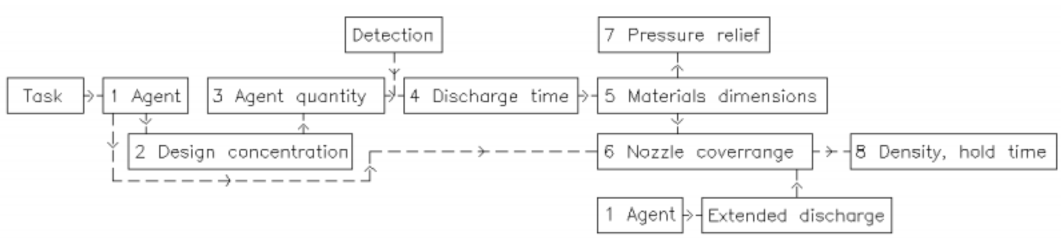


Figure 1: The workflow for clean agent system design [5]

2.2.1 Selection of Fire Extinguishing Agent

The types of inert gas agents developed to extinguish fires are listed in table 06. The selection of agents is strictly based on the type of fire to be suppressed and what needs to be protected [6]. The benefits of using IG-541 for fire extinguishment is numerous. They are friendly to the environment and safe for use in normally occupied areas because it allows the occupants to breathe even when oxygen level is reduced. Inert gas systems do no take up valuable floor space as the cylinder can be remotely place from the area being protected.

2.3 Design Concentration of Inert Gas Agents

Inert gas agents extinguish a fire by cooling/reducing the temperature of the flame while at the same time increasing the heat capacity of the enclosure. The inert gases reduce the oxygen concentration from 21.0% to approximately 12.0% to effectively extinguish a fire in the enclosure [2]. In

Table 6, extinguishing concentration of inert gas agents were recommended by National Fire Protection Association (NFPA) and International Standards Organization (ISO) standards. For IG-541, NFPA recommend 34.2% design concentration for fire that involves solids (class A fires) while the ISO standard recommends 36.5%. In [2], NFPA provided a specific volume constant for clean agent total flooding extinguishing system concentration for class A fires as shown in the table below.

Table 6: depicts the extinguishing concentration of inert gas agents [2].

Agent	Heptane MEC (NFPA 2001, 2008) (%)	ClassA design concen. NFPA 2001/UL (%)	Ratio Class A design to MEC (NFPA)	Class A design concen. (ISO 14520) (%)	Ratio Class A design concen. to MEC (ISO 14520	Ratio Class A design NFPA 2001 to ISO 14520
IG-01	42	–	–	41.9	1.0	-
IG-55	35	37.9	1.08	40.3	1.15	0.94
IG-100	31	-	–	40.3	1.3	-
IG-541	31	34.2	1.1	36.5	1.17	0.94

2.4 Design Agent Quantity

After determining the design concentration of the extinguishing agent, the next step will be to determine the quantity of the agent that will be sufficient to extinguish the fire in the protected area. Leakage areas are considered during the discharge and at the end of discharge time.

For inert gas agents, equation 1 is used to estimate the agent quantity assuming leakage occurs during discharge time, while equation 3 is used when leakage occurs at the end of discharge time [2].

$$W = \frac{V}{S}\left(\frac{C}{100-C}\right) \qquad 1$$

Where:

V = net volume of the protected area

C = design concentration (%)

W = weight of the discharge agent needed

S = specific volume

$$S = K_1 + K_2\,(T) \qquad 2$$

T is the minimum ambient temperature of the protected enclosure, and K_1 and K_2 are constants obtained from table 5 [2].

$$X = 2.303\,\frac{V}{S}\log\left(\frac{100}{100-C}\right)V_s \qquad 3$$

Where:

X = Inert gas volume required at 21.0 ºC

V_s = Specific volume at 21.0 ºC

V = Net protected hazard volume

S = specified volume at ambient temperature in the protected volume

The quantity of inert gas required to extinguish a fire in an enclosure without leakage has been studied. Xiaoqin Hu. *et al* [7] found that the quantity of inert gas is a function of k which is the ratio of the ventilation mass rate E_m to discharge mass rate R_m (i.e., $k = \frac{E_m}{R_m}$) and that the quantity of the inert gas required to extinguish the fire (attain the design oxygen level) per unit volume of the compartment decreases with increasing values of k.

2.5 Discharge Time of Inert Gas Agent

In NFPA 2001 [3], discharge time is stated to be the time required to discharge from the nozzle 95.0% mass of the agent at 21 ºC. The maximum discharge time for inert gas agents is 120 seconds for class A and for class C fires and 60 seconds for class B fires. There are two basic reasons to compel the discharge time of inert gas agents that form no decomposition products, they are: (1) to reduce the length of time the fire burns in the enclosure where oxygen concentration is low, and (2) to control and limit the damage caused by fire [2]. Class A fires are fire that involves solids, class B fires involve liquids and class C fires involves gases.

2.6 Installation of Inert Gas Suppression System

When the discharge time has been agreed on, the next phase of the design process is a selection of materials that will be used. Inert gas suppression system comprises numerous components. They include:

1. Cylinders used to store inert gases at high pressure
2. Electrical components that make up the detection, and alarm systems
3. Distribution pipes with nozzles

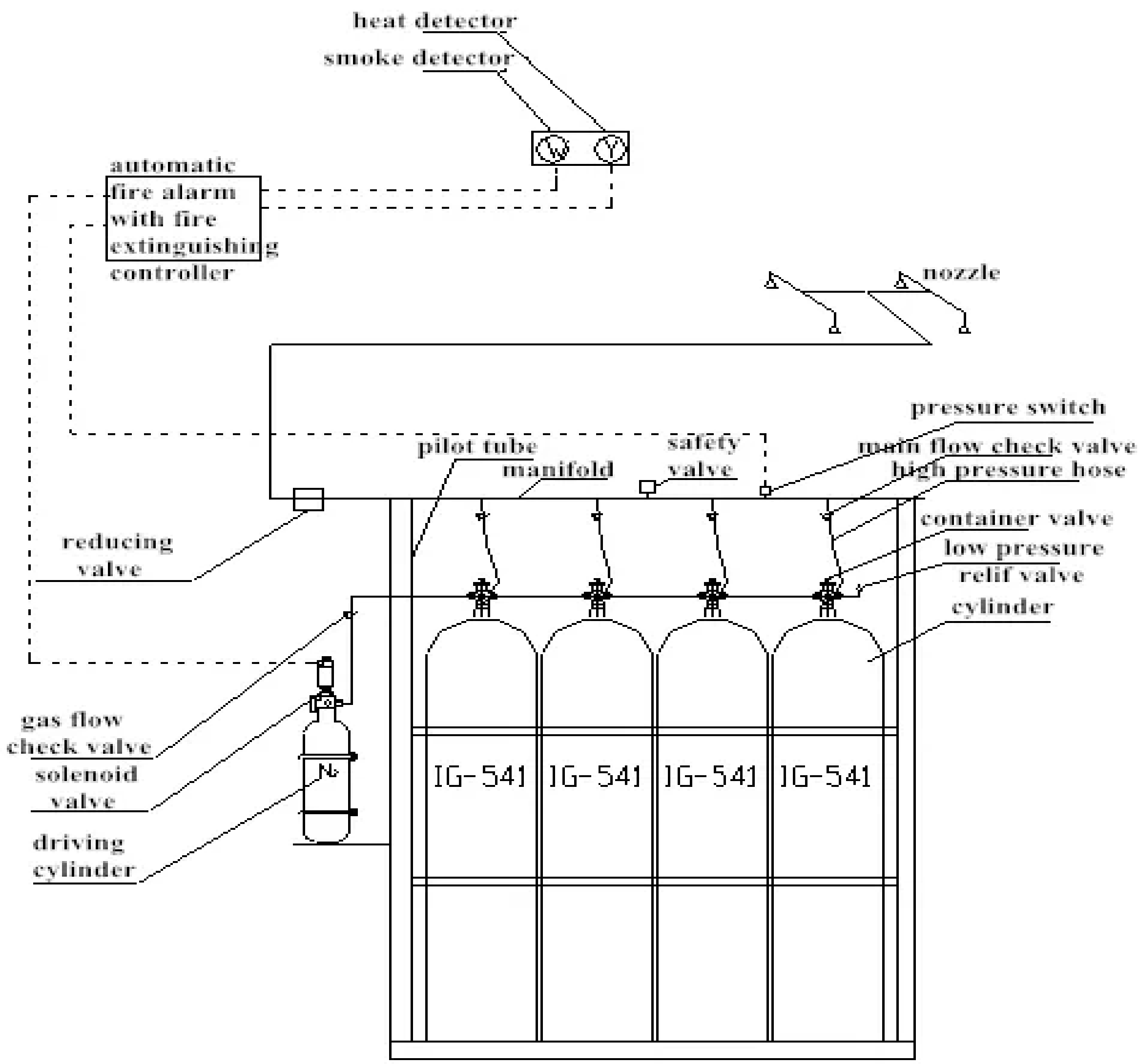


Figure 2: Essential components of gas fire suppression system [8]

2.6.1 Pressure cylinders

Inert gases are stored in pressure cylinders at different volumes in liters ranging from 5 liters to 80 liters at a pressure of 200 bars to 300 bars.

Table 7:Data on IG-541 cylinders (HH fire Eater 2022)

Cylinder Type	**IG-541 80L Steel Cylinder**	
Cylinder quantity	1	
Cylinder fill	15.0°C	300.0 barg
Cylinder storage	20.0°C	308.8 barg
Atmospheric pressure	1013.0 mbar	
Authority	EN 15004-1:2019	
Pressure relief resistance	1.0	
Volume of protected space	40.0 m^3	

2.6.2 Control panel

When a fire occurs in a room protected by a gas fire suppression system, the detection systems are first activated, and a signal is sent to the control panel [6]. The control panel relays the signal to the alarm system that triggers the alarm warning occupants of the build of a possible fire incident in the building structure. After the warning by the alarm system, the gas fire extinguishing agent is discharged in the space protected by the gas extinguishing system.

2.6.3 Detection system

The detection system is one of the most important parts of the fire suppression system, the protection of life and property against fire is dependent on the detection capability and efficiency of the fire detectors. The detectors must be designed to detect fires at the early stage. They are used to activate fire suppression systems and smoke control systems that are used to secure the environment during fire in a compartment. The design and installation of fire detection systems are goal-driven, they goals can be categorized into life safety, property protection, business protection and environmental concerns. Once the goal is set, the specific performance and design objective are established. The design may be performance-based design or prescriptive-based design [9]. Fire detection systems are classified into three: heat detectors, smoke detectors and radiant heat detectors. The best location to place a heat detector is directly over the fire, if a hazard is specified for protection, such hazard should have a detector place over it [9]. In [10], there is a procedure recommended to design a detector system.

2.6.4 Discharge Valves

The gas fire suppression system contains discharge valves. The valve contains a combination of a pressure switch and pressure gauge. The also valve contains an in-built actuator controlled by backpressure. It is connected to the manifold and is activated when the master cylinder connected to the manifold is activated [11].

2.6.5 Manifolds

The compressed inert gas extinguishing agent stored in a cylinder under pressure flows through the valve to the manifold which reduces the gas pressure by approximately 75 bar before the gas is distributed through the pipelines.

2.6.6 Nozzles

The fundamental and major requirement for a gas suppression system is the ability to deliver a uniform concentration of the discharge throughout the compartment being protected [2]. The nozzle design and minimum nozzle discharge pressure are critical in ensuring the distribution of discharge agent. It is critical to ensure that nozzle spacing, height and minimum pressure are not exceeded for each manufacturer’s hardware in a specific design [2]. The flow, mixing, and distribution of the discharge agent from the nozzle to the fire enclosure can be predicted theoretically for relatively simple nozzle designs using powerful computer models [12].

2.6.7 Pressure Relief

In a protected space with no opening or means of venting discharged gas, there may be a pressure build-up. To prevent damage to the compartment, evaluation for under/overpressure for the compartment is estimated. [13] stated procedures for estimating the over/under pressurization of an enclosure. Agent flow rate, leakages, fire size, the volume of the enclosure all play key roles in pressurization of compartments. Installation of pressure relief devices within the enclosure is important. The area of the needed pressure relief is determined using the equation below:

$$A = \frac{M \cdot V_g}{\sqrt{\Delta \cdot P \cdot V_{mix}}} \cdot \sqrt{\frac{C_1}{2}} \quad 4$$

Where:

$$V_{mix} = (1 - x) \cdot V_{air} + x \cdot V_g \quad 5$$

A= Pressure relief opening's area [m^2]

M= maximum flow of the extinguishing gas to time [kg/s]

V_{mix}= mixture's specific volume [m^3/kg]

x =extinguishing concentration of the agent [m^3 gas/m^3 volume room]

C_1 = the resistance figure for the pressure relief opening

V_{air} = the specific volume of air atmosphere [m^3/kg]

V_g =the volume of the extinguishing gas [m^3/kg]

$\Delta \cdot P$ =change in pressure within the protected area [Pa]

2.7 Agent Holding Time

When a fire extinguishing agent at a certain concentration is discharged in an enclosure, leakage may occur, which may delay fire extinguishment. Therefore, the system should be adequately designed to have an acceptable holding time. The holding time can be said to be the time the oxygen concentration in the protected apartment is within the concentration that extinguishes fire.

The capacity of an enclosure to maintain adequate concentrations of an agent is a function of the leakage of the compartment. In a fire enclosure, the holding time for the gas suppression system is designed to be between 10-20 minutes. The required holding time is designed to create time for emergency response, soak time required for deep-seated Class A fuels, and prevention of re-flash of the fire due to the presence of hot surfaces, electrical energy, and other reignition sources, particularly with flammable and combustible liquid applications [2]**.** Holding time of gaseous agents can be estimated in several ways. DiNenno, Forssell and Grant, modelled the leakage of a gas-air mixture from a compartment as a two-layer system with a uniform air above the interface. In this method, the mixture leaks through the bottom of the enclosure and the interface descends with time [2].

2.8 Enclosure Opening

Once there is fire, oxygen must be present in the surrounding for the fire to be sustained. In moderate volumes enclosures or compartments with very negligible leakage areas, the flame becomes oxygen-starved and may self-extinguish or continue to burn at a slow rate depending on the availability of oxygen. Openings such as doors and windows provide access for oxygen to contribute to fire development in a fire enclosure. The shape, size, and position of enclosure openings are important in fire development. In the initial stage of fire, openings act as an exhaust for the hot gases before the fire becomes ventilation controlled. The opening size and shape are very important when the fire becomes controlled by the availability of oxygen. The rate of burning depends on ventilation factor [14].

2.8.1 Opening Factor

Before determining the opening factor, first, the ventilation factor must be established. The ventilation factor has been found to be directly proportional to the mass flow rate of air in through an opening during fire. The opening factor is obtained by dividing the ventilation factor by the total surface area of the enclosure [14].

$$Ventlation\ factor = A_o\sqrt{H_o} \tag{6}$$

$$Opening\ Area = \frac{A_o\sqrt{H_o}}{A_t} \tag{7}$$

Where:

$A_o = Area\ opening$ [m^2]
$H_o = Hieght\ of\ opening$ [m]
$A_t = Total\ surface\ area\ of\ the\ enclosure$ [m^2]

The table below gives a summary of conversion of fire load density and opening factor. The factor K_f permits an equivalent fuel load density and equivalent opening factor to be calculated for different types of compartment fires. The opening factor is multiplied by the same K_f to give and equivalent opening factor [14].

Table 8: Conversion to Equivalent Fire Load Density and Equivalent Opening Factor [14]

		Factor k_f					
Fire compartment		**Actual Opening Factor ($m^{1/2}$)**					
Type	**Description of enclosing construction**	0.02	0.04	0.06	0.08	0.1	0.12
A	Thermal properties taken as average values for concrete, brick, and light weight concrete	1.0	1.0	1.0	1.0	1.0	1.0
B	Concrete	0.85	0.85	0.85	0.85	0.85	0.85
C	Lightweight concrete	3.0	3.0	3.0	3.0	3.0	2.5
D	50% Lightweight concrete, 50% concrete	1.35	1.35	1.35	1.5	1.55	1.65
E	50% lightweight concrete, 33% concrete and 17% (13mm gypsum plasterboard, 100 mineral wool and brickwork [from the inside outward])	1.65	1.5	1.35	1.5	1.75	2.0
F	80% uninsulated steel sheeting, 20% concrete (typically a warehouse with insulated ceiling and walls of steel sheeting and a concrete floor)	1.0-0.5	1.0-0.5	0.8-0.5	0.7-0.5	0.7-0.5	0.7-0.5
G	20% concrete, 80% (2 x 13 mm gypsum plasterboard,100 mm air gap and 2 x 13 mm gypsum plasterboard)	1.5	1.45	1.35	1.25	1.15	1.05
H	100% (steel sheeting, 100 mm mineral wool, steel sheeting)	3.0	3.0	3.0	3.0	3.0	2.5

2.8.2 Hydrostatic pressure

Enclosure opening provide a pathway for exchange of air contents between the surroundings and the enclosure. Therefore, it is important to study the hydrostatic effect.

There is hydrostatic pressure in the enclosure both with and without fire [14]. When there is no fire, the enclosure has a small difference in the temperature that can cause air to flow in and out because of the density difference between the ambient temperature and the temperature inside. In the event of a fire, the difference between the ambient density Pa and temperature Ta and the internal gas density g_a and temperature T_g increases. This causes a flow of cold air to enter the enclosure from the lower part of the enclosure, while the hot air seeks to flow out from the upper part. The hydrostatic pressure difference is responsible for this. A neutral plane within the enclosure occurs at the height where the pressure difference is zero, depending on the flow resistance of the upper and lower openings and the density difference [14].

With height, pressure in an enclosure decrease, and pressure relative to door becomes:

$$P = h \cdot p \cdot g \qquad 8$$

h = room height

p = room pressure

g = acceleration due to gravity.

The difference in pressure in the room with respect to the atmospheric pressure is P_0. The difference P-P_0 (ΔP), can be written as a force F= Ahpg in:

$\Delta P = \frac{F}{A}\ hpg$

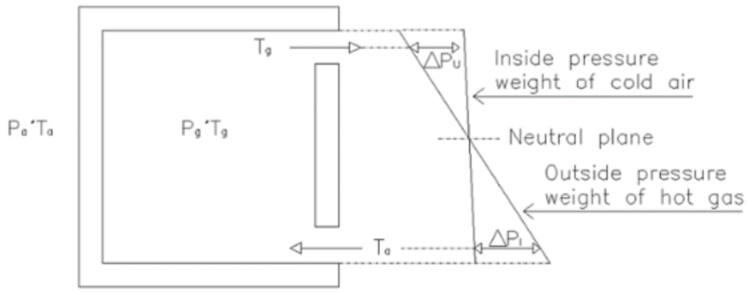


Figure 3: Hydrostatic pressure difference for a heated enclosure [18]

Where:

A = surface area.

Mass flow rates through opening can be estimated using the equations:

$$\dot{m}_g = C_d \cdot A_u \cdot P_g\sqrt{\frac{2h_u(p_a - p_g)\cdot g}{p_g}} \quad 9$$

$$\dot{m}_a = C_d \cdot A_i \cdot P_i\sqrt{\frac{2h_i(p_a - p_g)\cdot g}{p_g}} \quad 10$$

Equations 6 and 7 are used to determine the mass flow rate out and into the enclosure respectively.

Where:

$A_u\ and\ A_i$ are area of upper and lower vents

$p_a and\ p_g$ are air and gas pressure

g is acceleration due to gravity

2.9 Simulation Background

Computational fluid dynamics (CFD) is a division of fluid mechanics that uses data structure and numerical analysis to solve complex fluid problems. CFD model is used in analysing fluid flows, heat transfer and combustion [15]. A fire dynamic simulator (FDS) is a CFD model for solving fire-driven fluid flows. It is a large-eddy simulation (LES) for low – speed flows [16]. The software solves a form of the Navier-Stokes equations designed for thermally driven flows, low Mach flows, with an emphasis on smoke and heat transport from fires [16]. The equations governing the evolution of the low Mach flow are continuity, species concentration, momentum, energy, and ideal gas equation of state [17].

2.9.1 Conservation Equation

Equation of continuity

Basically, fire is described as a reaction of hydrocarbon fuel and oxygen that produces carbon dioxide and water vapor. It is an incomplete combustion process that involves multiple fuel gases that contains more than hydrogen atoms and carbon atoms. The number of gaseous species to keep track of in simulation is limitless. To make simulations tractable the number of fuels in the combustion is limited to one. The fuel is a single species, the air and products are referred to as lumped species, which represents a mixture of gas species that transport together. The transport equation for a single species has the form as the transport equation for lumped species.

$$\frac{\partial p}{\partial t} + \nabla \cdot (\rho u) = \dot{m}_b''' \qquad 11$$

Where:

$\rho =$ density of fluid [kg/m^3]

$u =$ velocity of fluid [m/s^2]

and $\dot{m}_b''' =$ mass production rate per unit volume.

Equation for momentum

Equation 9 implies that the total force acting on a controlled volume is equal to the rate of change of momentum at a point and momentum flux through the surfaces of a small control volume.

$$\frac{\partial \rho u}{\partial t} + \nabla \cdot (\rho \vec{u} u) = -\nabla p + \nabla \cdot \tau + f \qquad 12$$

Where ρ is the fluid density and u is the velocity of the fluid and p is the disturbance in pressure, τ is the stress tensor and f is external force.

Equation of Energy

The energy is equation is given as:

$$\frac{\partial \rho h_s}{\partial t} + \nabla \cdot (\rho h_s \vec{u}) = \frac{\partial \overline{P}}{\partial t} + \dot{q}''' - \nabla \cdot \dot{q}'' \qquad 13$$

Where h_s is sensible enthalpy, ρ is the density, u is the velocity, $\overline{p}$ background pressure $\dot{q}'''$ is the heat release rate per unit volume and $\dot{q}''$ is the heat flux.

Boundary Conditions

All solid surfaces are assigned thermal boundary conditions, plus information about the burning behaviour of the material. Heat and mass transfer to and from solid surfaces is usually handled with empirical correlations [18].

Mesh Resolution

Mesh is an important factor in fire simulations. The simulation results are dependent on the grid cell sizes. Better simulation results are obtained when smaller grid cell sizes are used in simulations. When setting up a simulation in FDS the user needs to do mesh sensitivity analysis, depending on the scenario being simulated [16]. Traditionally, the grid should start with coarse mesh, and gradually refine the mesh until the desired result is obtained. This is called a grid sensitivity analysis.

3.0 METHODOLOGY

In this chapter, description of the building, inert gas systems, and the detection systems will be discussed. In addition, this chapter will also give a discussion on the experimental and simulation setup of the study.

3.1 Description of the Building

The dummy apartment used for the experiment is a timber construction containing three rooms: a living room, bedroom, and bathroom. The apartment was built at the Hall of Flame with the help of HH Fire Eater AS. The apartment was designed to be used by the risk – group. A radiator was used to heat up the room temperature to 20°C.The apartment has two internal doors, two exit doors, and five windows. A fire detection system, gas fire suppression system, and ventilation system were installed in the apartment. Table 9 gives detailed information about the opening locations, building geometry, and dimension of the components of the building.

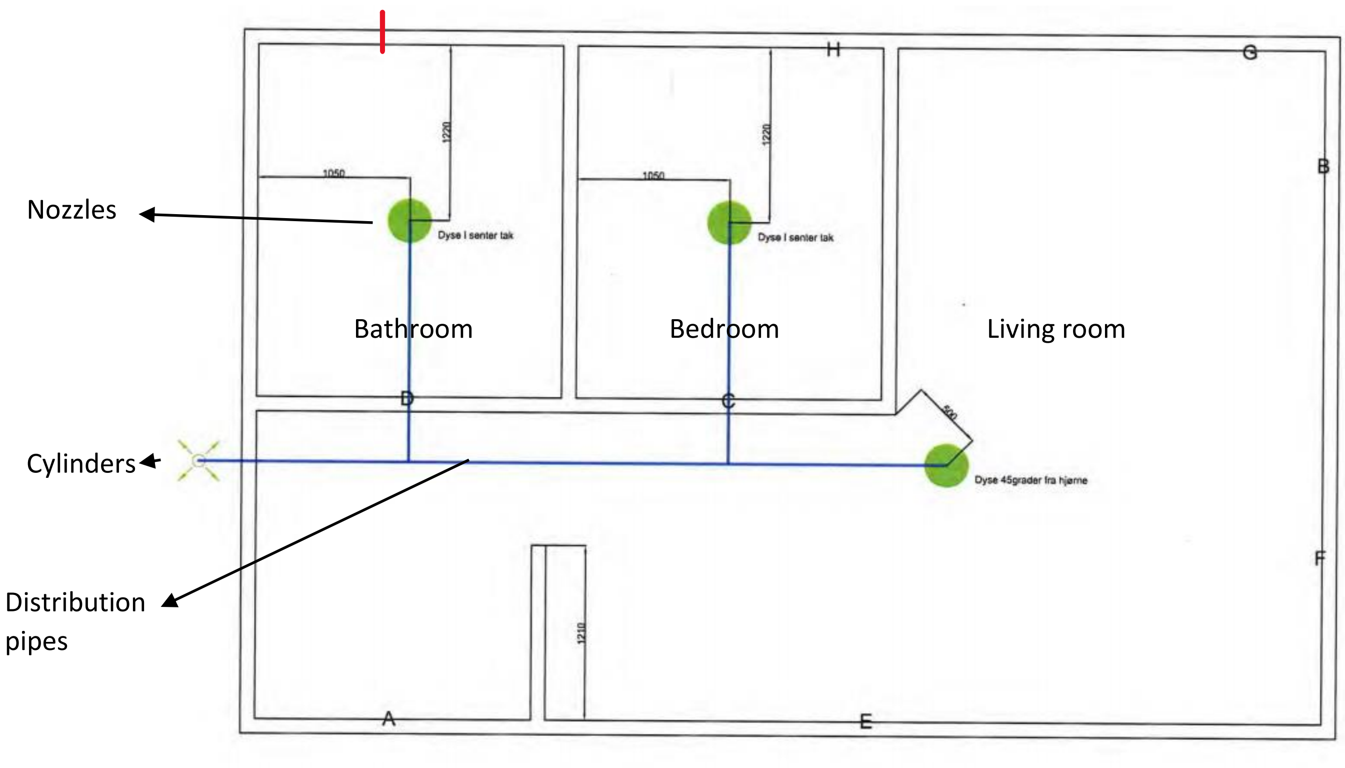


Figure 4: A schematic description of the building

Table 9: Description and dimension of building components

Building Information		
Building location		Hall of flame
Height of compartment		2.43 m
Length of compartment		7.34 m
Width of compartment		4.68 m
Volume of compartment		83.5 m^3
Wall thickness		0.1 m
Living room		17.2 m^2
Hall		4.3 m^2
Bedroom		5.4 m^2
Bathroom		5.4 m^2
Distance from window base to the floor		1.0 m
Building Component		**Dimension**
A	Door A	0.78 x 2.0 m
B	Door B	0.81 x 2.02 m
C	Door C	0.81 x 2.02 m
D	Door D	0.81 x 2.02 m
E	Window E	0.98 x 1.08 m
F	Window F	0.98 x 1.08 m
G	Window G	0.51 x 1.20 m
H	Window H	0.51 x 1.20 m
I	Window I	0.51 x 1.20 m

3.1.1 IG-541 Fire Extinguishing System

The building was protected with an inert gas fire extinguishing system containing the following components: 1 pressurized gas cylinder, a pressure gauge and actuator, manifolds and gas distribution pipes, a fire alarm, a multi-criteria smoke detector, and nozzles. The table below gives the system information of the inert gas fire extinguishing system.

