ASSESSMENT OF FIRE SAFETY FOR INTERMEDIATE FLOORS IN THE NEW ZEALAND ACCEPTABLE SOLUTION C/AS1

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ABSTRACT

This research project aims to investigate the level of risk/safety inherent in intermediate floors of buildings designed to the Compliance Document for the New Zealand Building Code, Fire Safety Clauses C1, C2, C3, C4 (C/AS1), and develop guidance for Fire Engineers on designing fire safety for firecells containing intermediate floors. The project also aims to develop a new set of prescriptive fire safety requirements for intermediate floors and proposes an outline of a verification method for designing fire safety for intermediate floors.

This study includes a literature review of the fire safety requirements for intermediate floors (mezzanines) of prescriptive requirements in New Zealand and other countries such as USA, Canada, UK and Australia. The results of this literature review found that the intermediate floor size is limited and varies with country. An intermediate floor that has an area exceeding the limit set out by the prescriptive requirements is considered as a storey in all the countries prescriptive requirements reviewed including the New Zealand prescriptive requirements prior to 1991. Since 1991, in New Zealand Acceptable Solutions, the intermediate floor that has an area exceeding the limit will not be treated as a storey, however, a smoke control system is required.

The level of risk was quantified using a factor of safety (FoS) - the ratio of Available Safe Egress Time (ASET) to Required Safe Egress Time (RSET). Two fire models; BRANZFIRE and FDS were used to calculate ASET and SIMULEX, an evacuation program, was used to calculate movement times of the occupants of the studied buildings. Unlike the traditional method in which RSET and FoS are assessed using single value, in this project the distribution of RSET and FoS were assessed using the @RISK software package. The analysis showed that the level of risk to the occupants of the firecells containing intermediate floors is always higher than that of the equivalent firecells without intermediate floors with the same occupant load and the differences in FoS range from 10% to 60%. The analysis also highlighted that the level of risk to the occupants of firecells having intermediate floors increases as the intermediate floor size increases, however, there are no clear cut-off points at which a higher level of fire safety precaution should be provided. The cut-off points in C/AS1 of 20% for a closed intermediate floor and 40% for an open intermediate floor, are not justified by this analysis. Occupant load has significant impact on the level of safety of the occupants of the firecells containing intermediate floors. The higher the occupant load the lower the level of safety is.

The definitions for open and closed intermediate floors are proposed to which open and closed intermediate floors are clearly distinguished. The term “limited area intermediate floor” in the current C/AS1 is proposed be removed and all related clauses are proposed to be amended or deleted accordingly. A proposed new set of prescriptive fire safety requirements for intermediate floors has been developed based on the occupant load of intermediate floors and not the intermediate floor size in the form of a table similar to the current Table 4.1 of C/AS1. The occupant load and fire safety precautions (FSPs) of the intermediate floors are determined based on the occupant load and their required FSPs of the equivalent firecells without intermediate floors that have the same factor of safety with the firecells containing intermediate floors. With the proposed FSPs, a firecell with lower occupant load would require lesser fire safety requirements than a firecell with higher occupant load regardless of intermediate floor size. Moreover, with the proposed FSPs for intermediate floors, the level of safety of the occupants of the firecells having intermediate floors would be very similar to the level of safety of the equivalent firecells without intermediate floors. In addition to the proposed tables of FSPs, some clauses regarding the changes in the fire safety requirement and definitions for intermediate floors are proposed.

Guidance for designers in designing fire safety for firecells containing intermediate floors in which the methods of modelling using BRANZFIRE and Fire Dynamics Simulator (FDS) are presented in detail, has been developed. The analysis has pointed out that the location of the exits is critical in designing fire safety for firecells containing intermediate floors and majority of exits from the lower floor should not be located under intermediate floors.

Although one of the main objectives of this research project was to propose an outline of a verification method for designing fire safety for intermediate floors, the analysis showed that it is very difficult to develop a rational verification method for designing fire safety for firecells containing intermediate floors.

Using the proposed FSPs for intermediate floors which are based on the occupant load of the intermediate floors in designing fire safety for firecells containing intermediate floors is recommended by this study. These recommendations do not preclude the use of specific fire engineering design for designing fire safety for firecells having intermediate floors.

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NOMENCLATURE

Abbreviations

ASET	Available Safe Egress Time
C/AS1	Compliance Document for New Zealand Building Code - Fire Safety Clauses C1, C2, C3, C4.
CL	C/AS1 Purpose Group - Crowd Large
CM	C/AS1 Purpose Group - Crowd Mercantile
CO	C/AS1 Purpose Group - Crowd Open
CS	C/AS1 Purpose Group - Crowd Small
DBH	New Zealand Government, Department of Building and Housing
F	C/AS1 Firecell Rating
FHC	Fire Hazard Category
FoS	Factor of Safety
FRR	C/AS1 - Fire Resistance Rating
FSP	C/AS1 Fire Safety Precautions
IA	C/AS1 Purpose Group - Intermittent Activities
ID	C/AS1 Purpose Group - Intermittent Dangerous
IE	C/AS1 Purpose Group - Intermittent Exitway
Int	Intermediate floor
Lower	Lower floor
NFPA	National Fire Protection Association (USA)
NRCC	National Research Council of Canada
NZ	New Zealand
NZBC	New Zealand Building Code
Open	The open area of a firecell containing intermediate floor
RSET	Required Safe Egress Time
S	C/AS1 Structural Endurance Rating

SA	C/AS1 Purpose Group - Sleeping Accommodation
SC	C/AS1 Purpose Group - Sleeping Care
SD	C/AS1 Purpose Group - Sleeping Detention
SH	C/AS1 Purpose Group - Sleeping Household
SR	C/AS1 Purpose Group - Sleeping Residential
Under	Under the intermediate floor
WH	C/AS1 Purpose Group - Working High (Fire load)
WL	C/AS1 Purpose Group - Working Low (Fire load)
WM	C/AS1 Purpose Group - Working Medium (Fire load)

Symbols

A	Floor area (m^2)
$\dot{m}_p$	Mass flow rate of air entrained into the plume (kg/s)
N	Occupant load (person)
h	The difference between the height of the ceiling and the base of the flames (m)
$\dot{Q}$	Total fire heat release rate (kW)
r	Radial distance of the detector from the vertical axis of the fire (m)
RTI	Response Time Index $(ms)^{0.5}$
T_∞	Ambient temperature (^oC)
t_a	Time from detection to alarm sounding (minutes)
t_d	Time to detection (minutes)
$T_{D,t}$	Detector or link temperature at time, t (^oC)
t_{ev}	Total evacuation time (minutes)
t_i	Time for occupants to investigate fire alarm (minutes)
$T_{jet,t}$	Same as $T_{jet,t+ t}$, but at the previous time step, t (^oC)
$T_{jet,t+ t}$	Temperature of the jet at the next time step, t+ t (^oC)
t_o	Time from alarm until occupants make decision (minutes)
t_p	Pre-movement time (minutes)
t_q	Queuing time (minutes)
$v_{jet,t}$	Velocity of the ceiling jet gases at time step, t (m/s)
z	Height of the smoke layer from the base of the fire (m)

1. INTRODUCTION

1.1 Background

In recent years, intermediate floors (mezzanines) have become a more popular architectural feature which can be found in many types of building, such as warehouses, factories, churches, halls, theatres, shopping malls, offices and others. The construction of intermediate floors can often provide additional space, which may be enclosed to the lower floors, e.g. storage, offices, etc; or cannot be enclosed, e.g. theatres, cinemas, etc. However, intermediate floors are also potentially less safe than a full floor, if a fire occurs on the lower floor.

In many countries, the concept that the level of risk to the occupants on the intermediate floors is dominated by the size of the intermediate floor and not the number of occupants has long been prevalent. The limit of the intermediate floor size, from which the intermediate floor is no longer to be considered as an intermediate floor and it is treated as a storey, is quite specific and varies between prescriptive requirements from different countries.

In USA [1], the aggregate area of mezzanines located within a room is limited at one-third of the open area of the room in which the mezzanines are located while in Canada [2] and UK [3] that figure is 40% and 50% respectively. In Australia [4], the aggregate area of mezzanines located within a room is less than 200 m^2 or one-third of the floor area of the room, whichever is the lesser.

In the NZS1900, Chapter 5, Fire Resisting Construction and Means of Egress [5], the area of the mezzanine was not allowed to exceed one-third of the area of the fire compartment in which it occurs. The aggregate area of intermediate floors was also limited for two-storey buildings at one-third of the lower floor in the NZBC, Approved Documents for Fire Safety C2, C3, C4 prior to 2001 [6].

In the current Acceptable Solution C/AS1 [7], total aggregate area of the intermediate floors at which the firecell containing intermediate floors requires the same FSPs as a single level firecell having the same total occupant load and escape height is limited at 20% and 40% for closed and open intermediate floors respectively. However, intermediate floor size is unlimited when a smoke control system is provided.

In the event of a fire, it is expected that the open intermediate floors will reach untenable conditions before the firecell floor due to the higher elevation of the intermediate floors. As the smoke layer drops, the occupants on the open intermediate floor may be exposed to smoke at an earlier stage than the occupants on the firecell floor. Therefore, firecells containing intermediate floors appear to be inherently less safe and may require a higher level of fire safety precautions than firecells without intermediate floors.

According to C/AS1, any floor having any permanent opening is treated as an intermediate floor. For example, a two-storey building with an enclosed interior staircase is normally treated as two separate firecells. However, if the enclosed interior staircase is non-fire rated or non-fire rated doors connect the staircase and floors, the building must be treated as a firecell containing a closed intermediate floor. This is a disadvantage of using C/AS1, where designers can alter planning and reduce costs by designing in accordance with the prescriptive requirements of C/AS1 when this results in an overall lower level of safety than other buildings, and lower than the authors of C/AS1 are thought to have intended.

In the current Acceptable Solution C/AS1 the intermediate floor percentage is defined as the ratio of area of the intermediate floor to the area of the firecell floor in which the firecell floor can be open or enclosed. Figure 1 and Figure 2 illustrate confusing scenarios caused by the above definition in C/AS1. Figure 1 shows the schematic of a firecell containing an open intermediate floor and non-partitioned lower floor. The lower floor is 1000 m^2 with an occupant load of 100 people and the intermediate floor is 100 m^2 (10% of the lower floor area) with 10 people. The intermediate floor is a limited area intermediate floor so the firecell is treated as a single level firecell with occupant load of 110 and escape height is the same as the height of the intermediate floor. A building the same as the building described in Figure 1 but with a partition (AB) on the lower floor dividing the lower floor into two parts 200 m^2 and 800 m^2 is shown in Figure 2. If the partition AB is fire rated construction then the building is treated as two separate firecells, in which the firecell containing the intermediate floor with an area of 50% of the lower floor area (100/200) requires a smoke control system as it contains a non limited area intermediate floor. If the partition is non-fire rated the building is treated as a single firecell, the same as the firecell described in Figure 1. Again, this also is a disadvantage of using C/AS1, where designers can alter planning and reduce costs by designing in accordance with the prescriptive requirements of C/AS1 when this results in an overall lower level of safety than other buildings, and lower than the authors of C/AS1 are thought to have intended.

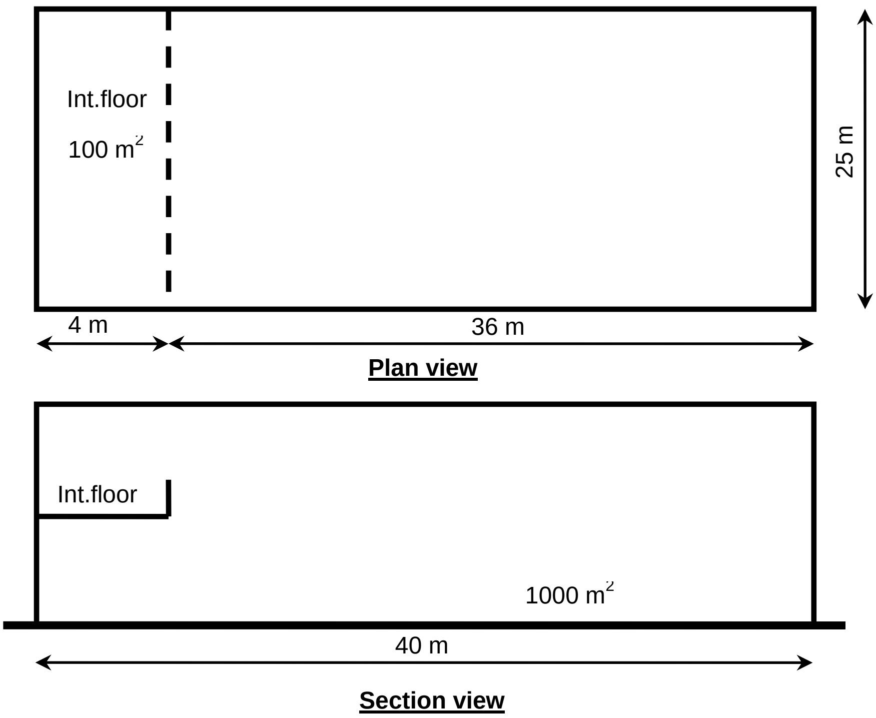


Figure 1: Schematic of a firecell containing open intermediate floor and non-partitioned lower floor. (Not to scale)

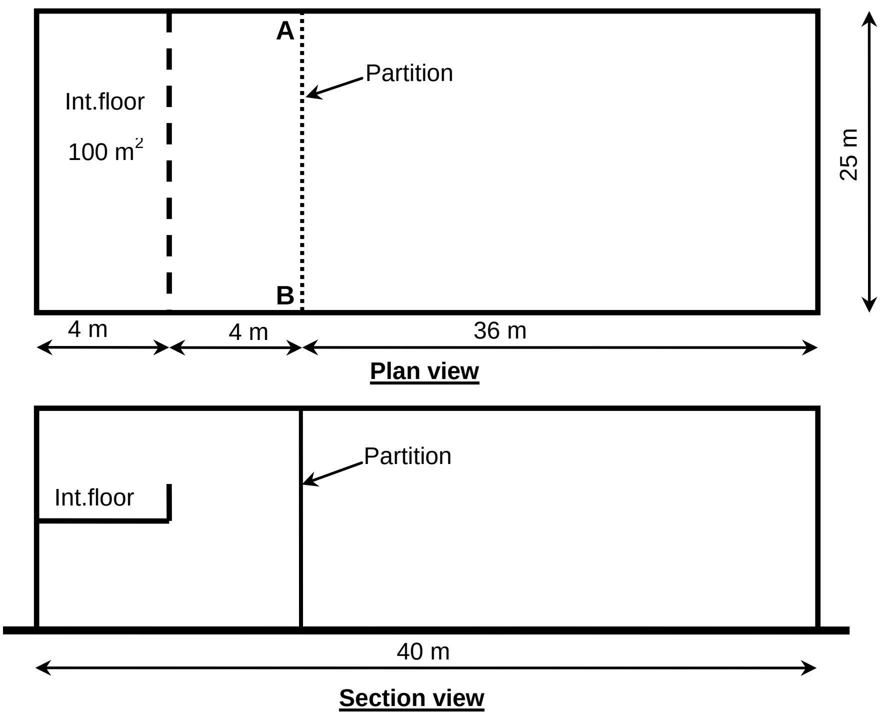


Figure 2: Schematic of a firecell containing open intermediate floor and partitioned lower floor. (Not to scale)

The question is whether the requirements for intermediate floors in the current Acceptable Solution C/AS1 have a rational basis.

This research project aims to investigate the level of risk/safety inherent in intermediate floors and develop guidance for Fire Engineers on designing fire safety for firecells containing intermediate floors with respect to the sizes of firecells and intermediate floors. This project also aims to develop a new set of prescriptive fire safety requirements for intermediate floors in which the fire safety precautions for intermediate floors are determined based on the occupant load of the intermediate floors and an outline of a verification method for designing fire safety for intermediate floors.

1.2 Objectives

The objectives of this research project are:

1. To document how fire safety for intermediate floors is currently addressed in prescriptive requirements in New Zealand and other countries; and
2. To examine the apparent comparative level of risk inherent in intermediate floors of the buildings designed to C/AS1; and
3. To develop guidance for Fire Engineers on designing fire safety for firecells containing intermediate floors for variations in sizes of firecells and intermediate floors; and
4. To develop and propose new prescriptive fire safety requirements for intermediate floors and an outline of a verification method for designing fire safety for intermediate floors; and
5. To provide recommendations on changing the requirements for intermediate floors to a future fire safety approved documents committee.

The first objective was achieved by reviewing the fire safety requirements in NZS 1900-Chapter 5: Fire Resisting Construction and Means of Egress [5], Acceptable Solution C2/AS1, C3/AS1 and C4/AS1 1992 [6], and the current Acceptable Solution C/AS1 (2008) [7]. The fire safety requirements for intermediate floors in the USA, Canada, UK, and Australia prescriptive requirements were also reviewed.

The second objective was accomplished by analyzing the level of risk of the occupants in a collection of hypothetical buildings. The level of risk was quantified using a factor of safety the ratio of ASET to RSET. Two fire models; BRANZFIRE and FDS were used to calculate ASET for all scenarios. The results from the more appropriate fire model between the two fire models were used to calculate FoS. SIMULEX, an evacuation program, was used to calculate movement times of the occupants of the studied buildings. Unlike the traditional method in which RSET and FoS are assessed using single value, in this project the distribution of RSET and FoS were assessed using the @RISK software package. The level of risk was judged by comparing the FoS of the occupants of firecells containing intermediate floors with the suggested FoS from literature. The FoS of the occupants of firecells containing intermediate floors were also compared with the FoS of the occupants of the equivalent firecells without intermediate floors having the same occupant load.

The last three objectives were attained based on the analysis that was carried out to achieve the second objective.

1.3 Outline of this report

This report consists of nine chapters. This Chapter contains general background information and objectives of the research.

Chapter 2 provides an overview of the New Zealand Building Control Framework.

Chapter 3 documents how fire safety for intermediate floors is currently addressed in prescriptive requirements in New Zealand and other countries. This Chapter focuses on the fire safety requirements in NZS 1900- Chapter 5: Fire Resisting Construction and Means of Egress, Acceptable Solution C2/AS1, C3/AS1 and C4/AS1 1992, and the current Acceptable Solution C/AS1 (2008). This Chapter also reviews the fire safety requirements for intermediate floors in USA, Canada, UK, and Australia prescriptive requirements.

Chapter 4 describes the buildings and occupant characteristics that were studied in this project.

Chapter 5 gives a detailed description on the ASET modelling of studied buildings.

The RSET modelling of the studied buildings are presented in detail in Chapter 6.

Chapter 7 pertains to Factor of Safety (FoS) analysis.

Chapter 8 contains discussions and recommendations for designers and a future fire safety approved documents committee in New Zealand.

The conclusion of the report is in the last Chapter (Chapter 9).

2. REGULATORY FRAMEWORK IN NEW ZEALAND

2.1 Overview

Up to 1992, the New Zealand building control framework governing the design and construction of buildings has been based on a prescriptive code environment. The method by which a minimum level of safety, amenity and quality is achieved is prescribed for each aspect of building construction in detail. Prior to the introduction of the New Zealand Building Act 1991 [8], each Territorial Authority had the right and obligation to set and enforce building standards by the use of by-laws (local government regulations). Almost all Territorial Authorities adopted the model building bylaw, NZS1900 published by the New Zealand Standards Organisation, however additional requirements were often imposed by some Territorial Authorities and some requirements from this standard were not enforced.

The New Zealand Building Act was passed in 1991 and came into force on 15 February 1992. The introduction of a performance based building code in New Zealand in 1992 [9] was a fundamental change in the building code regime and was the first national building code in New Zealand.

The leaky building crisis [10] led to the passing of the current Building Act 2004 [11]. The Act (2004) was amended and came into effect from 15 April 2005 by the Building Amendment Act 2005. The control system remains generally as it was under the previous Building Act 1991, except that it is now under direct Government control, with the previous Building Industrial Authority being replaced by the chief executive of the new Department of Building and Housing.

The regulation and performance of buildings sits under the following three-part framework [12].

- *The Building Act, which contains the provisions for regulating building work.*
- *The various Building Regulations, which contain prescribed forms, list specified systems, define 'change the use' and 'moderate earthquake', and set out the rate of levy and fees for determinations.*
- *The Building Code, contained in Schedule 1 of the Building Regulations 1992, which sets performance standards all new building work must meet, and covers aspects such as stability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency*.

Figure 3 below illustrates the hierarchy of New Zealand building controls, including the various compliance paths.

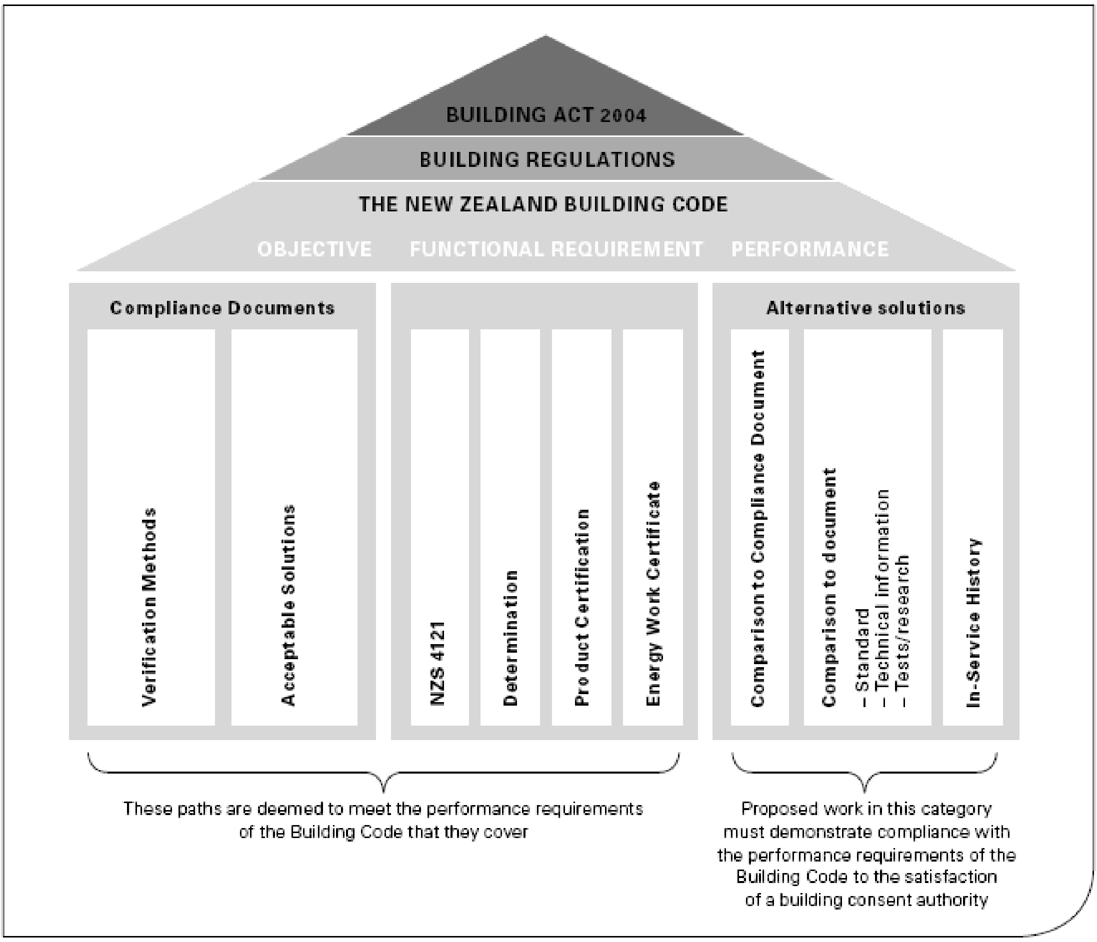


Figure 3: The New Zealand Building Control Framework. [12]

Under the Building Act 2004, the changes have been significant however, the codes and regulations for fire safety are still based on the performance code established in 1992 and the “prescriptive code”, Approved Document C/AS1 has been retained. In addition, under the Building Act 2004, the New Zealand Fire Service has been given a role at the design stage of a building project for certain classes of buildings to review and comment on the fire safety design and facilities for fire fighters, with respect to means of escape.

Although the Building Act 2004 is the main piece of legislation dealing with buildings, there are many other pieces of legislation that provide for building owners’ and users’ rights and obligations. In terms of fire safety design for a building in New Zealand, the relevant documents are as follows:

- Building Act 2004 [11]
- Building Regulations 1992 [13]

- First Schedule to the Building Regulations 1992 “ The Building Code” [9]
- Compliance Document for the New Zealand Building Code: Fire Safety Clauses C/AS1 [7]
- Fire Service Act 1975 [14]
- Fire Service Regulations 2003 [15]
- Fire Safety and Evacuation of Buildings Regulations 2006 [16]
- Health and Safety in Employment Act 1992 [17]
- Electricity Regulations 1997 [18]
- Gas Regulations 2009 [19]
- Hazardous Substances and New Organisms Act 1996 (HSNO Act) [20]

2.2 Building Act 2004

The Building Act 2004 is the legislation enacted by parliament that provides the mandatory framework for the building control system to be followed when undertaking building work in New Zealand.

The purpose of building controls is described by Section 3 of the New Zealand Building Act 2004 as follows [11]:

The purpose of this Act is to provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings, to ensure that:

> *(a) people who use buildings can do so safely and without endangering their health; and*
>
> *(b) buildings have attributes that contribute appropriately to the health, physical independence, and well being of people who use them; and*
>
> *(c) people who use a building can escape from the building if it is on fire; and*
>
> *(d) buildings are designed, constructed, and able to be used in ways that promote sustainable development.*

The applications of the Building Act 2004 are: building construction, alteration, demolition or removal and maintenance of a building’s specified systems, such as lifts and fire protection installations. The Act does not deal with planning and resource management and occupant safety and health [11].

The Building Act has five parts [11].

Part 1: Contains the purpose and principles of the Building Act, together with an overview, commencement dates for various Provisions and definitions. These sections provide an important reference when reading and interpreting the Building Act.

Part 2 (and Schedules 1 and 2): Outlines matters relating to the Building Code and building control (such as building consents), including requirements of building work, requirements for the use of buildings, Provisions for certain categories of buildings and Provisions for the safety of dams.

Part 3: Sets out the functions, duties and powers of the Chief Executive of the Department of Building and Housing (the Department), Territorial Authorities, Regional Authorities and Building Consent Authorities. It also deals with the accreditation and registration of building consent authorities, accreditation of dam owners, and product certification.

Part 4 (and Schedule): Covers matters relating to the licensing and disciplining of building practitioners.

Part 5 (and Schedule): Describes miscellaneous matters, including offences and criminal proceedings, implied terms of contracts, regulation-making powers, amendments to other enactments and the repeal of the former Act, and the transitional Provisions from the former Act to the Building Act.

The changes in the Building Act 2004 from the Act 1991 that are related to fire safety are as follows [21]:

- The Building Industry Authority (BIA) was replaced by the Department of Building and Housing (DBH) under section 11. The overview of the building control system is now by a government department and DBH has new power to issue warnings about or ban building methods or products (Section 26-30).
- Under the provisions of Section 45, building consent must be accompanied by plans and specifications that outline the building work to be carried out. An amendment to the consent must be applied for any alterations to the building work during the building process.
- Under the provisions of Sections 46 and 47, the New Zealand Fire Service must be notified of any alternative solutions submitted for compliance with the fire safety clauses C1 to C4 of the building code and given opportunity to comment. The New Zealand Fire Service Commission may comment on two aspects of design: means of

escape from fire and the needs of persons who enter the building to undertake fire-fighting operations. A Design Review Unit (DRU) has been established for this purpose.

- Provisions for alterations of existing buildings altered to avoid upgrading for fire safety and access and facilities for disabled when proposed work would improve either of these anyway. (Section 112).

2.3 Building Regulations 1992

Building regulations are made under and in accordance with the Building Act [12]. The Building Regulations 1992, and subsequent amendments [13], were made under the Building Act 1991 and have been amended a number of times. The Building Regulations 1992 were revoked on 31 March 2005 by the Building (Forms) Regulations 2004. The only part of the 1992 Regulations continuing in force is Schedule 1 containing the Building Code.

The New Zealand Building Regulations 1992 consists of eleven clauses which set out the responsibilities of the owner, Territorial Authority and Building Certifiers in the building consent and certification process.

The Building Code is covered in Clause 3 of the Building Regulations 1992 [13]:

> *3. Building code*
>
> > *(1) In accordance with Part 6 of the Act, the building code shall be the building code set out in the First Schedule to these regulations.*
> > *(2) Except as otherwise provided by the Act, each building shall achieve the performance criteria specified in the building code for the classified use of that building, and, if the building has more than one classified use, any part of it used for more than one classified use shall achieve the performance criteria for each such classified use.*
> > *(3) The classified use or uses of a building or part of a building shall be the ones that most closely correspond to the intended use or uses of that building or part of that building.*

2.4 Building Code and Compliance Documents

The Building Code is part of the Building Regulations 1992. The Building Code is referred to as a ‘performance based’ code. The Building Code contains mandatory rules for all building work [12]. Unlike the previous ‘prescriptive’ regulative and building laws, which set out specific details of how buildings were to be built, the Building Code now specifies what functions buildings must perform and criteria they must satisfy in performing each of those functions.

The Building Code consists of two definitions clauses, A1 and A2, and 35 technical clauses, B1 to H1. Each of the technical clauses is set out in the format [12]:

- *Objective: The social objectives that the building must achieve.*
- *Functional Requirement: The functions that the building must perform in order to meet the Objective.*
- *Performance: The criteria that the building must achieve. By meeting the Performance Criteria, the Objective and Functional Requirement can be achieved*.

The objectives and functional requirements are not mandatory requirements of the Building Code but the performance criteria are the mandatory requirements of the Building Code.

There is at least one Compliance Document for each of 35 technical clauses in the Building Code. The Compliance Documents that contain prescriptive specifications for how a building is to be constructed so as to comply with the Building Code are referred to as Acceptable Solutions. The Compliance Documents also contain methods such as calculations or tests by which compliance with the Building Code may be verified which are referred to as verification methods.

The requirements of the Building Code can be satisfied in several ways as follows:

- Acceptable Solutions
- Verification Methods
- Alternative Solutions
- Product Certification
- Energy Work Certificates
- NZS 4121: 2001, *Design for access and mobility: Buildings and associated facilities [22]*
- Determination

2.5 Fire Safety Clauses C1, C2, C3 and C4

The relevant New Zealand Building Code clauses for fire safety in buildings are:

- C1: Outbreak of fire

- C2: Means of Escape
- C3: Spread of Fire
- C4: Structural Stability during Fire

The Building Code specifies the objective, functional requirement and performance criteria for each fire safety clause.

The objectives of the four fire safety clauses can be summarised as follows:

- Life safety
- Protection of adjacent property
- Facilitating of rescue and fire fighting
- Protection of the environment

3. LITERATURE REVIEW

In this Chapter, the texts that are reproduced from the original documents are presented in italics.

3.1 NZS1990 – Chapter 5: Fire Resisting Construction and Means of Egress

3.1.1 *Introduction*

After the Hawke's Bay earthquake 1931, the New Zealand Standards Institute was formed in 1932 and started developing "Model Building By-Laws". The "Model Building By-Laws" firstly NZS95 was published in 1935, in which Part VII: Fire-resisting construction and means of Egress, covered fire safety [23]. The Model Building By-Law was not a binding code until adopted in part or full by a local council, it was often amended by individual councils and the level of enforcement was inconsistent. In early the 1960s, the "Model Building By-Laws" was superseded by NZS1900. These consisted of various chapters in which Chapter 5 was Fire Resisting Construction and Means of Egress [5].

NZS1990: Chapter 5 was a prescriptive document that was first published in 1965. There were four editions from 1965 to 1989, and eight amendments were incorporated.

This Chapter is set out in sections which generally apply as follows [5]:

i) Clauses 5.3 to 5.26 set out fire protection design and construction requirements necessary in all buildings hereafter erected.

ii) Clauses 5.27 to 5.54 set out the means of egress requirements for all buildings hereafter erected except single-unit dwellings.

iii) Clauses 5.55 and 5.56 set out the means of egress requirements for existing buildings.

Iv) Clauses 5.57 to 5.73 set out the additional requirements for all places of assembly except that clauses 5.59, 5.72.3, and 5.73 refer only to those places of assembly to which the special definitions of theatre, cinema, or public hall apply.

v) Clauses 5.74 to 5.86 set out additional requirements which apply to theatres only and in particular to the proscenium wall and stage area generally.

vi) Clauses 5.87 to 5.92 set out additional requirements for multi-storey buildings.

vii) Clause 5.93 sets out requirements for meatworks complexes.

viii) Schedules

First schedule – Fire risk classification of occupancies.
Second schedule – Specification for asbestos fabric for use in safety curtains.
Third schedule – Fire risk area defined.

3.1.2 *Requirements for mezzanine floors*

Mezzanine floor means intermediate floors in any storey or room. Where the area of any such mezzanine floor exceeds one-third of the area of the fire compartment in which it occurs, it shall be considered as constituting an additional storey:

> *Provided the mezzanine floor as permitted by subclause 5.16.1 (ii) shall not exceed the area permitted by table 1 or table 1A for the upper floor of a two storey building with a timber floor, and shall not be permitted in buildings of D3 occupancy." [5]*

According to the definition of mezzanine above, the allowable area of mezzanine is limited to one-third of the area of the fire compartment in which it is located. Whether a mezzanine can be open or enclosed because it is not mentioned in Chapter 5. Chapter 5 did not mention whether the area of the fire compartment to which the area of a mezzanine compared to is open or partly enclosed. Because the fire safety requirement is based on the building height, so a mezzanine which has an area exceeding one-third of the area of the fire compartment is considered as a storey. That storey must comply with the requirements of Fire Resistance Rating (FRR) of Subclause 5.16.1(ii) and maximum allowable area of Table 1 or 1A. A mezzanine floor is not permitted in commercial and industrial buildings with occupancy of high fire risk (D3 occupancy) [5].

In terms of means of egress, Chapter 5 required that the area of a mezzanine that is not regarded as a storey is added to the area of the floor in which it is located when calculating the required width of exits for that floor. The requirement is illustrated in Clause 5.35.1 as follows: "*Where a mezzanine is not regarded as a storey, its area shall be added to the area of the floor with which it is combined for the purpose of ascertaining the required unit of width for exitways from that floor".*

Clause 5.35.2 of Chapter 5 states: "*Where the area of a mezzanine floor exceeds 120 m2 protected means of egress complying with clauses 5.22, 5.41, and 5.43 shall be provided, except in the case where the mezzanine floor area is open and approved by the Engineer as a gallery, but in all cases complying with the requirements of clause 5.37 excluding the proviso to clause 5.37.1*".

Gallery is defined in the Chapter as "*a mezzanine floor from which all occupants have a clear view of the storey or room in which it is located such that the occupants of the mezzanine floor would become aware of any outbreak of fire on the lower level at effectively the same time as would occupants of the lower level*".

Clause 5.35.2 requires a mezzanine with an area greater than 120 m^2 to be treated as a storey except for the gallery as approved by the Engineer. Clauses 5.22, 5.41 and 5.43 set out the requirements for a storey regarding fire partitions enclosing vertical openings, hallways, passageways and internal stairways [5].

Where a mezzanine is not regarded as a storey, its internal stairways are not required to be enclosed as stated in Clause 5.43.2 "*Internal stairways, except to mezzanine by definition not regarded as a storey shall be enclosed as required by Clause 5.22"*.

3.2 Acceptable Solution C2/AS1, C3/AS1, C4/AS1 -1992

3.2.1 *Introduction*

In 1992, NZS1900: Chapter 5 was superseded by Approved Documents C1, C2, C3 and C4 with means of compliance Acceptable Solutions C1/AS1, C2/AS1, C3/AS1 and C4/AS1 and alternative solutions. These Acceptable Solutions were far more detailed and had more onerous requirements than NZS1900: Chapter 5.

3.2.2 *Requirements for intermediate floors*

An intermediate floor is defined as *"any upper floor within a firecell which because of its configuration provides an opening allowing smoke to spread from a lower to an upper level within the firecell*" [6].

According to the definition in C2/AS1, C3/AS1 and C4/AS1, an intermediate floor may be open, partly open or closed off from the opening through which smoke can spread with non-rated partitions including smoke separations. If closed off with fire separations the floor is no longer an intermediate floor and it becomes a firecell and is treated as a full floor.

The highest level of Fire Safety Precautions (FSPs) is applied through all spaces within a firecell, when the firecell has one or more intermediate floors with different Purpose Groups on each level as stated in Section B2.8.1:

"*Except as permitted by Paragraph B2.8.3, where a firecell contains one or more intermediate floors with different purpose groups on each level, the fire safety precautions for each level shall be determined and the highest level of fire safety precautions shall apply throughout all spaces within firecell*".

Fire safety precautions for a whole building (not only a firecell) which contains both intermediate and full floors are determined as the following steps in Section B2.8.2:

Where a building contains both full floors and intermediate floors, the fire safety precautions shall be determined for each purpose group by: Firstly evaluating separately each firecell containing intermediate floors, and secondly evaluating the whole building assuming all floors to be full floors. The appropriate fire safety precautions are then chosen on the following basis: See Table 1 for FSPs for purpose groups CS and CL that is extracted from Appendix B, C2, C3, and C4.

a) For each firecell containing intermediate floors, enter Table B1 using number of floors, or height as measured from the lowest floor of the firecell to the highest intermediate floor, and determine the required fire safety precautions using column 5, 6 and 7 of the table.

b) Using the building height to the highest floor level containing the purpose group being considered, and treating all floor (including intermediate floors) as full floors, determine the fire safety precautions required by columns 2, 3 and 4 of Table B1.

c) For firecells having intermediate floors adopt the most stringent fire safety precautions derived from (a) and (b) above. For firecells having only full floors adopt the most stringent fire safety precautions derived from (b) above.

d) Ensure that the FRRs applied to intermediate floors are no less than required by C3/AS1 Paragraph 2.2.4.

A firecell containing a limited area intermediate floor is a special case of firecell having intermediate floor and is defined in Section B2.8.3 for a two-floor building: "*Where one or more intermediate floors occur at approximately the same level, (not one above the other) in a firecell, entry to Table B1 shall be for a single floor building, using total occupant load in the firecell, and the fire safety precautions adopted shall be those taken from column 2, 3 and 4 provided all following conditions are satisfied:*

a) The firecell is under one management.

b) The total area of all intermediate floors is no more than one-third the area of the lower floor.

c) The F rating is selected from column 5 of Table B1 for a two floor building using total occupant load on those intermediate floors, and the FRRs of the intermediate floor are based on the F rating, but in no case shall be less than required by C3/AS1 Paragraph 2.2.4".

The one-third rule applies to determine whether an intermediate floor is limited area for a two-floor building. The limited area intermediate floor can be open, partly open or closed off and the area of the lower floor to which the area of the intermediate floor is compared with can be open or partly open. The number of intermediate floors is not limited but they must be located at nearly the same level not one above the other.

FIRE SAFETY
ANNEX

APPENDIX B **C2, C3, C4**

Table **B1/1: Fire safety precautions**						Purpose group **CS & CL**	
Occupant load or highest floor level	**Full floors**			**Intermediate floors**			
(For both total and max occupant load figures include only the purpose group being considered)	**Firecell rating and alarm type**	**Alternative firecell rating and alarm type**	**Other protection required**	**Firecell rating and alarm type**	**Alternative firecell rating and alarm type**	**Other protection required**	Amd 1 Dec '93
Single floor building							
Occupant load							
up to 50	F0						
51 to 100	F0 1*		16ad*				Amd 1 Dec '93
101 to 250	F0 2*e		16ad*				
251 to 500	F0 3f		16ad				
501 to 1000	F0 4		16d				
1001 to 2000	F0 6		16d				
over 2000	F0 7		16d				
Two floor building							
Total occupant load on both levels / Max occupant load on level 2							
up to 50 / up to 30	F15 1	F0 4		F15 2e			
51 to 100 / 31 to 60	F30 2e	F15 4f		F30 2f	F15 4f	10	Amd 1 Dec '93
101 to 250 / 61 to 125	F30 4f	F15 6	9,14,16ad	F30 4	F15 6	10,14,16ad	Amd 3 Dec '95
251 to 500 / 126 to 250	F60 4	F30 6	9,14,16ad	F60 6	F30 7	11,14,16d	
501 to 1000 / 251 to 500	F60 4	F30 6	9,14,16d	F60 7		11,14,16d	
over 1000 / over 500	F60 6	F30 7	9,14,16d	F60 7		11,14,16d	
Three floor building							
Total occupant load for 3 levels / Max occupant load on level 2 or 3							
up to 50 / up to 20	F30 1	F15 4		F30 4e	F15 6		Amd 1 Dec '93
51 to 100 / 21 to 40	F30 2e	F15 4f	14,16ad	F30 4f	F15 6	10,14,16d	
101 to 250 / 41 to 75	F60 4	F15 6	9,14,16d	F60 4	F30 6	10,14,16d	Amd 3 Dec '95
251 to 500 / 76 to 150	F60 4	F30 6	9,14,16d	F60 6	F30 7	11,14,16d	
501 to 1000 / 151 to 300	F60 6	F30 7	9,14,16d	F60 7		11,14,16d	
over 1000 / over 300	F60 7		9,14,16d	F60 7		11,14,16d	
Building of more than three floors							
Highest floor level containing the purpose group							
7 m not > 16 m	F30 4		14,16d	F60 4		11,14,16d	Amd 3 Dec '95
16 m not > 25 m	F60 4	F30 6	9,14,16d	F60 4		8,11,14,15,16d,18	
25 m not > 34 m	F60 6	F30 7	9,12,13,14,15,16d,18	F60 6		8,11,13,14,15, 16d,18	
34 m not > 46 m	F60 6		9,12,13,14,15,16d,18	F60 7		8,11,13,14,15,16d, 18,19	
46 m not > 58 m	F60 7		9,12,13,14,15,16d,18	F60 7		8,11,13,14,15,16d, 18,19	
58 m and greater	F60 7		9,12,13,14,15,16d, 18,19	F50 7		8,11,13,14,15,16d, 18,19	
Column 1	2	3	4	5	6	7	

* Alarms and emergency lighting required only in cinemas and theatres and any associated corridors and passageways used by the public. (Amd 1 Dec '93)

Building Industry Authority A25 1 December 1995

Table 1: FSPs for purpose group CS and CL (Table B1/1 of Appendix B C2, C3, C4) [6]

The allowed length of open path of intermediate floors is the same basic as other spaces within the firecell and set out in Table 3 of C2/AS1 [6]. The determining of open path length of an intermediate floor is stated in Clause 2.4.6 of C2/AS1 (Figure 4) as:

On intermediate floors, the assessed length of an open path shall be twice the measured length for any portion which is within 3.0 m of an open area overlooking a lower floor, and has a direction of travel towards or parallel to that opening.

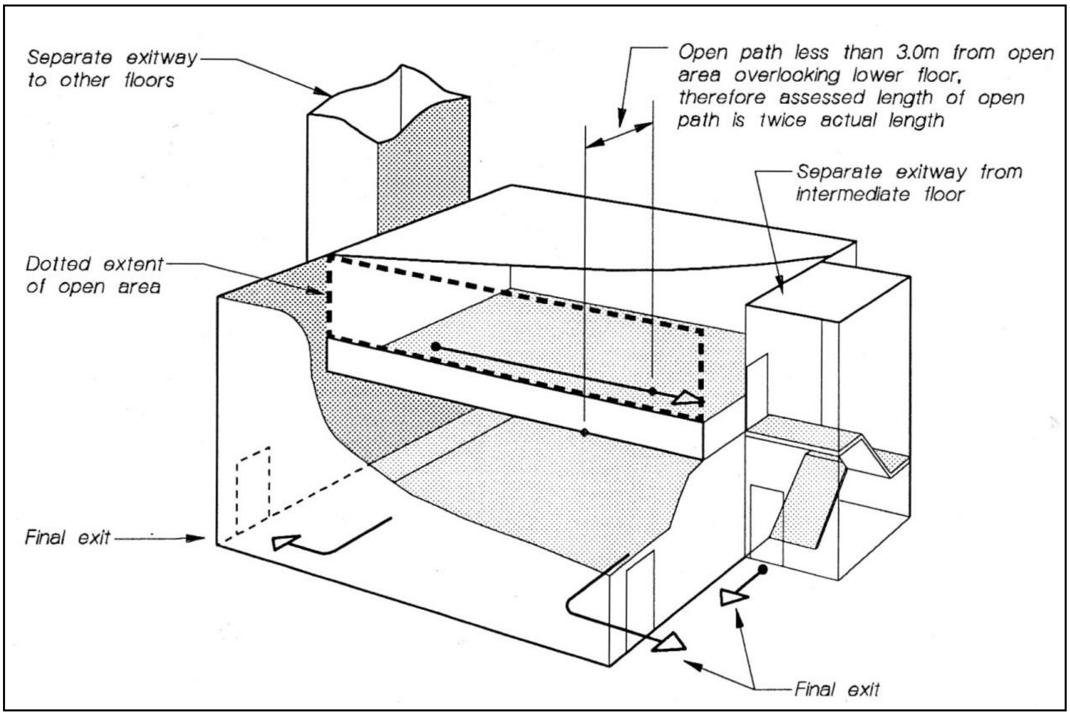


Figure 4: Determining open path length of intermediate floor. (Figure 9 of C2/AS1) [6]

The determining of open path length of an open intermediate floor is shown in Figure 4. It is expected that open intermediate floors will reach untenable conditions before the firecell floor due to the higher elevation of the intermediate floors. As the smoke layer drops, the occupants on the open intermediate floor will be exposed to smoke at an earlier stage than occupants on the firecell floor. The assessed open path length of an intermediate floor therefore is taken as twice the actual measured length. Which means the allowed length of open path of the open intermediate floor is reduced by 50% of that of the lower floor. Reduced open path travel distances are expected to result in reduced exposure time to smoke from the fire.

The FRR (Fire Resistance Rating) requirements of intermediate floors within a firecell are stated in Clause 2.2.4 of C3/AS1 as:

Intermediate floors and their supporting primary elements within the firecell shall have FRR's of no less than:

> *a) The F rating determined from Table B1, when the spaces above and below are open, or*
>
> *b) The greater of the F rating or 30/30/30, where spaces above and below are enclosed by building elements which are not fire rated.*

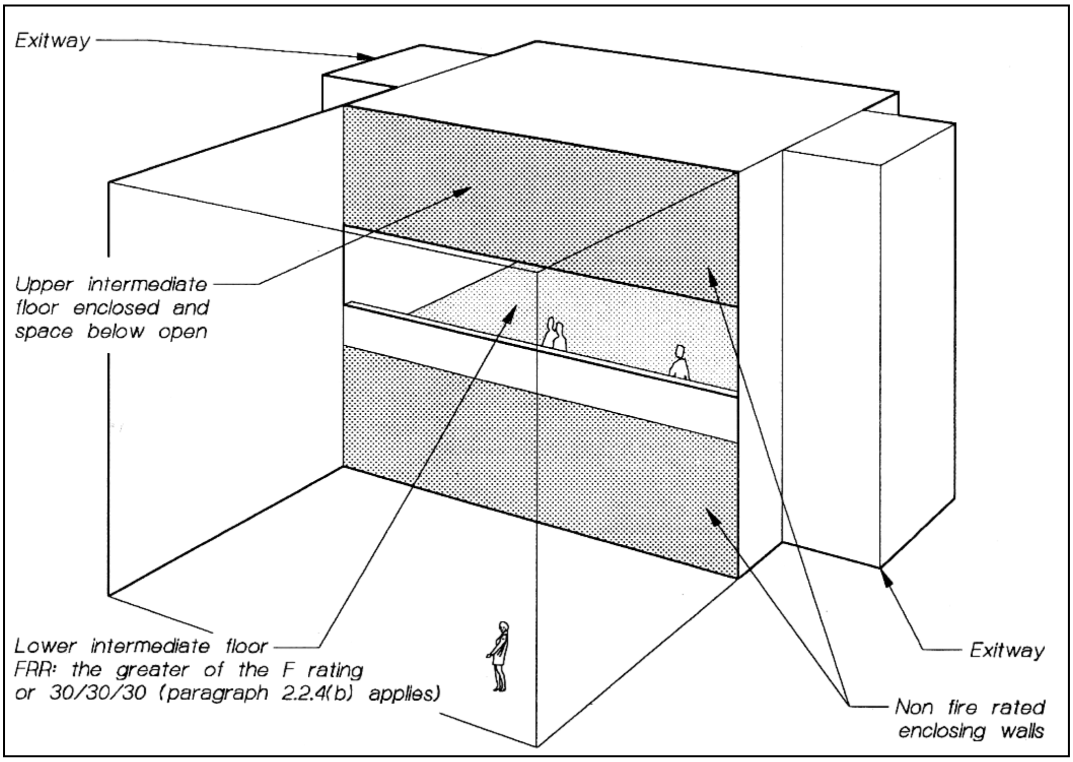


Figure 5: Determining FRR of intermediate floors. (Figure 2 of C3/AS1) [6].

Figure 5 illustrates how the FRRs of intermediate floors and its supporting elements are determined according to Clause 2.2.4 of C3/AS1. When spaces above and below the intermediate floor are open, an occupant on an open intermediate floor is expected to be physically aware of a fire occurring anywhere in the firecell, and the F rating determining from Table B1 and fire alarm requirements would provide an adequate time to escape for the occupant. However, when the space above or below an intermediate floor is enclosed by building elements which are not fire rated, occupants on the intermediate floor need the added protection provided by the FRR for the floor because they would have less awareness of a fire in the firecell than when the spaces above and below are open.

3.3 Acceptable Solution C/AS1-2008

3.3.1 *Introduction*

Since 2001 the individual documents C1, C2, C3 and C4 have been replaced by Approved Documents for the New Zealand Building Code, fire safety clauses C1, C2, C3 and C4 with means of compliance Acceptable Solution C/AS1 and alternative solutions. In C/AS1, the fire hazard risk is assessed according to the Purpose Group, Fire Hazard Category and Occupant Load [7].

The Purpose Group establishes the occupancy type, i.e. what type of people are in the building, what they are doing and what is their alertness. This has been classified into four main activities: crowd, sleeping, working, business or storage and intermittent with sixteen Purpose Groups.

The Fire Hazard Category (FHC) is a numerical grading from 1 to 4 (in order of increasing severity) based on the Fire Load Energy Density (FLED). The FLED is defined as the fire load of all combustible materials and contents measured in energy divided by the floor area (MJ/m^2).

The fire safety precautions play a key role in providing safety to the occupants of a building in the event of a fire. The fire hazard category, the purpose group, the occupant load and the escape height of the building are taken into consideration when determining the fire safety precautions. The fire safety precautions that were specified in Table 4.1 of C/AS1 [7] are summerised below:

Type 1	Domestic smoke alarm system
Type 2	Manual fire alarm
Type 3	Automatic fire alarm with heat detectors and manual call points (MCP).
Type 4	Automatic fire alarm with smoke detectors and MCP
Type 5	Automatic fire alarm system with modified smoke detection and MCP
Type 6	Automatic fire sprinklers with MCP
Type 7	Automatic fire sprinkler system with smoke detection and MCP
Type 8	Voice communication system
Type 9	Smoke control in air handling system
Type 10	Natural smoke venting

Type 11	Mechanical smoke extraction
Type 12	No type 12 currently specified
Type 13	Pressurisation of safe paths
Type 14	Fire hose reels
Type 15	Fire service lift control
Type 16	Visibility in escape routes
Type 17	Emergency power supply
Type 18	Fire hydrant system
Type 19	Refuge areas
Type 20	Fire systems centre

In addition to the above Fire Safety Precautions a number of limitations and dispensations are permitted when determining FSPs for a building. These are denoted a - f and are shown in detail in Appendix E and summarised as follows:

a	Not required. Identifies situations where particular FSP may be excluded.
b	Single escape routes that require a Type 4 alarm.
c	Provision for when a fire hydrant system is required.
e	Provision for when a Type 5 alarm is permitted.
f	Provision for when direct connection to the fire service is not required.

3.3.2 *Requirements for intermediate floors*

An intermediate floor is defined in C/AS1 [7] as "*Any upper floor within a firecell and which is not fire separated from the floor below. Upper floors within household units need not meet the specific fire safety requirements which apply to intermediate floors in all other situations*".

According to C/AS1, an intermediate floor may be open to the firecell or enclosed with non-fire rated construction. If enclosed with fire rated walls the floor is no longer an intermediate floor and another firecell is created. Household units purpose groups SR and SH, life safety provisions are governed by the limitations in permitted open path lengths therefore the requirements for intermediate floors are not applied. Any floor having any permanent opening is treated as an intermediate floor.

The provisions regarding number and width of escape routes for a building is stated in Clause 3.2.1 and 3.3.2 of C/AS1:

3.2.1: Except where Paragraph 3.15 allows the use of single escape routes, every occupied space in a building shall be served by two or more escape routes.

3.3.2: Widths of escape routes shall be no less than required by Table 3.2 for both the width of individual escape routes, and the total combined width of all available escape routes, but:

> *f) In firecells containing intermediate floors, both the vertical and horizontal parts of the open path escape route shall be wide enough to take the full occupant load from all contributing spaces.*

An intermediate floor is part of a building so it has to comply with the above requirements. When calculating the required number and width of escape routes, the total occupant load must include the occupants on the intermediate floor within a firecell.

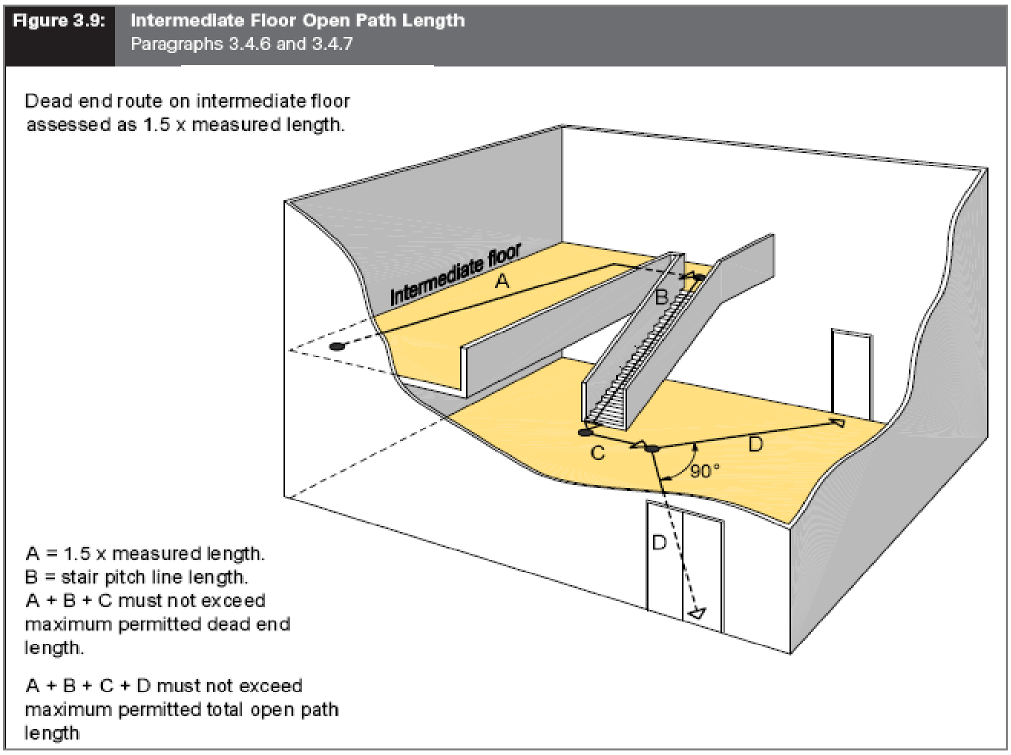


Figure 6: Intermediate floor open path length. (Figure 3.9 of C/AS1) [7]

The permitted open path lengths are listed in Table 3.3 of C/AS1, however, there are special requirements regarding open path lengths of intermediate floors as stated in Clause 3.4.6 of C/AS1:

*On intermediate floors (*see Figure 6*) the open path length, for compliance with Table 3.3, shall be taken as 1.5 times the measured length. However, the measured length may be used where either of the following conditions apply*:

a) A smoke control system (fire safety precaution Type 10 or Type 11) protecting the occupants of the intermediate floor is present, or

b) The intermediate floor is a smokecell and an escape route is available from the intermediate floor without passing through any lower space in the same firecell.

C/AS1 allows occupants from other spaces or firecells to escape via an intermediate floor if provision of Clause 3.9.13 is met. This situation often occurs when occupied spaces or other firecells at different levels open into an atrium space have escape routes via an intermediate floor. The requirements of Clause 3.9.13 are as follows:

An open path or protected path may pass from a firecell on to an intermediate floor and recommence as an open path or protected path provided that:

a) Where two or more escape routes are required from that firecell, only one escape route shall be via the intermediate floor,

b) The intermediate floor is served by at least two escape routes, separated as required by Paragraph 3.8.3, and terminating at separate firecells, exitways or final exits at the same level as the intermediate floor,

c) The intermediate floor open path lengths shall not exceed the requirements of Paragraph 3.4.6, and

d) If there are open intermediate floors at two or more levels in the firecell:

i) barriers shall have no openings, and
ii) the firecell containing the intermediate floors shall be protected by a smoke control system satisfying the requirements of Paragraphs 6.21.5 to 6.22.14.

The requirements regarding FRR of intermediate floors and their supporting elements are stated in Clause 6.14.3 of C/AS1 as:

Intermediate floors and their supporting primary elements within the firecell shall have FRRs of no less than 15/15/15 except where the area under the intermediate floor is enclosed the FRR shall be 30/30/30. The provision does not apply to purpose group SH or to household units in purpose group SR, and suites in purpose group SA.