Table 10: system information of the inert gas fire extinguishing system [19]

Parameter	Calculation	Limit
Cylinder pressure (fill) 15 ºC	300 barg	NA
Cylinder volume	80 L	NA
Number of cylinders	1	NA
Mass flow	1.37 kg/s	NA
Maximum pipe length	6.7 m	300
Pipe to cylinder volume	1.1%	20 % max
Discharge time to target	120 sec	120 sec (max)
Discharge time to 95% total IG 541	181.9 sec	30 – 300 sec
Max pipe pressure	122.7 barg	Define by pipe
Temperature (cylinder storage)	20 ºC	Nil
Living room nozzle flow	0.95 kg/s	
Bedroom nozzle flow	0.21 kg/s	
Bathroom nozzle flow	0.21 kg/s	
Number of nozzles	3 (type – IN 15)	100 (max)
Nozzle flow max/min	0.95/0.21 kg/s	NA
Mass of IG-541	66.28 kg	-

The process of the test conducted can be depicted as part of the basic fire extinguishing process. The process of the experiment is illustrated in the figure below.

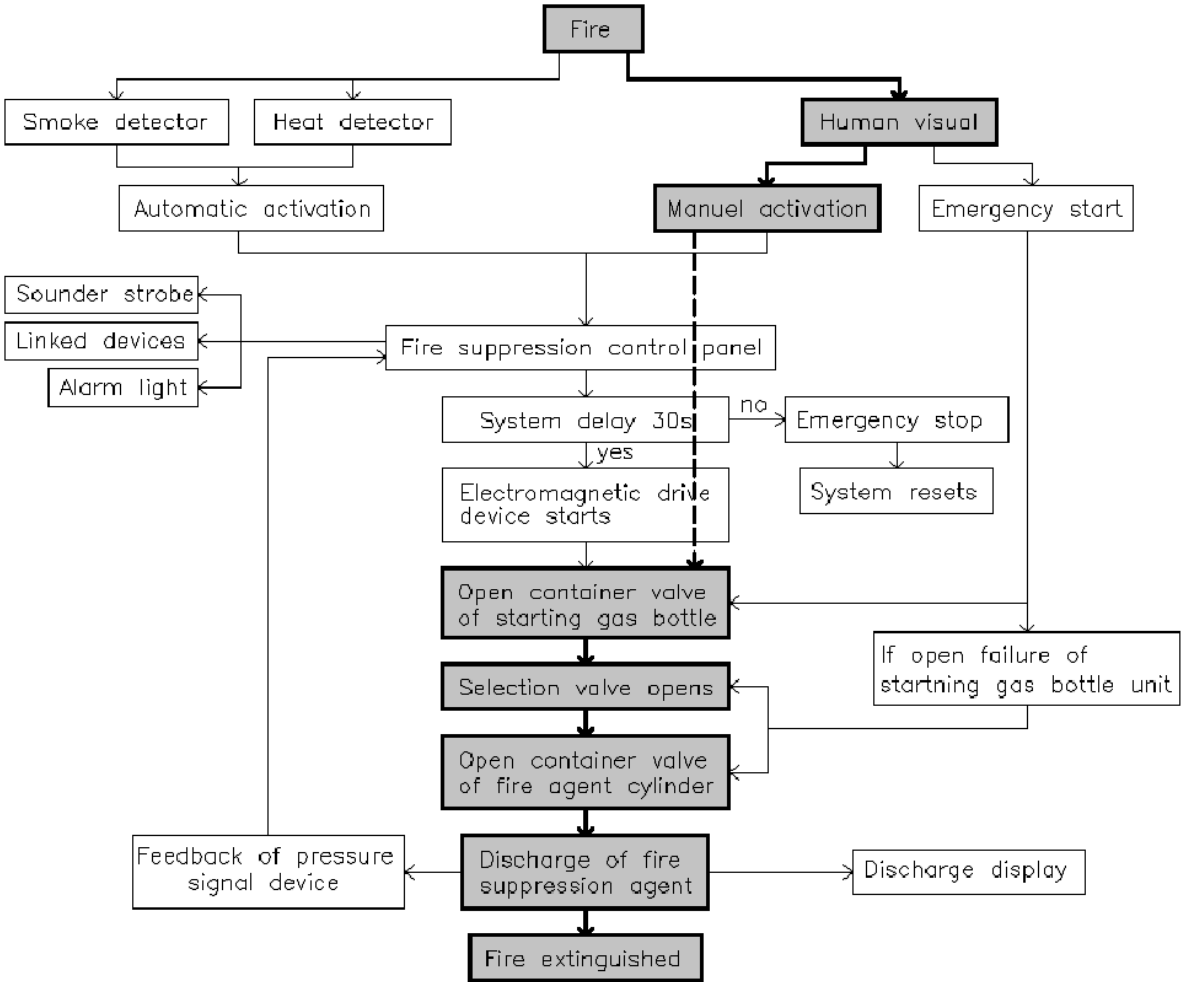


Figure 5: Flow diagram of a typical system design [20]

3.2 Experimental Set-up

This section addresses the choice of research method in this study, its characteristics, research validity, and reliability.

3.2.1 Oxygen Measuring Device Placement

When the gas fire extinguishing system is activated during a building fire, IG-541 is discharged into the protected space lowering the oxygen concentration in the enclosure. In this experiment, oxygen measuring devices were used to take the measurements of oxygen concentration at various locations in the building.

The oxygen measuring devices (D_0) were placed at 1.0 m and 2.0 m height from the floor, and 0.3 m away from the wall, at door A, window E, window F, and window G. They were fixed on a metal stand at these positions all through the duration of the experiment. The oxygen measuring devices placed at these heights were used to measure the level of oxygen at the middle and upper layers in the enclosure during the experiment.

Figure 6: Orientation of gas measuring device at different heights during the experiments (picture taken with RNE-L21-HUAWEI)

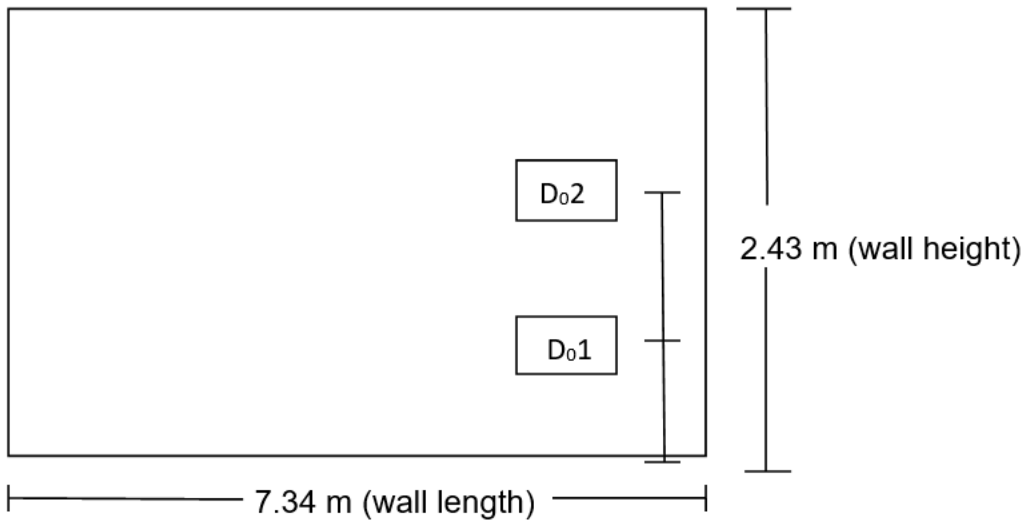


Figure 7: Placement of the oxygen measuring device in the enclosure

3.2.2 Ventilation system

A ventilation system was installed in the compartment to replace damp air inside with air from outside. For the ventilation system to function properly, duct size was determined based on-air velocity to avoid regenerating noise. The requirement was <2m/s, and 3m/s for the main duct at the ventilation unit and connection to the outside. The installation procedure of the ventilation system is listed in [21]. The procedure include:

- **Placing the valves** - The valve was placed in an area where it is assumed the occupants will not spend much time to minimize draught.
- **Placement of ventilation unit, silencers, and main duct** – The unit was placed in the compartment. It was placed at a point where noise generated by it will be minimal.
- **Air intake and exhaust** – an exhaust and intake ventilation duct were established outside the apartment.

The ventilation system installed in the apartment was used during the experiment. The figures below show the ventilation system in the apartment.

Figure 8: Ventilation system installed in the apartment at the Hall of Flame

3.2.3 Fire Alarm and Detection System

A fire alarm and detection system were installed in the apartment as shown in the figure below. Figure 9 show a control panel, power supply, and CO_2 detection unit, figure b is a control panel, while c is a multi-criteria and smoke detector. The components of the fire alarm and detection system installed are a fire alarm initiating device (multi-criteria detectors, smoke detectors), fire notification device (strobes), control panel, and power supply. The working principle of the system is designed as follows; when the smoke detector detects a fire in the apartment, it sends a signal to the control panel which in response activates the system.

a b c

Figure 9: Components of the fire alarm and detection system

Test Preparation and Execution

Traditionally, gas fire extinguishing systems are designed to extinguish or suppress fire in an air-tight space. The purpose of this experiment was to determine the performance of a gas fire suppression system when there is an opening in a building. Five different fire tests were conducted to achieve this aim. The tests include the following scenarios as indicated in table 11.

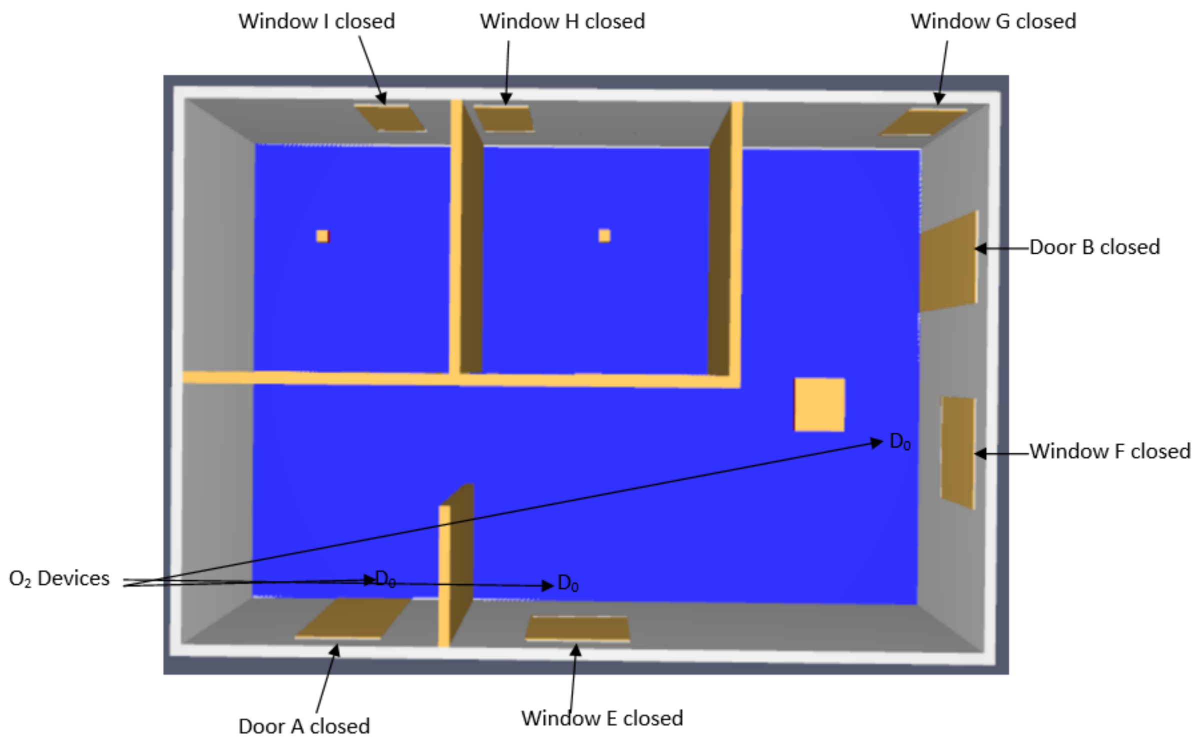


Table 11: Test, opening, and opening factor for each experiment conducted

Tests	Opening	Opening Factor
1	No opening	Nil
2	Door A (open)	0.02
3	Windows E and F (25cm open)	0.003
4	Window F (open)	0.01
5	Door A (14 cm open)	0.003

Though discharge nozzles are installed in all the rooms in the building, the experiment was conducted only in the living room.

The first test conducted was a reference case with all openings properly sealed. There were cracks on the ceiling and walls which will significantly affect the extinguishing effectiveness of IG-541. Every 10 seconds, the reading of oxygen concentration of the room was manually taken from the oxygen measuring devices placed at door A, window E, and window F. The two primary objectives for this reference test were:

1 Verify the possibility to create oxygen concentration levels in the living room between 10 – 15 % over time.

2 Evaluate IG 541 performance in relation to known holding time models for protected spaces with no opening.

Tests 2,3,4 and 5 were done using the same procedure as test 1. The primary objectives for these tests were:

- To investigate how small openings will affect gas fire suppression systems
- To investigate the effectiveness of a gas fire extinguishing system when the opening size is medium (when the door or window is slightly open)
- To study how large openings will affect the fire suppressions system (When a door or window is widely open)

The pictures below show the orientation of the enclosure opening for tests 3,4,5, and cracks on the ceiling respectively.

window E 25 cm open

window F 25 cm open

Figure 10: Compartment opening for test 3

window E open

Door A 14 cm open

Figure 11: opening orientations for tests 4 and 5 respectively

Figure 12: Crack on the ceiling

Table 12: Summary of the details from the experiment

Test ID	Gas Agent	Discharge Time (s)	Holding Time (s)	Duration of Experiment (minutes)
Test 1	IG - 541	120	720 minimum	47.2
Test 2	IG - 541	120	720 minimum	13.2
Test 3	IG - 541	120	720 minimum	25.2
Test 4	IG - 541	120	720 minimum	24.7
Test 5	IG - 541	120	720 minimum	29.8

3.3 Simulation Setup

The simulation was set up and run with Pyrosim software. It is a CFD model which has been used in fire simulations as it has been validated in many cases [22].

The geometry of the compartment built with Pyrosim include 7.34 m wall length, 4.68 m wall width, 2.43 m wall height, 0.1 m wall thickness, and 0.1 m ceiling thickness. The compartment has an extension of 1.0 m and 0.5 m on the front and right view respectively. The wall/ceiling is inert by default.

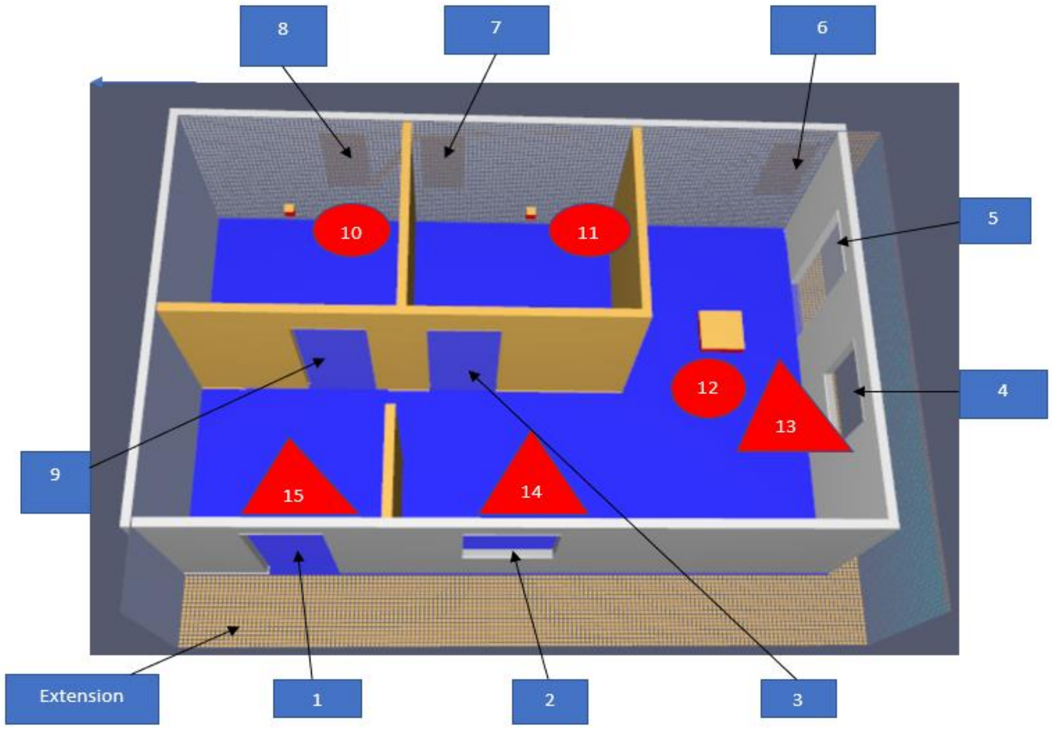


Figure 13: Simulation set up of the compartment using Pyrosim

Three nozzles were set up in the model in the bathroom, bedroom, and living room. The dimension of the nozzle includes: 0.1 m × 0.1 m × 0.1 m for bathroom and bedroom and 0.45m × 0.45m × 0.1m for the living room. The mass flow of the nozzles in the apartment was 1.37 kg/s, and the mass flux is 5.26 kg/s·m^2.

Table 13: Dimension and discharge rate of the nozzles

Room	Nozzle dimension	Discharge rate
Living room	0.45m × 0.45m × 0.1m	0.95 kg/s
Bedroom	0.1 m × 0.1 m × 0.1 m	0.21 kg/s
Bathroom	0.1 m × 0.1 m × 0.1 m	0.21 kg/s

The temperature of the compartment was 20°C, and the dimension of the doors and windows are obtained in table 9. The gas-phase devices were positioned at door A, window E and window F for all the scenarios except the third scenario where oxygen measuring devices (D_0) at window E were repositioned to window G. D_0 were placed at three different heights: 0.3, 1.0, 2.0 meters to measure the oxygen concentration in the room. To model the effect of a crack, a zone pressure leakage was set up. A leak surface was created with leakage area of 0.5 m^2. In other to obtain a reasonable result, a mesh was set up in the model. The mesh size of 5.0 cm was used. X Cells:158, Y cells: 120, and Z : cells: 48. The total number of mesh is 910,080. The simulation setup was with specifications from the experiment. The simulation script can be found in the Appendix section. The simulations were performed for the cases using different opening orientations. The five scenarios from the experiment were simulated. The difference between the simulation setup with the experiment setup is the number of D_0, while two were used in each location during the experiment, the simulation had three.

Table 14: Description of building components

1	Door A	6	Window G	11	Discharge nozzle bedroom
2	Window E	7	Window H	12	Discharge nozzle living room
3	Door C	8	Window I	13	Oxygen measuring device
4	Window F	9	Door D	14	Oxygen measuring device
5	Door B	10	Discharge nozzle bathroom	15	Oxygen measuring device

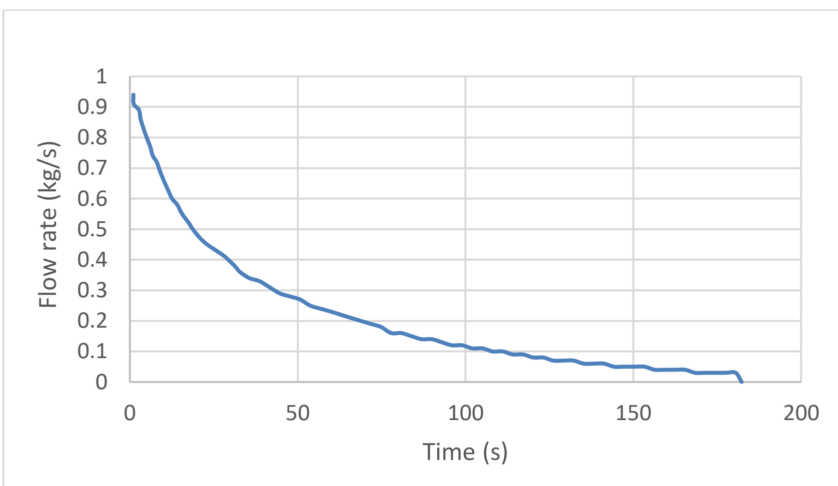


Figure 14: Mass flow of nozzles

4.0 RESULTS

This section discusses the experimental and simulation results using data obtained from both methods. The measurement was taken from three locations: door A, window E, and window F in the experiments, while in simulations, oxygen concentration considered the level of oxygen in all the enclosure. The concentration reduces when a gas fire extinguishing system discharge inert gas in the enclosure to suppress a fire. To achieve the objectives of this study, the effects of small, medium, and large openings will be investigated.

4.1 Experimental Results

In this section, the experimental results are discussed. A total of 5 tests were conducted. During the first test, all building components were closed. Although, there existed some openings on the walls and ceiling which accounted for leakage of the discharge agent during the experiments.

Test 1- No opening

The figures below show a graph of the oxygen concentration of the middle layer and upper layer in the compartment respectively.

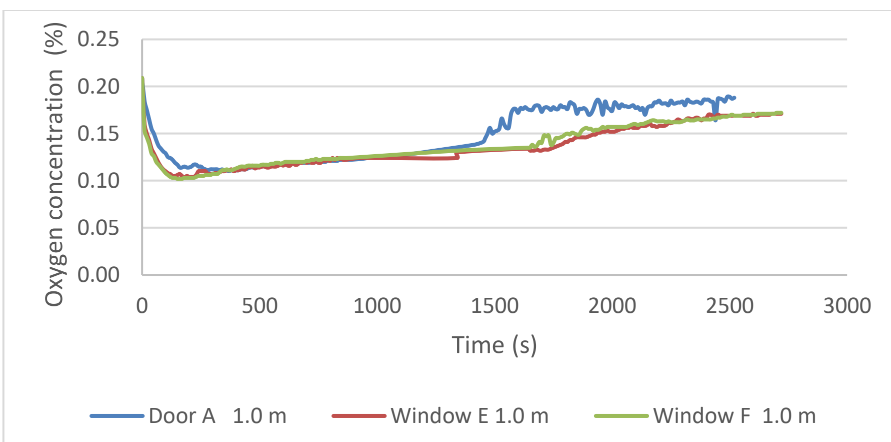


Figure 15: Oxygen concentration at a height of 1.0 m when all openings are closed.

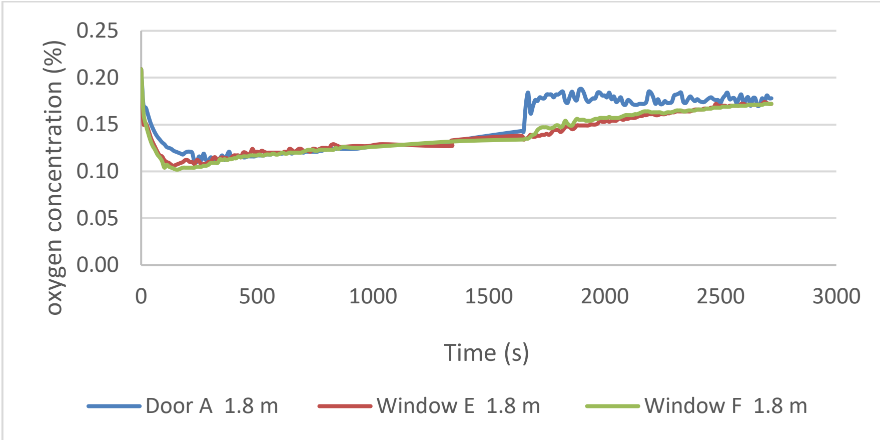


Figure 16: Oxygen concentration at 1.8 m height when all openings are closed.