Figure 7 illustrates the FRR requirements of intermediate floors and their supporting primary elements. When areas below the intermediate floor are open, an occupant on an open intermediate floor would be physically aware of a fire occurring anywhere in the firecell, the provisions for shorter open path length on intermediate floors, and for alarms and smoke control, allow occupants adequate time to escape to a safe place. However, when the space below an intermediate floor is enclosed by building elements which are not fire rated, occupants on the intermediate floor need the added protection provided by the FRR for the floor because they would have less awareness of a fire in the firecell than when the spaces above and below are open. Therefore, when the space below an intermediate floor is enclosed the required FRR is 30/30/30. Household units in purpose group SR and SH are not included in the definition of an intermediate floor for the provision of Clause 6.14.3. Suites in purpose group SA are similar to household units in purpose groups SH or SR so the provision of this clause does not apply.

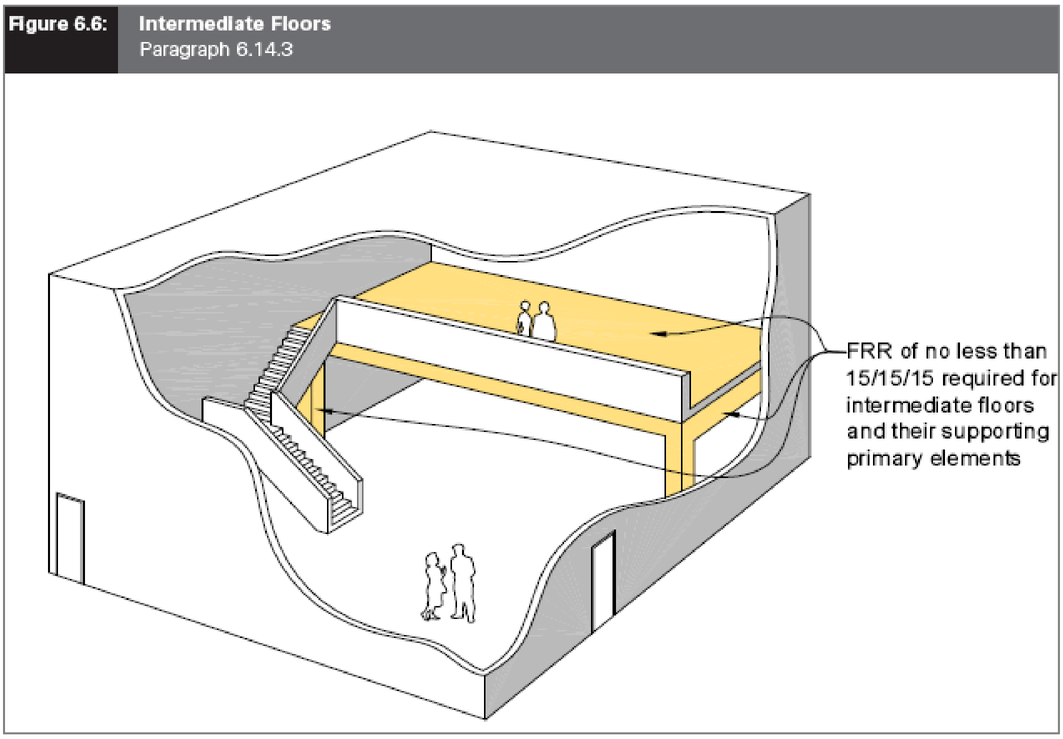


Figure 7: FRR of intermediate floor (Figure 6.6 of C/AS1) [7]

The required FSPs of intermediate floors are stated in Clause 4.5.16 as follows:

Intermediate floors and the supporting elements shall have a FRR in accordance with Paragraph 6.14.3. All other FSPs required for the firecell (at the firecell escape height) shall apply to the intermediate floor.

According to Clause 4.5.16, where a firecell contains intermediate floors a FRR of the intermediate floors and supporting elements is 15/15/15 if the area under the intermediate floor is open or 30/30/30 if the area under the intermediate floor is enclosed (Clause 6.14.3). All other FSPs are the same as the firecell in which it is located.

Special cases in terms of required FSPs for firecells containing intermediate floors are stated in Clauses 4.5.21 and 5.6.13 as:

4.5.21: Where spaces used by children are located on an intermediate floor within an early childhood centre no less than a Type 4 alarm is required throughout the firecell.

5.6.13: Firecells with FHC4 (fire hazard category)

> *a) In buildings with two or more full floors, or the total aggregated area of the intermediate floors in a firecell exceeds 35 m^2, all floors shall be sprinkler protected.*
>
> *b) For a single storey building in which an intermediate floor not exceeding 35 m^2 is provided 5.6.13 a) does not apply, but the building shall be considered by specific fire engineering design under Paragraph 5.6.11.*

The provision of Clause 5.6.13 allows a small intermediate floor of up to 35 m^2 within a FHC4 firecell without the requirement of protection from sprinklers for the whole firecell.

According to C/AS1 firecells containing limited area intermediate floors require the same fire safety precautions as single level firecells having the same total occupant load and escape height. Firecells containing limited area intermediate floors are defined in Clauses 6.21.5 and 6.21.6 as follows:

6.21.5 A firecell with intermediate floors satisfying the following conditions may be treated as a single floor firecell and a smoke control system Type 10 or Type 11 is not required where:

> *a) The fire hazard category of the firecell is no greater than 3, and*
>
> *b) Where there are two or more separate intermediate floors, the levels of those floors above the firecell floor differ by no more than 1.0 m, and*
>
> *c) The total occupant load on all intermediate floors is not greater than 100, and*
>
> *d) The total area of the intermediate floors is no greater than allowed by Paragraph 6.21.6.*

6.21.6 The total area of limited area intermediate floors within the firecell shall not exceed:

a) 20% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s) are enclosed or partitioned, or

b) 40% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s):

i) are completely open, or

ii) if enclosed or partitioned, a Type 4 or Type 7 alarm system with smoke detection is installed throughout the firecell.

Firecells containing intermediate floors that are not limited area intermediate floors must have a smoke control system as required in Clause 4.5.17 of C/AS1:

Except for limited area intermediate floors meeting the provisions of Paragraphs 6.21.5 and 6.21.6, all firecells containing intermediate floors shall have a smoke control system.

3.3.3 *Limited area atrium*

Limited area atrium is defined in C/AS1 as "*A single firecell in which individual occupied spaces at different levels open onto a common enclosed space. Limitations are placed on the number of intermediate floors (no more than two levels), individual floor areas and permitted occupant load, depending on the provisions for smoke detection, smoke control and the means of escape from fire*".

According to Clause 6.22.2 limited area atrium firecells must meet all the following requirements:

a) No more than two levels of intermediate floor.

b) No intermediate floor located more than 7.0 m above the firecell floor.

c) Where an intermediate floor has only a single escape route, that floor area shall be no greater than 200 m^2 and the occupant load no greater than 50. Only one such floor shall be permitted at any one level in the atrium.

d) Where the intermediate floor has two or more escape routes, and the occupant load exceeds 100, at least one escape route from that floor shall be a safe path.

e) The total area of all intermediate floors shall be no greater than 500 m^2.

f) The total occupant load on all intermediate floors shall be no greater than 500 where a smoke ventilation or extraction system is installed, or 250 where smoke control is by way of a smoke reservoir only.

g) A Type 4 (or Type 7 if sprinklered) alarm system shall be installed with smoke detection throughout the firecell.

Limited area atrium firecells must also meet the requirements of Clause 6.22.1 as follows:

Limited area atrium firecells shall be restricted to purpose groups CS, CL, CM, WL, IA, SA and SR with a fire hazard category of not greater than 2. Fire safety requirements depend on the number of escape routes, occupant load and the method of smoke control.

To allow the smoke plume to rise without spreading to the occupied spaces on sides of the atrium, the atrium dimensions are limited in Clause 6.22.3:

The minimum horizontal separation between occupied spaces across the atrium shaft shall be:

a) 4.0 m for sprinklered firecells, or

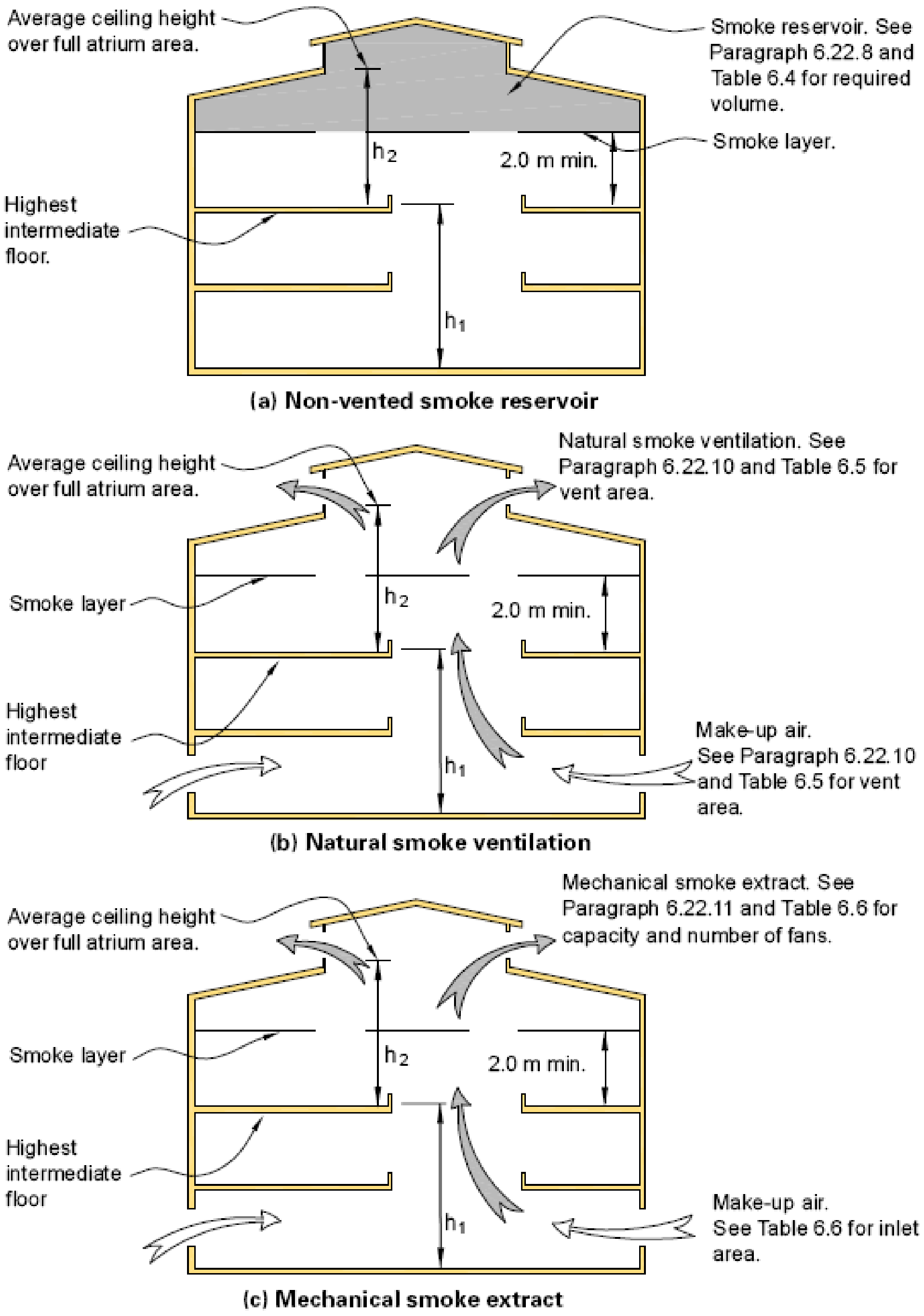
b) 6.0 m for unsprinklered firecells. Between an occupied space and a wall or non-occupied space the separation may be reduced to 4.0 m.

Smoke control methods for limited area atrium firecells are given in Clauses 6.22.8 to 6.22.14 which are illustrated in Figure 8 below. Refer to Clauses 6.22.8 to 6.22.14 of C/AS1 for more details.

Firecells containing intermediate floors other than limited area intermediate floors and limited area atrium must have a smoke control system that is specifically designed as stated in Clause 6.21.3:

Except where permitted by Paragraphs 6.21.4 to 6.22.14, smoke control in firecells containing intermediate floors shall be by specific fire engineering design.

Figure 6.14: Smoke Control for Limited Area Atrium Firecells with No More than Three Floor Levels
Paragraphs 6.22.1 and 6.22.8



Notes:

1. h_1 is the height of the highest *intermediate floor* above the *firecell* floor. h_1 shall not exceed 7.0 m.
2. h_2 is the average floor to ceiling height from the highest *intermediate floor*.
3. Specific *fire* engineering design is required where the highest *intermediate floor* is more than 7.0 m above the *firecell* floor level.

Figure 8: Smoke control for limited area atrium (Figure 6.14 of C/AS1) [7]

3.4 USA Prescriptive Requirements

The fire safety requirements for mezzanines have been addressed in the NFPA 101 Life Safety Code 2006 edition [1] and the NFPA 5000 Building Construction and Safety Code 2006 edition [24]. The requirements are the same in the two documents therefore the NFPA 101 Life Safety Code 2006 edition was reviewed in this section.

3.4.1 *NFPA 101 Life Safety Code*

The NFPA 101 Life Safety Code 2006 edition was approved as an American National Standard in 2005. For more than 80 years, the Life Safety Code has been developed and published by the National Fire Protection Association (NFPA).

3.4.2 *Requirements for mezzanine floors*

Mezzanine is defined in Section 3.3.156 as "*An intermediate level between the floor and the ceiling of any room or space*".

The egress capacity from mezzanines is set out in Section 7.3.1.6 of NFPA 101. "*Where any required egress capacity from a balcony or mezzanine passes through the room below, that required capacity shall be added to the required egress capacity of the room below*".

Section 7.4.1.1 of NFPA 101 sets the requirement for the number of escape routes for mezzanines as follows:

The number of means of egress from any balcony, mezzanine, story, or portion thereof shall be not less than two, except under one of the following conditions:

- *Where a single means of egress is permitted in Chapter 11 through Chapter 42.*
- *Where a single means of egress is permitted for a mezzanine or balcony and the common path of travel limitations of Chapter 12 through Chapter 42 are met*.

Again, mezzanines are considered as part of the room in which they are located so mezzanines are required to have the same amount of egress as a full storey with the same occupant load.

The area limitations of mezzanines are defined in Section 8.6.9.2.1 of NFPA 101:

"*The aggregate area of mezzanines located within a room, other than those located in special purpose industrial occupancies, shall not exceed one-third the open area of the room* *in which the mezzanines are located. Enclosed space shall not be included in a determination of the size of the room in which the mezzanine is located*".

According to Section 8.6.9.2.2 and 8.6.9.2.3 of NFPA 101, the number of mezzanines in a room is not limited and the aggregate area of the mezzanines is not included in the area of the room when calculating allowable mezzanine area.

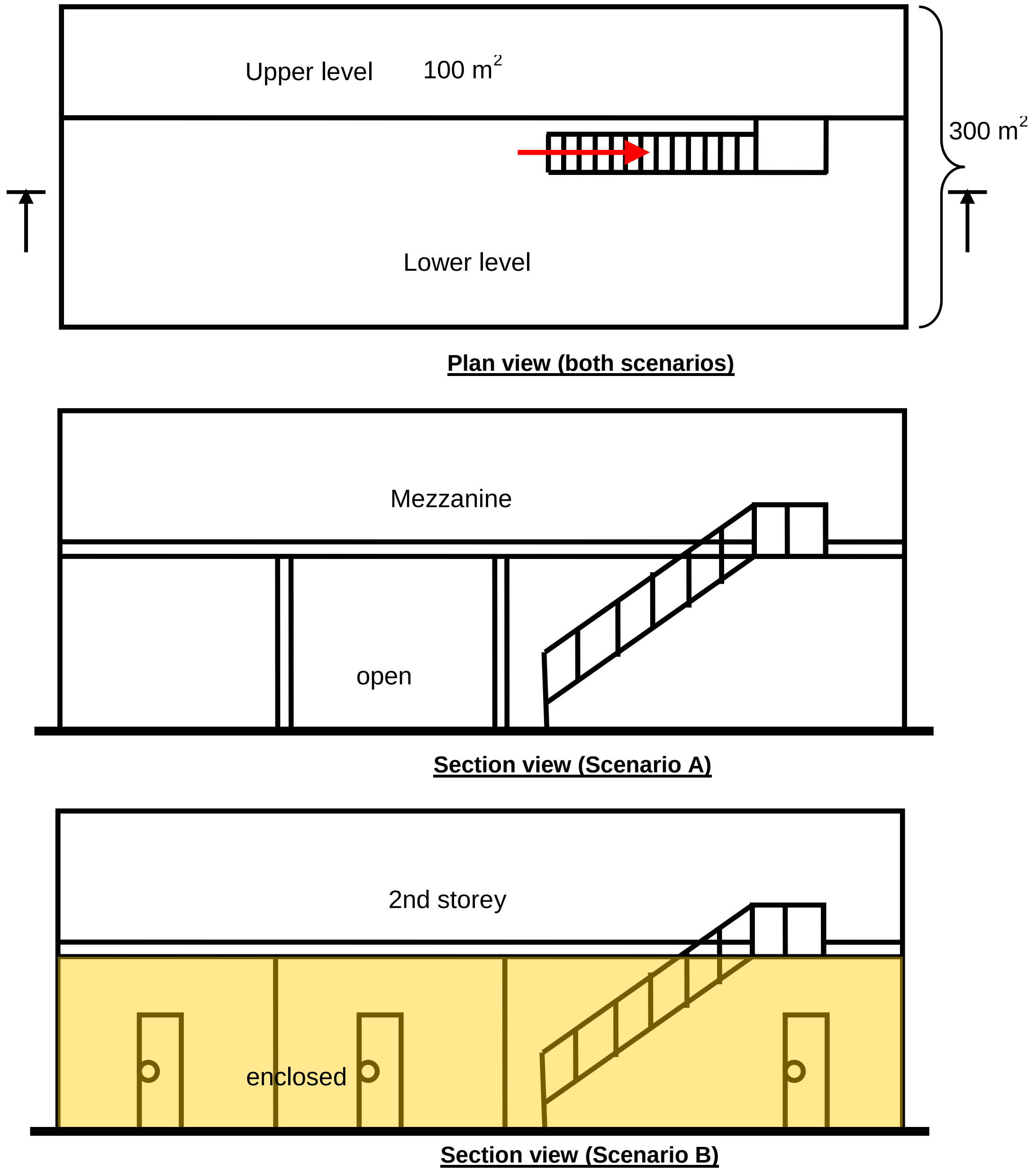


Figure 9: Determining a mezzanine

Figure 9 shows how the one-third rule is applied in determining whether a level is mezzanine. The room consists of two levels, the lower level is 300 m^2 and upper level is 100 m^2. The one-third rule compares the area of the upper level to the open area of the room in which the upper level is located therefore only the open space of the lower level is used in the calculation. In scenario A, the space under the upper level is open to the main room. The 100 m^2 area of the upper level is compared with 300 m^2 of the main room. The upper level is considered as a mezzanine as the one-third rule is met. In scenario B, the space under the upper level is closed so the area of the enclosure is not used in the calculation of the main room. The area of the upper level is 50% of the main room (100/200), the upper level therefore is considered as a storey, not a mezzanine.

The requirements of the openness of mezzanines are stated the NFPA 101 as follows:

> *8.6.9.3.1 All portions of a mezzanine, other than walls not more than 42 in. (1065 mm) high, columns, and posts, shall be open to and unobstructed from the room in which the mezzanine is located, unless the occupant load of the aggregate area of the enclosed space does not exceed 10.*
>
> *8.6.9.3.2 A mezzanine having two or more means of egress shall not be required to open into the room in which it is located if not less than one of the means of egress provides direct access from the enclosed area to an exit at the mezzanine level.*

The openness requirements of 8.6.9.3.1 provide the mezzanine occupants with a degree of awareness of the fire condition on the floor below that is equivalent to the awareness of the occupant on the lower floor. The wall height is not more than 1065 mm to achieve the openness requirement and to prevent falls over the open side of the mezzanine. Partially enclosed mezzanine is permitted by Section 8.6.9.3.1 if the total occupant load of the enclosed area is not greater than 10 people.

The provision of 8.6.9.3.2 allows for a total enclosed mezzanine if the mezzanine has two or more means of egress in which at least one of those means of egress provides direct access to an exit at the mezzanine level such as an enclosed staircase. Occupants of the mezzanine are judged as being adequately safe from a fire on the level below because one of their means of egress does not require them to escape via the room below even if they noticed that fire later than they would have if the mezzanine was open.

A mezzanine is not included in counting the number of building stories by NFPA 101 according to the following Section:

> *8.6.9.1.1 A mezzanine shall not be included as a story for the purpose of determining the allowable number of stories in a building.*

8.6.9.1.2 Multilevel residential housing areas in detention and correctional occupancies in accordance with Chapter 22 and Chapter 23 shall be exempt from the provisions of 8.6.9.2 and 8.6.9.3. (Refer to Chapter 6 of the NFPA 101 for classification occupancy).

Because NFPA 101 requirements are based on the number of building stories and a mezzanine size is limited by the one-third rule so it is exempted from being counted as a building storey.

3.5 Canadian Prescriptive Requirements

3.5.1 *National Building Code of Canada*

The National Building Code of Canada 2005 [2], together with the National Fire Code of Canada 2005 [25] and the National Plumbing Code of Canada 2005, is an objective-based National Model Code that can be adopted by provincial and territorial governments. The National Building Code (NBC) and National Fire Code (NFC) each contain provisions that deal with the fire safety of persons in buildings in the event of a fire and the protection of buildings from the effects of fire. The NBC generally applies at the time of construction and reconstruction while the NFC applies to the operation and maintenance of the fire related features of buildings in use. All requirements of fire safety for mezzanines are covered in the NBC.

The National Building Code of Canada 2005 is organised into three Divisions. Division A contains compliance, objectives and functional statements. Division B is the Acceptable Solutions and Division C contains administrative provisions.

3.5.2 *Requirements for mezzanine floors*

Mezzanine is defined in Article 1.4.1.2 as "*an intermediate floor assembly between the floor and ceiling of any room or storey and includes an interior balcony*".

The allowable area of the mezzanine at which the space above a mezzanine is not considered as a storey is defined in Article 3.2.1.1. The Article also states the openness requirements and the requirements for partial and completely enclosed mezzanines. Article 3.2.1.1 is repeated as follows:

> *3. Except as required by Sentence (5), the space above a mezzanine need not to be considered as a storey in calculating the building height, provided*
>
> > *a) the aggregate area of mezzanines that are not superimposed does not exceed 40% of the open area of the room in which they are located, and*
> > *b) except as permitted in Sentence (7) and 3.3.2.12.(3), the space above the mezzanine is used as an open area without partitions or subdividing walls higher than 1070mm above the mezzanine floor.*
>
> *4. Except as required by Sentence (5), the space above a mezzanine need not to be considered as a storey in calculating the building height, provided*

a) the aggregate area of mezzanines that are not superimposed and do not meet the conditions of Sentence (3) does not exceed 10% of the floor area in which they are located, and

b) the area of a mezzanine in a suite does not exceed 10% of the floor area of that suite. (Suite means a single room or series of rooms of complementary use, operated under a single tenancy, and includes dwelling units, individual guest rooms in motels, hotels, boarding houses, rooming houses and dormitories as well as individual stores and individual or complementary rooms for business and personal services occupancies).

5. Except as permitted by Sentence (6), each level of mezzanine that is partly or wholly superimposed above the first level of mezzanine shall be considered as a storey in calculating the building height.

6. Platforms intended solely for periodic inspection and elevated maintenance catwalks need not to be considered as floor assemblies or mezzanines for purpose of calculating the building height, provided

a) they are not used for storage, and

b) they are constructed with noncombustible materials, unless the building is permitted to be of combustible construction.

7. The space above a mezzanine conforming to Sentence (3) is permitted to include an enclosed space whose area does not exceed 10% of the open area of the room in which the mezzanine is located provide the enclosed space does not obstruct visual communication between the open space above the mezzanine and the room in which it is located.

The permitted area of the mezzanine for the purposes of determining the allowable percentage is to be based on the open area of the floor of the space in which the mezzanine is located. NBC does not restrict the enclosing of space below the mezzanine but the enclosed area must be deducted from the area of the overall space before applying the percentage allowance.

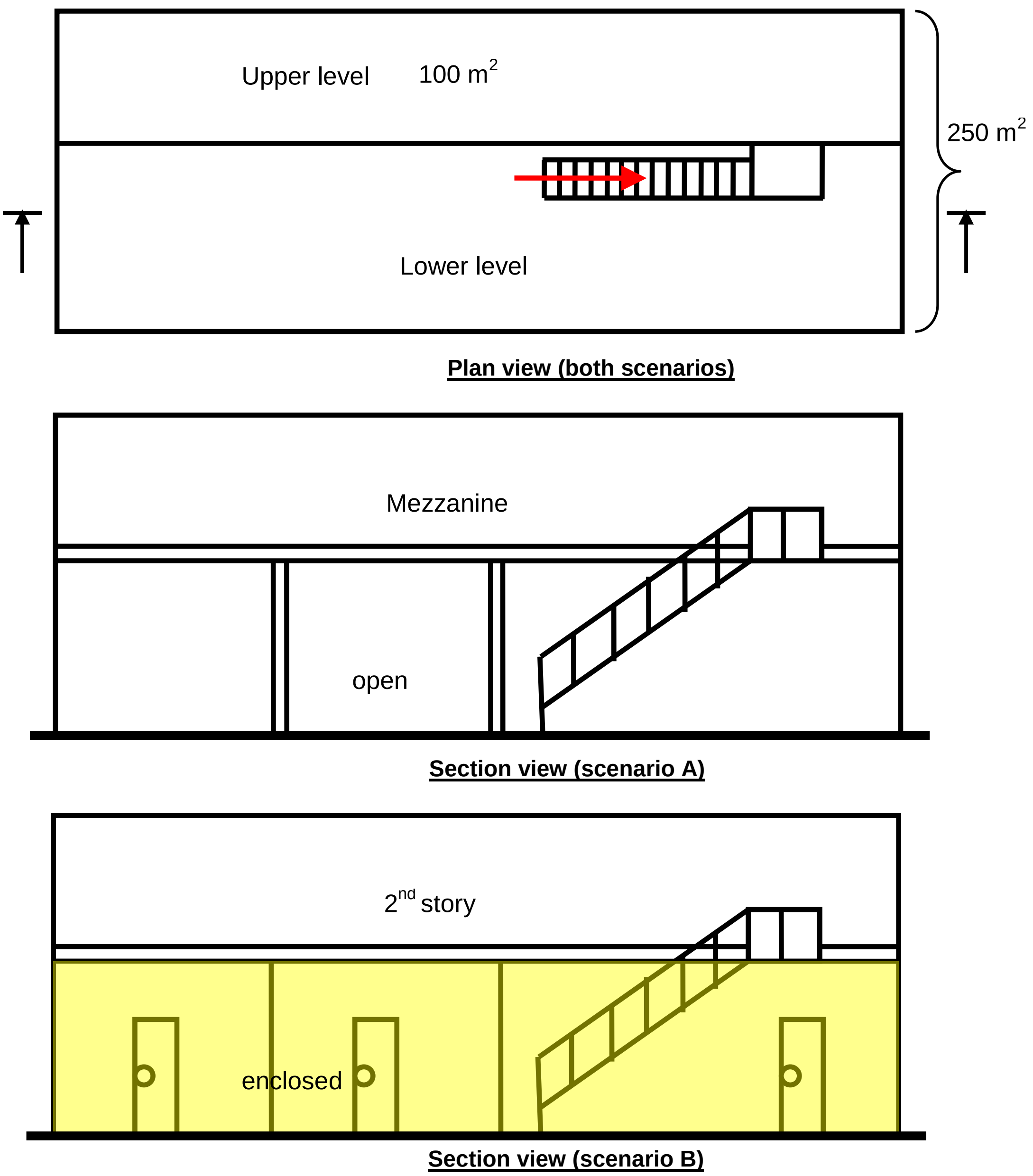


Figure 10: Determining a mezzanine in the National Building Code of Canada.

Figure 10 shows how the upper level of a building is determined as a mezzanine. The main floor (lower) is 250 m^2 with an upper level of 100 m^2. The 40% rule compares the area of the upper level to the open area of the room in which the upper level is located therefore only the open space of the lower level is used in the calculation. In scenario A, the space under the upper level is open to the main room. The 100 m^2 area of the upper level is compared with 250 m^2 of the main room. The upper level is considered as mezzanine as the 40% rule is met. In scenario B, the space under the upper level is closed so the area of the enclosure is not used in the calculation of the main room. The area of the upper level is two-thirds of the main room (100/150) the upper level therefore is considered as a storey not a mezzanine.

Clause 3.2.1.1(3).(b) contains the openness requirements of a mezzanine which provide the mezzanine occupants with a degree of awareness of fire conditions on the floor below. The wall height is not more than 1070 mm to achieve the openness requirement and to prevent occupants falling over the open side of the mezzanine.

The provision of Sentence 3.2.1.1(4) allows completely enclosed mezzanine if the aggregate of mezzanines area does not exceed 10% of the floor area in which the mezzanine is located. This provision also applies for a mezzanine in a suite if the area of the mezzanine does not exceed 10% of the suite floor area.

According to Sentence 3.2.1.1 (5), the number of level of mezzanines is limited at no more than one. NBC limits the aggregate area of mezzanines but does not limit the number of mezzanine at the same level.

The mezzanine that contains a completely enclosed space (partially enclosed mezzanine), is permitted by Sentence 3.2.1.1.(7) if the area of enclosed space of the mezzanine is less than 10 % of the open area of the main room in which the mezzanine is located.

A platform that satisfies conditions of Sentence 3.2.1.1 (6) is not considered as a storey or mezzanine in calculating the building height.

Means of egress from mezzanines of all buildings with three storeys or less, having a building area not exceeding 600 m^2 in Group C (residential occupancies), Group D (business and personal services occupancies), Group E (mercantile occupancies) and Group F, Division 2 and 3 (medium and low hazard industrial occupancies) are stated in Article 9.9.8.6 [2] as follows:

> *1) Except permitted by Sentence (2) and (3), the space above a mezzanine shall be served by means of egress leading to exits accessible at the mezzanine level on the same basic as floor areas.*
>
> *2) The means of egress from a mezzanine need not conform to Sentence (1), provided*
>
> > *a) the mezzanine is not required to terminate at a vertical fire separation, as permitted in Sentence 9.10.12.1.(2),*
> > *b) the occupant load of the mezzanine is not more than 60,*
> > *c) the area of the mezzanine does not exceed the area limits stated in Table 9.9.7.4., and*

d) the distance limits stated in Table 9.9.7.4., measured along the path of travel are not exceeded from any point on the mezzanine to

an egress door serving the space that the mezzanine overlooks, if the space is served by a single egress door, or

the egress stairway leading to an access to exit in the space below if that space is required to be served by 2 or more egress doorways in conformance with Sentence 9.9.7.4.(1).

3) One of the means of egress from a mezzanine that is not required to terminate at a fire separation, as permitted by Sentence 9.10.12.1.(2), and that exceeds the limits of Sentence (2) is permitted to lead through the room in which the mezzanine is located, provided all other means of egress from that mezzanine lead to exits accessible at the mezzanine level.

4) Except as provided in Sentence (2), the maximum travel distance from any point on a mezzanine to the nearest exit shall be not more than:

a) 40m in a business and personal services occupancy,

b) 45 in a floor area that is sprinklered throughout, provided it does not contain a high hazard industrial occupancy, or

c) 30m in any floor area not referred to in Clauses (a) or (b).

Means of egress from mezzanines of buildings other than the buildings described above are stated in Article 3.4.2.2 [2] as follows:

1) Except permitted by Sentence (2) and (3), the space above a mezzanine shall be served by means of egress leading to exits accessible at the mezzanine level on the same basis as floor areas.

2) The means of egress from a mezzanine need not conform to Sentence (1), provided

a) the mezzanine is not required to terminate at a vertical fire separation, as permitted in Sentence 3.2.8.2.(1),

b) the occupant load of the mezzanine is not more than 60,

c) the area of the mezzanine does not exceed the area limits stated in Table 3.4.2.2., and

d) the distance limits stated in Table 3.4.2.2., measured along the path of travel are not exceeded from any point on the mezzanine to

an egress door serving the space that the mezzanine overlooks, if the space is served by a single egress door, or *the egress stairway leading to an access to exit in the space below if that space is required to be served by 2 or more egress doorways in conformance with Sentence 3.3.1.5.(1).*

3) At least half of the required means of egress from a mezzanine shall comply with Sentence (1) if the mezzanine is not required to terminate at a fire separation, as permitted by Sentence 3.2.8.2.(1).

3.6 UK Prescriptive Requirements

3.6.1 *Approved Documents B - Fire Safety.*

In England and Wales, the Building Act 1984 is the primary legislation under which the Building Regulations and other secondary legislation are made.

If building work is being carried out, the Building Regulations are likely to apply and will require certain standards to be met. The Building Regulations are made under powers in the Building Act.

The Building Regulations 2000 (current) consist of:

- *Procedural regulations that set out what kind of work needs Building Regulations approval and how that approval should be obtained.*
- *Technical requirements that set the standards that should be achieved by the building work*.

The Building Regulations set out the technical requirements in Schedule 1. The Technical Requirements set out the broad objectives or functions which the individual aspects of the building design and construction should set out to achieve. The Technical Requirements comprise of fourteen parts labelled alphabetically from part A to H and known as Approved Documents.

The technical requirements regarding fire safety are set out in Approved Document B. Approved Document B has been published in two volumes. Volume 1 [26] deals with dwellinghouses and Volume 2 [3] deals with buildings other than dwellinghouses.

3.6.2 *Requirements for mezzanine floors (galleries)*

Dwellinghouses have their own requirements which were not studied in this project therefore; the requirements for galleries of buildings other than dwellinghouses were reviewed in this section.

Gallery is defined in the Approved Document B, Volume 2 for buildings other than dwellinghouses as "*A floor or balcony which does not extend across the full extent of a building's footprint and is open to the floor below*".

Storey is defined in the Approved Document B, Volume 2 for buildings other than dwellinghouses as:

a) any gallery in an assembly building (Purpose Group 5); and

b) any gallery in any other type of building if its area is more than half that of the space into which it projects; and

Note: Where there is more than one gallery and the total aggregate area of all the galleries in any one space is more than half of the area of that space then the building should be regarded as being a multi storey building.

c) a roof, unless it is accessible only for maintenance and repair.

According to the definition of gallery for buildings other than dwellinghouses above, a gallery must be open and an enclosed gallery is treated as a storey. The allowable aggregate area of galleries can be drawn from the definition of storey above which is no more than 50% of the area of the main room in which the galleries are located. The number of galleries in a room is not limited by the Approved Document B. A gallery is regarded as a storey in an assembly building.

The requirements regarding means of escape from galleries of a flat are stated in Clause 2.8 of Volume 2 [3] as follows:

A gallery should be provided with an alternative exit; or, where the gallery floor is not more than 4.5m above ground level, an emergency egress window which complies with paragraph 2.9. Where the gallery floor is not provided with an alternative exit or escape window, it should comply with the following:

a) the gallery should overlook at least 50% of the room below (see Diagram 1);

b) the distance between the foot of the access stair to the gallery and the door to the room containing the gallery should not exceed 3m;

c) the distance from the head of the access stair to any point on the gallery should not exceed 7.5m; and

d) any cooking facilities within a room containing a gallery should either:

i) be enclosed with fire-resisting construction; or
ii) be remote from the stair to the gallery and positioned such that they do not prejudice the escape from the gallery.

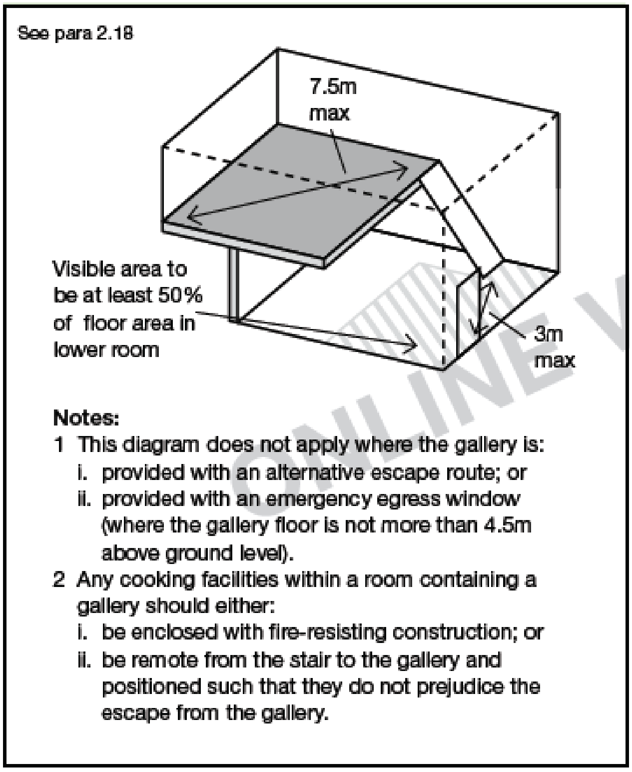


Figure 11: Gallery floors with no alternative exit. (Diagram 1 of Approved Documents B –Volume 2 [3])

According to the section above regarding means of egress for galleries, a gallery requires at least two exits where the gallery floor is greater than 4.5 m above ground level. When the gallery floor is no more than 4.5 m above ground level an emergency window egress is required apart from a normal exit. A single means of egress is allowed if a gallery satisfies the conditions illustrated in Figure 11. Refer to Clause 2.9 of the Approved Documents B-Volume 2 [3] for requirements of an emergency window egress.

Section 8.4: Escape from mezzanines and galleries of BS 5588: part 11 [27] recommends:

a) At least two escape routes should be provided from a mezzanine which is regularly occupied or accessible to members of the public, one of which should be via a protected stairway. The travel distance from any point on the mezzanine to the nearest storey exit should be in accordance with Table 1. (See Figure 12)

b) If combustible goods are stored or displayed under a mezzanine with a solid floor, the travel distance from any point on the mezzanine to the nearest storey exit, should be limited to that given in Table 1 for escape in one direction only unless a smoke detection system is installed on the underside of the floor which is linked to a fire alarm system or gives an audible warning of fire to the occupants of the mezzanine.

c) The travel distance from any point on a mezzanine which is only used for storage or access (for servicing or maintenance purposes) to the nearest storey exit on the storey below the mezzanine should be in accordance with Table 1. (See Figure 12)

Galleries are required to have the fire resistance as defined in Clause 7.2 of the Approved Documents B-Volume 2 [3] as:

Elements of structure such as structural frames, beams, columns, loadbearing walls (internal and external), floor structures and gallery structures, should have at least the fire resistance given in Appendix A, Table A1.

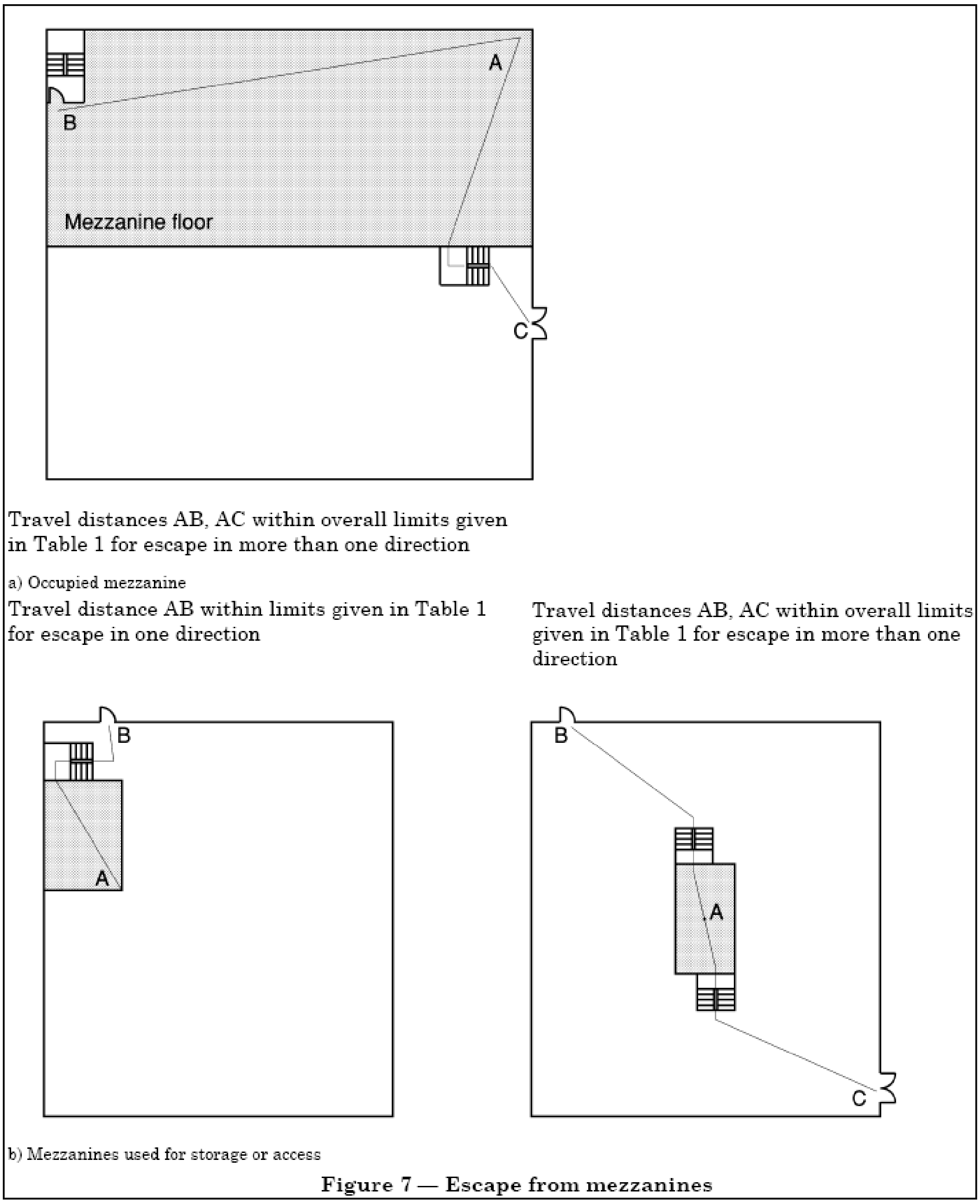


Figure 12: Escape from mezzanines (Figure 7 of BS 5588: part 11) [27]

3.7 Australian Prescriptive Requirements

3.7.1 *The Building Code of Australia*

The Building Code of Australia (BCA) [4] is a uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia which is produced and maintained by the Australian Building Codes Board on behalf of the Australian Government and each State and Territory Government.

The goals of the BCA are "*to enable the achievement of minimum necessary standards of relevant health, safety (including structural safety and safety from fire), amenity and sustainability objectives efficiently*" [4].

The BCA consists of two volumes: BCA matters regarding Class 2–9 buildings are in Volume One of the BCA. Matters regarding Class 1 and generally Class 10 buildings are in Volume Two. (Refer to the Part A3 of the BCA 2007 [4] for classification of buildings and structures).

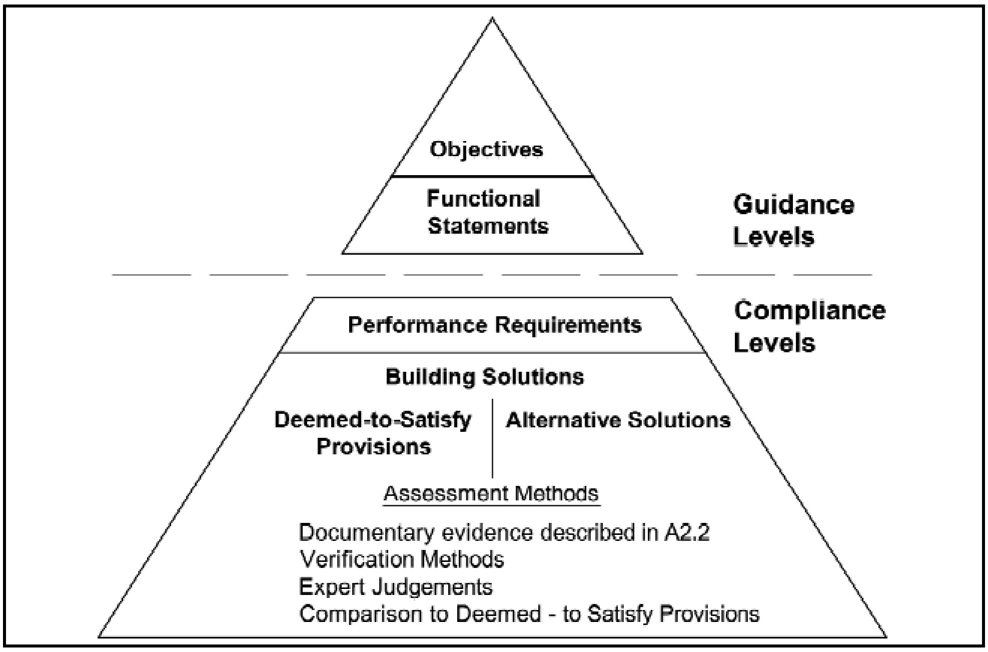


Figure 13: BCA structure [4]

The structure of the BCA comprise of two levels as shown in Figure 13. The guidance levels contain the Objectives and the Functional Statements. The compliance levels consist of the Performance Requirements and the Building Solutions.

A building solution will comply with the BCA if it shows that the performance requirements are met. The compliance with the performance requirements can only be achieved by [4]:

(a) complying with the Deemed-to-Satisfy Provisions; or

(b) formulating an Alternative Solution which—

(i) complies with the Performance Requirements; or

(ii) is shown to be at least equivalent to the Deemed-to-Satisfy Provisions; or

(c) a combination of (a) and (b).

The fire safety requirements for mezzanines are covered in Section C and D of the Volume One of the BCA. Section C is Fire Resistance and Section D is Access and Egress.

3.7.2 *Requirements for mezzanine floors*

Mezzanine is defined in Section A1.1 of the BCA as "*an intermediate floor within a room*".

According to the BCA a mezzanine must be part of a room. Figure 14 illustrates when an intermediate floor is regarded as a mezzanine or a storey. If an intermediate floor is enclosed by a wall it is regarded as a storey by the BCA.

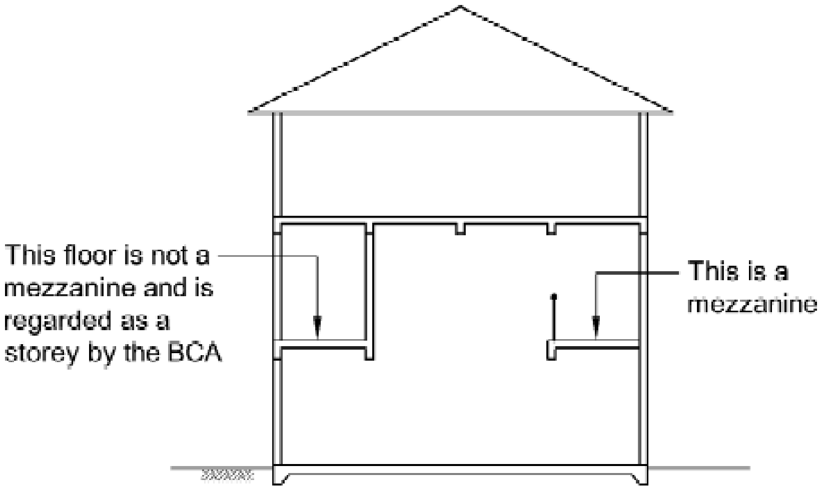


Figure 14: Section showing when an enclosed floor is regarded as a storey [4].

The allowable aggregate area of mezzanines is defined in Section C1.2 (d) of the BCA:

"For the purposes of calculating the rise in storeys of a building:

(i) a mezzanine is regarded as a storey in that part of the building in which it is situated if its floor area is more than 200 m^2 or more than 1/3 of the floor area of the room, whichever is the lesser; and

(ii) two or more mezzanines are regarded as a storey in that part of the building in which they are situated if they are at or near the same level and have an aggregate floor area more than 200 m^2 or more than 1/3 of the floor area of the room, whichever is the lesser."

The BCA does not limit the number of mezzanines if they are at or near the same level but the aggregate area of mezzanines is limited at one-third of the main room area or 200 m^2, whichever is lesser. The BCA also limits the number of levels of mezzanines at one level. The main room in which a mezzanine is located can be open or partially enclosed as it is not clearly defined in the BCA.

In terms of means of escape, mezzanines are treated as the same as stories of a building.

The requirements of Fire Resistance Level (FRL) of mezzanines are defined in clause 2.6 (b) of the BCA as follows:

> *(b) A mezzanine and its supports need not have an FRL or be non-combustible provided:*
>
> > *(i) the total floor area of all the mezzanines in the same room does not exceed 1/3 of the floor area of the room or 200 m^2, whichever is the lesser; and*
> > *(ii) the FRL of each wall and column that supports any other part of the building within 6 m of the mezzanine is increased by the amount listed below.*

Level otherwise required for any FRL criterion (mins)	Increase in level to (not less than):
30	60
60	90
90	120
120	180
180	240
The increase in level applies to each FRL criterion (*structural adequacy*, *integrity* or *insulation*) relevant to the building element concerned.	

Table 2: Increased FRLs-Construction surrounding mezzanines. (Table 2.6 of the BCA [4])

Table 2 requires an increase in each FRL criterion of each wall or column that supports any other part of the building, and is within six metres of the mezzanine.

According to the BCA, if a mezzanine complies with the conditions specified in Clause 2.6 (b), the mezzanine and its support may be constructed from materials that do not have an FRL and/or are combustible.

3.8 Literature review summary

The fire safety for mezzanines (intermediate floors) which is currently addressed in prescriptive requirements in New Zealand and other countries has been reviewed in this Chapter. Some key requirements are summarised as follows:

- The term for an "intermediate floor" varies with country. "*Mezzanine*" is used for most countries such as USA, Canada, and Australia. "*Gallery*" is the name for mezzanine in the UK while in New Zealand "*intermediate floor*" has been used since 1991, prior to which "*mezzanine*" was used.
- The simplest document regarding fire safety requirements for intermediate floor is *Deemed-to-Satisfy Provisions* of BCA (Building Code of Australia). Which allows only open mezzanines and an enclosed mezzanine is considered as a storey.
- The most complicated document regarding fire safety requirements for intermediate floors is the current Acceptable Solution C/AS1.
- The fire safety requirements for intermediate floors of NFPA 101 and NZS1900-Chapter 5 are very similar.
- Most requirements focus on floor areas and separation characteristics rather than occupant numbers.
- Enclosed and partly intermediate floors are allowed in all the countries prescriptive requirements reviewed, except for Australia, where only open intermediate floors are permitted.
- In the USA and Canada, when determining whether a level is considered as a mezzanine, the area of lower floor to which the area of an upper level is compared to is clearly defined as the open area of the lower floor in which the upper level is located. Enclosed space is not included in a determination of the size of the room in which the mezzanine is located. However, in Australia, UK and New Zealand, enclosed space can be included in calculating the size of the room in which the mezzanine is located.
- The allowable aggregate area of mezzanines varies with country. The one-third rule is applied for determining permitted aggregate area for both open and enclosed mezzanines in the USA and in New Zealand prior to 1991. In Canada, the allowable aggregate area of open mezzanines is 40% of the open area of the room in which the mezzanines are located while that figure is 10% for enclosed mezzanines. In Australia, the permitted aggregate area of mezzanines is one-third of the floor area of the room in which they are located or 200 m^2, whichever is the lesser. In the UK, 50% of the lower floor area is the allowable area of a gallery.

- Partly enclosed mezzanines are permitted in the USA, Canada and New Zealand but are not permitted in *Deemed-to-Satisfy Provisions* of the Australia building code. In the USA, a partly closed mezzanine is allowed if the total occupant load of the enclosed area is less than 10 people while in Canada, the requirement for a partly enclosed mezzanine is, the area of the enclosed area of a mezzanine does not exceed 10% of the area of the lower floor. In the Acceptable Solution C/AS1, partly enclosed limited area intermediate floor is permitted if smoke detection is installed throughout the whole firecell. Partly enclosed mezzanines are not mentioned in the UK Approved Documents.
- In the USA, Canada, Australia, UK and New Zealand prior to 1991 prescriptive requirements, when a mezzanine has an area exceeding the allowable area, the mezzanine is considered as a storey and all requirements for a storey are applied.
- In New Zealand, since 1991 there is no limitation on the area of intermediate floors.
    - From 1991 to 2001 - Acceptable Solution C2/AS1, C3/AS1, and C4/AS1: Limited area intermediate floors were introduced for two floor buildings where permitted area was one-third of the lower floor area. Firecells containing intermediate floors other than limited area intermediate floors required a smoke control system but the intermediate floors were still not treated as a storey.
    - From 2001 to present - Acceptable Solution C/AS1: there are two types of intermediate floor limited area and unlimited area. The allowable aggregate area of the limited area intermediate floors is 20% for completed enclosed intermediate floors and 40% for open; or partitioned or enclosed with smoke detection coverage throughout the firecell. Firecells containing limited area intermediate floors require the same fire safety precautions as single level firecells having the same total occupant load and escape height. Firecells containing intermediate floors other than limited area intermediate floors require a smoke control system but the intermediate floors are still not treated as a storey.
- In some scenarios, there is a requirement of having at least one means of egress that provides direct access to an exit at the mezzanine level such as an enclosed staircase in the USA, Canada and UK prescriptive requirements. However, there is not that requirement in *Deemed-to-Satisfy Provisions* of the Building Code of Australia and the Acceptable Solution C/AS1.

4. BUILDING AND OCCUPANT CHARACTERISTICS

4.1 Building geometries

There are many types of buildings containing intermediate floors such as warehouses, factories, churches, halls, theatres, shopping malls, offices. The size and the number of occupants of the buildings containing intermediate floors are in a very broad range. A firecell having intermediate floors can be a small office with an area of approximately 10 square metres or less and a couple of people in it or a very large warehouse or exhibition space with an area of thousands of square metres and an occupant load of thousands of people.

In order to investigate the level of risk to occupants of the firecells containing intermediate floors, three different firecell sizes with two purpose groups; crowd activity (CS and CL) and working activity (WL and WM) were chosen.

These firecells and intermediate floors are assumed to be in rectangular shape with flat ceiling. Intermediate floors have the same width as the lower floor and are located at one end of the firecell, hence the open area is located at the other end of the firecell as shown in Figure 15 and Figure 16. The three firecell sizes analysed are shown in Table 3.

Firecell	**Width** (m)	**Length** (m)	**Area** (m^2)	**Ceiling height** (m)	**Intermediate floor height** (m)
Small	4	10	40	6	3
Medium	10	25	250	6	3
Large	25	40	1000	8	5

Table 3: Studied firecells containing intermediate floors.

The term “ceiling height” and “intermediate floor height” are referred to the height of ceiling of the firecell and the height of intermediate floor above the lower floor level respectively.

The studied firecell sizes were chosen because they are quite typical in practice. Furthermore, C/AS1 sets out the cut-off points in terms of occupant load at which the required Fire Safety Precautions (FSPs) for two-floor buildings have been increased at 100, 500 and 1000 people which correspond to the requirement of Type 2, Type 3, Type 4 and Type 7 respectively. The small and medium firecells containing intermediate floors in any size, with the chosen occupant load density of 1.0 person per square metre (see section 4.3) will have the occupant loads not exceeding 100 and 500 people respectively. The large firecell having intermediate floors in any size, with the occupant load of 1.0 person per square metre will have the occupant load greater than 1000 people.