Figure 15 shows the oxygen concentration of the middle layer, while figure 16 shows the oxygen concentration of the upper layer. The blue and red lines represent oxygen concentration measured at door A and window E respectively, while the green line represents the oxygen level at window F. Before the discharge of the inert gas agent, the concentration of oxygen in the compartment was 21.0%. At door A, window E, and window F, the minimal design concentration of oxygen was 12.0 % after 180 seconds (end of discharge time). It can be observed that there was a gradual increase in oxygen level at the locations almost throughout the post-discharge time. There was a rapid increase in oxygen level at door A at 1460 seconds. The rapid increase of oxygen level at door A was obtained because the door was opened at that time which created a pathway for oxygen from the surroundings to be re-introduced into the compartment while IG-541 is leaked out at the same time.

4.1.1 Effects of Large Opening on Inert Gas Systems

In this section, the effects of large openings are investigated. The large opening in the compartment is the door which was completely kept open during the experiment.

Test 2 – One door open (Door A)

Figures 17 and 18 show graphs of oxygen concentration in the middle and upper layers of the compartment at three locations respectively. From the figures, it can be observed the oxygen concentration at locations away from the door opening (Windows E and F) was reduced to below 15.0% during the discharge time. 15.0% of oxygen is the most negligible concentration of oxygen to sustain a flaming fire in an enclosure. The implication is that fire will be extinguished in the compartment when the inert gas fire extinguishing system is activated. However, after the discharge period, due to the loss of the fire extinguishing agent through the opening at the door, the concentration of oxygen in the compartment began to rise.

At the door location, the concentration of oxygen was above 15.0% in both layers during the discharge period. This was due to the close distance from the door opening as ambient oxygen easily made its way into the compartment. The holding time of the inert gas system in this apartment is 3.8 minutes.

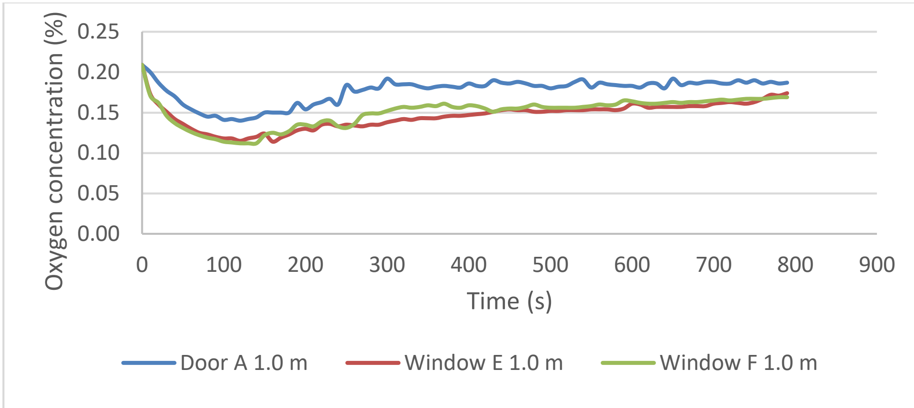


Figure 17: Oxygen concentration at height 1.0 m at door A, window E, and window F. TEST 2.

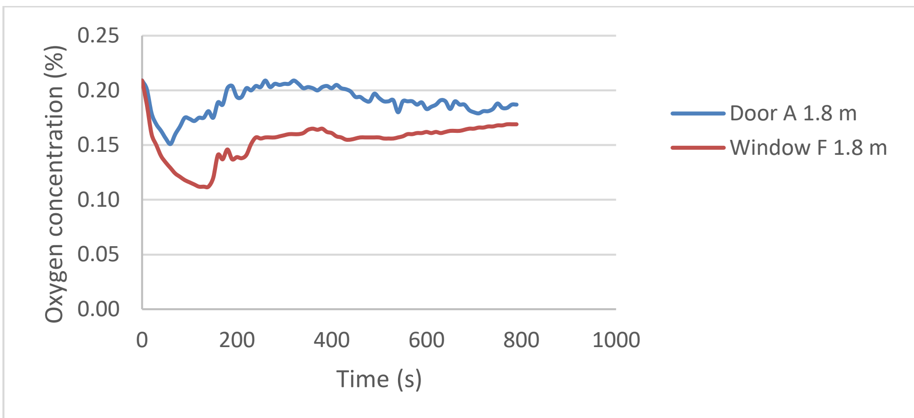


Figure 18: Oxygen concentration at height 1.8 m at door A, and window F. TEST 2.

In figure 18, there was not data obtained for oxygen concentration at window E location because the oxygen detector placed at the upper layer malfunctioned during the experiment.

4.1.2 Effect of Medium Openings on Inert Gas Systems

In this section, the effects of medium openings are investigated. The medium opening in the compartment is at window F which was completely kept open during the experiment.

Test 4 – 1 window open (Window F)

In this experiment, the opening location was at window F. In figure 19, it can be observed that the oxygen concentration at window E and door A were reduced to below 15.0%. These locations are farther from the opening compared to window F location with the highest concentration of oxygen. Since the concentration of oxygen is lower at these locations, therefore it implies that fire extinguishment will be achieved in event of fire in the apartment when the opening size is medium. At window F, the concentration is above the design concentration of oxygen that will extinguish fire. Oxygen level increased in the post-discharge period. Oxygen concentration at window E and door A locations descended below 15.0% at 50 seconds during the discharge time and increase above the same percentage at 400.0 seconds. Therefore, holding time of the inert gas system in the enclosure when the opening size is medium is 5.8 minutes. The holding time of the IG-541 gas extinguishing system obtained in this experiment was below the requirement as stated in [2].

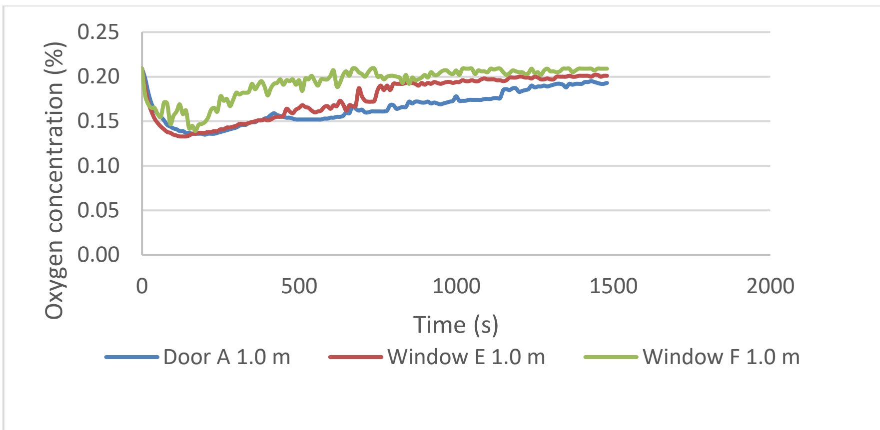


Figure 19: Oxygen concentration at height 1.0 m, at door A, window E and Window F. TEST 4

In figure 20, The oxygen concentration at window E and door A decreased below 15.0% at 50 seconds. However, the locations experienced an increased in concentration at different times during the post discharge time. At window E, the level of oxygen rose above 15.0% in 200 seconds while same scenario occurred at door A in 280 seconds. Window E is closer to Window F which explains why oxygen level first increased at the location. Since the oxygen concentration at these locations were reduced below 15.0% by the fire extinguishing agent, it implies that fire will be extinguished at this layer.

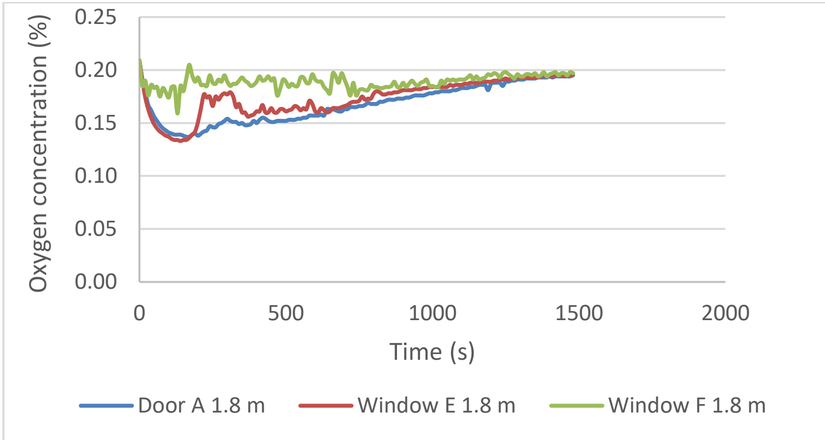


Figure 20: Oxygen concentration at height 1.8 m at door A, window E, and window F. TEST 4.

4.1.3 Effect of Small Openings on Inert Gas Systems

In this section, the effects of small openings are investigated. The small opening in the compartment is at window E and F, and door A which were kept 25 cm and 14 cm open respectively during the experiment.

Test 3 – 25 cm opening at 2 windows (Window E and Window F)

The figures 21 and 22 show a graph of the oxygen concentration of the middle layer and upper layer in the compartment respectively. Oxygen concentration was measured at window F, window G, and door A locations. In other experiments, the oxygen level was measured at window E. Oxygen level was measured at window G in this experiment because of its close distance to fire as the experiment was conducted with a burning flame. Taking measurements at this location became difficult because of smoke and heat from the fire.

From figure 21 and figure 22, it can be observed that the concentration of oxygen at window G and door A did not fall below the required concentration of oxygen to extinguish a fire (15.0%). Since there were two openings in this experiment, it may have led to loss of more IG-541 gas which resulted in the oxygen level in the compartment not reducing below the required threshold to extinguish fire.

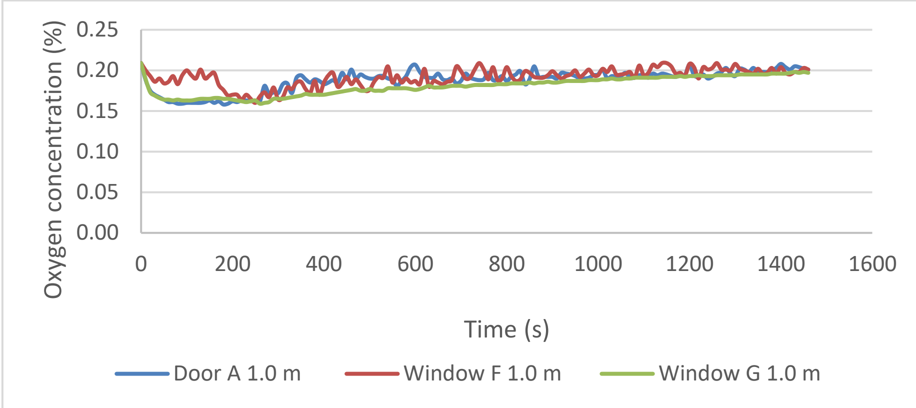


Figure 21: Oxygen concentration at height 1.0 m at door A, window F, and window G. TEST 3.

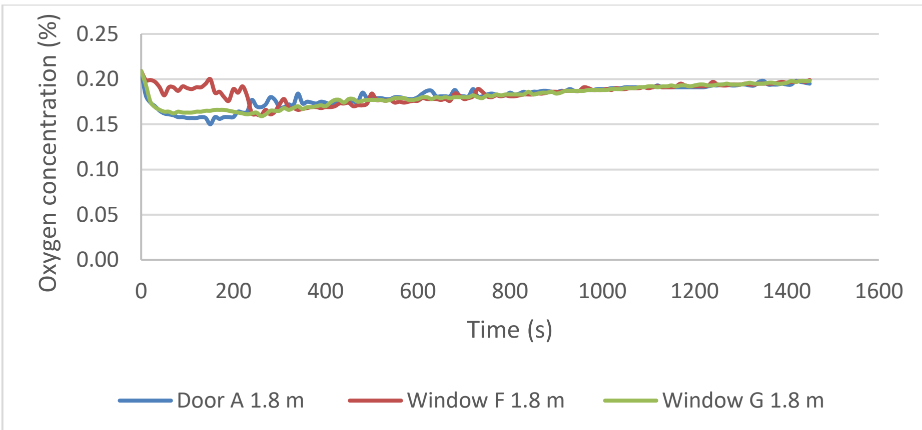


Figure 22: Oxygen concentration at height of 1.8 m at door A, window F, and window G. TEST 3.

Test 5 – Door open 14 cm

In **Figure 23**, it can be observed that the oxygen level at the 3 locations followed the same trend during the discharge period. They had approximately the same oxygen distribution during and after the discharge time. This was because of the size of the opening at the door which was little and therefore, a limited quantity of IG-541 was permitted to flow out of the enclosure. The minimum oxygen level obtained was 11.0%. During the discharge time, the oxygen concentration at window E and window F were slightly lower than at door A. In all the locations, the concentration of oxygen measured were within the threshold to extinguish a fire.

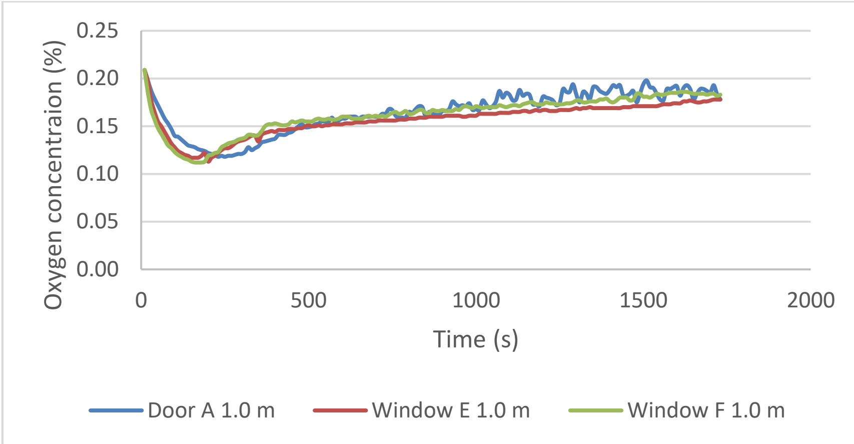


Figure 23: Oxygen concentration at height 1.0 m at door A, window E, and window F. TEST 5.

In figure 24, during discharge period, the oxygen concentration in the compartment was reduced to the region where fire extinguishment would occur. The oxygen level at the window locations were lower than what was obtained at the door location. The concentration as obtained in figure 23 were reduced below 15.0% which will eventually extinguish a fire. There was a rapid rise of oxygen level at the end of discharge time (180 seconds). Just as obtained in the previous experiments with openings, the holding time of the inert gas agent was shorter compared to the recommendations as stated in [2]. The holding time for this Test is 6.8 minutes.

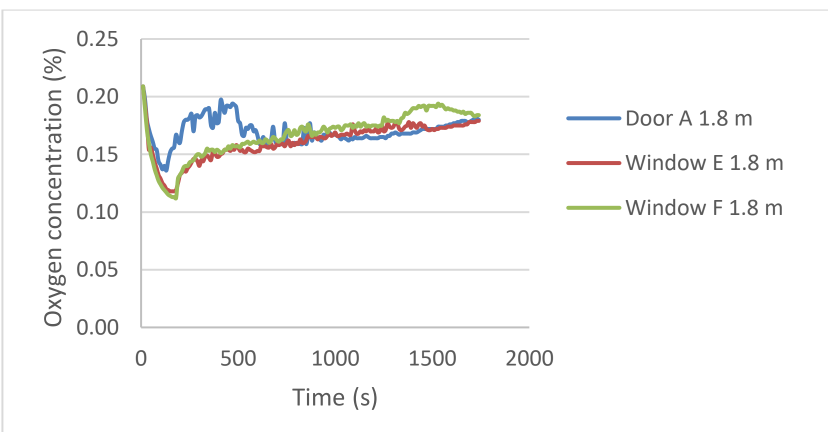


Figure 24: Oxygen concentration at height 1.8 m at door A, window E, and window F. TEST 5.

4.1.4 Opening factor vs Holding Time

The opening factor is an important parameter that determines flow rates through the openings of an enclosure. It is a function of the dimension of an opening. Table 15 below shows the summary of the opening factors of the enclosure openings, the oxygen level at locations far from the opening during the discharge time, and the level of oxygen at the minimum holding time for each scenario. From the table, it can be observed that test 1 had a negligible opening factor and the oxygen concentration of the compartment during the discharge period and post-discharge period was kept within the threshold to extinguish fire (below 15.0%) in both layers. In test 2, the opening factor is 0.02. In the middle layer, the oxygen concentration in the apartment at 120 seconds was 11.0% implying that the effect of the opening was little during the discharge time. At 720 seconds, the oxygen concentration increased 16.0% which shows that the opening had a significant effect on the inert gas system during post-discharge time in the middle layer. At the upper region test 2, the effect of the opening was the same as seen in the middle layer. In test 3, the opening factor is 0. 003. In 120 seconds, the oxygen level at the middle layer of the apartment was 16.2%, while at the end of post-discharge time at was 18.6%. In the upper layer, the oxygen level at the end of discharge time was 16.05% which increased to 18.55% in 720 seconds. The effect of the opening on the inert gas system is not very significant. Test 4 has an opening factor of 0.01, the opening factor affected the inert gas system significantly. In the last scenario, the opening factor is 0.003. The oxygen level was 12.0% at the end of discharge time and 15.85% 110 minutes later in the lower layer. In the upper layer, the increment was from 12.1% to 16.1%. The opening also affected the system significantly.

Table 15: Effects of opening factor, opening height and number of openings on oxygen concentration

Tests	Opening	Opening Factor	O_2 conc. middle layer		O_2 conc. upper layer	
			120 sec	**720 sec**	**120 sec**	**720 sec**
1	No opening	Nil	11.17%	12.03%	11.3%	12.2%
2	Door A open	0.02	11.0%	16.0%	11.0%	17. 5%
3	Windows E and F (25cm open)	0.003	16.2%	18.6%	16.05%	18.55%
4	Window F	0.01	13.6%	16.6%	13.65%	16.7%
5	Door A 14 cm open	0.003	12.0%	15.85%	12.1%	16.1%

4.1.5 Concluding Remarks

The experimental results on effects on enclosure opening have been presented in this chapter. Oxygen concentration as a function of time has been presented for different openings. From the results, it was observed that oxygen concentration was reduced (to below 15.0%) at locations far from the openings. The overall oxygen level in the compartment during the discharge period was seen to be reduced to a threshold within which fire extinguishment would occur when the number of openings is one. When the opening is more than one, the oxygen level in the apartment did not go down below 15.0%. At this point, extinguishing fire may be a difficult task.

4.2 Simulation Results

In this chapter, the simulation result is presented. The results are compared with the experimental results to determine how well the Pyrosim/FDS could predict the experimental results. Furthermore, in this section, the oxygen distribution in different locations at different heights is analyzed.

4.2.1 Experiment vs Simulation

The graphs show the results obtained from the simulation using Pyrosim/FDS. The result is compared with the experimental result to see how simulation methods can be used to reproduce the experimental results. The simulation has been performed for the same scenarios as obtained in the experiments. The result in scenario 1 and scenario 2 shows the effect of enclosure openings on gas fire extinguishing systems. In most cases, the simulation result gave a reasonable prediction of the experimental result. In tables 16 and 17, the experimental and simulation results are compared. Results for scenario 3, 4, and 5 is found in appendix A section.

Scenario 1 – No opening

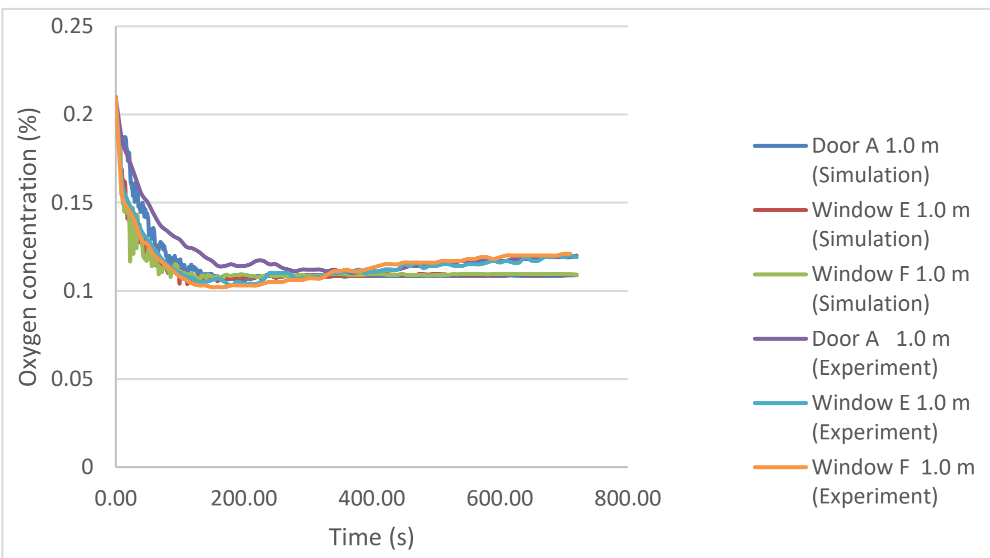


Figure 25: Comparison between experimental and simulation results of oxygen level at a height of 1.0 m when all openings in the compartment are closed.

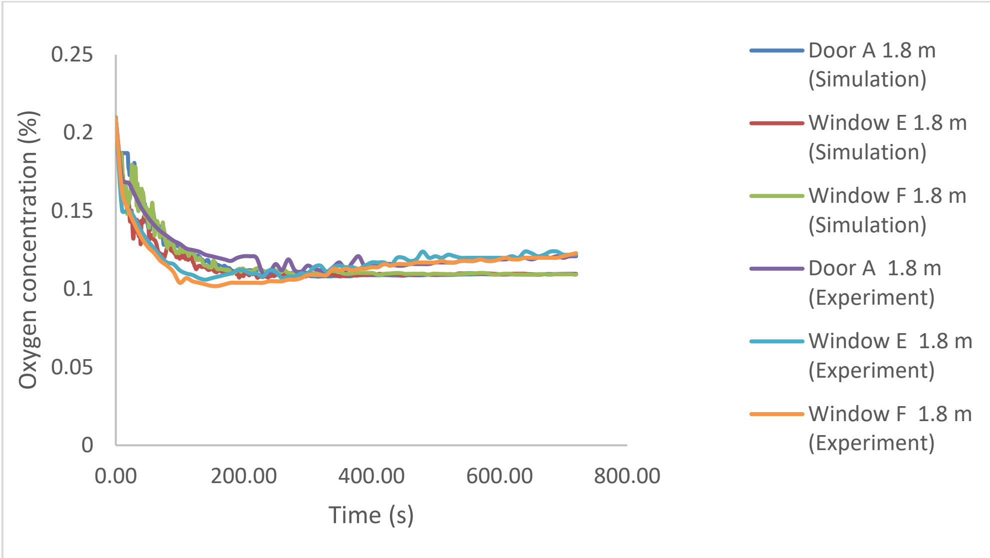


Figure 26: Comparison between experimental and simulation results of oxygen level at a height of 1.8 m when all openings in the compartment are closed.

Figure *25* and Figure *26* show the results of the comparison between the experimental results and simulation results for the closed compartment. The comparison done is for the oxygen concentration at 1.0 m and 1.8 m above the floor of the enclosure. From the figures above, the simulation result overestimated the amount of oxygen gas in the enclosure after the discharge time. It should be noted that the decrease in oxygen concentration in a compartment implies a rise in the level of IG – 541 gas concentration in the apartment. It can also be observed that the simulation result predicted an even distribution of IG-541 across the entire space as obtained from the experimental results. Furthermore, the simulation result indicated a minimal deviation from the experiment during the post-discharge time. While the result from the experiment showed a gradual increase in oxygen concentration during the post-discharge time, the simulation result showed approximately the same oxygen concentration. The deviation obtained from the simulation was because of the leakage areas in the compartment. The dummy apartment used for the experiment contained more leakage area than the simulation, hence more IG-541 inert gas agent was lost to the surroundings. In the scenario with no openings, the simulation result gave a very good prediction of the of the experimental result.

In table 16, the experimental and simulation results are compared for the first scenario.

Table 16: Comparison of the experimental and simulation result

Scenario 1 height 1.0 m	
Experiment	**Simulation**
Oxygen concentration reduced to 15.0% in 20 seconds at the window locations.	Oxygen concentration reduced to 15.0% in 20 seconds at the window locations.
The minimum design concentration to extinguish fire (10.0%) was reached in 180 seconds.	The minimum design concentration to extinguish fire (11.0%) was reached in 180 seconds.
Oxygen concentration increased to 12.0% 10 minutes after the discharge time.	Maintained a constant concentration (11.0%) during post-discharge time.
Oxygen concentration reduced to 15.0% at door A after 50 seconds.	Oxygen concentration at door A reduced to 15.0% after 26 seconds.
Adequate holding time as recommended in [2] was attained.	Adequate holding time as recommended in [2] was attained.
Scenario 1 height 1.8 m	
Oxygen level was reduced to 15.0% after 20 seconds at the window locations.	Oxygen level was reduced to 15.0% after 20 seconds at the window locations.
Oxygen level was reduced to 15.0% after 50 seconds at the door location.	Oxygen level was reduced to 15.0% after 50 seconds at the door location
Minimum extinguishing concentration (10.8%) was reached in 180 seconds.	Minimum extinguishing concentration (10.8%) was reached in 180 seconds.
Oxygen level increased to 12.0% after 720 seconds.	Oxygen level remained constant (11.0%) after 720 seconds.

Scenario 2 – One door open (Door A)

In the figures below, the results from Pyrosim/FDS simulation were compared with the experimental results of oxygen concentration when one door was open. From **Figure *27***, it can be observed that the FDS result presents a similar trend to the experimental result at 1.0 m. For both methods, the oxygen level increased after the discharge of the inert gas in the enclosure. However, the simulation result predicted a lower oxygen concentration at door A, while a higher oxygen level was measured in the experiments. The simulation result indicated a higher oxygen level at windows E and F after the discharge period as opposed to the experiment where a lower oxygen concentration was measured. Generally, the simulation result indicated a shorter holding for the IG-541 gas extinguishing system.