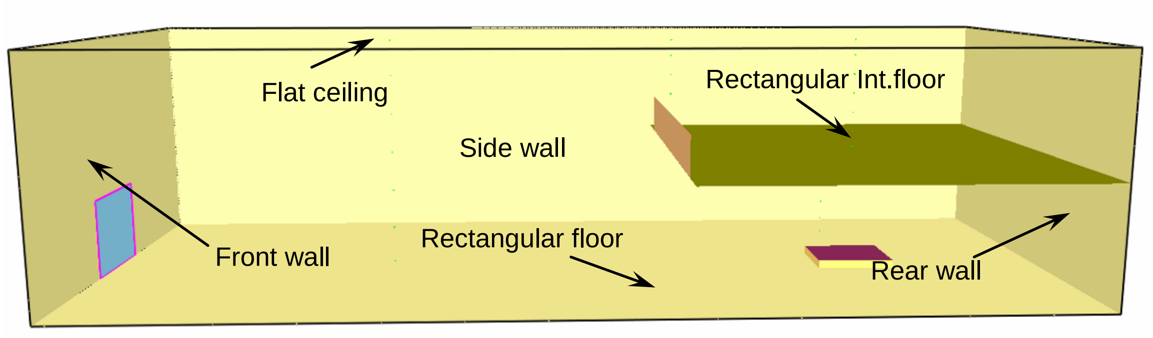


Figure 15: Schematic of a hypothetical firecell containing intermediate floor used in this study (perspective)

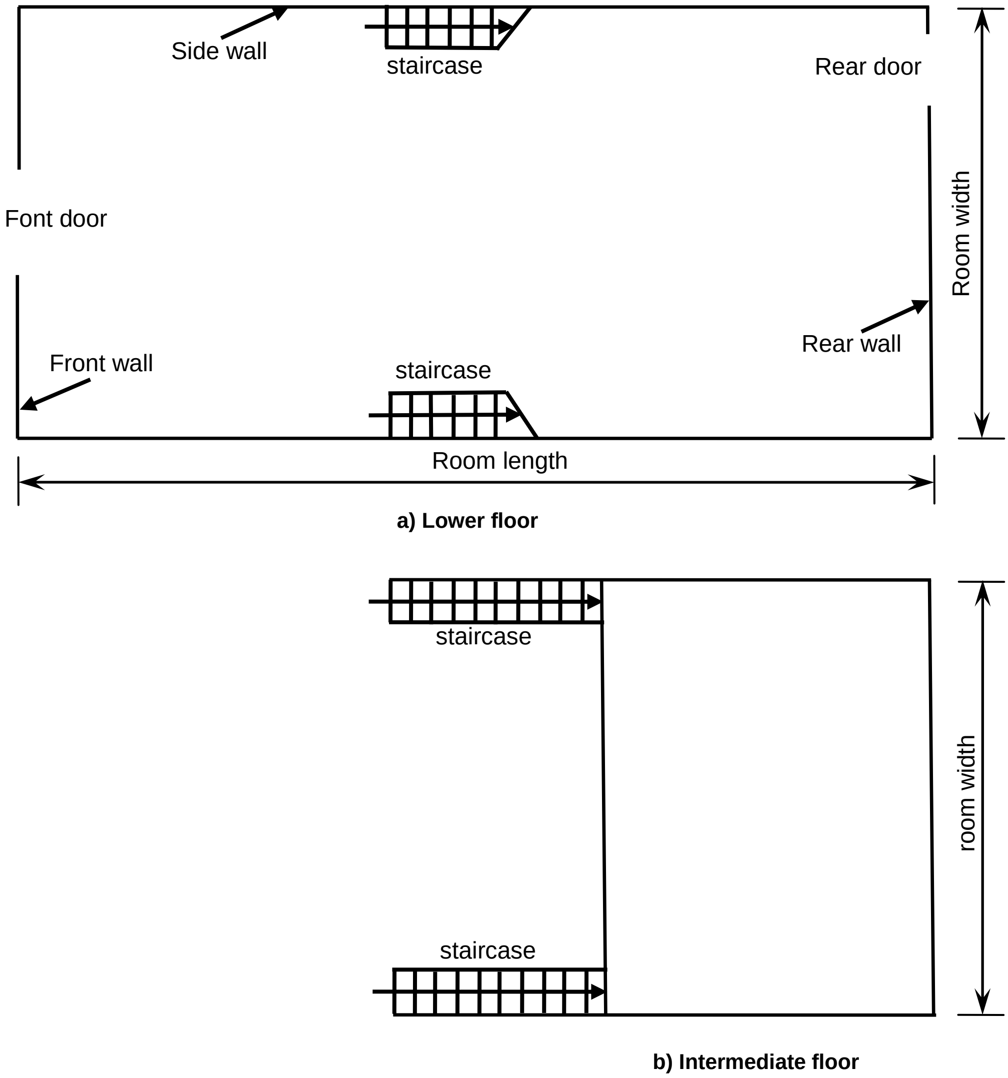


Figure 16: Schematic of plans of a hypothetical firecell containing intermediate floor used in this study (not to scale)

To investigate the effect of ceiling height on the level of safety of the occupants in the firecells containing intermediate floors, in addition to the large firecell with 8 m ceiling height, the large firecell was also studied with a ceiling height of 10 m and 12 m that has the same intermediate floor height of 5 m. In this project, the terms “large 8m”, “large 10m” and “large 12m” refer to the large firecells with ceiling heights of 8, 10 and 12 m respectively.

To study the effect of intermediate floor height on the level of safety of the occupants in the firecells containing intermediate floors, the large firecell with a ceiling height of 8 m was studied with two different intermediate floor heights; 5 m and 3 m.

For each type of firecell, a different range of firecell floor area with intermediate floor areas of 0%, 20%, 40%, 60% and 90% of firecell floor area were assessed. Above percentages of intermediate floors were chosen to assess because:

- 0% of the firecell floor area represents the firecell without intermediate floors.
- 20% and 40% of the firecell floor area are the cut off points of C/AS1.
- 60% of the firecell floor area is the transition from the cut-off point 40% to the scenario when only the staircase is open (90%).
- 90% of the firecell floor area represents the scenario when only the staircase is open (for a small firecell).

In addition for medium and large firecells, an opening area of 10 square metres was studied for the scenario when only the staircase is open which corresponds to the intermediate floor sizes of 96% and 99% for the medium and large firecells respectively.

Two types of firecell containing intermediate floors that were assessed are: firecells containing completely open or closed intermediate floors. There is no requirement to provide an escape route for an intermediate floor (open and closed) which is protected from smoke and hot gases from the floor below until it reaches a final exit in the current C/AS1. Therefore, in this project, the occupants of the intermediate floors (open and closed) are assumed to have to escape via the lower floors.

The number and total width of exits of the firecell were chosen as the minimum requirements in accordance with Table 3.1 and 3.2 of C/AS1 [7]. The total door width of the firecells was chosen as the minimum required by C/AS1 which is 7 mm per occupant or 1000 mm whichever is greater.

The requirements for unusable escape route are stated in Clause 3.3.2.b) of C/AS1: “*Except where dead ends and single escape routes are permitted, in unsprinklered firecells the total* *required width shall still be available should one of the escape routes be unusable due to the location of the fire or any other reason*."

Clause 3.3.2.c) of C/AS1 states "*Where the firecell is sprinklered it is unnecessary to provide extra width to allow for the possibility that one escape route may be unusable*".

In this project, no additional escape routes were provided to the unsprinklered firecells but each escape route was sized to ensure that the remaining unblocked escape routes of the firecells provide the required total width. No extra width was provided to the total escape width of the sprinklered firecells as stated above in 3.3.2.c).

The distribution of location of the required exits is presented in Table 4. An exit is located at the front wall if the required number of exits is less than two. If the required number of exits is two, then one exit is located at each end of the firecell (Figure 16). Two exits are located at the front wall (the open area) and one exit at the rear wall (intermediate floor area) when the requirement of the exit number is three. Two exits are located at each end of the firecell if the required exit number is four.

Required number of exits	Number of front exits	Number of rear exits
1	1	0
2	1	1
3	2	1
4	2	2

Table 4: Distribution of exits

The number of staircases and total width of staircases were also selected in accordance with Table 3.1 and 3.2 of C/AS1. The total width of the staircases was chosen with 9 per occupant or 1000 mm whichever is greater. Staircases are located along the side walls of a firecell. The sizes of treats, rises and landings are chosen in accordance with D1/AS1 [28].

The number and total width of exits, and the number and total width of staircases of studied firecells required by C/AS1 are presented in Table 6, Table 7 and Table 8 (see section 4.4).

4.2 Building construction, ventilation and initial condition

Concrete was assumed as material for the walls, ceiling/roof and floors which has the emissivity of 0.5, density of 2300 kg/m³, thermal conductivity of 1.2 W/m°C and specific heat of 0.88 kJ/kg°C [29]. The thickness of walls, ceiling/roof and floors was assumed to be 100mm.

The door height varies with the type and size of buildings. Typical door height ranges from approximately 2.0 m to 3.0 m. Therefore, it is reasonable to assume that the heights of the doors were 3.0 m for large rooms and 2.0 m for small and medium rooms. The doors were assumed to be closed initially but they would be fully open following the activation of the automatic fire alarms as occupants start to evacuate. For the studied firecells that do not require automatic fire alarms by C/AS1 (see section 4.4), the doors were assumed to be open after the fire was manually detected. See section 6.1 for the manual detection times.

An ambient temperature of 20°C and 65% relative humidity was assumed inside and outside. Building materials were also assumed to have an initial temperature of 20°C throughout.

4.3 Occupant characteristics

The two types of occupancy that were assessed in this project are crowd activity (CS and CL) and working activity (WL and WM). Table 5 shows the summary of occupant loads for both intermediate and lower floors of each purpose group which are taken from C/AS1 [7]. The occupant density of the purpose groups CS and CL was chosen as 1.0 person per square metre for both firecell and intermediate floors. For working activity (WL and WM), occupant density of the intermediate floors was chosen as 0.1 person per square metre which represents a typical occupant density for office or staff room whereas 0.03 person per square metre is the occupant density chosen for the lower floor which is a typical occupant density of warehouse storage or heavy industry [7].

Purpose group	**Floor**	**Occupant density** (ppl/m^2)
CL, CS	Lower	1.00
	Intermediate	1.00
WL, WM	Lower	0.03
	Intermediate	0.10

Table 5: Summary of occupant density

4.4 Required FSPs, exits and staircases for studied buildings

The FSPs, exits (number and total width), and staircases (number and total width) of studied firecells with different intermediate floor sizes required by C/AS1 are summarised in Table 6, Table 7 and Table 8 below. Refer to section 3.3.1 for keys of FSPs.

Purpose group	% of Int.fl	Total occ. load (ppl)	No of exits	Total exit width (m)	No of staircases	Total width of staircases (m)	FSPs
CS	0%	40	1	1.00	NA	NA	2af, 16, 18c
	20%	48	1	1.00	1	1.00	
	40%	56	2	2.00	1	1.00	
	60%	64	2	2.00	1	1.00	4, 16, 18c 10 or 11
	90%	76	2	2.00	1	1.00	
WL, WM	0%	2	1	1.00	NA	NA	2af, 16, 18c
	20%	3	1	1.00	1	1.00	
	40%	4	1	1.00	1	1.00	
	60%	5	1	1.00	1	1.00	4, 16, 18c 10 or 11
	90%	6	1	1.00	1	1.00	

Table 6: FSPs, number and total width of exits and staircases for small firecells with different purpose groups and intermediate floor sizes.

Purpose group	% of Int.fl	Total occ. load (ppl)	No of exits	Total exit width (m)	No of staircases	Total width of staircases (m)	FSPs
CL	0%	250	2	2.00	NA	NA	3f,16, 18c
	20%	300	2	2.10	1	1.00	
	40%	350	2	2.45	2	2.00	
	60%	400	2	2.80	2	2.00	4, 16, 18c 10 or 11
	90%	475	2	3.40	2	2.10	
WL, WM	0%	8	2	2.00	NA	NA	2af,16, 18c
	20%	13	2	2.00	1	1.00	
	40%	18	2	2.00	2	2.00	
	60%	23	2	2.00	2	2.00	4, 16, 18c 10 or 11
	90%	31	2	2.00	2	2.00	

Table 7: FSPs, number and total width of exits and staircases for medium firecells with different purpose groups and intermediate floor sizes.

Purpose group	% of Int.fl	Total occ. load (ppl)	No of exits	Total exit width (m)	No of staircases	Total width of staircases (m)	FSPs
CL	0%	1000	3	7.00	NA	NA	4,16,18c
	20%	1200	4	8.40	2	2.00	7,9,16,18c
	40%	1400	4	9.80	2	3.60	
	60%	1600	4	11.20	3	5.40	7,9,16,18c 10 or 11
	90%	1900	4	13.30	3	8.10	
WL, WM	0%	30	2	2.00	NA	NA	3b,16,18c
	20%	50	2	2.00	2	2.00	
	40%	70	2	2.00	2	2.00	
	60%	90	2	2.00	2	2.00	4,16,18c 10 or 11
	90%	120	2	2.00	2	2.00	

Table 8: FSPs, number and total width of exits and staircases for large firecells with different purpose groups and intermediate floor sizes.

5. ASET MODELLING

Fire growth computer models are used to calculate the time for conditions to become life-threatening. That time is the time when certain tenability limits are exceeded.

In this project, FDS 5.2.0 (Fire Dynamics Simulator) and BRANZFIRE 2009.1 were used to calculate ASET.

5.1 Tenability limits

As fire growth models are used to predict smoke filling in compartments, tenability criteria are required to establish the acceptability of the assessment. These tenability criteria are measures of the time for life-threatening conditions to develop.

In this project, tenability criteria will be concerned with the effect that one or more of the following phenomena have on occupants while within the building or within its escape routes.

- Convective heat.
- Radiant heat.
- Visibility through a smoke layer.

The reference smoke layer height of 2.0 m [7] is chosen to assess ASET. The radiant heat criterion is assessed when smoke layer is above the 2.0 m reference height. If the smoke layer descends below this reference height, the convective heat and visibility criteria are both assessed.

5.1.1 *Radiant heat*

Exposure to radiant heat will occur when occupants must pass close to a fire or under a hot effluent layer. Radiant heat causes erythema (reddening of the skin and pain), partial skin burns and eventually full thickness skin burns. A conservative tenability criterion for exposure to radiant heat is that radiant heat flux from the upper layer should not exceed 2.5 kW/m^2 at the reference height (this corresponds to an upper layer temperature of approximately 200°C). Above this, the tolerance time is less than 20 seconds [30].

5.1.2 *Convection*

For convected heat, the main considerations are skin pain and hyperthermia. The degree of hyperthermia depends on the activity of the person and the type of clothing they are wearing.

Critical temperatures for convective heat depend on the exposure time and the moisture content of the gases in which the occupant is in. A conservative tenability criterion for exposure to convected heat is 60°C (saturated, exposure time 30 minutes) [30].

5.1.3 *Visibility*

Ability to escape through smoke depends upon the effects of irritancy and visual obscuration on ability to move through building spaces and ability to locate escape routes and exits number. Some people may refuse to pass through even dilute smoke, while others will attempt to move through dense smoke, particularly in extreme situations. People that do travel through smoke will move slower than in clear conditions. FCRC (1996) [31] and the British provisional standard *PD 7974-part 6, 2004* [32] recommend the visibility tenability criteria of 5 metres for "small" rooms or domestic enclosures and 10 metres for larger enclosures.

In this project, three firecell sizes with intermediate floor size ranges from 20% to 90% or 99% were studied. The intermediate floor of the small and medium firecells with an area of 20% of the lower floor (the smallest studied intermediate floor size) can be considered as a small room. In addition, the visibility tenability criteria were assessed for both the lower and intermediate floors. Therefore, it is reasonable to use the visibility tenability criteria of 5 metres for the small and medium firecells, and 10 metres for the large firecell.

Because the calculated visibility is greatly influenced by the soot (carbon) yield (g/g) selected as input to the computer model so this value was carefully selected. A considerable collection of yields of fire products generated from combustion of fuel is given in Table 3.4.14 of the SFPE Handbook of Fire Protection Engineering [33]. The soot yield level ranges from 0.008 g/g for natural materials such as wool to 0.227 g/g for synthetic materials such as polyurethane foam (GM23) [33]. A recent study of soot yield values for modelling for residential occupancies carried out by Robbins and Wade [34] recommended 0.07 g/g for modelling purposes based on measurements taken during flaming combustion of full-sized items of upholstered furniture.

It is reasonable to assume that a typical building would contain approximately 60 to 70 percent of wood based products and 30 to 40 percent of polyurethane foam. In this research project, a soot yield level of 0.055 g/g was chosen which would be generated from combustion of fuel that contains about 35% of polyurethane (soot yield = 0.131 g/g) and 65% wood product (soot yield = 0.015 g/g).

5.1.4 *Summary of acceptance criteria*

The acceptance criteria that were used to assess ASET in this project is summarised in Table 9.

Category	Criteria
Convective Heat	Temperature < 60°C when smoke layer is below 2.0 m
Radiant Heat	Smoke layer temperature < 200°C when layer is above 2.0 m
Visibility (@ 2m)	When smoke layer is below 2.0 m • 5 m for small and medium rooms • 10 m for large rooms

Table 9: Summary of acceptance criteria

5.2 Design fires and fire locations

5.2.1 *Design fires*

In all cases the “t” squared with fast growth rate fire was used. The peak heat release rate (HRR) of 2.0, 4.0 and 10 MW was chosen for the small, medium and large firecells respectively, as shown in Figure 17. In this project, the simulations were stopped when the acceptance criteria is reached, so the exact peak heat release rate for design fire was not considered to be critical. However, those design fires above are reasonable and may be used in practice for buildings of these sizes.

In FDS, the fire areas were taken as 1.0 x 1.5 m, 1.5 x 2.0 m and 1.5 x 2.0 m, located at floor level for small, medium and large firecells respectively. The HRR per unit area at peak therefore were 1.33, 1.33 and 3.33 MW for small, medium and large firecells respectively. FDS allows the fire to be precisely located in the compartment while BRANZFIRE allows a centre location in the room of fire origin for entrainment to take place on all sides.

The fuel was assumed to contain about 35% of polyurethane and 65% of wood product with the following properties:

- Heat of combustion 19.0 kJ/g [33]
- Radiant loss fraction 0.33 [35]
- Carbon monoxide yield 0.004 kg/kg [33]
- Soot yield 0.055 kg/kg.(see Section 5.1.3)

The same fire specification was used in both the BRANZFIRE and FDS simulations.

In addition, to investigate the effect of the fire growth rate on the level of risk of the occupants, some selected scenarios were also modelled with ultra fast, moderate and slow "t' squared fires (see section 5.6).

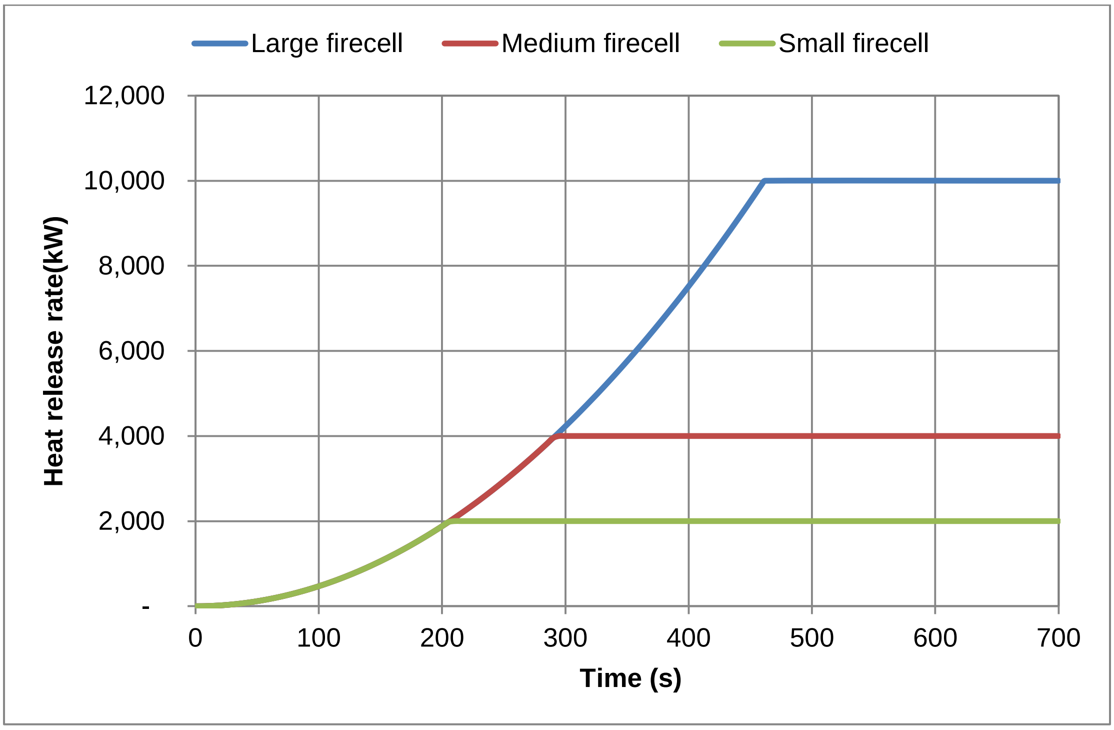


Figure 17: Heat release rates versus time

5.2.2 *Fire locations*

A fire could occur anywhere within the building; on the lower floor or on the intermediate floor. Figure 18 illustrates three typical fire locations in a firecell containing an intermediate floor, in which two scenarios are on the lower floor; a fire under the intermediate floor and a fire in the open area.

The scenario with a fire located on the intermediate floor (location 3) is very similar to the scenario with two separate firecells in which one firecell is above the other when a fire occurs in the top firecell. This scenario is therefore not included in this study.

Therefore in this project the two typical fire locations assessed are under the intermediate floor (location 1) and in the open area (location 2).

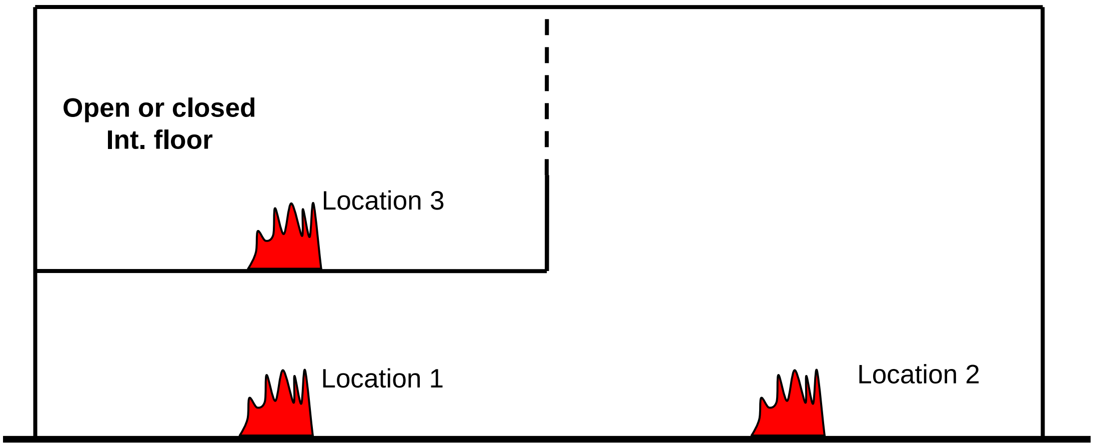


Figure 18: Schematic diagrams of a firecell containing open or closed intermediate floor and three possible fire locations (section view).

5.3 FDS (Fire Dynamics Simulator)

5.3.1 *Overview*

Fire Dynamics Simulator (FDS) is a computational fluid dynamics model used to calculate fire phenomena. The use of computer models such as FDS is becoming more widespread within the fire engineering community. *"The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Thermal radiation is computed using a finite volume technique on the same grid as the flow solver. Lagrangian particles are used to simulate smoke movement, sprinkler discharge, and fuel sprays"* [36].

Building enclosure is divided into a large number of cells and the governing equations of fluid dynamics for the conservation of mass, momentum and energy are solved for each. The energy release of a fire can be specified by the user in the form of a heat release rate per unit area of burning surface or by letting the burning rate be predicted from the fuel properties.

Smokeview [36] is a companion application to FDS that provides the results in images and animations. The simulation outputs from FDS can be visualised graphically in an interactive 3D environment. A schematic of a firecell with an open intermediate floor visualised in smoke view of FDS modelling is presented in Figure 19.

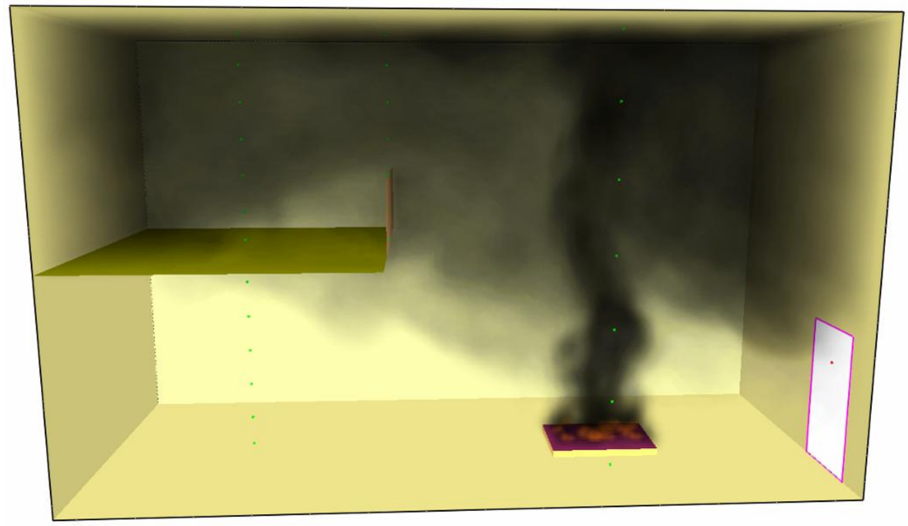


Figure 19: FDS modelling of a room with an open intermediate floor

5.3.2 *FDS models setting*

The grid size for each firecell size was determined based on the non-dimensional expression $D^* / \delta x$ [37], a measure of how well the flow field is resolved. The FDS user guide [37] recommends a $D^* / \delta x$ ratio between 4 and 16 to accurately resolve fire size.

where

δx is the nominal size of a mesh cell.

D* is a characteristic fire diameter given by [37]:

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}} \right)^{2/5} \quad (1)$$

With ρ_∞ = 1.2 kg/m^3, c_p = 1.005 Ws/kg.K, T_∞ = 293 K and g =9.81 m/s^2 [29] the nominal mesh cell for each firecell size were calculated using equation (1) and summarised in Table 10 below.

Firecell	**Heat release rate (MW)**	**D***	δx **max= D*/4 (m)**	δx **min= D*/16 (m)**
Small	2.0	1.267	0.32	0.08
Medium	4.0	1.672	0.42	0.11
Large	10.0	2.412	0.60	0.15

Table 10: Range of the nominal grid size for three firecell sizes.

Based on the nominal grid sizes calculated in Table 10 in consideration of the firecell sizes, the grid sizes of 0.1 m, 0.2 m and 0.3 m were chosen for the modelling of small, medium and large firecells respectively. In this project, a single uniform grid was used in each scenario.

Fire engineers often need to estimate the location of the interface between the hot, smoke-laden upper layer and the cooler lower layer in a burning compartment. Relatively simple fire models, often referred to as two-zone models such as BRANZFIRE, compute this quantity directly, along with the average temperature of the upper and lower layers. In a computational fluid dynamics (CFD) model like FDS, there are not two distinct zones, but rather a continuous profile of temperature. Nevertheless, there are methods that have been developed to estimate layer height and average temperatures from a continuous vertical profile of temperature. The FDS data was reduced to an equivalent upper and lower layer by integration of the temperature data over the height of the compartment at the location of interest using functionality provided within the FDS program.

In FDS modelling, three parameter control smoke production and visibility; each parameter is input on the REAC line. The first parameter is SOOT_YIELD, which is the fraction of fuel mass that is converted to soot if the mixture fraction model is being used. The SOOT_YEILD value of 0.055 g/g was used in all simulations as discussed in Section 5.1.3.

The second parameter is called the MASS_EXTINCTION_COEFFICIENT, and it is the K_m. The value K_m of 8700 m^2/kg was used in this project which is the suggested value for flaming combustion of wood and plastics [38].

The third parameter is called the VISIBILITY_FACTOR, denoted C, is a non-dimensional constant characteristic of the type of object being viewed through the smoke, i.e. C = 8 for a light-emitting sign and C = 3 for a light-reflecting sign [39]. The value C = 3 was used in this project.

In this project, a series of interested points where virtual devices were located to record temperatures at interval of 0.5 or 1.0 m from the floor to the ceiling was chosen to assess ASET as shown in Figure 20 and Figure 21 . At those locations, for additional comparison with BRANZFIRE model results, an effective LAYER HEIGHT, UPPER TEMPERATURE, LOWER TEMPERATURE and VISIBILITY were calculated by the inbuilt FDS function for integrating over the height of the compartment at specific locations.

- Point #1: Located under the intermediate floor on the lower floor.
- Point #2: Located in the open area on the lower floor.
- Point #3: Located in the centre of the intermediate floor.

The ASET of point 3 represents the ASET of the intermediate floors: the ASET for the intermediate floors was assessed as the time at which untenable conditions of point 3 is reached. Similarly, the ASET of the lower floors are represented by the ASET of point 1 or 2: the lower floors ASET were calculated as the time to reach untenable conditions earlier at point 1 or point 2.

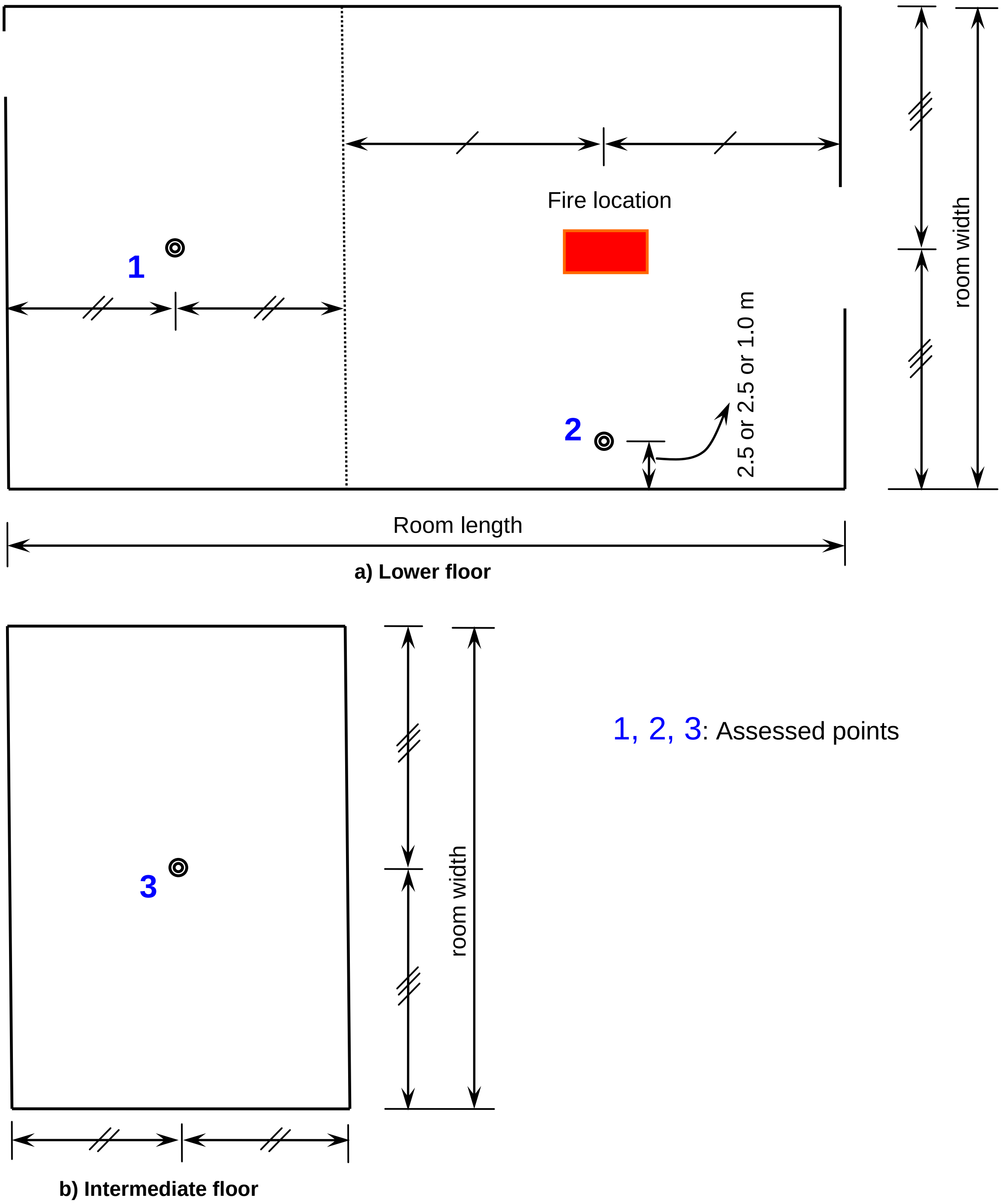


Figure 20: Schematic of assessed point locations in FDS modelling with a fire located in the open area (Plan view)

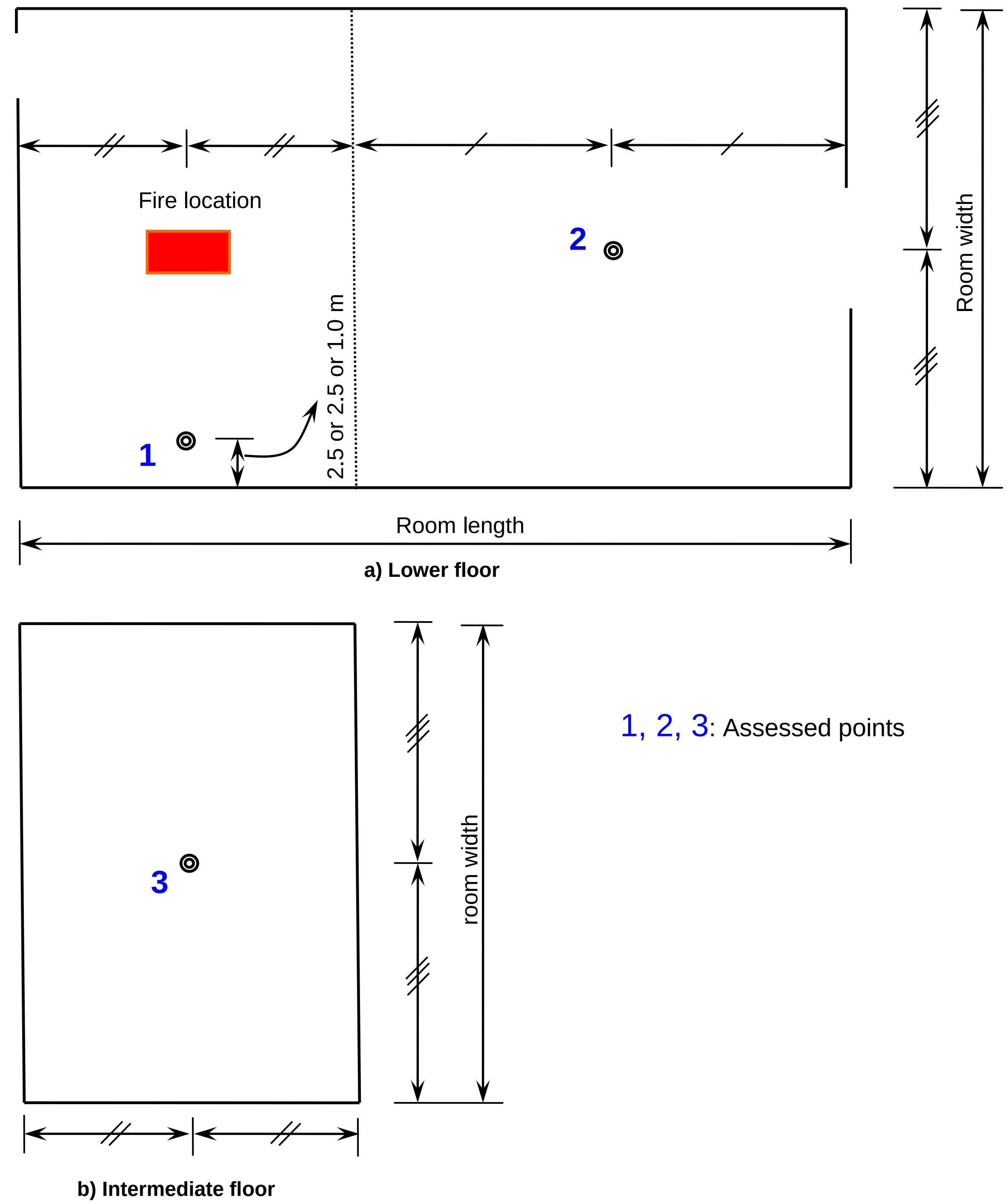


Figure 21: Schematic of assessed point locations in FDS modelling with a fire located under intermediate floor (Plan view)

5.4 BRANZFIRE

5.4.1 *Overview*

BRANZFIRE [40] is an enclosure zone model with an optional fire growth model for combustible linings. The BRANZFIRE zone model is developed using principles of mass and energy conservation to predict various phenomena associated with room fires. The model allows for up to 10 interconnected rooms. A schematic of a fire zone model showing the mass flows into and out of a single compartment is shown in Figure 22 [40].

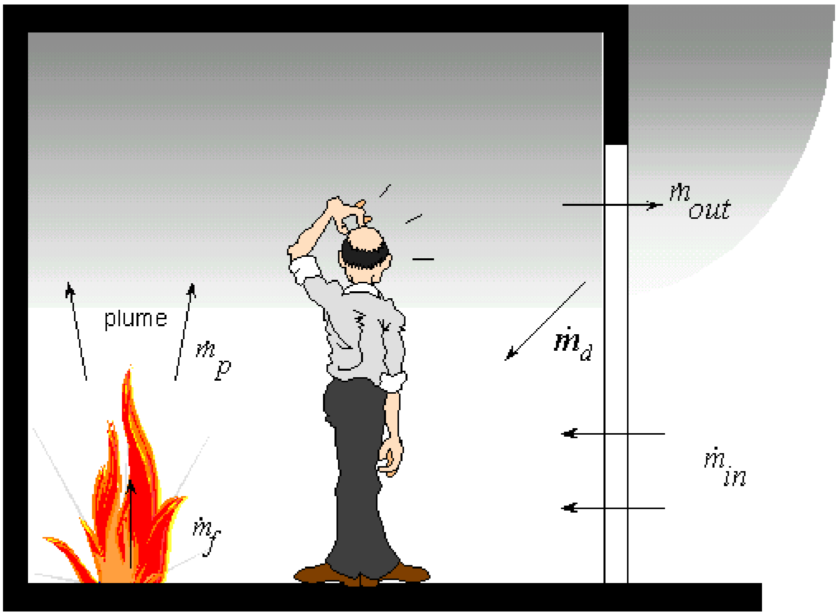


Figure 22: Schematic of a zone model [40].

In BRANZFIRE, the modelling equations used take the mathematical form of an initial value problem for a system of ordinary differential equations [40]. They are derived using the conservation of mass, the conservation of energy, the ideal gas law and relations for density and internal energy. They predict as functions of time, quantities such as pressure, layer heights and temperatures given the accumulation of mass and enthalpy in each of the two layers. Smoke transport between rooms is driven by the hydrostatic pressure profiles over the height of the openings [40].

The major assumption upon which zone models (BRANZFIRE) are premised is that the properties (temperature, density and concentrations) of the gas layer control volumes are uniform at any instant in time. Most zone models including BRANZFIRE use just two control volumes to divide each room into an upper and lower layer. In zone models, the plume provides a mechanism for transporting mass and energy from the fire and ambient entrained air from the lower layer to the upper layer. Empirical correlations are used to determine how much air is entrained into the plume and mixed with the combustion products. The entrainment is a function of the size of the fire and the vertical distance between the fuel and interface layer between the two control volumes.

Two plume entrainment models are included in BRANZFIRE: Delichatsios and McCaffrey. McCaffrey's plume correlations is the default and was used in this project. McCaffrey's correlations are empirical, fitted to experimental data. The mass flux entrained into the plume for the continuous flaming, intermittent and buoyant plume regions respectively is given by [40]:

$$\dot{m}_p / \dot{Q}_f = 0.011 \left(\frac{Z}{\dot{Q}_f^{2/5}} \right)^{0.566} \quad \text{for} \quad 0 \le \frac{Z}{\dot{Q}_f^{2/5}} < 0.08 \tag{2}$$

$$\dot{m}_p / \dot{Q}_f = 0.026 \left(\frac{Z}{\dot{Q}_f^{2/5}} \right)^{0.909} \quad \text{for} \quad 0.08 \le \frac{Z}{\dot{Q}_f^{2/5}} < 0.20 \tag{3}$$

$$\dot{m}_p / \dot{Q}_f = 0.124 \left(\frac{Z}{\dot{Q}_f^{2/5}} \right)^{1.895} \quad \text{for} \quad 0.20 \le \frac{Z}{\dot{Q}_f^{2/5}} \tag{4}$$

There are also other means of moving mass and enthalpy between the control volumes, including mixing between the layers at the location of the vents. Again, empirical equations (correlations) are used to determine the magnitude of these transfer flows, and these result in mass being removed from one control volume and being deposited into another. Additional entrainment may also occur for a vent flow into a connected room. All entrainment coefficients are empirically derived. Vent flows are driven by pressure differences across an opening resulting from variations in gas temperature and density on each side of the vent over its height.

Flow through vents is a dominant component of any fire model because it is sensitive to small changes in pressure and transfers the greatest amount of enthalpy on an instantaneous basis of all the source terms (except of course for the fire and plume). Its sensitivity to environmental changes arise through its dependence on the pressure difference between compartments which can change rapidly [41].

Zone models use “rules” to determine how/where mass, enthalpy and products of combustion are exchanged between rooms connected by a vertical vent (e.g. door and windows). These deposition rules impact on the development of the layer in the receiving room, and on the position of the layer interface height in both rooms.

The ceiling jet model was selected as the NIST ceiling jet model described by Davis [42] in the simulations.

5.4.2 *Virtual room methodology*

A multi-cell approach that divides a large compartment into a number of smaller compartments connected by large (full width/height vents) has been suggested by several authors in the literature as a means of allowing zone models to produce more realistic results in larger compartments. A disadvantage to this approach is that additional uncertainties and propagation of errors in the vent entrainment calculations are accumulated each time gases pass through a vent opening.

Smoke filling of seven enclosures ranging in area from 625 to 5000 m^2 and height 6 to 12 m was simulated using the zone model BRANZFIRE and the FDS were studied by Wade and Robbins [35]. For the large floor area up to about 5000 m^2, multi-room simulations were investigated using the zone model. The study found that the multi–room approach provides more realistic representation of the smoke layer position compared to a zone model single room simulation, however average gas temperatures may be overestimated close to the fire plume and underestimated far from the plume.

Jones [43] stated that for multi-compartment modelling that most zone models produce good agreement for a three room configuration but more data are needed for a larger number of connected rooms.

Rockett [44] discussed the potential application of pseudo-rooms for large area, low ceiling rooms (or long corridors). He noted that it was an attractive but untested approach, but satisfactory where internal construction such as beams or other structures within the room provide natural subdivisions of the space.

Duong [45] modelled fires in an aircraft hangar (94 × 54 × 15 m) using various zone models. The building was modelled using multiple adjacent compartments. The results for the four MW fire scenario were in reasonable agreement compared to previous experimental data for all modelling considered. For the 36 MW fire, the model results using FAST over-predicted the experimental results. Also it was noted that selection of the plume equation influenced the model results for the large enclosure. This was attributed to the influence on the heat and mass transfer into the hot layer.

Chow [46] applied the multi-cell concept to simulate fire in a large compartment (60 x 60 x 3 m high) by subdividing it into sub-compartments. There was a 20 m wide by 3 m high vent to the outside. He investigated 1, 3, 9 and 15 sub-compartments and used the CFAST model. Each sub-compartment was connected to its neighbour with a full height/width opening. Chow concluded that a zone model is suitable for simulating fire in a big space but further experimental verification is necessary.

Hu et al [47] used a multi-cell concept using CFAST to simulate the smoke filling process due to a fast growing 2 MW fire in a domestic boarding-arrival passage of an airport terminal, 392.5 m long x 7.5 m wide x 3.5 m high with an aspect ratio of about 50. The terminal enclosure was modelled in CFAST using 9, 19 and 29 compartments in series connected with full height/width vents. The results were also compared with FDS simulations. They present comparisons to show that more reasonable results for the layer temperature and the smoke layer interface height are achieved using this multi-cell method compared to using the traditional one room two layer zone model. They also say that better results were achieved when the passage was divided into smaller compartments (i.e. more cells). The time taken for the smoke layer to start descending at the end of the passage was noted to be somewhat earlier than that predicted by FDS.

Due to the natural geometry of the firecell containing intermediate floors, it is necessary to use the virtual room methodology in the BRANZFIRE modelling, as it is it not possible to model a fire under the intermediate floor any other way. In this project, the virtual room methodology therefore was used in the BRANZFIRE simulations. The details showing how the method was used are presented in the next sections.

5.4.3 *Open intermediate floors*

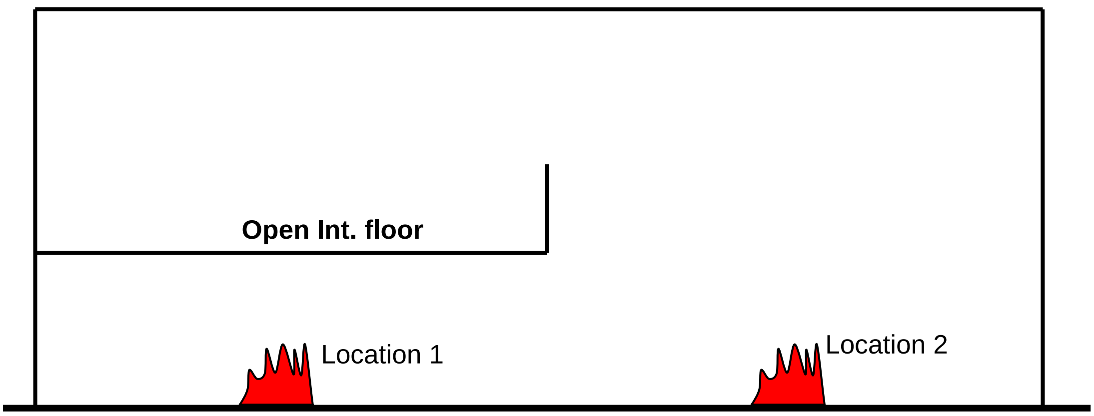


Figure 23: Schematic diagram of a firecell containing an open intermediate floor and fire locations (section view)

The schematic of a firecell containing an open intermediate floor with two typical fire locations is shown in Figure 23.

In BRANZFIRE, the vent flow algorithm VENTCF2A [48] is used for modelling the gas flows through a ceiling or floor vent. The vent may connect to the outside, or it may connect to another room. The flow is driven by cross-vent pressure differences and, when appropriate, combined pressure and buoyancy-driven flows which occur when the density configuration is unstable. This occurs when a dense cooler gas layer is above the vent and a less dense hot gas layer is directly below the vent. These vent flow routines are applicable where the vent area is small compared to the ceiling area. They should not be used to model large openings in floors to accommodate atria etc. Wade [40] suggests that in such cases it is better to model a void as a separate space connected to adjacent rooms with wall vents.

The width of a virtual wall vent that connects two virtual rooms is normally taken as full width of the room while the height of a wall vent can be chosen as full height from floor to ceiling (without transom) or less than the height from floor to ceiling (with transom).

The effect of the assumed transom depth of the virtual wall vent on the smoke filling time of large spaces was studied by Wade and Robbins [35] using BRANZFIRE and FDS, in which the transom depth was selected to approximate the depth of the ceiling jet (0.1H). Where H is the height from the floor to the ceiling. The study found that when using a virtual room approach where the assumed depth of the transom at the top of the vent was 10% of the ceiling height, the time taken for the smoke layer to start descending in the furthest compartment was closer to the prediction of FDS. If no transom is selected in the BRANZFIRE models, a closer agreement with the FDS average layer temperature predictions was obtained but BRANZFIRE predicted a shorter time for smoke layer to descend than FDS.

In this project, where virtual wall vents were used in BRANZFIRE simulations, no transom was selected. Thus, the virtual wall vents were assumed with full width and height of the room.

The firecell can be modelled as two virtual rooms connected to each other by a virtual ceiling vent as shown in Figure 24. However, the virtual ceiling vent area is relatively large compared to the ceiling area so it would be better to model the firecell using virtual rooms that are connected to each other by wall vents.

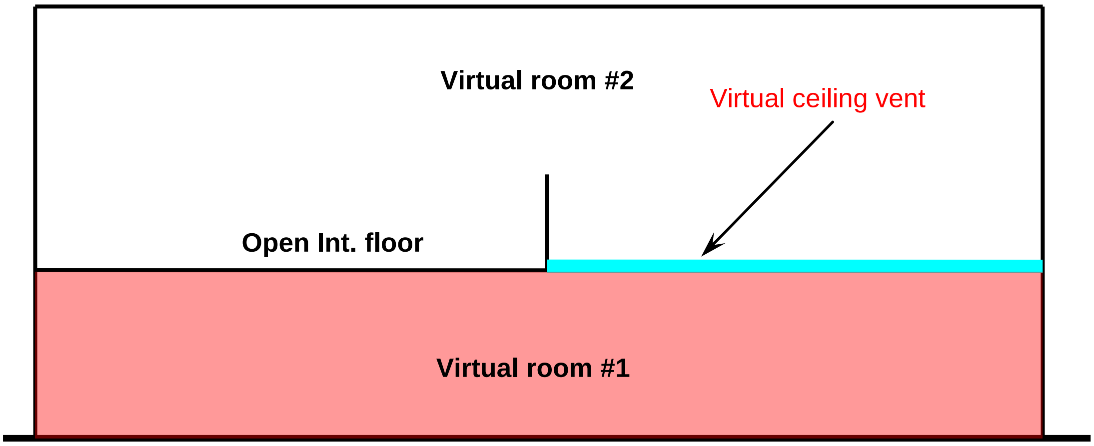


Figure 24: Schematic of virtual rooms connected by a virtual ceiling vent in BRANZFIRE modelling (section view)

5.4.3.1 Fire located under the intermediate floor

Figure 25 shows a firecell with a fire located under the open intermediate floor which was divided as three virtual rooms for modelling in BRANZFIRE. Virtual room #1 is the area under the intermediate floor, the open area is modelled as virtual room #2 and the intermediate floor is modelled as virtual room #3. Virtual room #2 is connected to virtual rooms #1 and #3 by virtual wall vents.

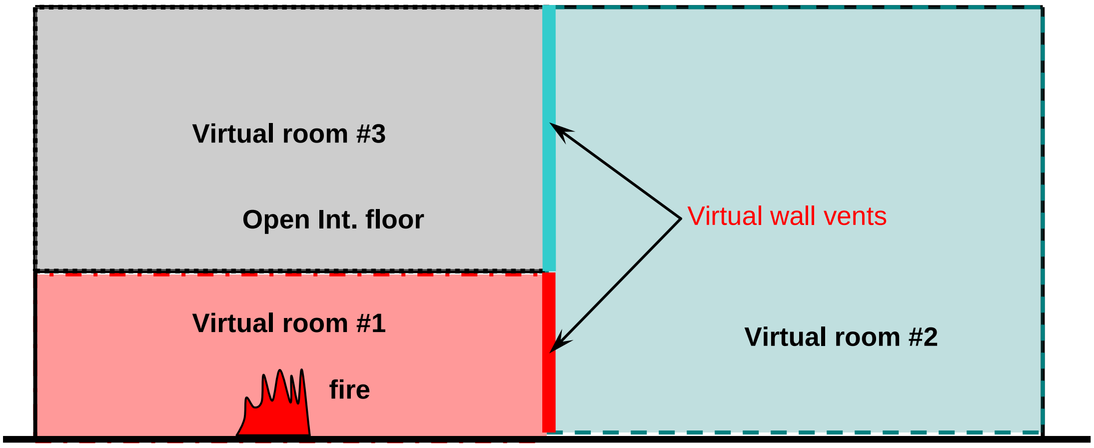


Figure 25: Schematic of virtual rooms connected by virtual wall vents in BRANZFIRE modelling (section view)

The ASET of the intermediate floor is calculated as the time when untenable conditions of virtual room #3 is reached while the ASET of the lower floor is calculated as the time to reach untenable conditions of either virtual room #1 or #2 whichever is less.

5.4.3.2 Fire located in the open area

For the scenario when a fire is located in the open area, the firecell can be modelled as a single room (Figure 26) or as three virtual rooms (Figure 27) connected to each other by virtual wall vents. In this project, this type of firecell was modelled in both methods: one room and three virtual rooms, the results were then compared with the FDS results to find out a more appropriate method.

Figure 26 shows the firecell containing an open intermediate floor with a fire located in the open area which was modelled as a single room in BRANZFIRE.

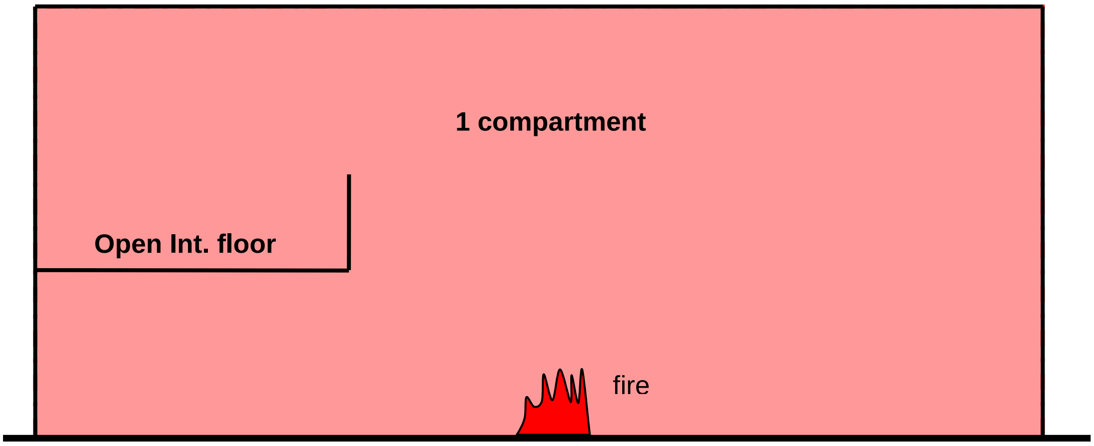


Figure 26: Schematic of a single compartment in BRANZFIRE modelling (section view)

A schematic of a firecell containing an open intermediate floor with a fire located in the open area which was modelled as three virtual rooms connected by virtual wall vents in BRANZFIRE is illustrated in Figure 27. The ASET of the intermediate floor is calculated as the time when untenable conditions of the virtual room #3 is reached while the ASET of the lower floor is calculated as the time to reach untenable conditions of either virtual room #1 or #2 whichever is less.

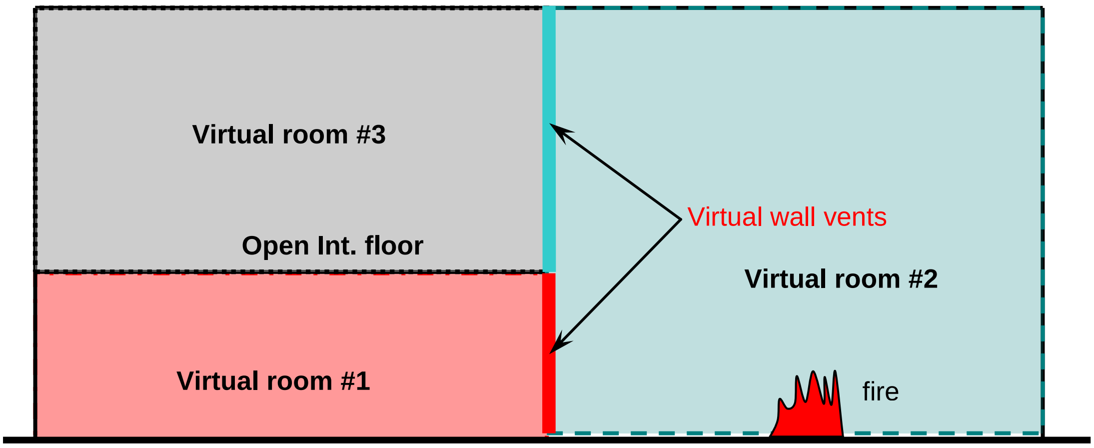


Figure 27: Schematic of virtual rooms connected by virtual wall vents in BRANZFIRE modelling (section view)

5.4.4 *Closed intermediate floors*

The schematic of a firecell containing a closed intermediate floor and fire locations is illustrated in Figure 28. Similar to the firecell containing open intermediate floors, two typical fire locations were assessed which are under the intermediate floor (location 1) and in the open area (location 2).

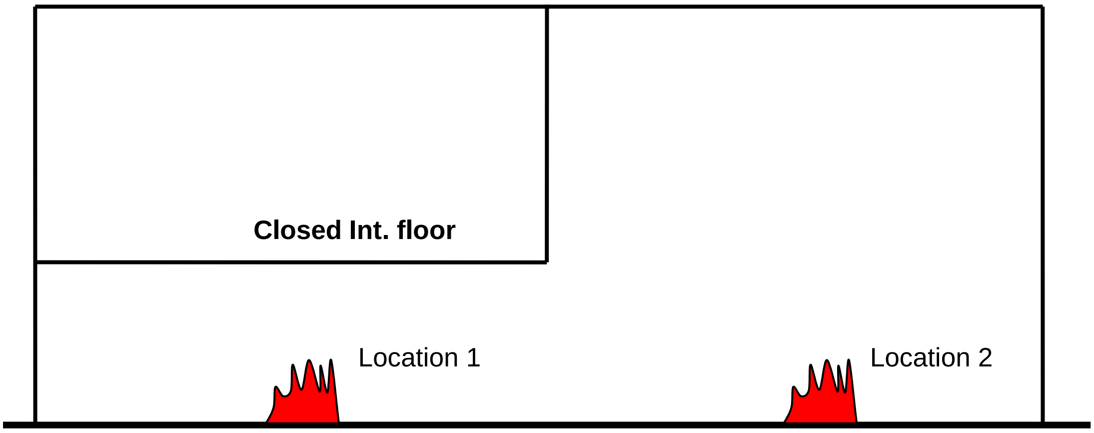


Figure 28: Schematic diagram of a firecell containing a closed intermediate floor and fire locations (section view)

As mentioned earlier, the firecell should not be modelled as two virtual rooms connected by a virtual ceiling vent. The firecell therefore is modelled as two virtual rooms connected to each other by a wall vent as shown in Figure 29. The closed intermediate floor was not included in the BRANZFIRE modelling as it is completely closed. Because occupants on the intermediate floor escape via the lower floor so the ASET of the intermediate floor was assessed as the ASET of the lower floor. The ASET of the lower floor is calculated as the time to reach untenable conditions of either virtual room #1 or #2, whichever is less.