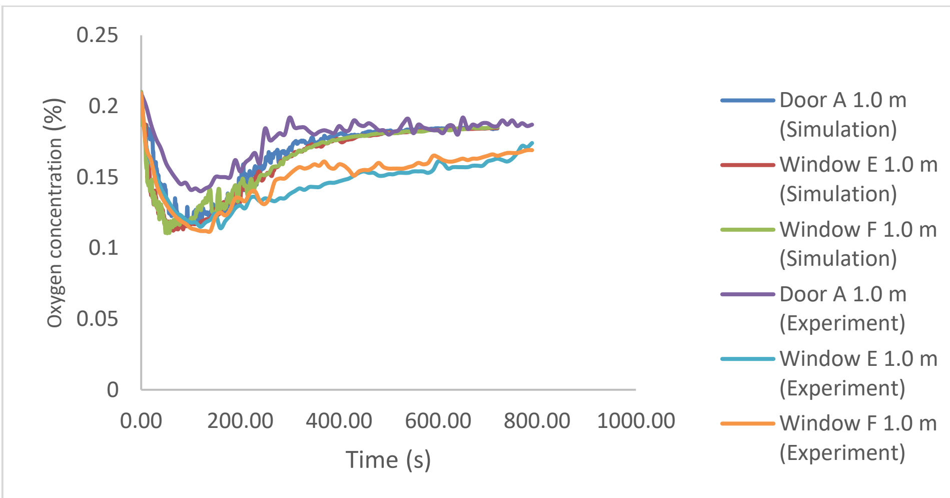


Figure 27:Comparison between experimental and simulation results of oxygen level at a height of 1.0 m when 1 door is open in the compartment.

In Figure *28*, the oxygen concentration measured at a height of 1.8 m in the experiments at the various locations was compared with the result obtained from the simulation. The result from simulations shows the same trend as the experiment. Both results indicated a significant difference in the distribution of oxygen at the locations with opening and locations with no opening. The oxygen concentration at the door during the discharge time did not show a regular pattern from the simulation. The chaotic pattern may be because of the interaction of air and IG – 541 gas. After discharge time, the simulation result predicted a constant oxygen concentration at the upper layer (figure 29). As recorded from the experiment, the simulation indicated a reduced holding time which is correct as indicated by the experimental result. In table 17, the experimental and simulation results are compared for the second scenario.

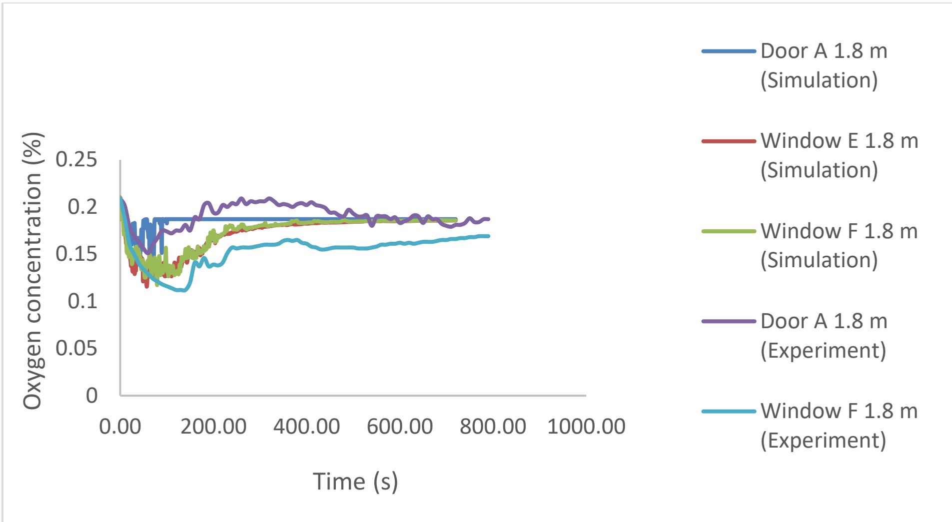


Figure 28: Comparison between experimental and simulation results of oxygen level at a height of 1.8 m when Door A is open

Table 17: Comparisons of simulation and experimental results for the second scenario

Scenario 2 height 1.0 m	
Experiment	**Simulation**
Oxygen level reduced to 15.0% after 70 seconds at the door A location.	Oxygen level reduced to 15.0% after 32 seconds at the door A location.
Oxygen level reduced to 15.0% after 30 seconds at the window locations.	Oxygen level reduced to 15.0% after 20 seconds at the window locations.
At the end of discharge time (180 sec), the oxygen concentration at door A was 15.0%.	At the end of discharge time (180 sec), the oxygen concentration at door A was 13.0%.
At the end of discharge time (180 sec), the oxygen concentration at the window locations were 12.0%.	At the end of discharge time (180 sec), the oxygen concentration at the window locations were 13. 0%.
In 720 seconds, the oxygen level was 19.0% and 16.0% at the door and windows respectively.	Prediction 18.0% oxygen level in all the location at the end of the post-discharge period.
Scenario 2 height 1.8 m	

Oxygen level reduced to 15.0% in 60 seconds at the door location.	Oxygen level reduced to 15.0% in 40 seconds at the door location.
Oxygen level reduced to 15.0% in 30 seconds at the window locations.	Oxygen level reduced to 15.0% in 24 seconds at the window locations.
At the end of discharge time, the oxygen level was 20.2% at the door.	At the end of discharge time, the oxygen level was 19.0% at the door.
At the end of discharge time, the oxygen level at the window locations were 14.0%.	At the end of discharge time, the oxygen level at the window locations were 15.0%.
Minimum extinguishing concentration (11.0%) was reached in 120 seconds.	Minimum extinguishing concentration (13.0%) was reached in 87 seconds.
Oxygen level after 720 seconds is 17.0%.	Oxygen level after 720 seconds is 19.0%.

4.3 Oxygen Distribution at 0.3 m, 1.0 m, and 1.8 m Heights

IG – 541 has a higher density than air. During discharge in a compartment, IG – 541 flows towards the lower region displacing the oxygen in the process. The oxygen content displaced is a function of height. At a lower height, more oxygen is displaced creating an atmosphere of lower oxygen concentration. In this section, the oxygen distribution across three different layers in the enclosure was analyzed. The layers analyzed are the lower, middle, and upper layers. Scenarios 1 and 2 are discussed in this section. The results of scenarios 3, 4, and 5 are presented in Appendix B

4.3.1 Oxygen Level at Door A, Window E, and Window F

Scenario 1- No Opening

In Figure *29*,Figure *30*, and Figure *31*, the oxygen concentration at three heights above the floor of the enclosure when there is no open is presented. From the figure, it can be observed that during the discharge time, the oxygen concentration increases with height. At minimum height (0.3m), the least oxygen level was recorded followed by the medium height (1.0m). The Upper layer (1.8m) recorded the highest concentration of oxygen. During the post-discharge time, the oxygen level at all heights were approximately the same. discharged at the initial stage than it would be at the door A location. During the post-discharge time, the distribution of oxygen was even across all the locations.

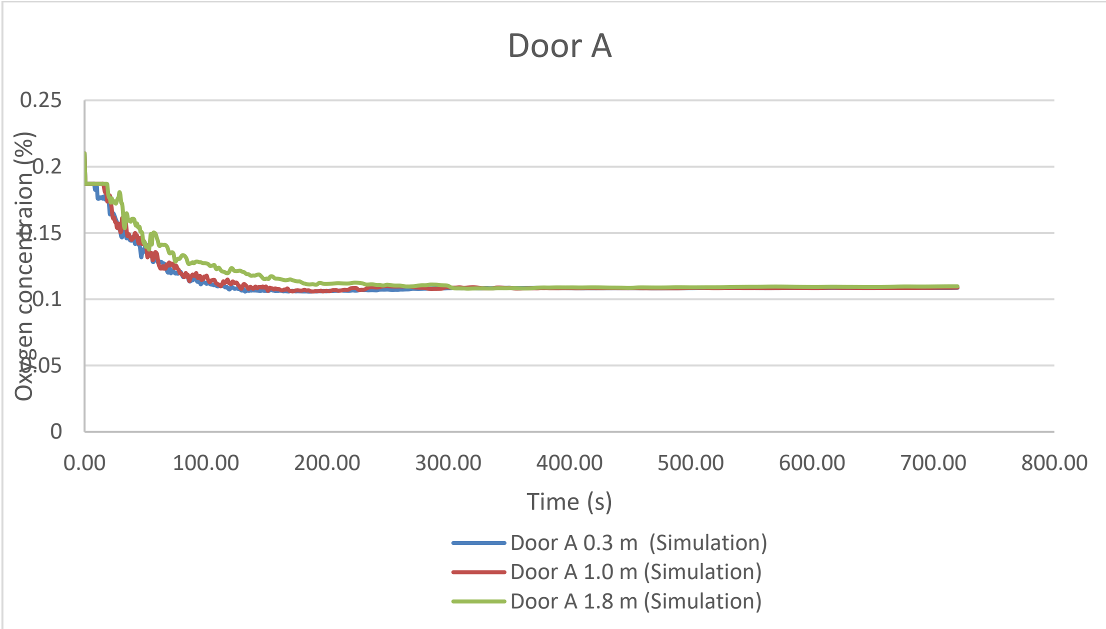


Figure 29: Oxygen concentration at different heights at door A location

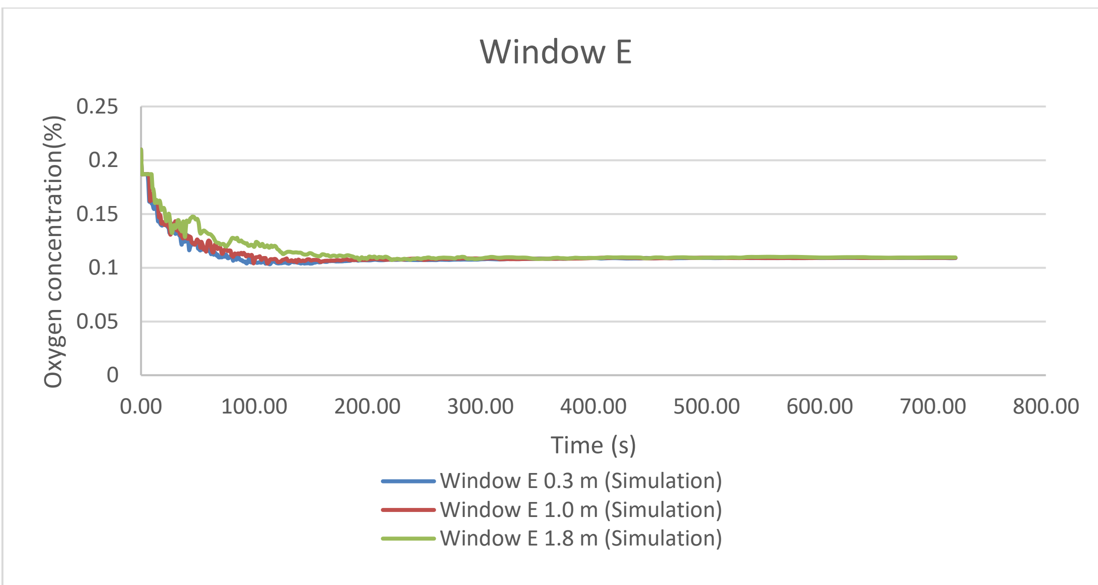


Figure 30: Oxygen concentration at different heights at window E location

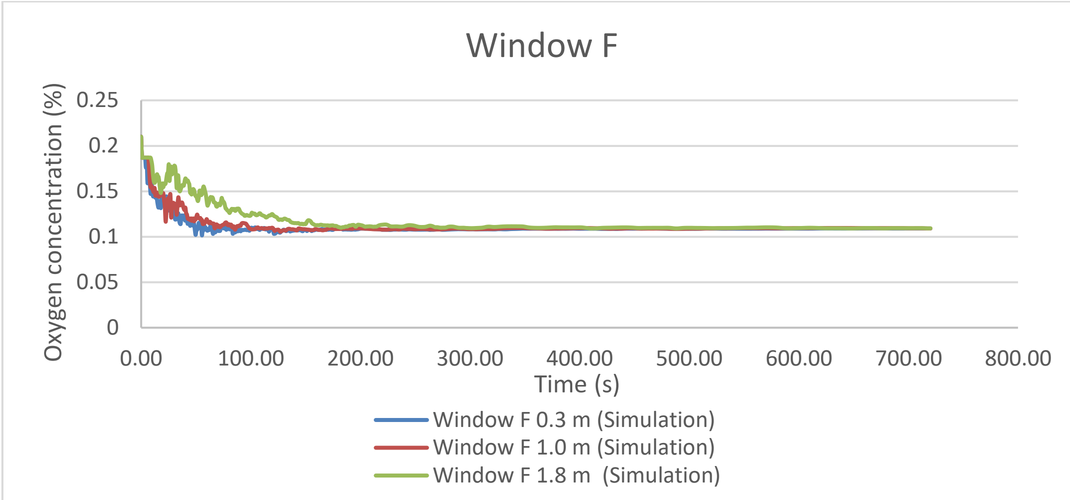


Figure 31: Oxygen concentration at different heights at window F location

Scenario 2 – Door A open

Figure *32*,Figure *33*, and Figure *34***,** shows the oxygen concentration at the lower, middle, and upper levels of the compartment when door A is open at the three locations. From the figure, it can be observed that the highest oxygen level is obtained at the 1.8 m which is the greatest height. During the discharge time, the oxygen level at the middle and lower layers were approximately the same. After the time of discharge the oxygen level at the three layers increased at different rates creating a significant difference of concentration at the layers.

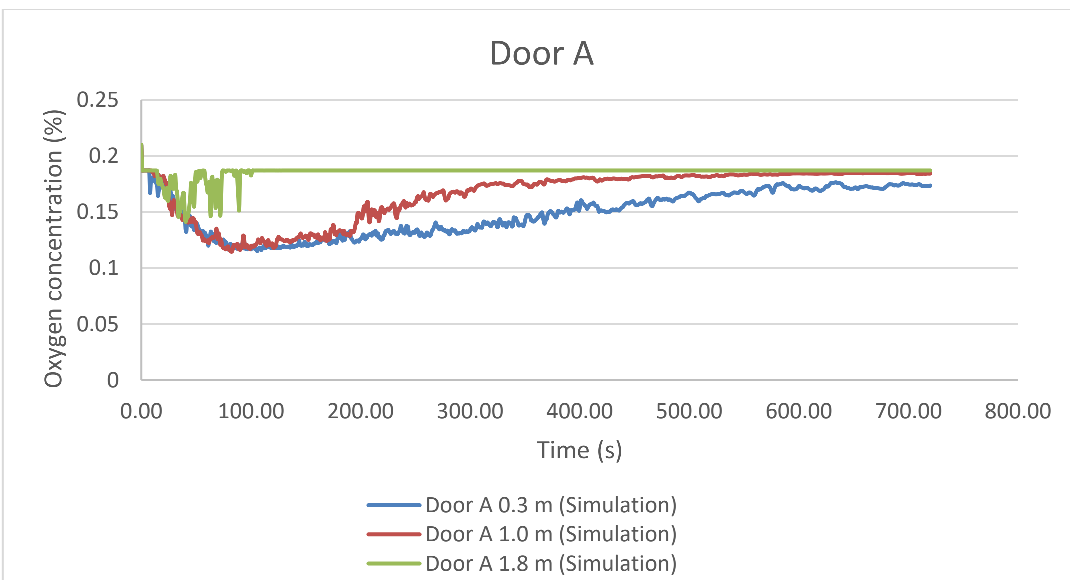


Figure 32:Oxygen concentration at different heights at door A

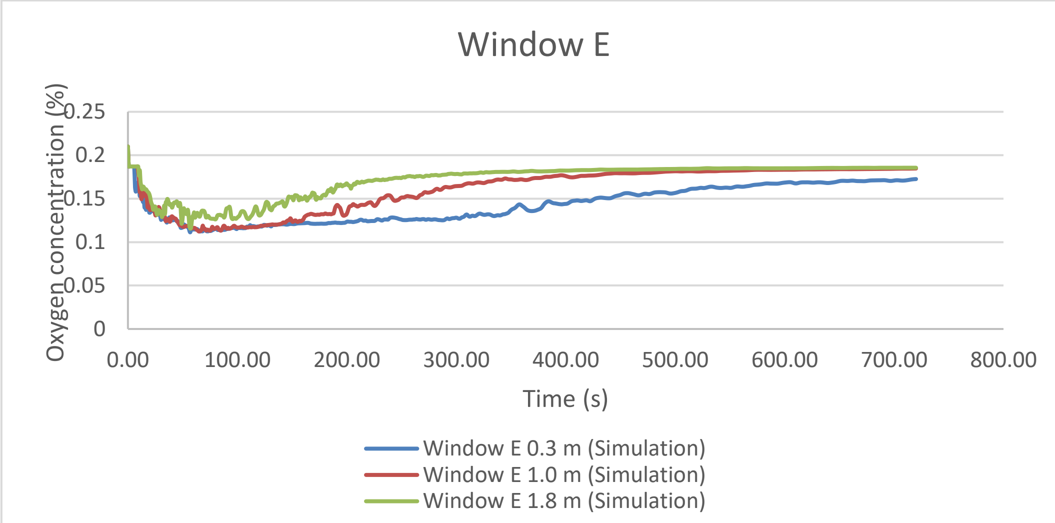


Figure 33: Oxygen concentration at different heights at window E

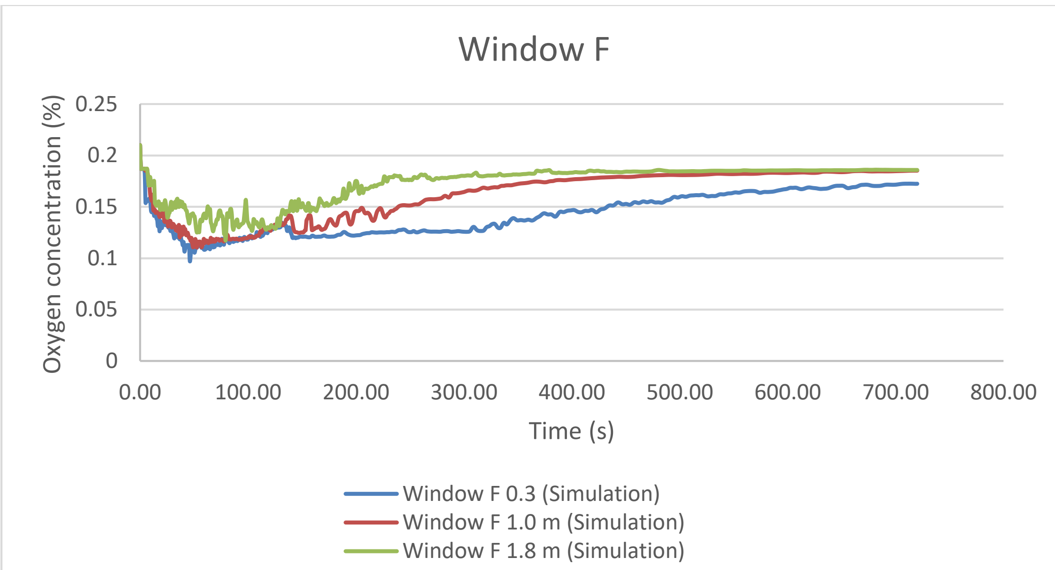


Figure 34: Oxygen concentration at different heights at window F

4.3.2 Effect of Opening Size on the Oxygen Level

In this section, the simulation profile is used to illustrate the flow pattern of the oxygen in the compartment. From the experimental results, the size of opening affected the concentration of oxygen in the compartment.

Large Opening – Door A completely opening

Figure 35 below shows the compartment with the door completely open. The figure also depicts the flow profiles of oxygen in the compartment. The oxygen level in the room begins to decrease immediately the nozzle begins to discharge IG-541 in apartment. The extinguishing gas due to its high density than air begins to flow towards the floor of the compartment. In the absence of an opening in the compartment, the gas particles (IG-541) will circulate within the enclosure colliding with the walls of the space under protection without escaping to the outside.

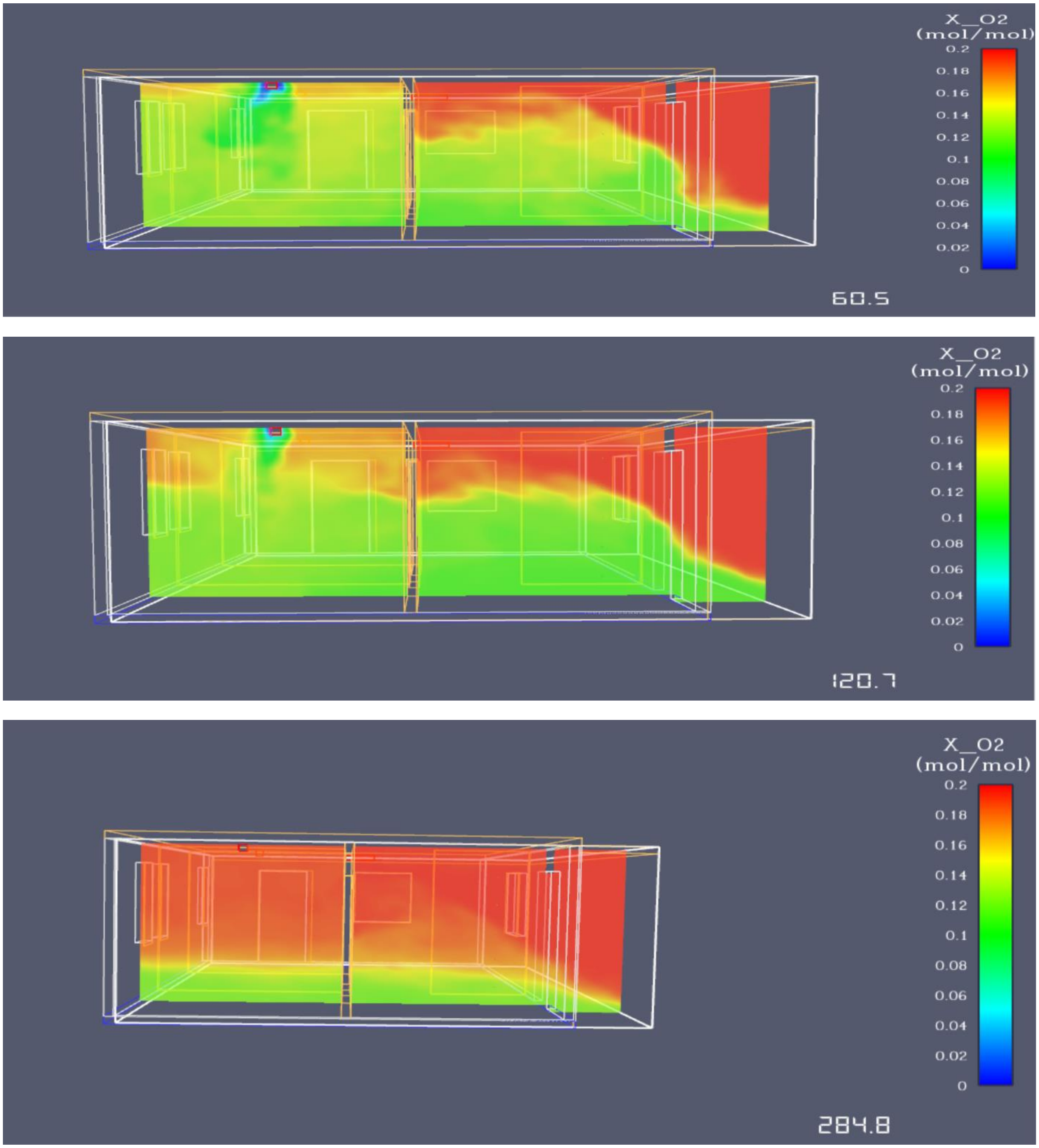
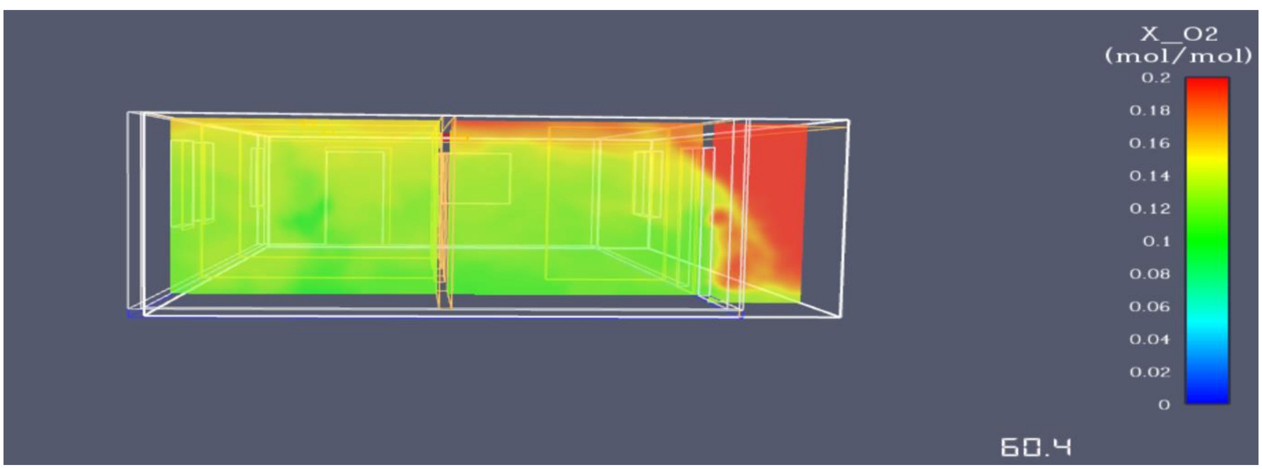


Figure 35:Oxygen level in the compartment at 60s, 120s, and 284s (large opening)

However, the compartment has a large leakage area (door A). IG-541 flows out through the lower part of the opening while at the same time oxygen from the surrounding is introduced into the apartment from the upper side, thereby significantly increasing the oxygen concentration in the apartment. From the figure above, it can be observed that the oxygen level in the apartment increases as time increases.