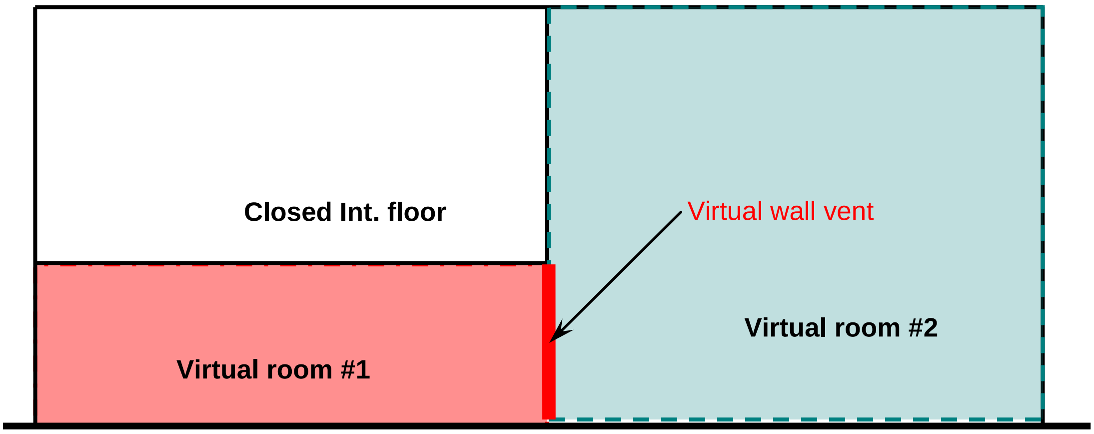


Figure 29: Schematic of virtual rooms connected by a virtual wall vent in BRANZFIRE modelling for closed intermediate floors (section view)

5.5 FDS and BRANZFIRE modelling results with fast fires

5.5.1 *Determining ASET of the intermediate and lower floors*

Figure 30 and Figure 31 show the layer heights, visibilities and upper and lower layer temperatures predicted by FDS with a fast fire located in the open area for a small firecell containing an open intermediate floor with an area of 20% of the lower floor. The layer heights at point #2 (the open area), point #3 (the intermediate floor) and point #1 (the area under the intermediate floor) drop to 2 m at 40, 50 and 80 seconds respectively, whereas the corresponding visibility at the head height (2 m) of those points reduce to 5 m at 100, 75 and 105 seconds respectively, as illustrated in Figure 30. The upper layer temperatures of three selected points were predicted to be less than 180°C after a simulation time of 160 seconds (see Figure 31). The lower layer temperature of point #3 (the intermediate floor) was predicted to reach 60ºC after about 110 seconds while the lower layer temperatures of point #2 (the open area) and point #1 (the area under the intermediate floor) did not reach 40ºC after a simulation time of 160 seconds.

The ASET of the intermediate and the lower floors therefore were determined as 75 and 100 seconds respectively which are the time for the visibilities at the head height reduce to 5 m but the temperature criteria are not reached.

The same procedure was carried out to determine the ASET of the intermediate and lower floors predicted by both FDS and BRANZFIRE for all other scenarios. In this project, visibility is the critical criteria because it always reaches the design limit before the temperature criteria. Refer to Appendix A for the details of the ASET of intermediate and lower floors predicted by FDS and BRANZFIRE by the variation of fire locations, the intermediate floor and firecell sizes.

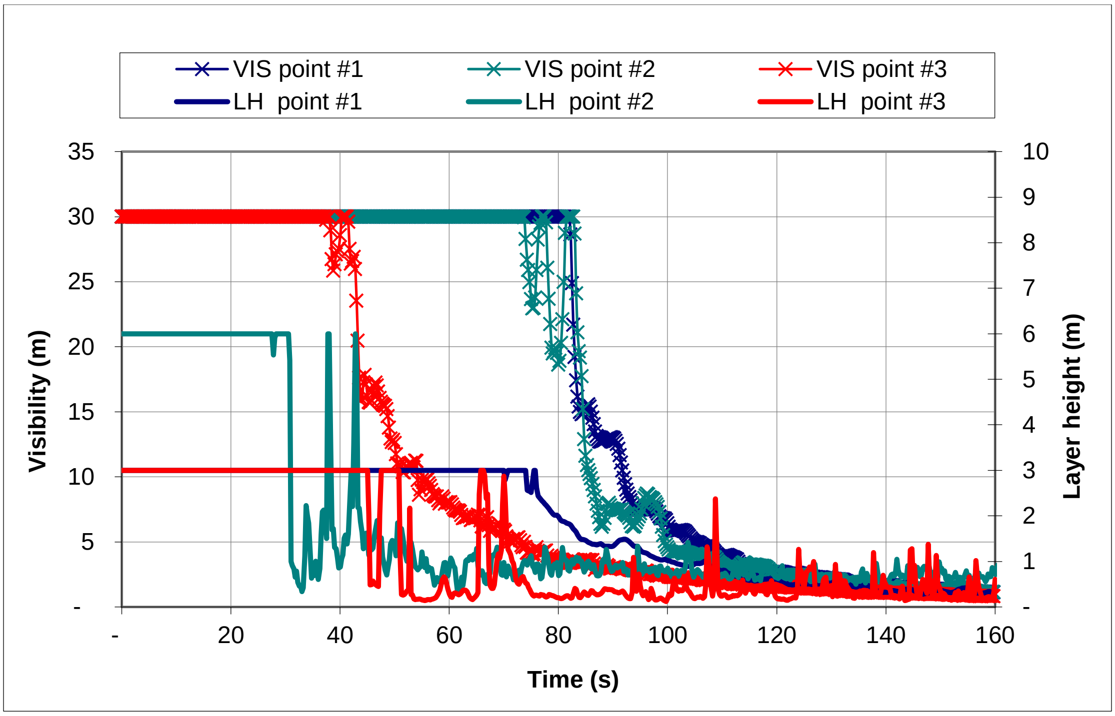


Figure 30: Layer heights and visibilities of a small firecell with 20% open intermediate floor with a fast fire located in the open area predicted by FDS. The locations of the points are shown in Figure 20.

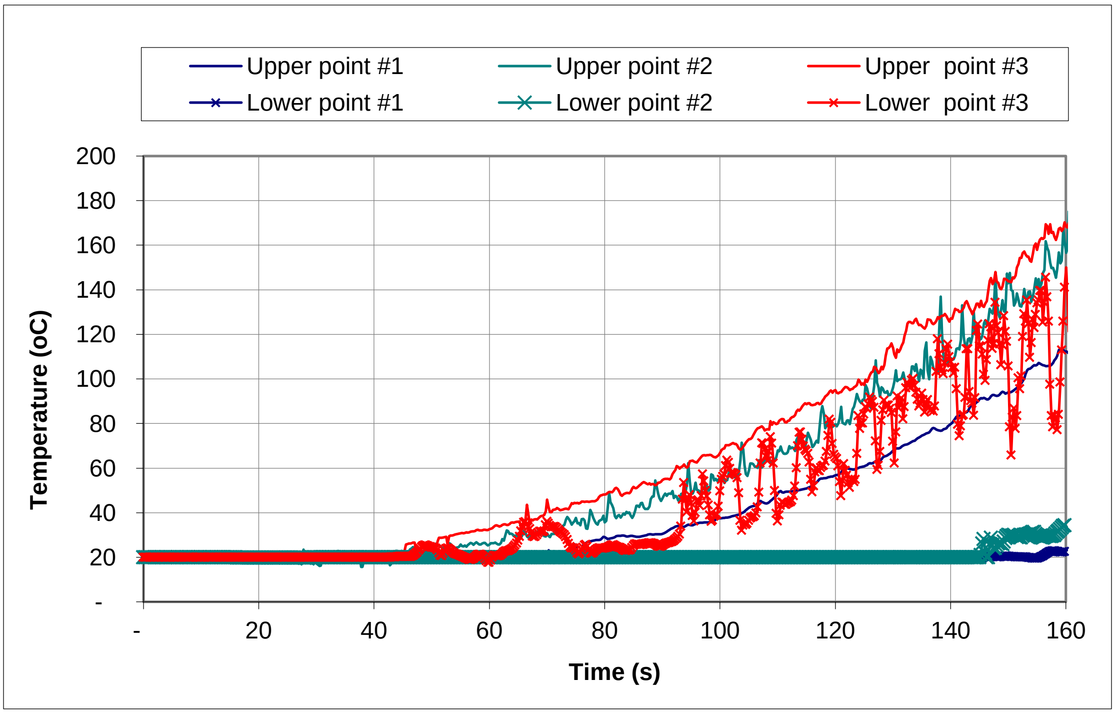


Figure 31: Upper and lower layer temperatures of a small firecell with 20% open intermediate floor with a fast fire located in the open area predicted by FDS. The locations of the points are shown in Figure 20.

5.5.2 *Open intermediate floors with a fire under the intermediate floor*

Figure 32 and Figure 33 illustrate two examples of firecells containing open intermediate floors with a fire located under the intermediate floors. The intermediate floors range from 20% or 60% of the lower floors (Figure 32) to 90% or 99% of the lower floors (Figure 33).

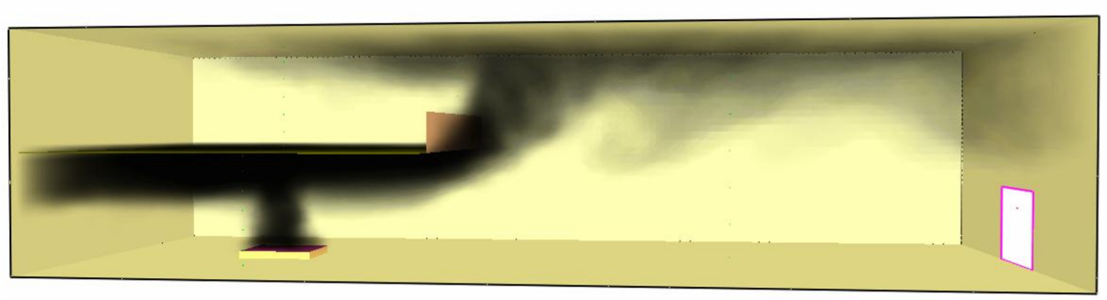


Figure 32: Firecell containing an open intermediate floor with a fire located under the intermediate floor.

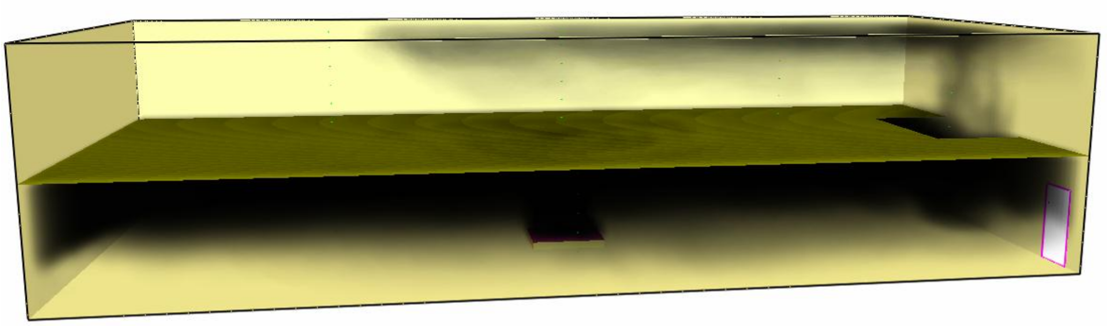


Figure 33: Firecell containing an open intermediate floor with a fire located under the intermediate floor. (very small opening)

The ASET of intermediate and lower floors predicted by FDS and BRANZFIRE with a fast fire located under the open intermediate floor by the variation of the intermediate floor sizes for the five studied firecell sizes; small, medium, large with 8 m ceiling height, large with 10 m ceiling height and large with 12 m ceiling height are plotted in Figure 34 to Figure 38. All firecells were modelled with intermediate floors of 20%, 40%, 60% and 90%. In addition, the medium and large firecells were modelled with 96% and 99% of the firecell floor respectively (very small openings: 10 m^2) that represent scenarios when only the staircase is open as stated in section 4.1 of this report.

The figures show that the ASET predicted by FDS and BRANZFIRE for the firecells without intermediate floors (i.e. 0% intermediate floor) are always greater ASET than the ASET of the lower floor of the firecells containing open intermediate floors. When the intermediate floor size increases, the ASET of the intermediate floors predicted by FDS for all five firecells increase. The ASET of the lower floors change very little and decline when the intermediate floors exceed 60% of the firecell floors.

For the small and medium firecells (Figure 37 and Figure 38), the predictions of ASET of the intermediate floors by FDS are always greater than that of lower floors regardless of the intermediate floor size.

For the large firecells (Figure 34, Figure 35 and Figure 36), the ASET of the lower floors predicted by FDS vary little with a change in intermediate floor size ranging from 20 to 60% of the firecell floors. When the intermediate floor size exceeds 60% of the firecell floor the ASET of the lower floors start to decrease to less than that of the intermediate floors. If the fire is located under the intermediate floors the smoke layer forms underneath the intermediate floors and it descends faster than the smoke layer on the upper floors as shown in Figure 32 and Figure 33.

With the intermediate floor sizes ranging from 20 to 60%, the results predicted by BRANZFIRE have the same trend with FDS for all firecell sizes. For the medium and large firecells, when the intermediate floors sizes exceed 60% of the firecell floors, the ASET of the intermediate floors, as predicted by FDS, increase significantly to about double that of the lower floors but the ASET predicted by BRANZFIRE are almost unchanged and still are less than the ASET of the lower floors.

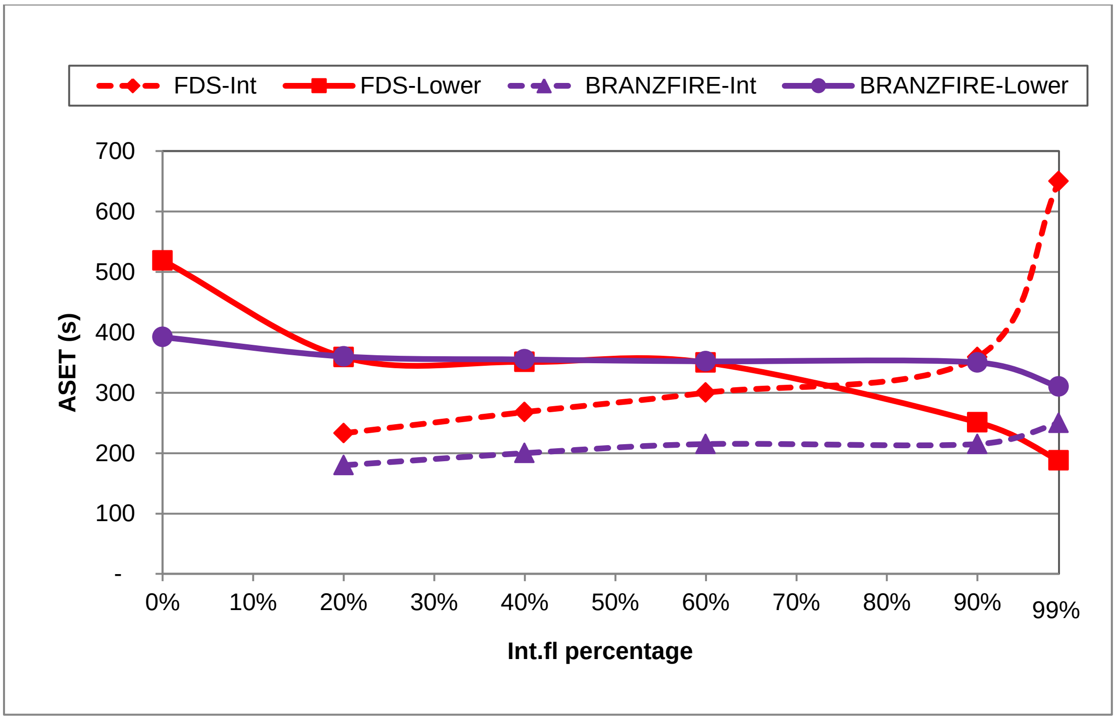


Figure 34: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located under the intermediate floor for large 12m firecell.

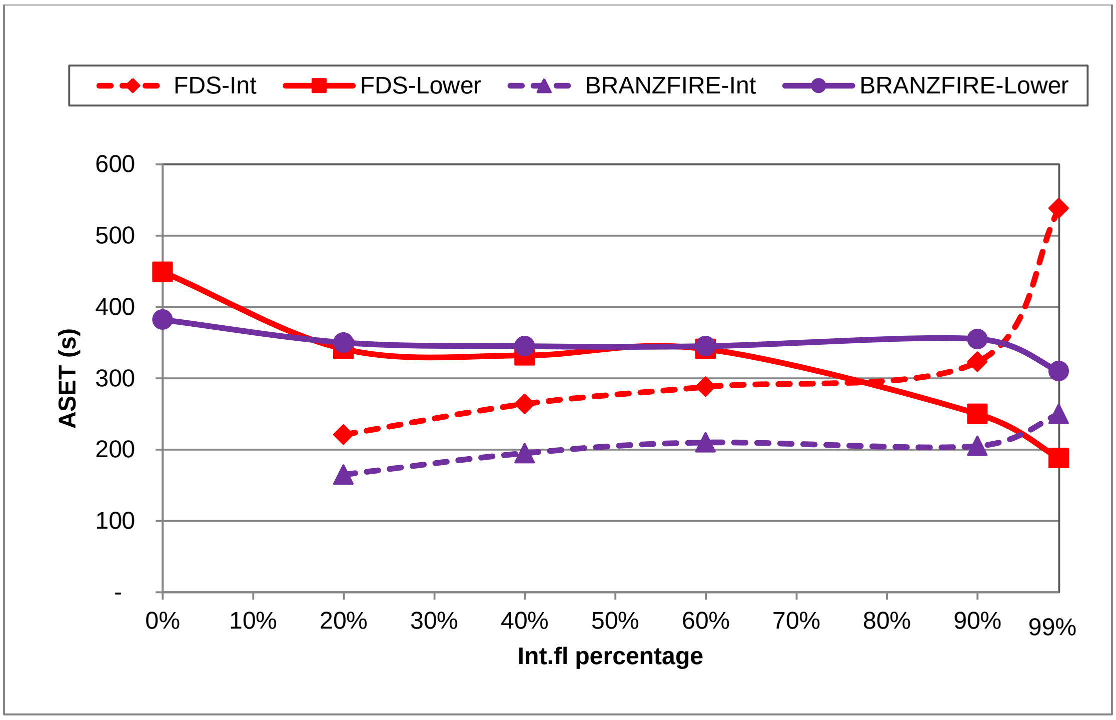


Figure 35: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located under the intermediate floor for large 10m firecell.

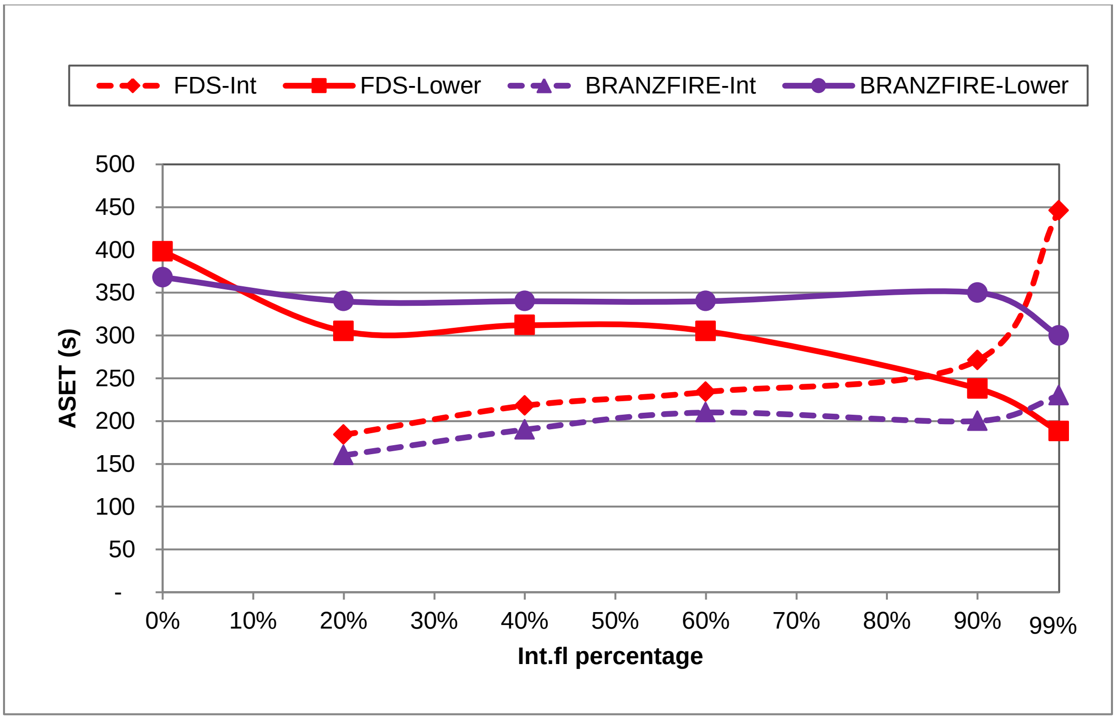


Figure 36: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located under the intermediate floor for large 8m firecell.

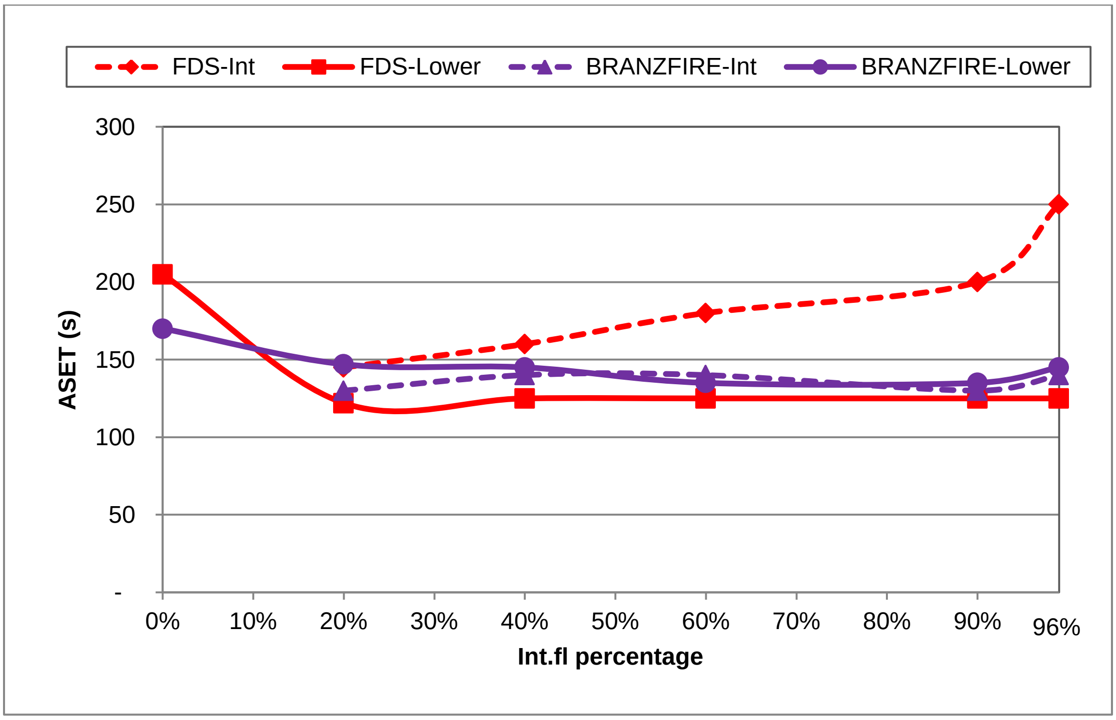


Figure 37: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located under the intermediate floor for medium firecell.

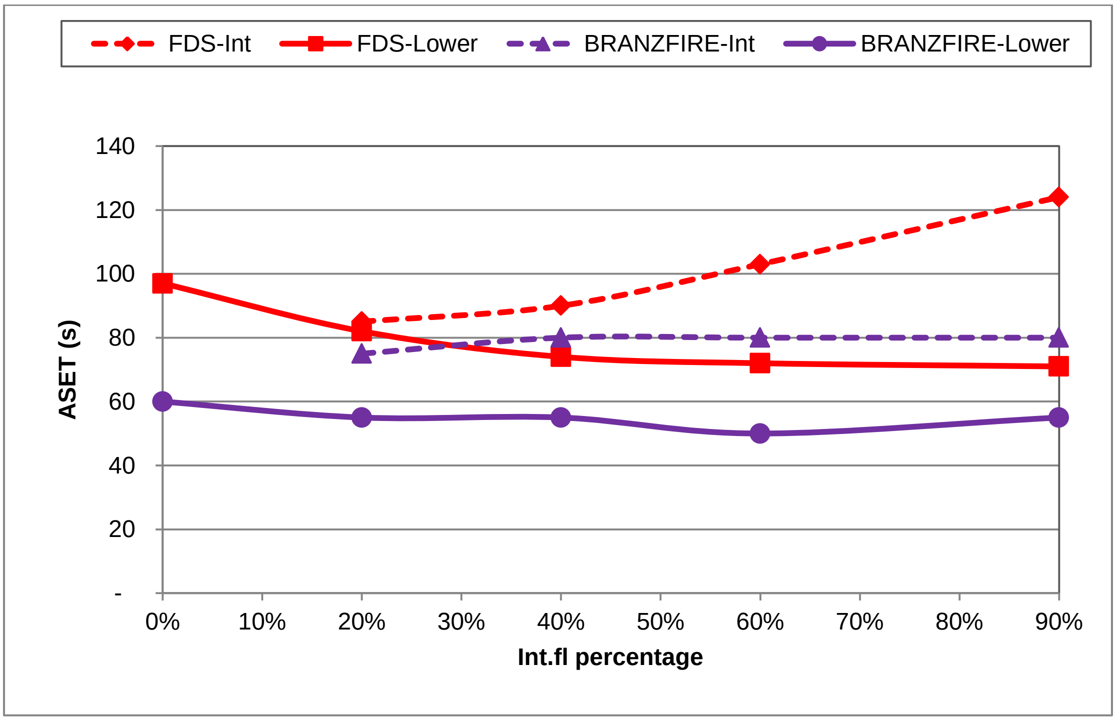


Figure 38: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located under the intermediate floor for small firecell.

In this scenario, if a fire were to occur under the intermediate floor, a horizontally moving buoyant layer of hot smoky gases will form under the intermediate floor. This layer will spread laterally and flow towards the opening to the open space. The smoke will then rotate around the free edge of intermediate floor and more air will be entrained into this region. This region is often known as the turning or rotation region and this type of plume is commonly known as a balcony spill plume as shown in Figure 39. In general, a balcony spill plume provides the worst case condition in terms of the volume of smoke production for this scenario [49] but with more air entrainment into the plume, the soot concentration of the smoke is reduced and the visibility therefore will be higher. The tenability conditions caused by the smoke logging of unchannelled balcony spill plume are an extremely complicated phenomena which are currently being studied by Harrison and Tiong at the University of Canterbury.

As mentioned earlier, in this scenario the firecells were modelled as three virtual rooms connected to each other by wall vents in BRANZFIRE. In BRANZFIRE the CFAST rules applied to determine how/where mass, enthalpy and products of combustion are exchanged between rooms connected by a vertical vent which impact on the development of the layer in the receiving room, and on the position of the layer interface height in both rooms. The BRANZFIRE model however does not include the balcony spill plume which will occur in this scenario that explained the differences in predicting smoke filling time between the two models (FDS and BRANZFIRE).

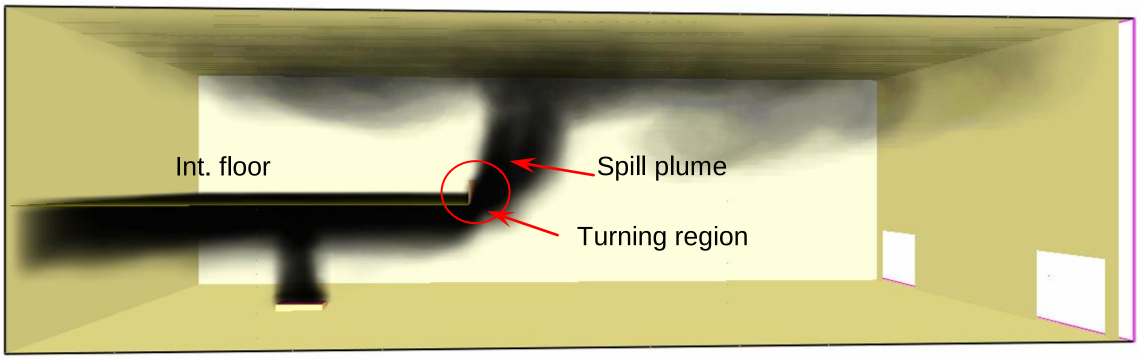


Figure 39: Spill plume at the edge of the intermediate floor.

The analysis above shows that the results predicted by BRANZFIRE have significant disagreement with FDS when the intermediate floors size exceeds 60% of the firecell floor. Therefore, BRANZFIRE is not suitable to simulate firecells containing large intermediate floors (greater than 60%) with a fire located under the intermediate floors.

The differences of ASET predicted by FDS and BRANZFIRE with a fast fire located under the intermediate floors with different sizes of the intermediate and lower floors are presented in Table 11. The positive figures indicate that the ASET predicted by FDS are greater than that of BRANZFIRE and vice versa for the negative figures.

The predictions of BRANZFIRE of ASET for the small firecell are always less than that of FDS and the differences in ASET range from 11% to 38%.

For medium and large firecells, the ASET of the intermediate floors predicted by BRANZFIRE are always less than the predictions of FDS but the ASET of the lower floors predicted by BRANZFIRE are slightly greater than that of FDS.