Small openings – Door A 14 cm open

Figure 36 below is the simulation profile of the with door A slightly open. The colour chat on the right part of the diagram illustrates the oxygen concentration in the apartment. From the figure, it can be observed that the concentration of oxygen in the compartment at 60 seconds was low, because of minimal loss of IG-541 (compared to large opening at 60 seconds) that was discharged in the apartment. At 120 seconds, the oxygen level in the apartment decreased further which indicated that more quantity of IG-541 has been discharged. This is an indication that the compartment was able to hold more quantity of the fire extinguishing agent because of the smaller opening size. At 284 seconds, the oxygen level further increased. After the discharge time, more oxygen is introduced into the apartment through the opening. However, comparing the oxygen level at this time (284 seconds) with the previous scenario (large opening), it will be observed that there exists a significant difference in the level of oxygen for both cases.



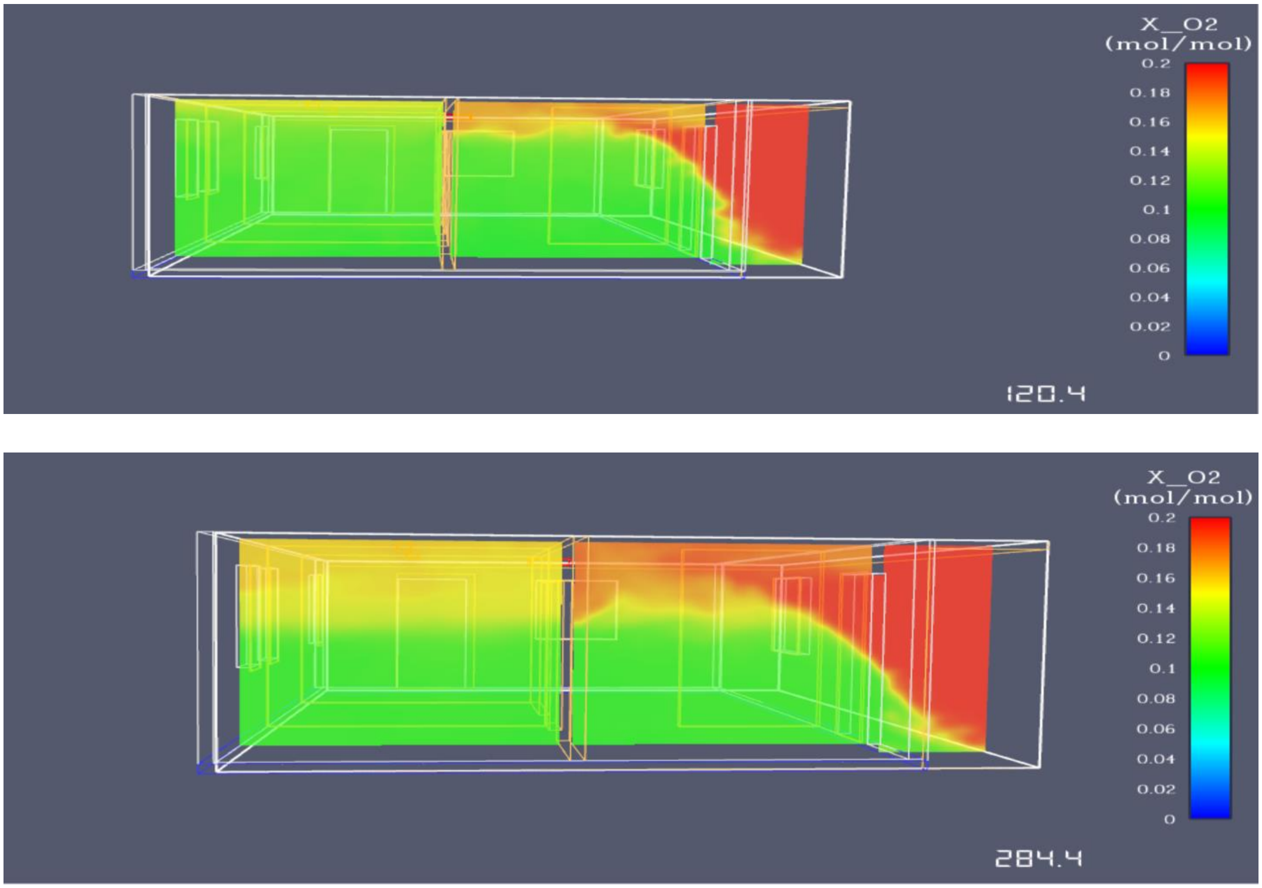


Figure 36:Oxygen level in the compartment at 60s, 120s, and 284s (small opening)

4.3.3 Large Opening Vs Small opening

In figure 37, the effects of large and small opening are compared. The results show different oxygen concentration at the same time. For the large opening, the figure shows a high oxygen level while for small opening the oxygen level is relatively low.

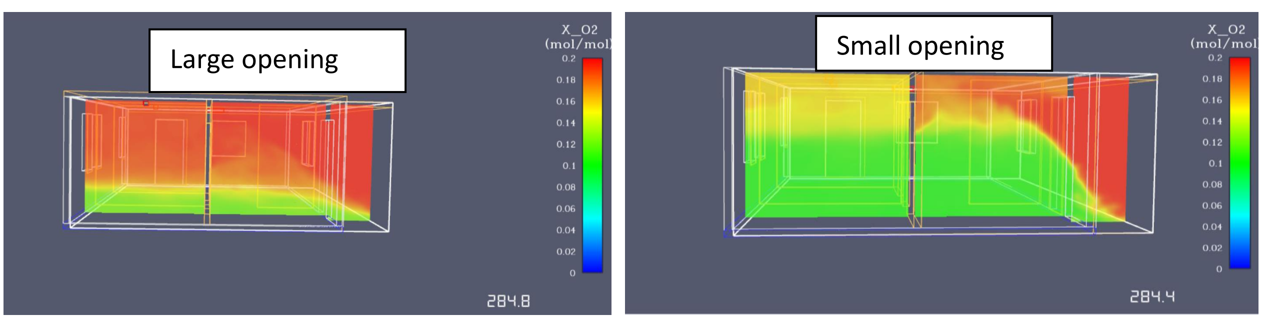


Figure 37: Comparison between oxygen level of large and small opening at the same time

4.3.4 Effect of Opening Height on the Oxygen Level

In this section, the effect of opening height is studied using the simulation result. The openings in the apartment were at different heights taking reference from the floor of the apartment. The doors are 2.0

m high while the windows have a height of 1.09 m. Figure 13 shows the position of doors and windows in the apartment.

Window Heights – Window E open

In figure 38, the flow pattern of oxygen when the height of the opening is at the window height is investigated. From the figure, it can be observed that oxygen flows into the apartment from the upper side of the window to occupy the upper layer of the enclosure. The IG-541 that is discharged is lost through the lower part of the window. At first, IG-541 discharged flows towards the direction of the opening and in the process is lost through the window. However, as time progresses, IG-541 flows direct to the floor of the apartment colliding with the floor. The collision causes an upthrust effect on the IG-541 gaseous particles which causes them to flow upwards towards the opening direction which eventually leads to loss of the agent.

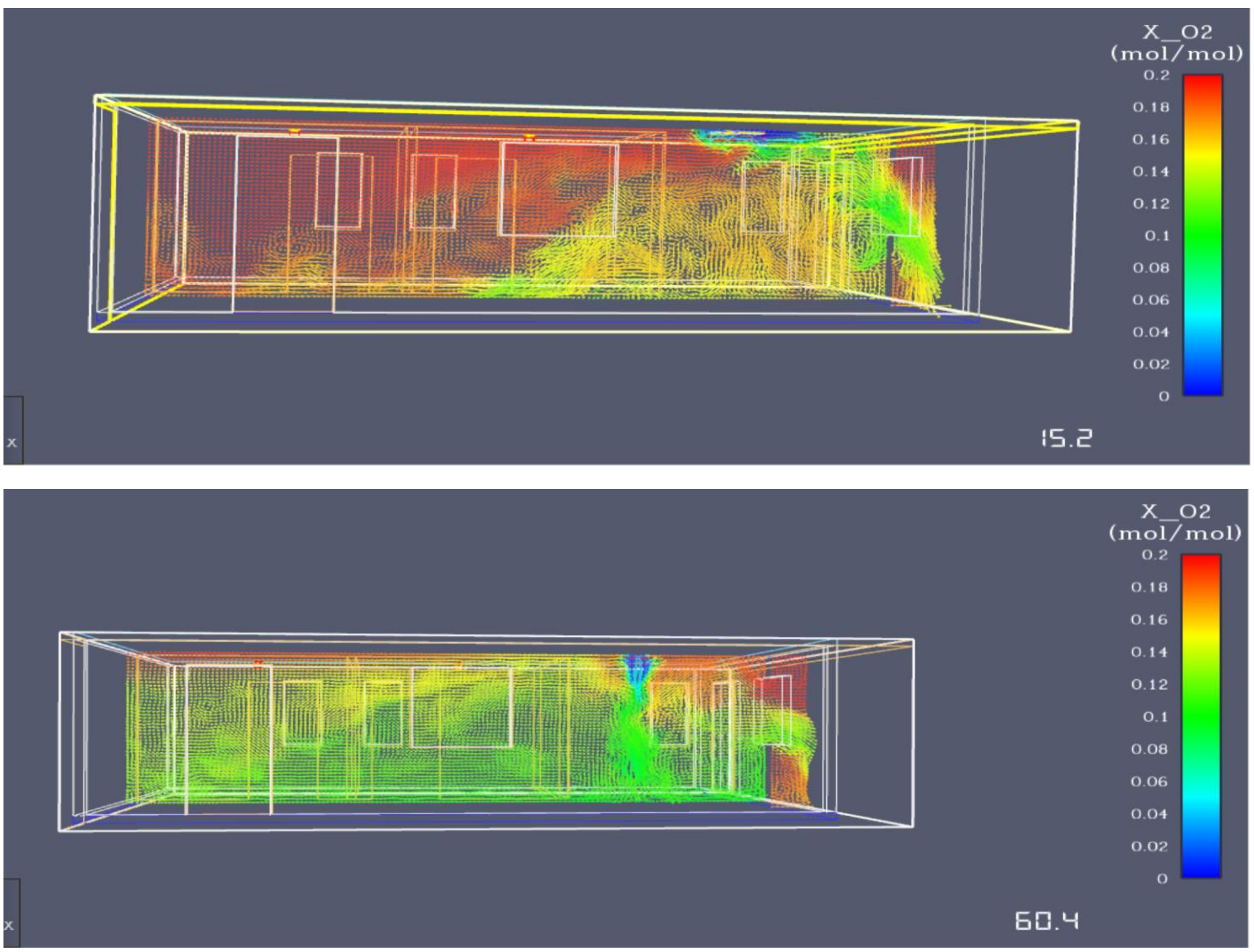


Figure 38: Flow pattern of oxygen when height of the opening is at window level

Door Height – Door A Open

In figure 39, the flow pattern of oxygen when the height of the opening is at the window height is investigated. From the figure, the inert gas discharge is lost to through the opening almost immediately after discharge. Unlike in figure 37 where the gas initially is flows direct to the opening, the gas in this case flows to the floor of the apartment and thereafter finds a way towards the opening. As stated in previous cases, the oxygen re-enters into the apartment through the upper side of the opening while IG-541 flows out through the bottom part.

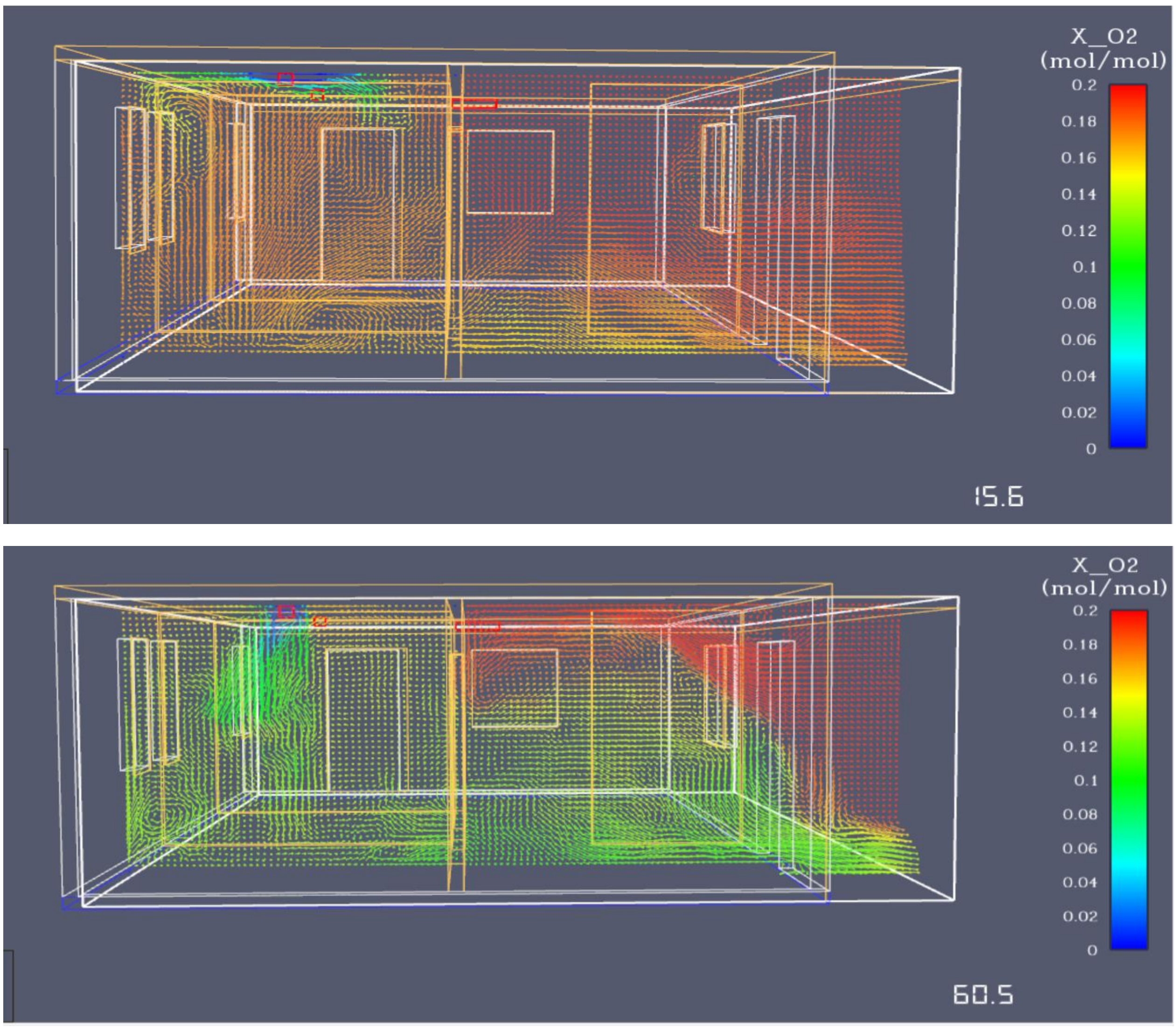


Figure 39: Flow pattern of oxygen when height of the opening is at window level

5.0 DISCUSSION

Experiment and simulation have been conducted to determine the effects of enclosure openings on inert gas fire suppression systems. Different opening sizes were used to conduct the experiment and simulation to investigate the effect on inert gas system. It has been found how different opening orientations affect the effectiveness of IG-541 fire suppression system. It was also found that opening size and location is a critical factor which determines how efficient an enclosure will hold up the discharged fire extinguishing agent. Under normal conditions, the oxygen concentration needed for healthy breathing is 21.0%. When an inert gas fire suppression system is activated during a fire, the discharge agent reduces the oxygen level in the room to a concentration that will prevent fire growth and development. In this study, the criterion used to perform the investigation is reducing the oxygen concentration to 12.0% which is the design concentration and is sufficient to extinguish a fire.

5.1 Effects of Enclosure Opening on the Fire Suppression System

The effects of openings on gas fire suppression systems have been studied using experimental methods. The results from the experiments show that opening sizes, number, and height affects the effectiveness of the suppression system. In Figures 15 and 16 where the trend for oxygen concentration for enclosure without openings was depicted. the compartment was able to sustain the oxygen level for a longer period.

5.1.1 Effects of Large opening on Inert Gas Fire Suppression Systems

In figures 17 and 18 (door A), IG-541 discharged in the room was lost through the openings which affected the effectiveness of the gas fire suppression/extinguishing system. It can be observed that the oxygen concentration at the location away from the opening (windows E and F) was reduced to a threshold that would effectively extinguish a fire. It took approximately 30 seconds for the inert gas agent to reduce the oxygen concentration in those locations to 15.0%, while it took a longer period for the oxygen level at the door to be reduced to the same concentration. The compartment maintained the extinguishing concentration until 430 seconds when the oxygen level at the locations away from the door rose above the design concentration to extinguish fire (15.0%). The holding time in the apartment was approximately 3.8 minutes. The work in [2] stated that the minimum holding time for inert gas system is 10 minutes, this requirement was not achieved by the in this experiment. However, from the results, it is reasonable to say that inert gas system may not readily be efficient in such cases but can extinguish fire and keep the occupant and structure safe until the arrival of the fire department.

5.1.2 Effects of medium opening on Inert Gas Fire Suppression Systems

In this experiment, the effect of medium opening was investigated. The opening location was at window F. In figure 19, from observation, the oxygen concentration at window E and door A were reduced to below 15.0%. These locations are farther from the opening compared to window F location with the highest concentration of oxygen. Since the concentration of oxygen is lower at these locations, it implies that fire extinguishment will be achieved in event of fire in the apartment. At window F, the concentration is above the design concentration of oxygen that will extinguish fire. Oxygen level increase in the post- discharge period with time. Oxygen concentration at window E and door A locations descended below 15.0% at 50 seconds during the discharge time and increase above the same percentage at 400.0 seconds. Therefore, holding time of the inert gas system in the enclosure when the opening size is medium is 5.8 minutes. The holding time of the IG-541 gas extinguishing system obtained in this experiment was below the requirement as stated in [2].

In figure 20, The oxygen concentration at window E and door A decreased below 15.0% at 50 seconds. However, the locations experienced an increased in concentration at different times during the post discharge time. At window E, the level of oxygen rose above 15.0% in 200 seconds while same scenario occurred at door A in 280 seconds. Window E is closer to Window F which explains why oxygen level first increased at the location. Since the oxygen concentration at these locations were reduced below 15.0% by the fire extinguishing agent, it implies that fire will be extinguished at this layer.

5.1.3 Effects of small opening on Inert Gas Fire Suppression Systems

In **Figure 23** (door A 14 cm open), it can be observed that the oxygen level at the 3 locations followed the same trend during the discharge period. They had approximately the same oxygen distribution during and after the discharge time. This was because of the size of the opening at the door which was little and therefore, a limited quantity of IG-541 was permitted to flow out of the enclosure. The minimum oxygen level obtained was 11.0%. During the discharge time, the oxygen concentration at window E and window F were slightly lower than at door A. In all the locations, the concentration of oxygen measured were within the threshold to extinguish a fire.

In figure 24, during discharge period, the oxygen concentration in the compartment was reduced to the region where fire extinguishment would occur. The oxygen level at the window locations were lower than what was obtained at the door location. The concentration as obtained in figure 23 were reduced below 15.0% which will eventually extinguish a fire. There was a rapid rise of oxygen level at the end of discharge time (180 seconds). Just as obtained in the previous experiments with openings, the holding time of the inert gas agent was shorter compared to the recommendations as stated in [2]. The holding time in this case was 6.8 minutes.

Generally, in figures 35, 36, and 37. The simulation depicts how different opening sizes contributes towards the build-up of oxygen level in an apartment. For small size openings, the loss of IG-541 to the environment was minimal which resulted in low oxygen concentration in the compartment for a longer period. For large openings, the loss of IG-541 was more significant and the oxygen level was quiet high. Figure 38 and 39 the effects of opening height was investigated. The results indicated that door openings contributed majorly to the increase of oxygen concentration in the room than the window opening.

5.2 Oxygen Level vs Height

In figures 38 and 39, the effects of opening height were investigated. In figure 38, the opening is a window which originated from a height 1.0 m above the floor. The fire extinguishing agent initially discharged flows towards the opening direction (window F) and was lost through it. With increase in time, more inert gas agent was discharged from the nozzle filling the compartment and gases travelled towards the floor. The collision of the gaseous particles with the floor caused a reverse effect on the inert gas and changed its direction to the opposite. Then the gases are lost through the lower part of the window and oxygen enters the apartment from the upper part.

In figure 39, the opening height originated from the floor of the apartment. Upon discharge of the inert gas, the agent instantly travelled towards the floor and is lost through the lower part of the opening leaving room for oxygen to flow in from the upper part.

6.0 CONCLUSION

In this study, the effects of opening on a gas extinguishing system have been investigated using experiment and simulation models. The experiment was performed in a fire compartment constructed by HH Fire Eater AS and simulated using Pyrosim/FDS model. The building structure was protected with inert gas fire suppression system, with IG-541 as the discharge agent. Five experiments and simulations were performed using open doors and windows to study the effectiveness of an enclosure opening on a gas suppression system.

From the experiments, the investigation shows oxygen concentration was evenly distributed at upper layer and middle across all locations. Oxygen concentration was also within extinguishing region at locations away from the opening. From the findings, the opening size and height are critical factors when finding investigated the efficiency of in inert gas system. In test 1, the oxygen concentration during and after the discharge time was within 12.0% and 15.0% for a period of more than 10 minutes which is the minimum holding time. In test 2 (large opening), the holding time decreased to 3.8 minutes. In test 4 (medium opening), the holding time was 5.8 minutes, while for test 5 (small opening), the holding time of 6.8 minutes was recorded. The size of opening and height determined the period the compartment would be able to maintain the concentration of oxygen within the required threshold to extinguish fire. Smaller opening has a higher fire extinguishing and gas holding capacity.

A Pyrosim/FDS model was used to simulate the experiment. The simulation results were compared to the experimental results to determine how close simulation models can be used to predict the results from the experiment. The simulation gave a reasonable prediction, therefore can be used for further studies.

In conclusion, the opening in the compartment is a major factor that will make fire extinguishment difficult since it may lead to loss of fire extinguishing agent and increase in concentration of oxygen. Therefore, to effectively extinguish fire when and increase the holding time of an enclosure with opening, more quantity of inert gas agent is required to be discharged.

7.0 FURTHER WORK

This study looked at the performance of fire suppression systems when there is significant opening in building during fire emergency. The maximum opening area investigated in the study is 1.62 m^2 (door). As a continuation to this work, a larger opening should be investigated.

In this study, 80L of IG-541 was used as fire extinguishing agent which in most of the tests successfully reduce the oxygen concentration of the enclosure to below 15.0% which is lower than the design concentration of oxygen to extinguish fire. In future studies, it is recommended that more quantity of the fire suppression/extinguishing agent be used to investigate the effectiveness of the gas fire suppression system since the opening size in this case may be larger.

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APPENDIX

A.1 Comparison between experimental and simulation results of oxygen level

Scenario 3 – window E and window F 25 cm open

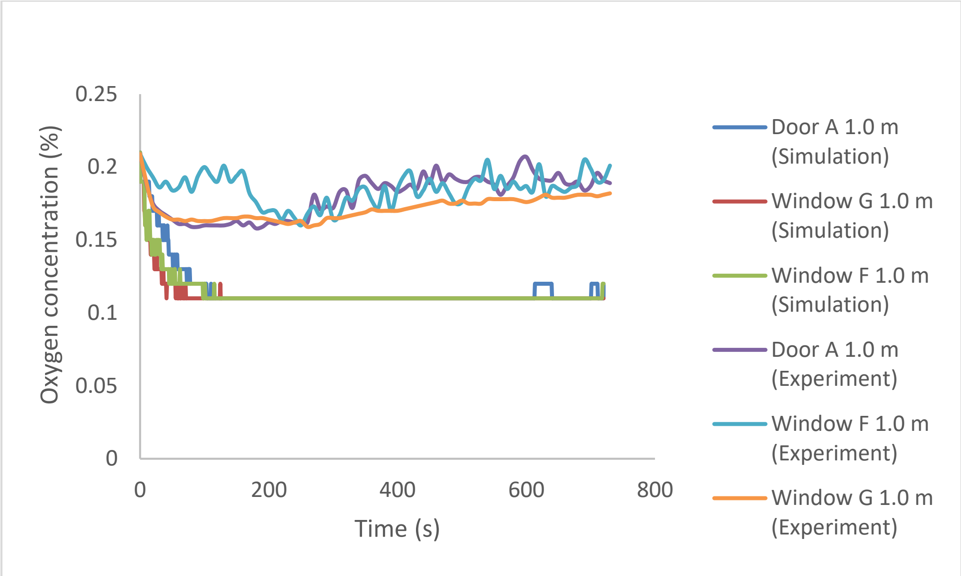

Figure 40: Comparison between experimental and simulation results of oxygen level at a height of 1.0 m when window E and window F is 25 cm open

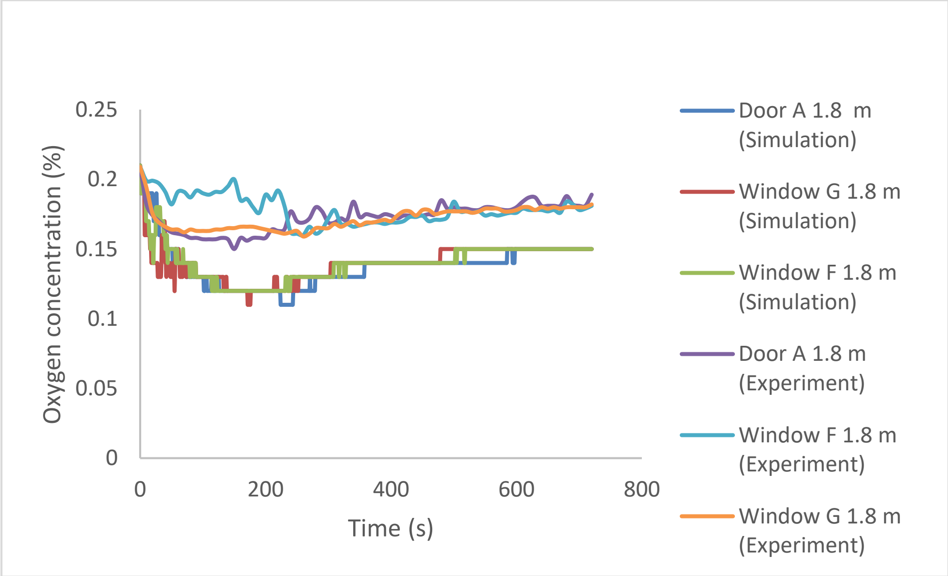

Figure 41: Comparison between experimental and simulation results of oxygen level at a height of 1.8 m when window E and window F is 25 cm open

Scenario 4 – window F open

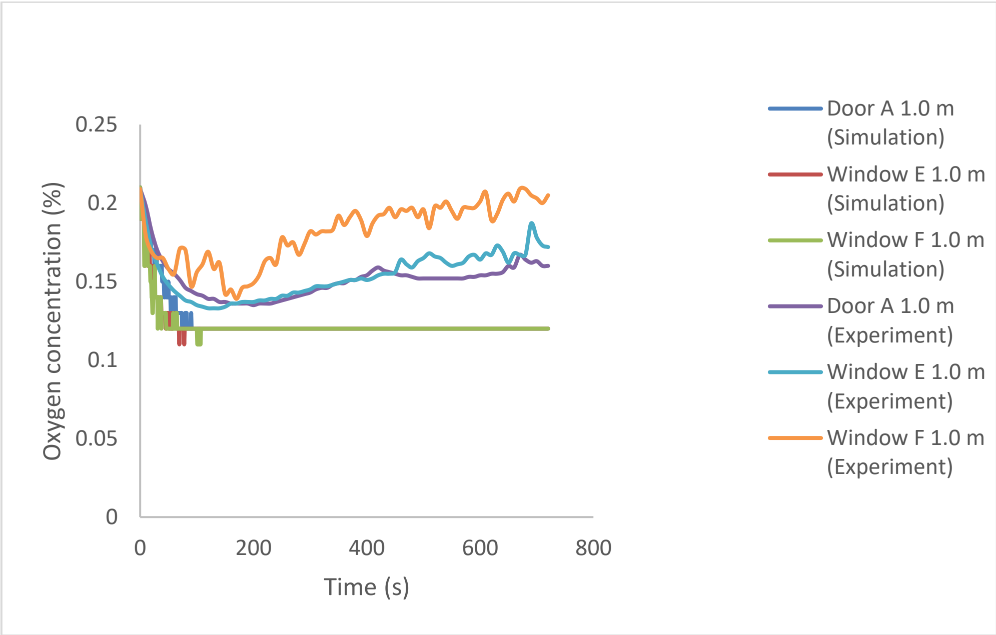

Figure 42: Comparison between experimental and simulation results of oxygen level at a height of 1.0 m when window F is open

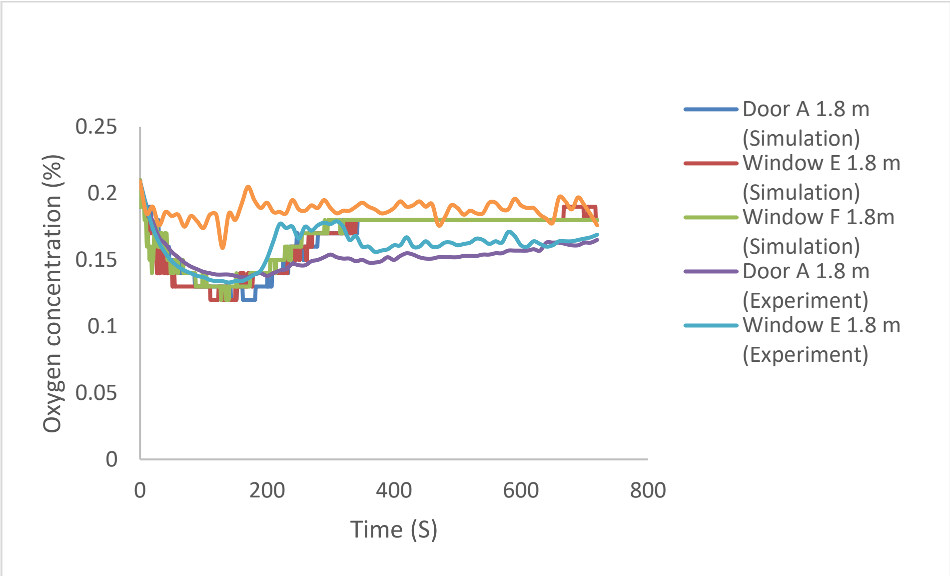

Figure 43: Comparison between experimental and simulation results of oxygen level at a height of 1.8 m when window F is open

Scenario 5 – Door A 14 cm open

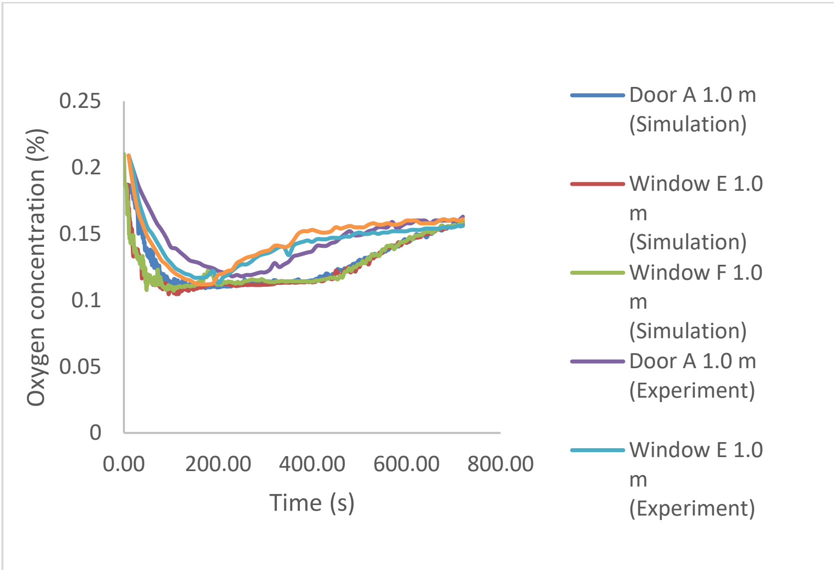

Figure 44: Comparison between experimental and simulation results of oxygen level at a height of 1.0 m when door A is 14 cm open

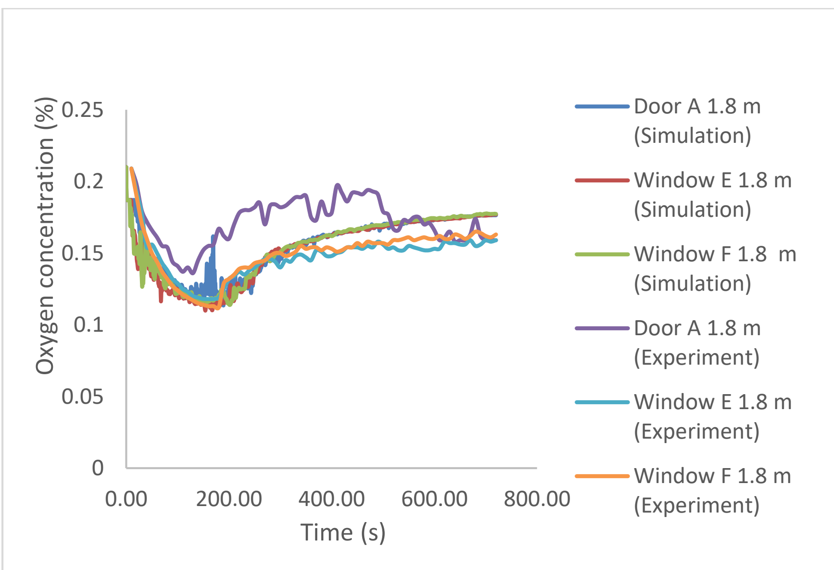

Figure 45: Comparison between experimental and simulation results of oxygen level at a height of 1.8 m when door A is 14 cm open

B.1 Simulation Results for O_2 Concentration distribution at Heights 0.3 m, 1.0 m and 1.8m

Scenario 3 – window E and window F 25 cm open

Figure 46: Oxygen concentration at door A

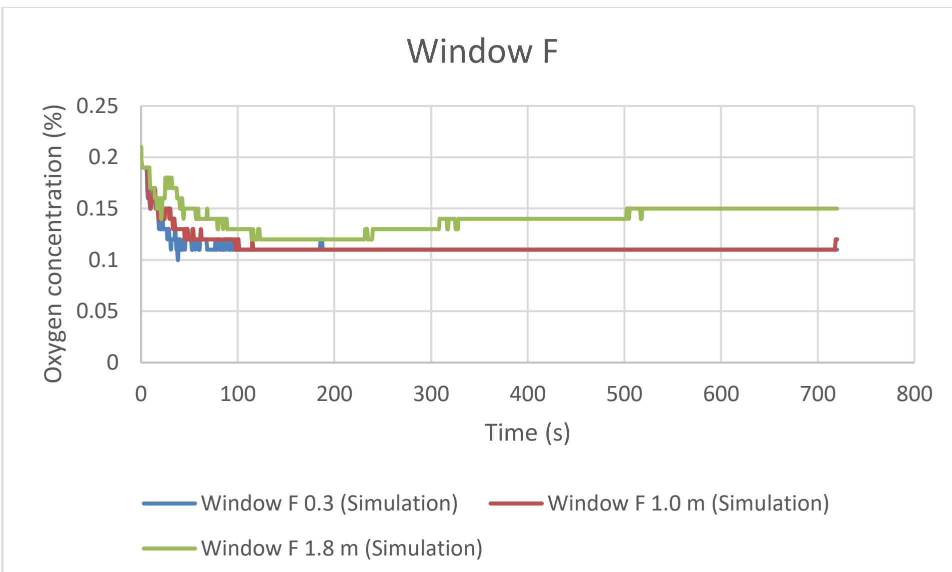

Figure 47: Oxygen concentration at window F

Figure 48: Oxygen concentration at window G

Scenario 4- Window F open

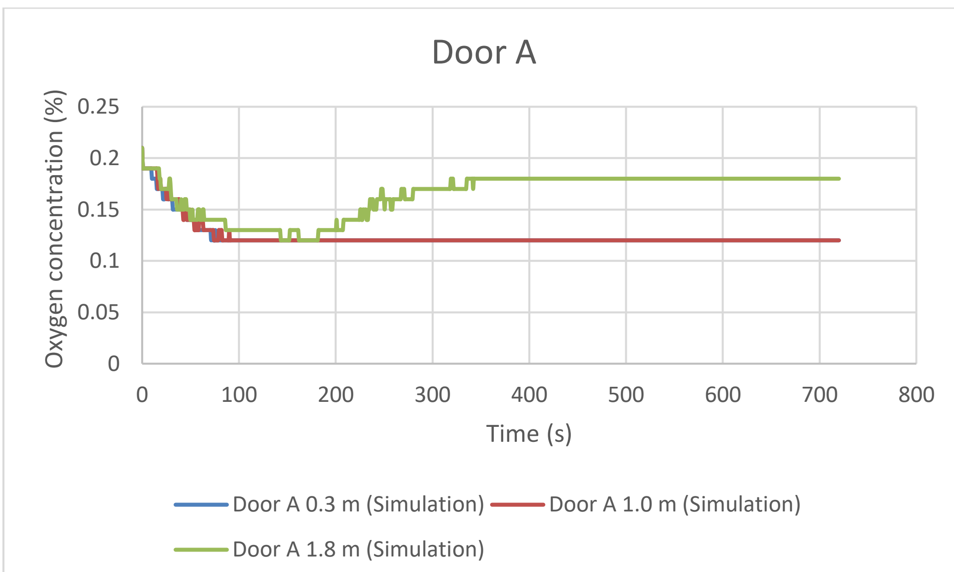

Figure 49: Oxygen concentration at door A

Figure 50: Oxygen concentration at window E

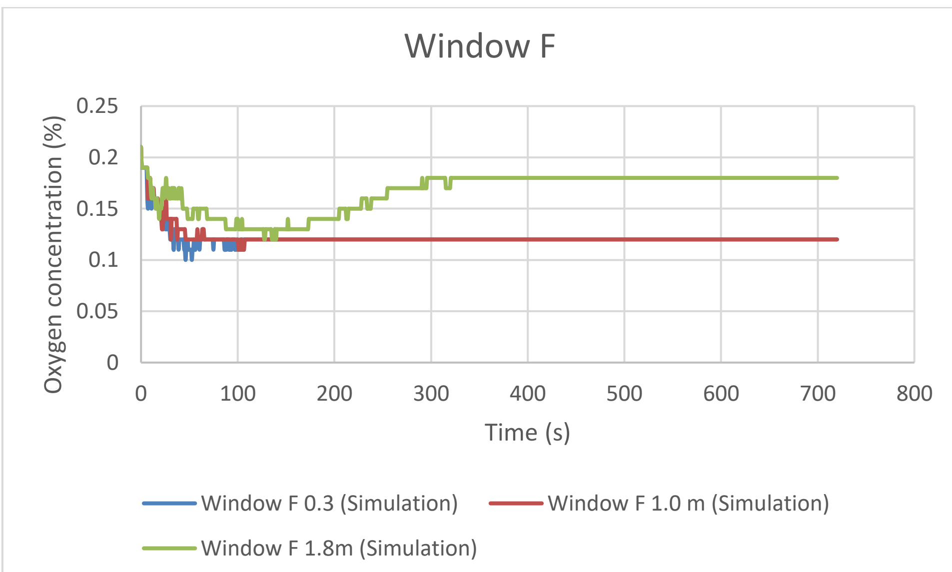

Figure 51:Oxygen level at window F

Scenario 5 – Door A 14cm open

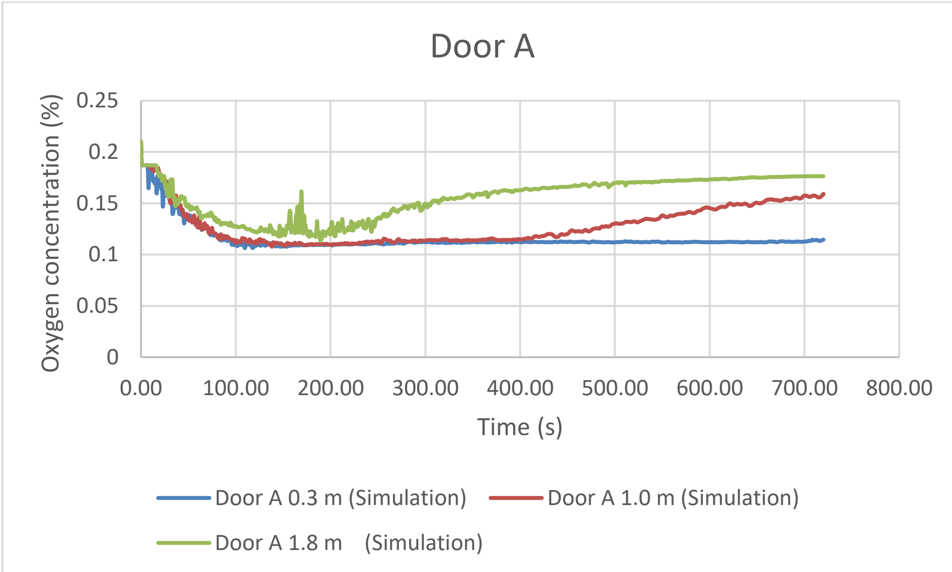

Figure 52: Oxygen concentration at door A

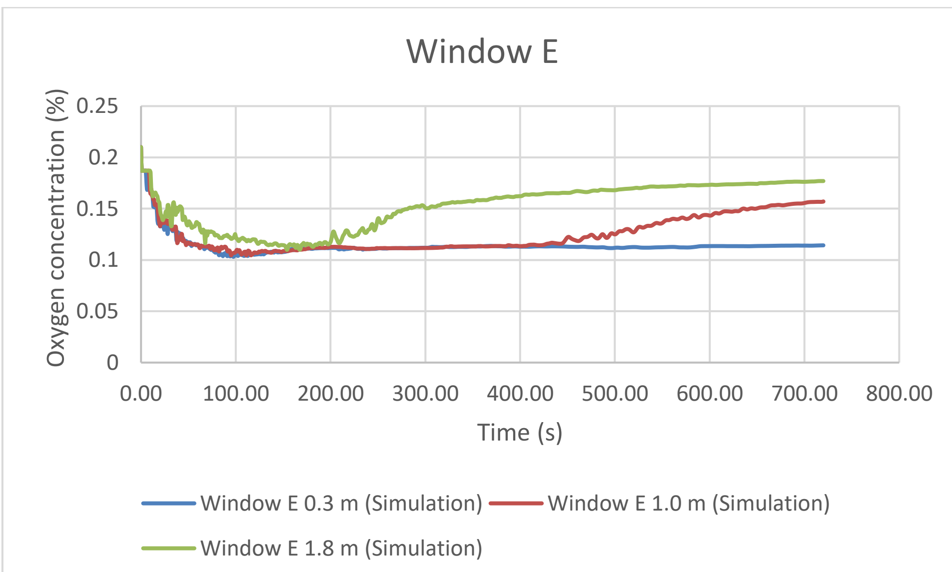

Figure 53: Oxygen concentration at window E

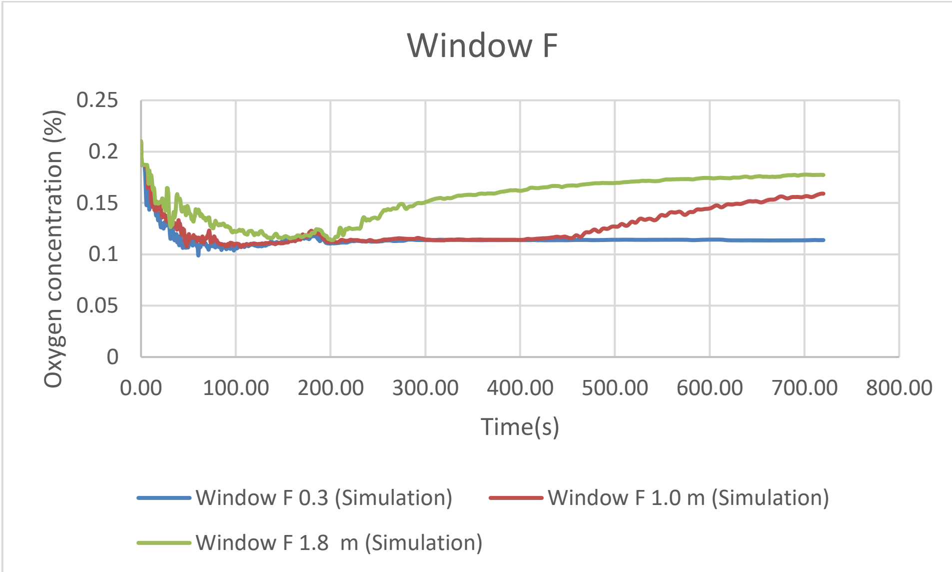

Figure 54: Oxygen concentration at window F

C. Pictorial Result from the Simulation

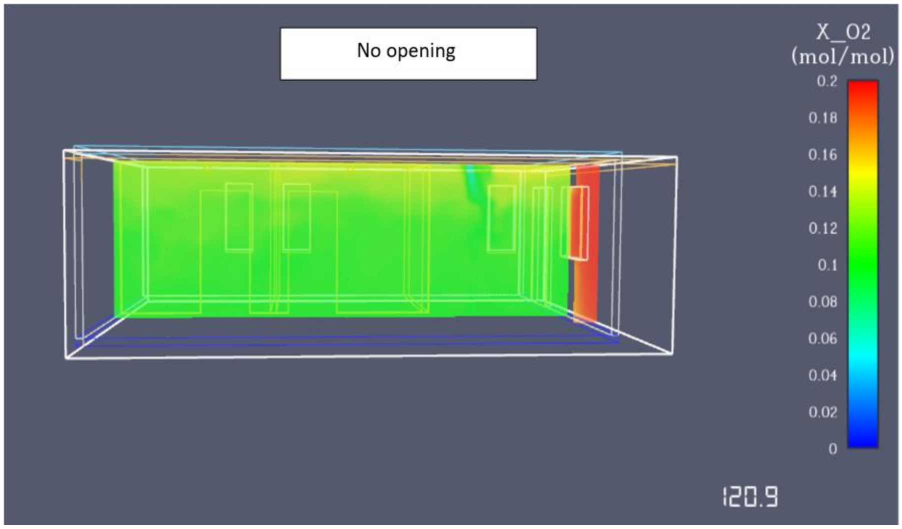

Figure 55: Oxygen level at 120 seconds SCENARIO 1

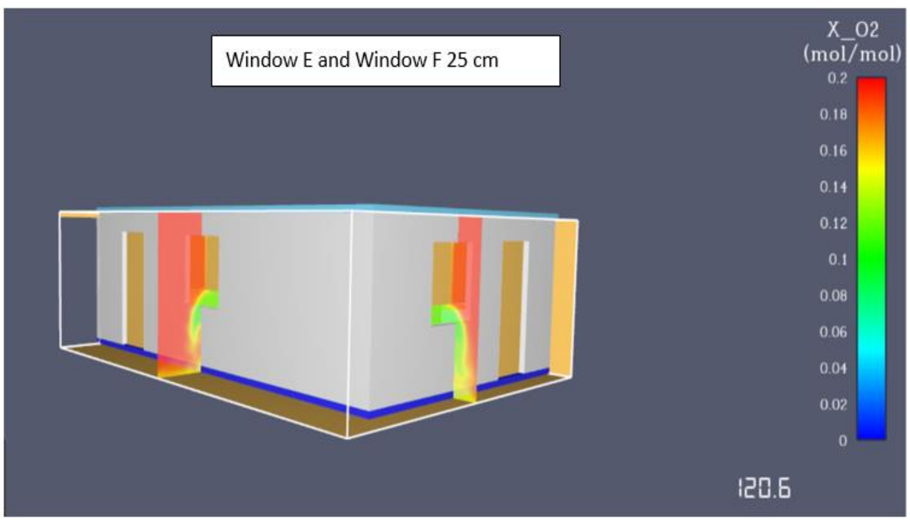

Figure 56: Oxygen level at 120 seconds SCENARIO 3 realistic view

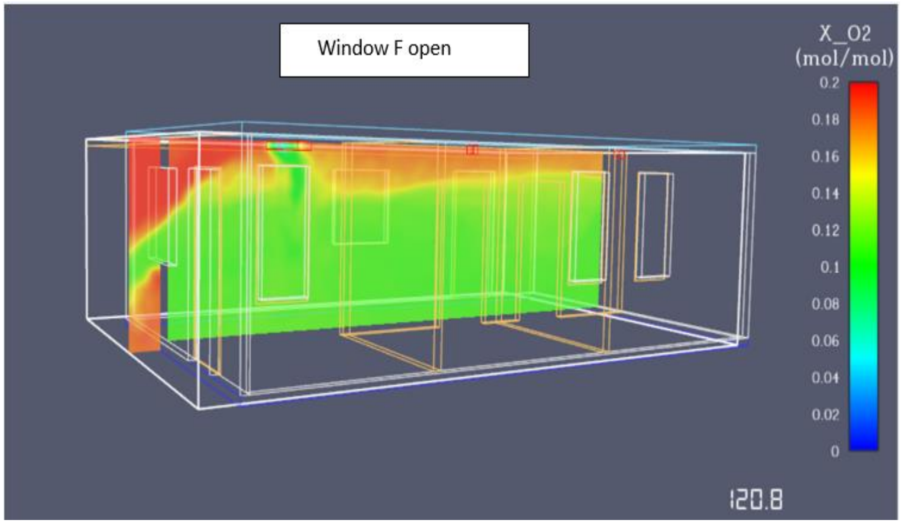

Figure 57: Oxygen level at 120 seconds SCENARIO 4

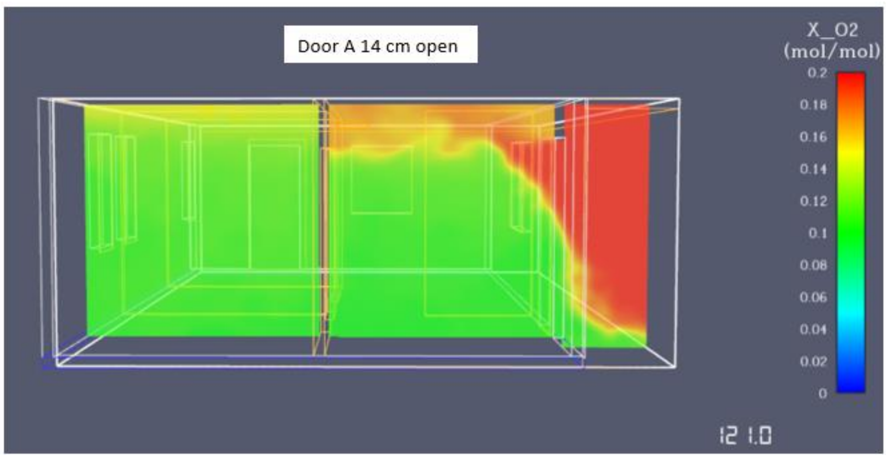

Figure 58: Oxygen level at 120 seconds SCENARIO 5

D.1 Simulation input file

Scenario 1 – No opening

No_opening_fds.

Generated by PyroSim - Version 2021.4.1201

Jun 13, 2022 4:32:46 PM

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&TIME T_END=720.0/

&DUMP DT_RESTART=300.0, DT_SL3D=0.25/

&MISC Y_O2_INFTY=0.21/

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&RAMP ID='Nozzle Surface_RAMP_MF', T=126.17, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=129.19, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=132.2, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=135.22, F=0.06/

&RAMP ID='Nozzle Surface_RAMP_MF', T=138.24, F=0.06/

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&RAMP ID='Nozzle Surface_RAMP_MF', T=147.3, F=0.05/

&RAMP ID='Nozzle Surface_RAMP_MF', T=150.47, F=0.05/

&RAMP ID='Nozzle Surface_RAMP_MF', T=153.34, F=0.05/

&RAMP ID='Nozzle Surface_RAMP_MF', T=156.36, F=0.04/

&RAMP ID='Nozzle Surface_RAMP_MF', T=159.38, F=0.04/

&RAMP ID='Nozzle Surface_RAMP_MF', T=162.4, F=0.04/

&RAMP ID='Nozzle Surface_RAMP_MF', T=165.41, F=0.04/

&RAMP ID='Nozzle Surface_RAMP_MF', T=168.43, F=0.03/

&RAMP ID='Nozzle Surface_RAMP_MF', T=171.45, F=0.03/

&RAMP ID='Nozzle Surface_RAMP_MF', T=174.47, F=0.03/

&RAMP ID='Nozzle Surface_RAMP_MF', T=177.49, F=0.03/

&RAMP ID='Nozzle Surface_RAMP_MF', T=180.51, F=0.03/

&RAMP ID='Nozzle Surface_RAMP_MF', T=182.29, F=0.0/

&OBST ID='Floor', XB=-0.1,7.44,-0.1,4.78,0.0,0.1, RGB=51,51,255, SURF_ID='INERT'/

&OBST ID='Obstruction', XB=2.36,2.46,0.0,1.21,0.1,2.43, SURF_ID='INERT'/

&OBST ID='Door B Obstruction', XB=7.32,7.34,2.9,3.82,0.1,2.12, SURF_ID='INERT'/

&OBST ID='Window G Obstruction', XB=6.67,7.24,4.67,4.68,0.9,2.16, SURF_ID='INERT'/

&OBST ID=' Window H Obstruction', XB=2.6,3.14,4.67,4.68,0.9,2.16, SURF_ID='INERT'/

&OBST ID='Window E Obstruction', XB=3.13,4.15,0.0,0.02,1.0,2.1, SURF_ID='INERT'/

&OBST ID='Obstruction', XB=0.0,5.1,2.24,2.34,0.1,2.43, SURF_ID='INERT'/

&OBST ID='Obstruction', XB=2.44,2.54,2.34,4.68,0.1,2.43, SURF_ID='INERT'/

&OBST ID='Obstruction', XB=5.0,5.1,2.34,4.68,0.1,2.43, SURF_ID='INERT'/

&OBST ID='Obstruction', XB=-0.1,7.34,4.68,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='leakage sufface'/

&OBST ID='Obstruction', XB=0.0,7.34,-0.1,0.0,0.1,2.43, COLOR='GRAY 94', SURF_ID='leakage sufface'/

&OBST ID='Obstruction', XB=-0.1,0.0,-0.1,4.68,0.1,2.43, COLOR='GRAY 94', SURF_ID='leakage sufface'/

&OBST ID='Obstruction', XB=7.34,7.44,-0.1,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='leakage sufface'/

&OBST ID='Ceiling', XB=-0.1,7.44,-0.1,4.78,2.43,2.53, SURF_ID='leakage sufface'/

&OBST ID='Discharge vent bedroom', XB=3.8,3.9,3.48,3.58,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge vent livingroom', XB=5.6,6.05,1.88,2.33,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge Vent bathroom', XB=1.22,1.32,3.46,3.56,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Door A Obstruction', XB=0.95,1.78,0.0,0.02,0.1,2.12, SURF_ID='INERT'/

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&OBST ID=' Window I Obstruction', XB=1.49,2.02,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID=' Door C Obstruction', XB=2.739,3.549,2.24,2.34,0.1,2.0, SURF_ID='INERT'/
&OBST ID='Door D Obstruction', XB=1.29,2.1,2.24,2.34,0.1,2.0, SURF_ID='INERT'/
&OBST ID='Window F obstruction', XB=7.32,7.34,1.185,2.162,1.0,2.1, SURF_ID='INERT'/

&HOLE ID='DoorD', XB=1.29,2.1,2.24,2.34,0.1,2.0/
&HOLE ID='DoorC', XB=2.739,3.549,2.24,2.34,0.1,2.0/
&HOLE ID='Window E', XB=3.15,4.125,-0.1,0.0,1.01,2.09/
&HOLE ID='Window F', XB=7.34,7.44,1.186,2.161,1.01,2.09/
&HOLE ID='Window G', XB=6.71,7.22,4.68,4.78,0.945,2.15/
&HOLE ID='Window H', XB=2.62,3.13,4.68,4.78,0.945,2.15/
&HOLE ID='DoorA', XB=0.96,1.77,-0.1,0.0,0.1,2.1/
&HOLE ID='DoorB', XB=7.34,7.44,3.0,3.81,0.1,2.1, COLOR='GRAY 94'/
&HOLE ID='Window I', XB=1.5,2.01,4.68,4.78,0.945,2.15/

&VENT ID='Mesh Vent: MESH-01-01 [XMIN]', SURF_ID='OPEN', XB=0.0,0.0,-0.936,-0.1,0.0,2.34/
&VENT ID='Mesh Vent: MESH-01-01 [YMIN]', SURF_ID='OPEN', XB=0.0,7.836,-0.936,-0.936,0.0,2.34/
&VENT ID='Vent', SURF_ID='INERT', XB=0.0,7.836,-0.936,-0.1,2.43,2.43/
&VENT ID='Vent living room 01', SURF_ID='Nozzle Surface', XB=5.6,5.6,1.88,2.33,2.33,2.43/
&VENT ID='Vent living room 02', SURF_ID='Nozzle Surface', XB=6.05,6.05,1.88,2.33,2.33,2.43/
&VENT ID='Vent living room 03', SURF_ID='Nozzle Surface', XB=5.6,6.05,1.88,1.88,2.33,2.43/
&VENT ID='Vent living room 04', SURF_ID='Nozzle Surface', XB=5.6,6.05,2.33,2.33,2.33,2.43/
&VENT ID='Vent bed room 05', SURF_ID='Nozzle Surface', XB=3.8,3.8,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 06', SURF_ID='Nozzle Surface', XB=3.9,3.9,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 07', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.48,3.48,2.33,2.43/
&VENT ID='Vent bed room 08', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.58,3.58,2.33,2.43/
&VENT ID='Vent bath room 01', SURF_ID='Nozzle Surface', XB=1.22,1.22,3.46,3.56,2.33,2.43/
&VENT ID='Vent bath room 02', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.46,3.46,2.33,2.43/
&VENT ID='Vent bath room 03', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.56,3.56,2.33,2.43/
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&VENT ID='Vent bath room 04', SURF_ID='Nozzle Surface', XB=1.32,1.32,3.46,3.56,2.33,2.43/

&VENT ID='Mesh Vent: MESH-01-01 [XMAX]01', SURF_ID='OPEN', XB=7.836,7.836,-0.936,4.68,0.0,2.34/

&VENT ID='Ceiline Xmax', SURF_ID='INERT', XB=7.34,7.836,-0.1,4.68,2.43,2.43/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=1.3/

&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=1.3/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=1.3/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=3.6/

&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=3.6/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=3.6/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=1.8/

&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=1.8/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=3.4/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=3.4/

&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=3.4/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=1.8/

&DEVC ID='[Species: OXYGEN] Volume Fraction_MEAN', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', SPATIAL_STATISTIC='MEAN', XB=0.0,7.34,0.0,4.68,0.0,2.43/

&TAIL /

Scenario 2 – Door A open

Final_simulation_one_door_A_open_fds.fds

Generated by PyroSim - Version 2021.4.1201

Jun 13, 2022 4:39:01 PM

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&HEAD CHID='Final_simulation_one_door_A_open_fds'/
&TIME T_END=720.0/
&DUMP DT_RESTART=300.0, DT_SL3D=0.25/
&MISC Y_O2_INFTY=0.21/

&MESH ID='MESH-01-01', IJK=158,120,48, XB=0.0,7.836,-0.936,4.68,0.0,2.43/

&ZONE ID='Zone01', XB=0.0,7.34,0.0,4.68,0.1,2.43, LEAK_AREA=0.5/

&SPEC ID='ARGON', LUMPED_COMPONENT_ONLY=.TRUE./
&SPEC ID='IG541',
  SPEC_ID(1)='ARGON',
  SPEC_ID(2)='CARBON DIOXIDE',
  SPEC_ID(3)='NITROGEN',
  VOLUME_FRACTION(1)=0.4,
  VOLUME_FRACTION(2)=0.08,
  VOLUME_FRACTION(3)=0.52/

&DEVC ID='vel-01', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,2.0, VELO_INDEX=1/
&DEVC ID='vel-02', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.6, VELO_INDEX=1/
&DEVC ID='vel-03', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.2, VELO_INDEX=1/
&DEVC ID='vel-04', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.8, VELO_INDEX=1/
&DEVC ID='vel-05', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.4, VELO_INDEX=1/
&DEVC ID='pre-01', QUANTITY='PRESSURE', XYZ=1.01,0.6,2.0/
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&DEVC ID='pre-02', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.6/

&DEVC ID='pre-03', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.2/

&DEVC ID='pre-04', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.8/

&DEVC ID='pre-05', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.4/

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&DEVC ID='Oxygen concentration door A_02_(Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.8/

&DEVC ID='Oxygen concentration door A_03_ (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=1.3,0.3,1.8/

&DEVC ID='Oxygen concentration window E_01 (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.3/

&DEVC ID='Oxygen concentration window E_02_ (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.8/

&DEVC ID='Oxygen concentration window E_03_ (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=3.6,0.3,1.8/

&DEVC ID='Oxygen concentration window F_01 (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.3/

&DEVC ID='Oxygen concentration window F_02_ (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.8/

&DEVC ID='Oxygen concentration window F_03_ (Simulation)', QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', XYZ=7.0,1.2,1.8/

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LEAK_PATH=1,0/

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TMP_FRONT=-18.0,

MASS_FLUX=5.26,

SPEC_ID='IG541',

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&RAMP ID='Nozzle Surface_RAMP_MF', T=3.21, F=0.91/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=14.12, F=0.62/
&RAMP ID='Nozzle Surface_RAMP_MF', T=15.56, F=0.59/
&RAMP ID='Nozzle Surface_RAMP_MF', T=17.58, F=0.55/
&RAMP ID='Nozzle Surface_RAMP_MF', T=18.75, F=0.53/
&RAMP ID='Nozzle Surface_RAMP_MF', T=20.99, F=0.5/
&RAMP ID='Nozzle Surface_RAMP_MF', T=23.02, F=0.48/
&RAMP ID='Nozzle Surface_RAMP_MF', T=25.71, F=0.46/
&RAMP ID='Nozzle Surface_RAMP_MF', T=28.32, F=0.44/
&RAMP ID='Nozzle Surface_RAMP_MF', T=31.2, F=0.4/
&RAMP ID='Nozzle Surface_RAMP_MF', T=32.81, F=0.38/
&RAMP ID='Nozzle Surface_RAMP_MF', T=35.59, F=0.36/
&RAMP ID='Nozzle Surface_RAMP_MF', T=38.61, F=0.35/
&RAMP ID='Nozzle Surface_RAMP_MF', T=41.63, F=0.33/
&RAMP ID='Nozzle Surface_RAMP_MF', T=44.65, F=0.31/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=53.71, F=0.27/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=62.84, F=0.23/
&RAMP ID='Nozzle Surface_RAMP_MF', T=65.79, F=0.22/
&RAMP ID='Nozzle Surface_RAMP_MF', T=68.8, F=0.21/
&RAMP ID='Nozzle Surface_RAMP_MF', T=71.82, F=0.2/
&RAMP ID='Nozzle Surface_RAMP_MF', T=74.84, F=0.19/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=80.88, F=0.17/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=126.17, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=129.19, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=132.2, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=135.22, F=0.06/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=141.26, F=0.06/
&RAMP ID='Nozzle Surface_RAMP_MF', T=144.28, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=147.3, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=150.47, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=153.34, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=156.36, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=159.38, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=162.4, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=165.41, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=168.43, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=171.45, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=174.47, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=177.49, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=180.51, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=182.29, F=0.0/

&OBST ID='Floor', XB=-0.1,7.44,-0.1,4.78,0.0,0.1, RGB=51,51,255, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.36,2.46,0.0,1.21,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Door B  Obstruction', XB=7.32,7.34,2.9,3.82,0.1,2.12, SURF_ID='INERT'/
&OBST ID='Window G Obstruction', XB=6.67,7.24,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID=' Window H Obstruction', XB=2.6,3.14,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID='Window E Obstruction', XB=3.13,4.15,0.0,0.02,1.0,2.1, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=0.0,5.1,2.24,2.34,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.44,2.54,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=5.0,5.1,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
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&OBST ID='Obstruction', XB=0.0,7.34,-0.1,0.0,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
&OBST ID='Obstruction', XB=-0.1,0.0,-0.1,4.68,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
&OBST ID='Obstruction', XB=7.34,7.44,-0.1,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
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&OBST ID='Ceiling', XB=-0.1,7.44,-0.1,4.78,2.43,2.53, SURF_ID='INERT'/

&OBST ID='Discharge vent bedroom', XB=3.8,3.9,3.48,3.58,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge vent livingroom', XB=5.6,6.05,1.88,2.33,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge Vent bathroom', XB=1.22,1.32,3.46,3.56,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID=' Window I Obstruction', XB=1.49,2.02,4.67,4.68,0.9,2.16, SURF_ID='INERT'/

&OBST ID=' Door C Obstruction', XB=2.739,3.549,2.24,2.34,0.1,2.0, SURF_ID='INERT'/

&OBST ID='Door D Obstruction', XB=1.29,2.1,2.24,2.34,0.1,2.0, SURF_ID='INERT'/

&OBST ID='Window F obstruction', XB=7.32,7.34,1.185,2.162,1.0,2.1, SURF_ID='INERT'/


&HOLE ID='DoorD', XB=1.29,2.1,2.24,2.34,0.1,2.0/

&HOLE ID='DoorC', XB=2.739,3.549,2.24,2.34,0.1,2.0/

&HOLE ID='Window E', XB=3.15,4.125,-0.1,0.0,1.01,2.09/

&HOLE ID='Window F', XB=7.34,7.44,1.186,2.161,1.01,2.09/

&HOLE ID='Window G', XB=6.71,7.22,4.68,4.78,0.945,2.15/

&HOLE ID='Window H', XB=2.62,3.13,4.68,4.78,0.945,2.15/

&HOLE ID='DoorA', XB=0.96,1.77,-0.1,0.0,0.1,2.1/

&HOLE ID='DoorB', XB=7.34,7.44,3.0,3.81,0.1,2.1, COLOR='GRAY 94'/

&HOLE ID='Window I', XB=1.5,2.01,4.68,4.78,0.945,2.15/


&VENT ID='Mesh Vent: MESH-01-01 [XMIN]', SURF_ID='OPEN', XB=0.0,0.0,-0.936,-0.1,0.0,2.34/

&VENT ID='Mesh Vent: MESH-01-01 [YMIN]', SURF_ID='OPEN', XB=0.0,7.836,-0.936,-0.936,0.0,2.34/

&VENT ID='Vent', SURF_ID='INERT', XB=0.0,7.836,-0.936,-0.1,2.43,2.43/

&VENT ID='Vent living room 01', SURF_ID='Nozzle Surface', XB=5.6,5.6,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 02', SURF_ID='Nozzle Surface', XB=6.05,6.05,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 03', SURF_ID='Nozzle Surface', XB=5.6,6.05,1.88,1.88,2.33,2.43/

&VENT ID='Vent living room 04', SURF_ID='Nozzle Surface', XB=5.6,6.05,2.33,2.33,2.33,2.43/

&VENT ID='Vent bed room 05', SURF_ID='Nozzle Surface', XB=3.8,3.8,3.48,3.58,2.33,2.43/
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&VENT ID='Vent bed room 06', SURF_ID='Nozzle Surface', XB=3.9,3.9,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 07', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.48,3.48,2.33,2.43/
&VENT ID='Vent bed room 08', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.58,3.58,2.33,2.43/
&VENT ID='Vent bath room 01', SURF_ID='Nozzle Surface', XB=1.22,1.22,3.46,3.56,2.33,2.43/
&VENT ID='Vent bath room 02', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.46,3.46,2.33,2.43/
&VENT ID='Vent bath room 03', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.56,3.56,2.33,2.43/
&VENT ID='Vent bath room 04', SURF_ID='Nozzle Surface', XB=1.32,1.32,3.46,3.56,2.33,2.43/
&VENT ID='Mesh Vent: MESH-01-01 [XMAX]01', SURF_ID='OPEN', XB=7.836,7.836,-0.936,4.68,0.0,2.34/
&VENT ID='Ceiline Xmax', SURF_ID='INERT', XB=7.34,7.836,-0.1,4.68,2.43,2.43/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=1.8/

&DEVC ID='[Species: OXYGEN] Volume Fraction_MEAN', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', SPATIAL_STATISTIC='MEAN', XB=0.0,7.34,0.0,4.68,0.0,2.43/


&TAIL /
```

Scenario 3 – window E and Window F 25 cm open

2Final_simulation_two_windows_open_fds.fds

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Jun 13, 2022 4:44:03 PM

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&HEAD CHID='2Final_simulation_two_windows_open_fds'/
&TIME T_END=720.0/
&DUMP DT_RESTART=300.0, DT_SL3D=0.25/
&MISC Y_O2_INFTY=0.21/

&MESH ID='MESH-01-01', IJK=158,120,48, XB=0.0,7.836,-0.936,4.68,0.0,2.43/

&ZONE ID='Zone01', XB=0.0,7.34,0.0,4.68,0.1,2.43, LEAK_AREA=0.5/

&SPEC ID='ARGON', LUMPED_COMPONENT_ONLY=.TRUE./
&SPEC ID='IG541',
  SPEC_ID(1)='ARGON',
  SPEC_ID(2)='CARBON DIOXIDE',
  SPEC_ID(3)='NITROGEN',
  VOLUME_FRACTION(1)=0.4,
  VOLUME_FRACTION(2)=0.08,
  VOLUME_FRACTION(3)=0.52/

&DEVC ID='vel-01', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,2.0, VELO_INDEX=1/
&DEVC ID='vel-02', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.6, VELO_INDEX=1/
&DEVC ID='vel-03', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.2, VELO_INDEX=1/
&DEVC ID='vel-04', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.8, VELO_INDEX=1/
&DEVC ID='vel-05', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.4, VELO_INDEX=1/
&DEVC ID='pre-01', QUANTITY='PRESSURE', XYZ=1.01,0.6,2.0/
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&DEVC ID='pre-02', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.6/

&DEVC ID='pre-03', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.2/

&DEVC ID='pre-04', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.8/

&DEVC ID='pre-05', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.4/

&DEVC ID='Oxygen concentration door A_01_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.3/

&DEVC ID='Oxygen concentration door A_02_(Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.8/

&DEVC ID='Oxygen concentration door A_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,1.8/

&DEVC ID='Oxygen concentration window G_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,4.2,0.3/

&DEVC ID='Oxygen concentration window G_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,4.2,0.8/

&DEVC ID='Oxygen concentration window G_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,4.2,1.8/

&DEVC ID='Oxygen concentration window F_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.3/

&DEVC ID='Oxygen concentration window F_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.8/

&DEVC ID='Oxygen concentration window F_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,1.8/


&SURF ID='Leakage Surface',

    RGB=127,221,255,

    LEAK_PATH=1,0/

&SURF ID='Nozzle Surface',

    RGB=251,7,19,

    TMP_FRONT=-18.0,

    MASS_FLUX=5.26,

    SPEC_ID='IG541',

    RAMP_MF='Nozzle Surface_RAMP_MF'/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=1.07, F=1.0/
&RAMP ID='Nozzle Surface_RAMP_MF', T=1.14, F=0.97/
&RAMP ID='Nozzle Surface_RAMP_MF', T=2.72, F=0.95/
&RAMP ID='Nozzle Surface_RAMP_MF', T=3.21, F=0.91/
&RAMP ID='Nozzle Surface_RAMP_MF', T=4.06, F=0.88/
&RAMP ID='Nozzle Surface_RAMP_MF', T=5.01, F=0.85/
&RAMP ID='Nozzle Surface_RAMP_MF', T=6.06, F=0.82/
&RAMP ID='Nozzle Surface_RAMP_MF', T=6.85, F=0.79/
&RAMP ID='Nozzle Surface_RAMP_MF', T=8.0, F=0.77/
&RAMP ID='Nozzle Surface_RAMP_MF', T=8.97, F=0.73/
&RAMP ID='Nozzle Surface_RAMP_MF', T=10.07, F=0.7/
&RAMP ID='Nozzle Surface_RAMP_MF', T=11.3, F=0.67/
&RAMP ID='Nozzle Surface_RAMP_MF', T=12.57, F=0.64/
&RAMP ID='Nozzle Surface_RAMP_MF', T=14.12, F=0.62/
&RAMP ID='Nozzle Surface_RAMP_MF', T=15.56, F=0.59/
&RAMP ID='Nozzle Surface_RAMP_MF', T=17.58, F=0.55/
&RAMP ID='Nozzle Surface_RAMP_MF', T=18.75, F=0.53/
&RAMP ID='Nozzle Surface_RAMP_MF', T=20.99, F=0.5/
&RAMP ID='Nozzle Surface_RAMP_MF', T=23.02, F=0.48/
&RAMP ID='Nozzle Surface_RAMP_MF', T=25.71, F=0.46/
&RAMP ID='Nozzle Surface_RAMP_MF', T=28.32, F=0.44/
&RAMP ID='Nozzle Surface_RAMP_MF', T=31.2, F=0.4/
&RAMP ID='Nozzle Surface_RAMP_MF', T=32.81, F=0.38/
&RAMP ID='Nozzle Surface_RAMP_MF', T=35.59, F=0.36/
&RAMP ID='Nozzle Surface_RAMP_MF', T=38.61, F=0.35/
&RAMP ID='Nozzle Surface_RAMP_MF', T=41.63, F=0.33/
&RAMP ID='Nozzle Surface_RAMP_MF', T=44.65, F=0.31/
&RAMP ID='Nozzle Surface_RAMP_MF', T=47.67, F=0.3/
&RAMP ID='Nozzle Surface_RAMP_MF', T=50.69, F=0.29/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=53.71, F=0.27/
&RAMP ID='Nozzle Surface_RAMP_MF', T=56.73, F=0.26/
&RAMP ID='Nozzle Surface_RAMP_MF', T=60.0, F=0.24/
&RAMP ID='Nozzle Surface_RAMP_MF', T=62.84, F=0.23/
&RAMP ID='Nozzle Surface_RAMP_MF', T=65.79, F=0.22/
&RAMP ID='Nozzle Surface_RAMP_MF', T=68.8, F=0.21/
&RAMP ID='Nozzle Surface_RAMP_MF', T=71.82, F=0.2/
&RAMP ID='Nozzle Surface_RAMP_MF', T=74.84, F=0.19/
&RAMP ID='Nozzle Surface_RAMP_MF', T=77.86, F=0.17/
&RAMP ID='Nozzle Surface_RAMP_MF', T=80.88, F=0.17/
&RAMP ID='Nozzle Surface_RAMP_MF', T=83.9, F=0.16/
&RAMP ID='Nozzle Surface_RAMP_MF', T=86.92, F=0.15/
&RAMP ID='Nozzle Surface_RAMP_MF', T=90.0, F=0.15/
&RAMP ID='Nozzle Surface_RAMP_MF', T=92.96, F=0.14/
&RAMP ID='Nozzle Surface_RAMP_MF', T=95.98, F=0.13/
&RAMP ID='Nozzle Surface_RAMP_MF', T=99.0, F=0.13/
&RAMP ID='Nozzle Surface_RAMP_MF', T=102.01, F=0.12/
&RAMP ID='Nozzle Surface_RAMP_MF', T=105.03, F=0.12/
&RAMP ID='Nozzle Surface_RAMP_MF', T=108.05, F=0.11/
&RAMP ID='Nozzle Surface_RAMP_MF', T=111.07, F=0.11/
&RAMP ID='Nozzle Surface_RAMP_MF', T=114.09, F=0.1/
&RAMP ID='Nozzle Surface_RAMP_MF', T=117.11, F=0.1/
&RAMP ID='Nozzle Surface_RAMP_MF', T=120.23, F=0.09/
&RAMP ID='Nozzle Surface_RAMP_MF', T=123.15, F=0.09/
&RAMP ID='Nozzle Surface_RAMP_MF', T=126.17, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=129.19, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=132.2, F=0.07/
&RAMP ID='Nozzle Surface_RAMP_MF', T=135.22, F=0.06/
&RAMP ID='Nozzle Surface_RAMP_MF', T=138.24, F=0.06/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=141.26, F=0.06/
&RAMP ID='Nozzle Surface_RAMP_MF', T=144.28, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=147.3, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=150.47, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=153.34, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=156.36, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=159.38, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=162.4, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=165.41, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=168.43, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=171.45, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=174.47, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=177.49, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=180.51, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=182.29, F=0.0/

&OBST ID='Floor', XB=-0.1,7.44,-0.1,4.78,0.0,0.1, RGB=51,51,255, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.36,2.46,0.0,1.21,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Door B  Obstruction', XB=7.32,7.34,2.9,3.82,0.1,2.12, SURF_ID='INERT'/
&OBST ID='Window G Obstruction', XB=6.67,7.24,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID=' Window H Obstruction', XB=2.6,3.14,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID='Window E Obstruction', XB=3.13,4.15,0.0,0.02,1.26,2.1, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=0.0,5.1,2.24,2.34,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.44,2.54,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=5.0,5.1,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=-0.1,7.34,4.68,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
&OBST ID='Obstruction', XB=0.0,7.34,-0.1,0.0,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
&OBST ID='Obstruction', XB=-0.1,0.0,-0.1,4.68,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
&OBST ID='Obstruction', XB=7.34,7.44,-0.1,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage Surface'/
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&OBST ID='Ceiling', XB=-0.1,7.44,-0.1,4.78,2.43,2.53, SURF_ID='Leakage Surface'/

&OBST ID='Discharge vent bedroom', XB=3.8,3.9,3.48,3.58,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge vent livingroom', XB=5.6,6.05,1.88,2.33,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge Vent bathroom', XB=1.22,1.32,3.46,3.56,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Door A Obstruction', XB=0.95,1.78,0.0,0.02,0.1,2.12, SURF_ID='INERT'/

&OBST ID=' Window I Obstruction', XB=1.49,2.02,4.67,4.68,0.9,2.16, SURF_ID='INERT'/

&OBST ID=' Door C Obstruction', XB=2.739,3.549,2.24,2.34,0.1,2.0, SURF_ID='INERT'/

&OBST ID='Door D Obstruction', XB=1.29,2.1,2.24,2.34,0.1,2.0, SURF_ID='INERT'/

&OBST ID='Window F  Obstruction', XB=7.32,7.34,1.185,2.162,1.26,2.1, SURF_ID='INERT'/


&HOLE ID='DoorD', XB=1.29,2.1,2.24,2.34,0.1,2.0/

&HOLE ID='DoorC', XB=2.739,3.549,2.24,2.34,0.1,2.0/

&HOLE ID='Window E', XB=3.15,4.125,-0.1,0.0,1.01,2.09/

&HOLE ID='Window F', XB=7.34,7.44,1.186,2.161,1.01,2.09/

&HOLE ID='Window G', XB=6.71,7.22,4.68,4.78,0.945,2.15/

&HOLE ID='Window H', XB=2.62,3.13,4.68,4.78,0.945,2.15/

&HOLE ID='DoorA', XB=0.96,1.77,-0.1,0.0,0.1,2.1/

&HOLE ID='DoorB', XB=7.34,7.44,3.0,3.81,0.1,2.1, COLOR='GRAY 94'/

&HOLE ID='Window I', XB=1.5,2.01,4.68,4.78,0.945,2.15/


&VENT ID='Mesh Vent: MESH-01-01 [XMIN]', SURF_ID='OPEN', XB=0.0,0.0,-0.936,-0.1,0.0,2.34/

&VENT ID='Mesh Vent: MESH-01-01 [YMIN]', SURF_ID='OPEN', XB=0.0,7.836,-0.936,-0.936,0.0,2.34/

&VENT ID='Vent', SURF_ID='INERT', XB=0.0,7.836,-0.936,-0.1,2.43,2.43/

&VENT ID='Vent living room 01', SURF_ID='Nozzle Surface', XB=5.6,5.6,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 02', SURF_ID='Nozzle Surface', XB=6.05,6.05,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 03', SURF_ID='Nozzle Surface', XB=5.6,6.05,1.88,1.88,2.33,2.43/

&VENT ID='Vent living room 04', SURF_ID='Nozzle Surface', XB=5.6,6.05,2.33,2.33,2.33,2.43/
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```
&VENT ID='Vent bed room 05', SURF_ID='Nozzle Surface', XB=3.8,3.8,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 06', SURF_ID='Nozzle Surface', XB=3.9,3.9,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 07', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.48,3.48,2.33,2.43/
&VENT ID='Vent bed room 08', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.58,3.58,2.33,2.43/
&VENT ID='Vent bath room 01', SURF_ID='Nozzle Surface', XB=1.22,1.22,3.46,3.56,2.33,2.43/
&VENT ID='Vent bath room 02', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.46,3.46,2.33,2.43/
&VENT ID='Vent bath room 03', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.56,3.56,2.33,2.43/
&VENT ID='Vent bath room 04', SURF_ID='Nozzle Surface', XB=1.32,1.32,3.46,3.56,2.33,2.43/
&VENT ID='Mesh Vent: MESH-01-01 [XMAX]01', SURF_ID='OPEN', XB=7.836,7.836,-0.936,4.68,0.0,2.34/
&VENT ID='Ceiline Xmax', SURF_ID='INERT', XB=7.34,7.836,-0.1,4.68,2.43,2.43/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=1.8/

&DEVC ID='[Species: OXYGEN] Volume Fraction_MEAN', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', SPATIAL_STATISTIC='MEAN', XB=0.0,7.34,0.0,4.68,0.0,2.43/

&TAIL /
```

Scenario 3 – window F open

Final_simulation_one_window_open_fds.fds

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Jun 13, 2022 4:47:38 PM

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&HEAD CHID='_Final_simulation_one_window_open_fds'/
&TIME T_END=720.0/
&DUMP DT_RESTART=300.0, DT_SL3D=0.25/
&MISC Y_O2_INFTY=0.21/

&MESH ID='MESH-01-01', IJK=158,120,48, XB=0.0,7.836,-0.936,4.68,0.0,2.43/

&ZONE ID='Zone01', XB=0.0,7.34,0.0,4.68,0.1,2.43, LEAK_AREA=0.5/

&SPEC ID='ARGON', LUMPED_COMPONENT_ONLY=.TRUE./
&SPEC ID='IG541',
 SPEC_ID(1)='ARGON',
 SPEC_ID(2)='CARBON DIOXIDE',
 SPEC_ID(3)='NITROGEN',
 VOLUME_FRACTION(1)=0.4,
 VOLUME_FRACTION(2)=0.08,
 VOLUME_FRACTION(3)=0.52/

&DEVC ID='vel-01', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,2.0, VELO_INDEX=1/
&DEVC ID='vel-02', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.6, VELO_INDEX=1/
&DEVC ID='vel-03', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.2, VELO_INDEX=1/
&DEVC ID='vel-04', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.8, VELO_INDEX=1/
&DEVC ID='vel-05', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.4, VELO_INDEX=1/
&DEVC ID='pre-01', QUANTITY='PRESSURE', XYZ=1.01,0.6,2.0/
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&DEVC ID='pre-02', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.6/

&DEVC ID='pre-03', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.2/

&DEVC ID='pre-04', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.8/

&DEVC ID='pre-05', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.4/

&DEVC ID='Oxygen concentration door A_01_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.3/

&DEVC ID='Oxygen concentration door A_02_(Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.8/

&DEVC ID='Oxygen concentration door A_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,1.8/

&DEVC ID='Oxygen concentration window E_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.3/

&DEVC ID='Oxygen concentration window E_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.8/

&DEVC ID='Oxygen concentration window E_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,1.8/

&DEVC ID='Oxygen concentration window F_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.3/

&DEVC ID='Oxygen concentration window F_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.8/

&DEVC ID='Oxygen concentration window F_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,1.8/


&SURF ID='Leakage surface',
    RGB=127,221,255,
    LEAK_PATH=1,0/
&SURF ID='Nozzle Surface',
    RGB=251,7,19,
    TMP_FRONT=-18.0,
    MASS_FLUX=5.26,
    SPEC_ID='IG541',
    RAMP_MF='Nozzle Surface_RAMP_MF'/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=1.07, F=1.0/

&RAMP ID='Nozzle Surface_RAMP_MF', T=1.14, F=0.97/

&RAMP ID='Nozzle Surface_RAMP_MF', T=2.72, F=0.95/

&RAMP ID='Nozzle Surface_RAMP_MF', T=3.21, F=0.91/

&RAMP ID='Nozzle Surface_RAMP_MF', T=4.06, F=0.88/

&RAMP ID='Nozzle Surface_RAMP_MF', T=5.01, F=0.85/

&RAMP ID='Nozzle Surface_RAMP_MF', T=6.06, F=0.82/

&RAMP ID='Nozzle Surface_RAMP_MF', T=6.85, F=0.79/

&RAMP ID='Nozzle Surface_RAMP_MF', T=8.0, F=0.77/

&RAMP ID='Nozzle Surface_RAMP_MF', T=8.97, F=0.73/

&RAMP ID='Nozzle Surface_RAMP_MF', T=10.07, F=0.7/

&RAMP ID='Nozzle Surface_RAMP_MF', T=11.3, F=0.67/

&RAMP ID='Nozzle Surface_RAMP_MF', T=12.57, F=0.64/

&RAMP ID='Nozzle Surface_RAMP_MF', T=14.12, F=0.62/

&RAMP ID='Nozzle Surface_RAMP_MF', T=15.56, F=0.59/

&RAMP ID='Nozzle Surface_RAMP_MF', T=17.58, F=0.55/

&RAMP ID='Nozzle Surface_RAMP_MF', T=18.75, F=0.53/

&RAMP ID='Nozzle Surface_RAMP_MF', T=20.99, F=0.5/

&RAMP ID='Nozzle Surface_RAMP_MF', T=23.02, F=0.48/

&RAMP ID='Nozzle Surface_RAMP_MF', T=25.71, F=0.46/

&RAMP ID='Nozzle Surface_RAMP_MF', T=28.32, F=0.44/

&RAMP ID='Nozzle Surface_RAMP_MF', T=31.2, F=0.4/

&RAMP ID='Nozzle Surface_RAMP_MF', T=32.81, F=0.38/

&RAMP ID='Nozzle Surface_RAMP_MF', T=35.59, F=0.36/

&RAMP ID='Nozzle Surface_RAMP_MF', T=38.61, F=0.35/

&RAMP ID='Nozzle Surface_RAMP_MF', T=41.63, F=0.33/

&RAMP ID='Nozzle Surface_RAMP_MF', T=44.65, F=0.31/

&RAMP ID='Nozzle Surface_RAMP_MF', T=47.67, F=0.3/

&RAMP ID='Nozzle Surface_RAMP_MF', T=50.69, F=0.29/

&RAMP ID='Nozzle Surface_RAMP_MF', T=53.71, F=0.27/

&RAMP ID='Nozzle Surface_RAMP_MF', T=56.73, F=0.26/

&RAMP ID='Nozzle Surface_RAMP_MF', T=60.0, F=0.24/

&RAMP ID='Nozzle Surface_RAMP_MF', T=62.84, F=0.23/

&RAMP ID='Nozzle Surface_RAMP_MF', T=65.79, F=0.22/

&RAMP ID='Nozzle Surface_RAMP_MF', T=68.8, F=0.21/

&RAMP ID='Nozzle Surface_RAMP_MF', T=71.82, F=0.2/

&RAMP ID='Nozzle Surface_RAMP_MF', T=74.84, F=0.19/

&RAMP ID='Nozzle Surface_RAMP_MF', T=77.86, F=0.17/

&RAMP ID='Nozzle Surface_RAMP_MF', T=80.88, F=0.17/

&RAMP ID='Nozzle Surface_RAMP_MF', T=83.9, F=0.16/

&RAMP ID='Nozzle Surface_RAMP_MF', T=86.92, F=0.15/

&RAMP ID='Nozzle Surface_RAMP_MF', T=90.0, F=0.15/

&RAMP ID='Nozzle Surface_RAMP_MF', T=92.96, F=0.14/

&RAMP ID='Nozzle Surface_RAMP_MF', T=95.98, F=0.13/

&RAMP ID='Nozzle Surface_RAMP_MF', T=99.0, F=0.13/

&RAMP ID='Nozzle Surface_RAMP_MF', T=102.01, F=0.12/

&RAMP ID='Nozzle Surface_RAMP_MF', T=105.03, F=0.12/

&RAMP ID='Nozzle Surface_RAMP_MF', T=108.05, F=0.11/

&RAMP ID='Nozzle Surface_RAMP_MF', T=111.07, F=0.11/

&RAMP ID='Nozzle Surface_RAMP_MF', T=114.09, F=0.1/

&RAMP ID='Nozzle Surface_RAMP_MF', T=117.11, F=0.1/

&RAMP ID='Nozzle Surface_RAMP_MF', T=120.23, F=0.09/

&RAMP ID='Nozzle Surface_RAMP_MF', T=123.15, F=0.09/

&RAMP ID='Nozzle Surface_RAMP_MF', T=126.17, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=129.19, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=132.2, F=0.07/

&RAMP ID='Nozzle Surface_RAMP_MF', T=135.22, F=0.06/

&RAMP ID='Nozzle Surface_RAMP_MF', T=138.24, F=0.06/

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&RAMP ID='Nozzle Surface_RAMP_MF', T=141.26, F=0.06/
&RAMP ID='Nozzle Surface_RAMP_MF', T=144.28, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=147.3, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=150.47, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=153.34, F=0.05/
&RAMP ID='Nozzle Surface_RAMP_MF', T=156.36, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=159.38, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=162.4, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=165.41, F=0.04/
&RAMP ID='Nozzle Surface_RAMP_MF', T=168.43, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=171.45, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=174.47, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=177.49, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=180.51, F=0.03/
&RAMP ID='Nozzle Surface_RAMP_MF', T=182.29, F=0.0/

&OBST ID='Floor', XB=-0.1,7.44,-0.1,4.78,0.0,0.1, RGB=51,51,255, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.36,2.46,0.0,1.21,0.1,2.43, COLOR='INVISIBLE', SURF_ID='INERT'/
&OBST ID='Door B  Obstruction', XB=7.32,7.34,2.9,3.82,0.1,2.12, SURF_ID='INERT'/
&OBST ID='Window G Obstruction', XB=6.67,7.24,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID=' Window H Obstruction', XB=2.6,3.14,4.67,4.68,0.9,2.16, SURF_ID='INERT'/
&OBST ID='Window E Obstruction', XB=3.13,4.15,0.0,0.02,1.0,2.1, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=0.0,5.1,2.24,2.34,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=2.44,2.54,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=5.0,5.1,2.34,4.68,0.1,2.43, SURF_ID='INERT'/
&OBST ID='Obstruction', XB=-0.1,7.34,4.68,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage surface'/
&OBST ID='Obstruction', XB=0.0,7.34,-0.1,0.0,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage surface'/
&OBST ID='Obstruction', XB=-0.1,0.0,-0.1,4.68,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage surface'/
&OBST ID='Obstruction', XB=7.34,7.44,-0.1,4.78,0.1,2.43, COLOR='GRAY 94', SURF_ID='Leakage surface'/
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&OBST ID='Ceiling', XB=-0.1,7.44,-0.1,4.78,2.43,2.53, SURF_ID='Leakage surface'/

&OBST ID='Discharge vent bedroom', XB=3.8,3.9,3.48,3.58,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge vent livingroom', XB=5.6,6.05,1.88,2.33,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Discharge Vent bathroom', XB=1.22,1.32,3.46,3.56,2.33,2.43, SURF_IDS='INERT','Nozzle Surface','INERT'/

&OBST ID='Door A Obstruction', XB=0.95,1.78,0.0,0.02,0.1,2.12, SURF_ID='INERT'/

&OBST ID=' Window I Obstruction', XB=1.49,2.02,4.67,4.68,0.9,2.16, SURF_ID='INERT'/

&OBST ID=' Door C Obstruction', XB=2.739,3.549,2.24,2.34,0.1,2.0, SURF_ID='INERT'/

&OBST ID='Door D Obstruction', XB=1.29,2.1,2.24,2.34,0.1,2.0, SURF_ID='INERT'/


&HOLE ID='DoorD', XB=1.29,2.1,2.24,2.34,0.1,2.0/

&HOLE ID='DoorC', XB=2.739,3.549,2.24,2.34,0.1,2.0/

&HOLE ID='Window E', XB=3.15,4.125,-0.1,0.0,1.01,2.09/

&HOLE ID='Window F', XB=7.34,7.44,1.186,2.161,1.01,2.09/

&HOLE ID='Window G', XB=6.71,7.22,4.68,4.78,0.945,2.15/

&HOLE ID='Window H', XB=2.62,3.13,4.68,4.78,0.945,2.15/

&HOLE ID='DoorA', XB=0.96,1.77,-0.1,0.0,0.1,2.1/

&HOLE ID='DoorB', XB=7.34,7.44,3.0,3.81,0.1,2.1, COLOR='GRAY 94'/

&HOLE ID='Window I', XB=1.5,2.01,4.68,4.78,0.945,2.15/


&VENT ID='Mesh Vent: MESH-01-01 [XMIN]', SURF_ID='OPEN', XB=0.0,0.0,-0.936,-0.1,0.0,2.34/

&VENT ID='Mesh Vent: MESH-01-01 [YMIN]', SURF_ID='OPEN', XB=0.0,7.836,-0.936,-0.936,0.0,2.34/

&VENT ID='Vent', SURF_ID='INERT', XB=0.0,7.836,-0.936,-0.1,2.43,2.43/

&VENT ID='Vent living room 01', SURF_ID='Nozzle Surface', XB=5.6,5.6,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 02', SURF_ID='Nozzle Surface', XB=6.05,6.05,1.88,2.33,2.33,2.43/

&VENT ID='Vent living room 03', SURF_ID='Nozzle Surface', XB=5.6,6.05,1.88,1.88,2.33,2.43/

&VENT ID='Vent living room 04', SURF_ID='Nozzle Surface', XB=5.6,6.05,2.33,2.33,2.33,2.43/

&VENT ID='Vent bed room 05', SURF_ID='Nozzle Surface', XB=3.8,3.8,3.48,3.58,2.33,2.43/
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&VENT ID='Vent bed room 06', SURF_ID='Nozzle Surface', XB=3.9,3.9,3.48,3.58,2.33,2.43/
&VENT ID='Vent bed room 07', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.48,3.48,2.33,2.43/
&VENT ID='Vent bed room 08', SURF_ID='Nozzle Surface', XB=3.8,3.9,3.58,3.58,2.33,2.43/
&VENT ID='Vent bath room 01', SURF_ID='Nozzle Surface', XB=1.22,1.22,3.46,3.56,2.33,2.43/
&VENT ID='Vent bath room 02', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.46,3.46,2.33,2.43/
&VENT ID='Vent bath room 03', SURF_ID='Nozzle Surface', XB=1.22,1.32,3.56,3.56,2.33,2.43/
&VENT ID='Vent bath room 04', SURF_ID='Nozzle Surface', XB=1.32,1.32,3.46,3.56,2.33,2.43/
&VENT ID='Mesh Vent: MESH-01-01 [XMAX]01', SURF_ID='OPEN', XB=7.836,7.836,-0.936,4.68,0.0,2.34/
&VENT ID='Ceiline Xmax', SURF_ID='INERT', XB=7.34,7.836,-0.1,4.68,2.43,2.43/

&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=1.3/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBX=3.6/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=1.8/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='IG541', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='U-VELOCITY', VECTOR=.TRUE., PBY=3.4/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', VECTOR=.TRUE., PBY=1.8/

&DEVC ID='[Species: OXYGEN] Volume Fraction_MEAN', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', SPATIAL_STATISTIC='MEAN', XB=0.0,7.34,0.0,4.68,0.0,2.43/


&TAIL /
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Scenario 5 – Door A 14 cm open

2Final_simulation_door_a_14cm_open_fds.fds

Generated by PyroSim - Version 2021.4.1201

Jun 13, 2022 4:50:51 PM

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&HEAD CHID='2Final_simulation_door_a_14cm_open_fds'/
&TIME T_END=720.0/
&DUMP DT_RESTART=300.0, DT_SL3D=0.25/
&MISC Y_O2_INFTY=0.21/

&MESH ID='MESH-01-01', IJK=158,120,48, XB=0.0,7.836,-0.936,4.68,0.0,2.43/

&ZONE ID='Zone01', XB=0.0,7.34,0.0,4.68,0.0,2.43, LEAK_AREA=0.5/

&SPEC ID='ARGON', LUMPED_COMPONENT_ONLY=.TRUE./
&SPEC ID='IG541',
  SPEC_ID(1)='ARGON',
  SPEC_ID(2)='CARBON DIOXIDE',
  SPEC_ID(3)='NITROGEN',
  VOLUME_FRACTION(1)=0.4,
  VOLUME_FRACTION(2)=0.08,
  VOLUME_FRACTION(3)=0.52/

&DEVC ID='vel-01', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,2.0, VELO_INDEX=1/
&DEVC ID='vel-02', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.6, VELO_INDEX=1/
&DEVC ID='vel-03', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,1.2, VELO_INDEX=1/
&DEVC ID='vel-04', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.8, VELO_INDEX=1/
&DEVC ID='vel-05', QUANTITY='U-VELOCITY', XYZ=1.01,0.6,0.4, VELO_INDEX=1/
&DEVC ID='pre-01', QUANTITY='PRESSURE', XYZ=1.01,0.6,2.0/
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&DEVC ID='pre-02', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.6/

&DEVC ID='pre-03', QUANTITY='PRESSURE', XYZ=1.01,0.6,1.2/

&DEVC ID='pre-04', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.8/

&DEVC ID='pre-05', QUANTITY='PRESSURE', XYZ=1.01,0.6,0.4/

&DEVC ID='Oxygen concentration door A_01_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.3/

&DEVC ID='Oxygen concentration door A_02_(Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,0.8/

&DEVC ID='Oxygen concentration door A_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=1.3,0.3,1.8/

&DEVC ID='Oxygen concentration window E_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.3/

&DEVC ID='Oxygen concentration window E_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,0.8/

&DEVC ID='Oxygen concentration window E_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=3.6,0.3,1.8/

&DEVC ID='Oxygen concentration window F_01 (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.3/

&DEVC ID='Oxygen concentration window F_02_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,0.8/

&DEVC ID='Oxygen concentration window F_03_ (Simulation)', QUANTITY='VOLUME FRACTION',
SPEC_ID='OXYGEN', XYZ=7.0,1.2,1.8/


&SURF ID='Leakage Surface',

    RGB=127,221,255,

    LEAK_PATH=1,0/

&SURF ID='Nozzle Surface',

    RGB=251,7,19,

    TMP_FRONT=-18.0,

    MASS_FLUX=5.26,

    SPEC_ID='IG541',

    RAMP_MF='Nozzle Surface_RAMP_MF'/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=1.07, F=1.0/
&RAMP ID='Nozzle Surface_RAMP_MF', T=1.14, F=0.97/
&RAMP ID='Nozzle Surface_RAMP_MF', T=2.72, F=0.95/
&RAMP ID='Nozzle Surface_RAMP_MF', T=3.21, F=0.91/
&RAMP ID='Nozzle Surface_RAMP_MF', T=4.06, F=0.88/
&RAMP ID='Nozzle Surface_RAMP_MF', T=5.01, F=0.85/
&RAMP ID='Nozzle Surface_RAMP_MF', T=6.06, F=0.82/
&RAMP ID='Nozzle Surface_RAMP_MF', T=6.85, F=0.79/
&RAMP ID='Nozzle Surface_RAMP_MF', T=8.0, F=0.77/
&RAMP ID='Nozzle Surface_RAMP_MF', T=8.97, F=0.73/
&RAMP ID='Nozzle Surface_RAMP_MF', T=10.07, F=0.7/
&RAMP ID='Nozzle Surface_RAMP_MF', T=11.3, F=0.67/
&RAMP ID='Nozzle Surface_RAMP_MF', T=12.57, F=0.64/
&RAMP ID='Nozzle Surface_RAMP_MF', T=14.12, F=0.62/
&RAMP ID='Nozzle Surface_RAMP_MF', T=15.56, F=0.59/
&RAMP ID='Nozzle Surface_RAMP_MF', T=17.58, F=0.55/
&RAMP ID='Nozzle Surface_RAMP_MF', T=18.75, F=0.53/
&RAMP ID='Nozzle Surface_RAMP_MF', T=20.99, F=0.5/
&RAMP ID='Nozzle Surface_RAMP_MF', T=23.02, F=0.48/
&RAMP ID='Nozzle Surface_RAMP_MF', T=25.71, F=0.46/
&RAMP ID='Nozzle Surface_RAMP_MF', T=28.32, F=0.44/
&RAMP ID='Nozzle Surface_RAMP_MF', T=31.2, F=0.4/
&RAMP ID='Nozzle Surface_RAMP_MF', T=32.81, F=0.38/
&RAMP ID='Nozzle Surface_RAMP_MF', T=35.59, F=0.36/
&RAMP ID='Nozzle Surface_RAMP_MF', T=38.61, F=0.35/
&RAMP ID='Nozzle Surface_RAMP_MF', T=41.63, F=0.33/
&RAMP ID='Nozzle Surface_RAMP_MF', T=44.65, F=0.31/
&RAMP ID='Nozzle Surface_RAMP_MF', T=47.67, F=0.3/
&RAMP ID='Nozzle Surface_RAMP_MF', T=50.69, F=0.29/
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&RAMP ID='Nozzle Surface_RAMP_MF', T=53.71, F=0.27/
&RAMP ID='Nozzle Surface_RAMP_MF', T=56.73, F=0.26/
&RAMP ID='Nozzle Surface_RAMP_MF', T=60.0, F=0.24/
&RAMP ID='Nozzle Surface_RAMP_MF', T=62.84, F=0.23/
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