Refer to Table A1 and Table A2 of Appendix A for the details of the ASET of intermediate and lower floors predicted by FDS and BRANZFIRE with a fast fire located under the open intermediate floor by the variation of intermediate floor and firecell sizes.

Firecell	Small room		Medium room		Large room H= 8m		Large room H= 10m		Large room H= 12m	
Floor	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower
0%	NA	38%	NA	17%	NA	8%	NA	15%	NA	24%
20%	12%	33%	10%	-20%	13%	-11%	25%	-3%	23%	0%
40%	11%	26%	13%	-16%	13%	-9%	26%	-4%	25%	-1%
60%	22%	31%	22%	-8%	10%	-11%	27%	-1%	28%	-1%
90%	35%	23%	35%	-8%	26%	-47%	37%	-42%	40%	-39%

Table 11: Differences of ASET predicted by FDS and BRANZFIRE with a fast fire located under the intermediate floor by the variation of intermediate floor and firecell sizes.

Conclusions for modelling firecells containing open intermediate floors with a fire located under the intermediate floor:

- BRANZFIRE is not suitable to model the firecells containing large open intermediate floors when a fire is located under the intermediate floor (exceeding 60% of the firecell floor in this research project).
- The ASET of the firecells without intermediate floors predicted by both FDS and BRANZFIRE are always greater than the ASET of the lower floors of firecells containing intermediate floors.
- For small firecells, BRANZFIRE predictions of ASET for both intermediate and lower floors are always less than predictions of FDS. For medium and large firecells, the ASET of the intermediate floors predicted by BRANZFIRE are always less than FDS but the ASET of the lower floors predicted by BRANZFIRE are slightly greater than that of FDS. This is expected results as BRANZFIRE and zone models in general are more applicable to small rooms.

5.5.3 *Open intermediate floors with fire in the open area*

Figure 40 shows an example of a firecell containing an open intermediate floor with a fire located in the open area. It is expected that the open intermediate floors with fire located in the open area will reach untenable conditions before the lower floor due to the higher elevation of the intermediate floors.

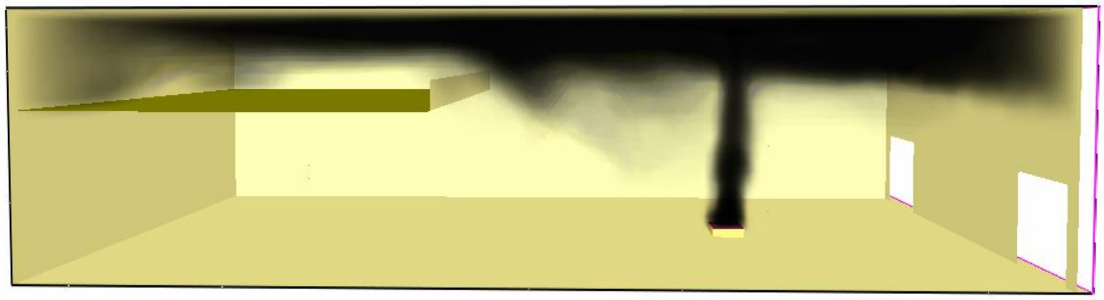


Figure 40: Firecell containing an open intermediate floor with a fire located in the open area.

In BRANZFIRE, the firecells were modelled as three virtual rooms as well as a single room, the results were then compared to FDS results to determine a more appropriate method among the two. Because a fire is unlikely to occur in the staircase area therefore the scenario when only the staircase is open, which correspond to the intermediate floor size of 90%, 96% and 99% for the small, medium and large firecells respectively, were not assessed.

ASET of the lower and intermediate floors predicted by FDS and BRANZFIRE with a fast fire located in the open area by the variation of intermediate floor sizes for five different firecell sizes: small, medium, large with 8 m ceiling height, large with 10 m ceiling height and large with 12 m ceiling height are shown in Figure 41 to Figure 45.

The figures show that the ASET of the intermediate and lower floors predicted by FDS and BRANZFIRE for the firecells containing intermediate floors are always less than that of the firecells without intermediate floors (i.e 0% intermediate floor). The ASET of both intermediate and lower floors predicted by FDS and BRANZFIRE change very little as the intermediate floor size increases.

Regardless of the intermediate floor and firecell sizes, the ASET of the intermediate floors predicted by both FDS and BRANZFIRE in which the firecell were modelled as a single room in BRANZFIRE are always less than that of the lower floors but the predictions of FDS are much greater than BRANZFIRE.

When the firecells were modelled as three virtual rooms, BRANZFIRE results have the same trend as FDS for the large and medium firecells; the ASET of the intermediate floors are less than that of the lower floors as shown in Figure 41 to Figure 44. However, for the small room BRANZFIRE predicts that the ASET of lower floors are less than that of the intermediate floors (Figure 45).

The analysis above shows that the ASET predicted by BRANZFIRE in which the firecells were modelled as three virtual rooms, are not consistent by variation of firecell sizes while when the firecells were modelled as a single room, the ASET predicted by BRANZFIRE are the same trend as the prediction of FDS, regardless of the firecell size. Therefore, it appears that firecells containing open intermediate floors with a fire located in the open area should be modelled as a single room in BRANZFIRE and not three virtual rooms connected to each other by wall vents.

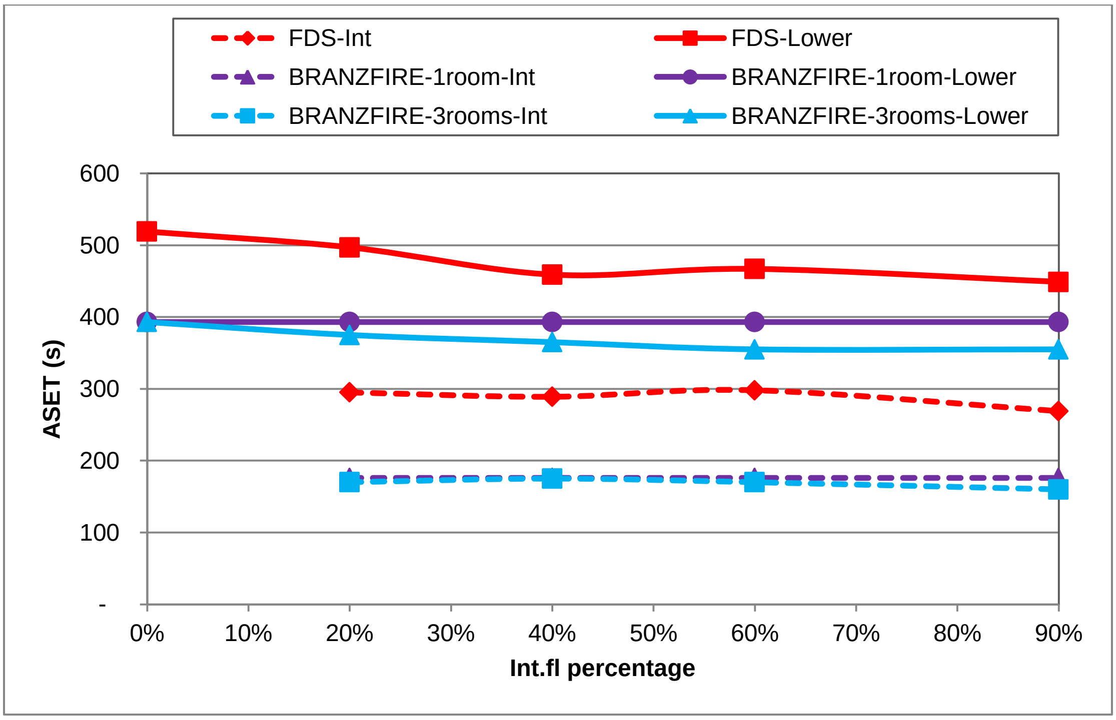


Figure 41: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located in the open area for large 12m firecell.

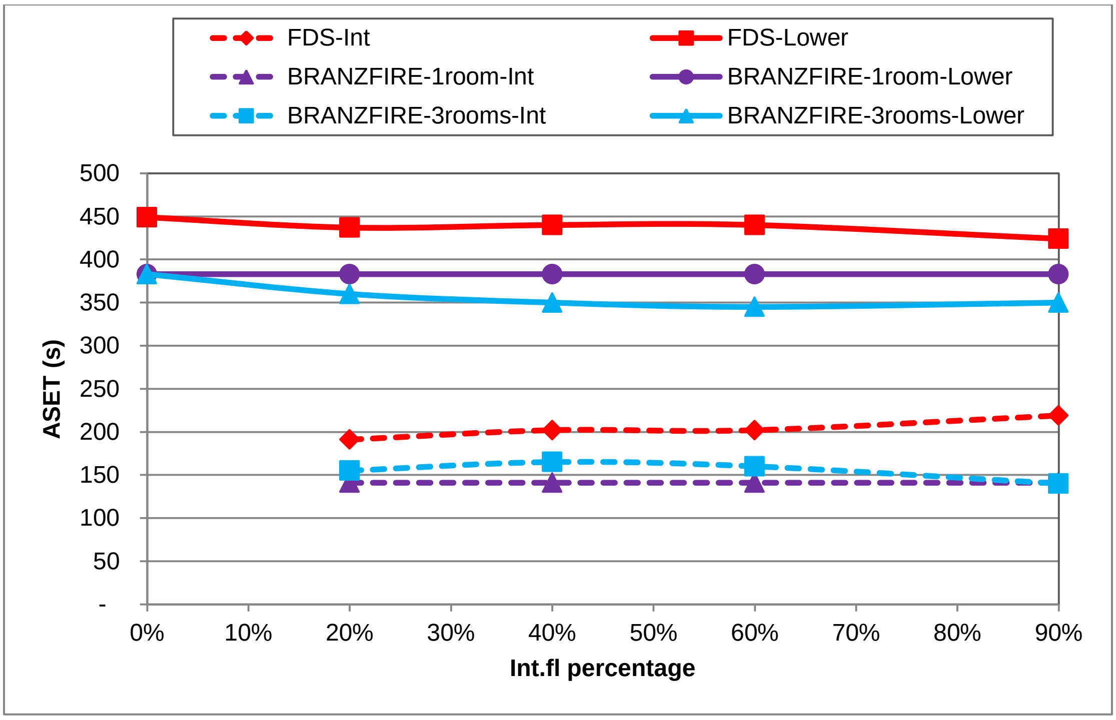


Figure 42: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located in the open area for large 10m firecell.

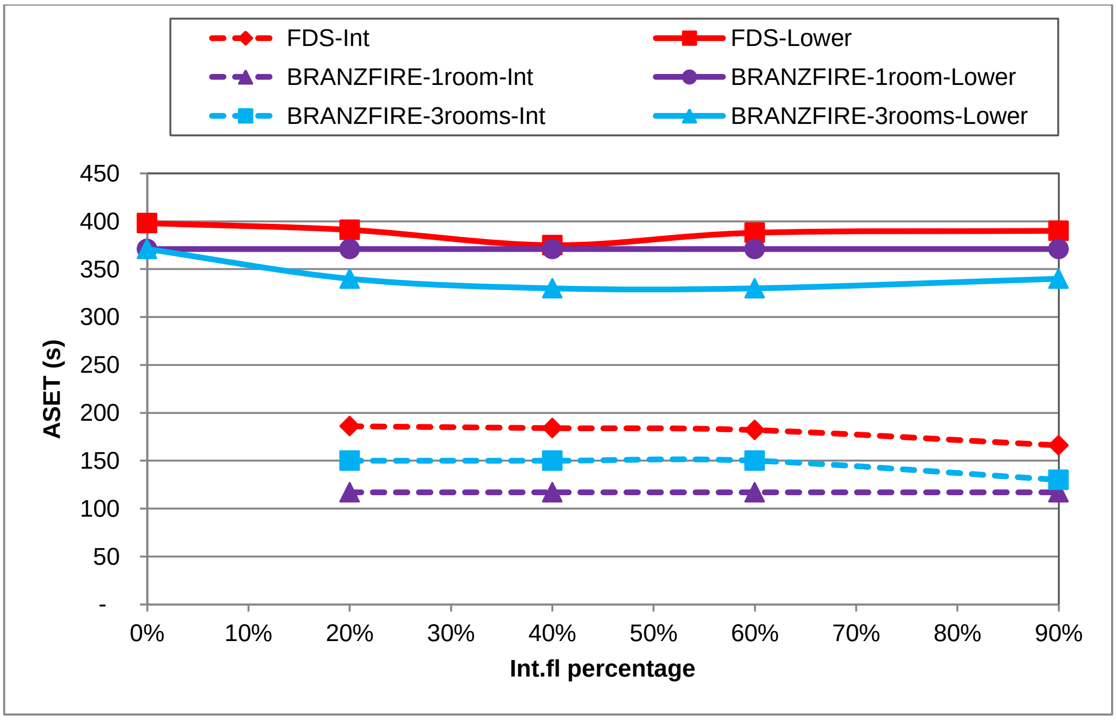


Figure 43: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located in the open area for large 8m firecell.

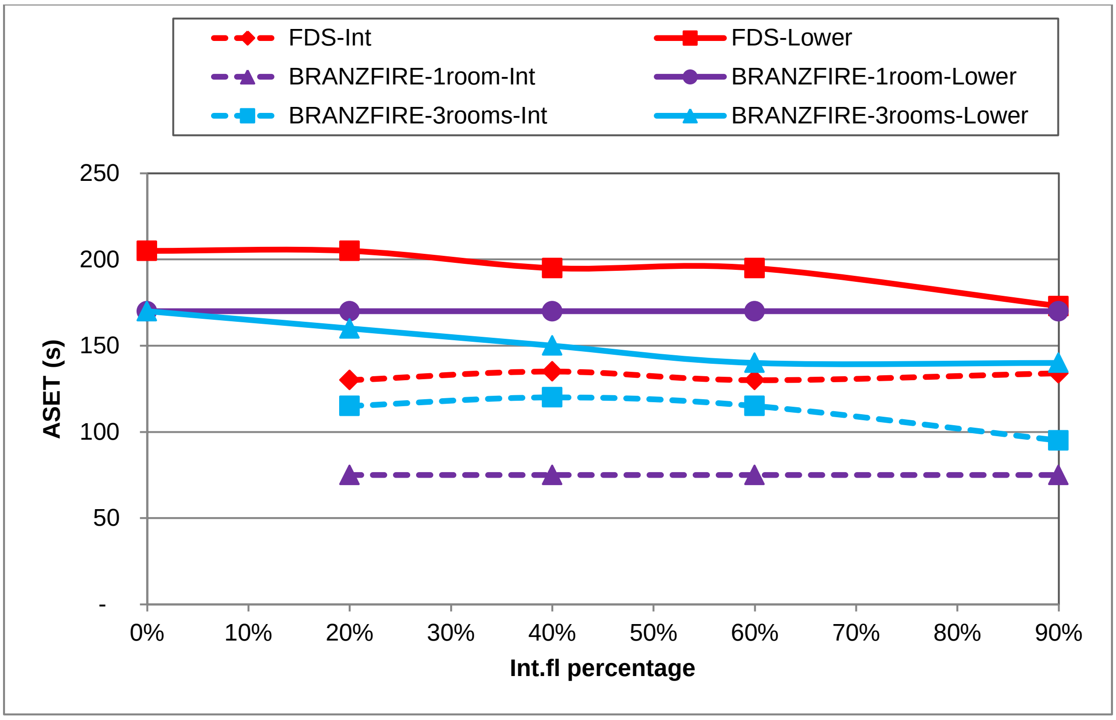


Figure 44: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located in the open area for medium firecell.

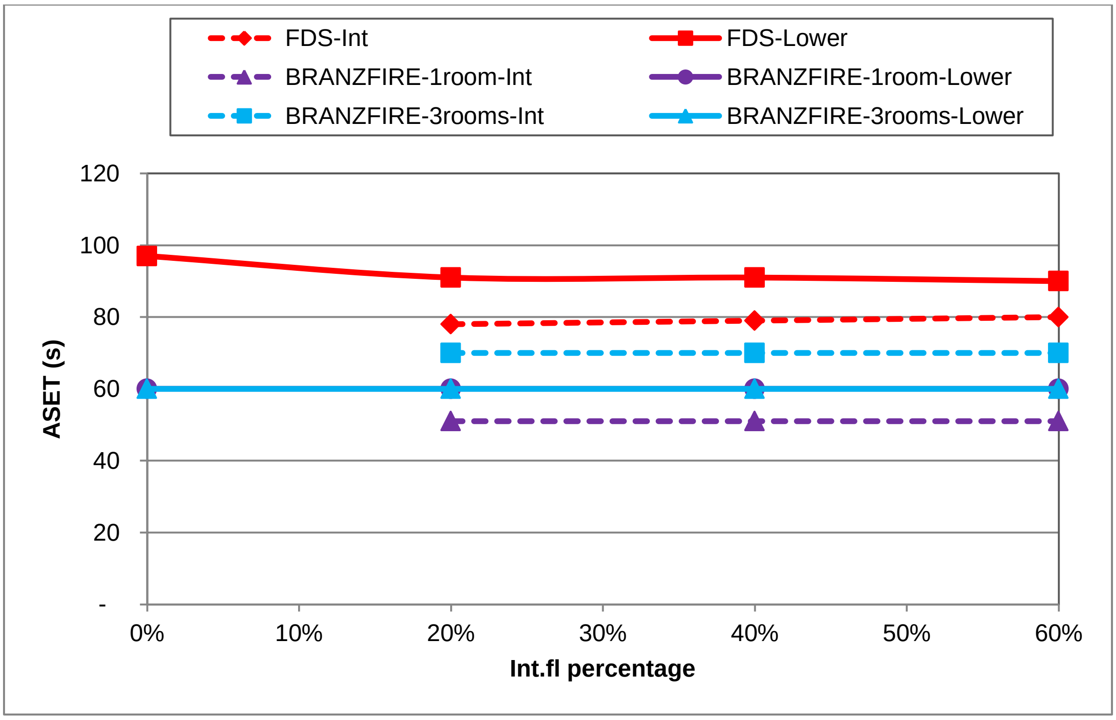


Figure 45: ASET predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes with a fast fire located in the open area for small firecell.

Table 12 shows the differences of ASET predicted by FDS and BRANZFIRE with a fast fire located in the open area with different sizes of the intermediate and firecell floors in which the firecells were modelled as a single room in BRANZFIRE. The positive figures indicate that the ASET predicted by FDS is greater than that of BRANZFIRE.

Firecell	Small room		Medium room		Large room H= 8m		Large room H= 10m		Large room H= 12m	
Floor	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower
0%	NA	38%	NA	17%	NA	7%	NA	15%	NA	24%
20%	35%	34%	42%	17%	37%	5%	26%	12%	40%	21%
40%	35%	34%	44%	13%	36%	1%	30%	13%	39%	14%
60%	36%	33%	42%	13%	36%	4%	30%	13%	41%	16%
90%	NA	NA	44%	2%	30%	5%	36%	10%	35%	12%

Table 12: Differences of ASET predicted by FDS and BRANZFIRE with a fast fire located in the open area by the variation of intermediate and firecell floor sizes.

In general, ASET of both intermediate and lower floors predicted by BRANZFIRE are always less than that of FDS which agree with findings from work done by Wade [35]. The differences of ASET predicted by FDS and BRANZFIRE vary from 1% to about 44%. For small firecells, the difference of ASET is consistent by the variation of intermediate floor sizes which is about 34% for both intermediate and lower floors. However, for medium and large firecells the differences of ASET of the lower floors are considerably less than that of the intermediate floors.

The details of the ASET of the lower and intermediate floors predicted by both FDS and BRANZFIRE, with a fast fire located in the open area by the variation of intermediate floor and firecell sizes, can be found in Table A3 to Table A5 of Appendix A.

<u>Conclusions for modelling firecells containing open intermediate floors with a fire located in the open area:</u>

- The firecells should be modelled as a single room and not three virtual rooms connected to each other by virtual wall vents in BRANZFIRE.
- The ASET of the firecells with no intermediate floors are always greater than the ASET of the intermediate and lower floors of firecells containing intermediate floors.
- The ASET of the intermediate floors are always less than that of the lower floors.
- The ASET for both intermediate and lower floors predicted by BRANZFIRE are always less than that of FDS regardless of the firecell and intermediate floor sizes.

- For small firecells, the difference of ASET predicted by BRANZFIRE and FDS is consistent over the variation of intermediate floor sizes. For medium and large firecells, the differences of ASET predicted by BRANZFIRE and FDS for intermediate floors are considerably greater than that of the lower floors. This is expected results as BRANZFIRE and zone models in general are more applicable to small rooms.

5.5.4 *Effect of fire locations on the ASET*

The ASET of the intermediate floors of the large 8m, medium and small firecells containing open intermediate floors predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes and fire locations are illustrated in Figure 46, Figure 47 and Figure 48 respectively. The terms “under” and “open” used in the graphs are referred to the scenarios when a fire occurs under the intermediate floor and in the open area respectively.

The figures show that regardless of the intermediate floor and firecell sizes, the ASET of the intermediate floors predicted by both FDS and BRANZFIRE, when a fire is located under the intermediate floor, are always greater than when a fire occurs in the open area. The figures also indicate that the ASET of the intermediate floors predicted by BRANZFIRE are always less than that of FDS.

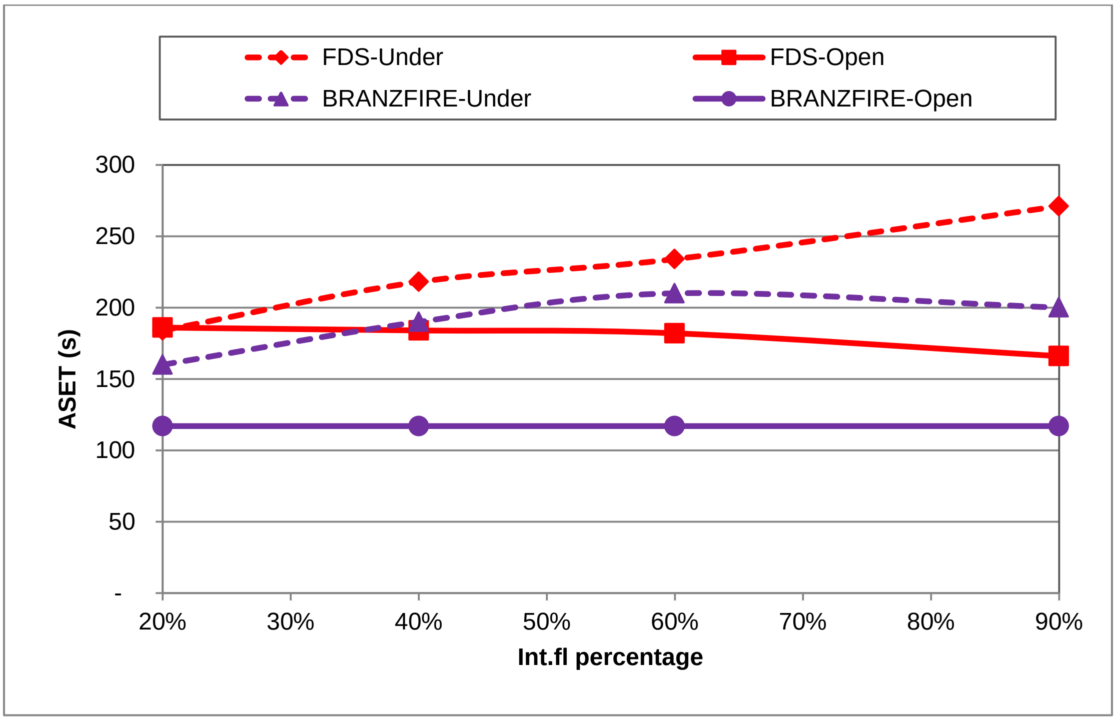


Figure 46: ASET of the intermediate floors by the variation of intermediate floor sizes and fire locations for the large 8m firecell.

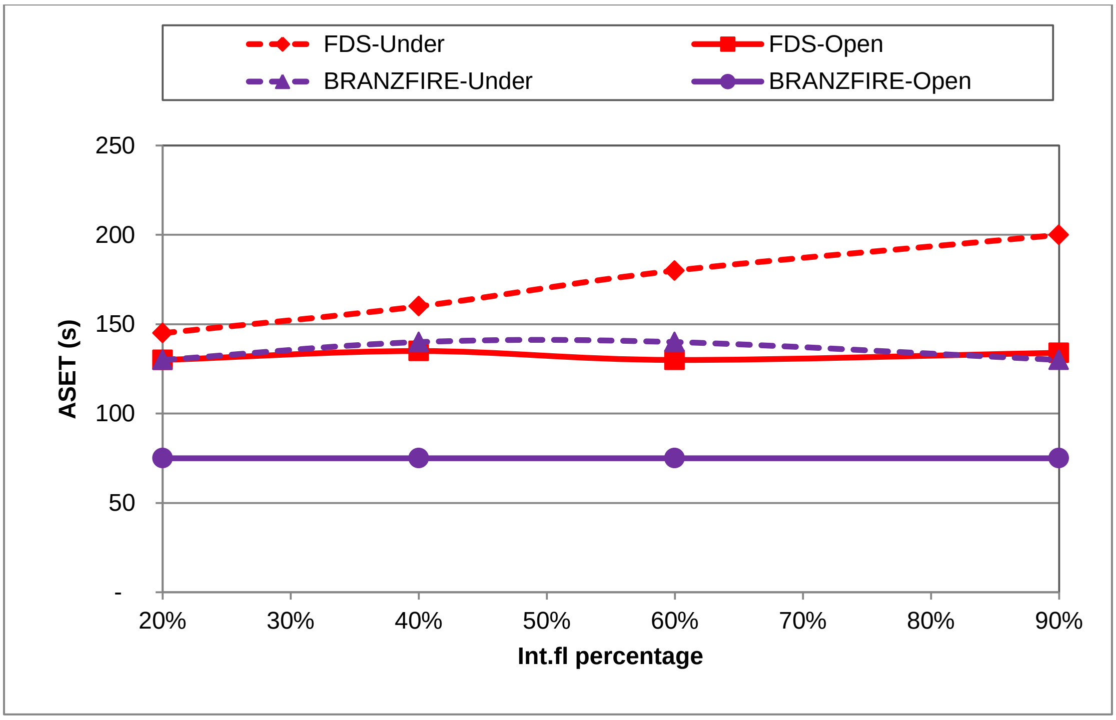


Figure 47: ASET of the intermediate floors by the variation of intermediate floor sizes and fire locations for the medium firecell.

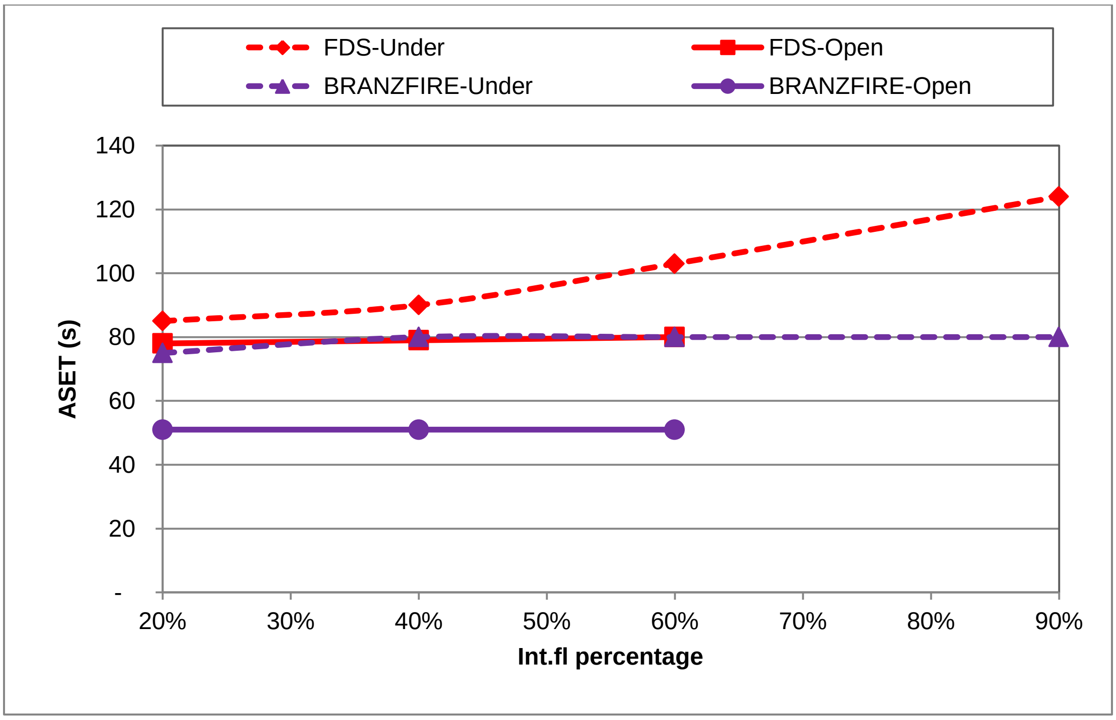


Figure 48: ASET of the intermediate floors by the variation of intermediate floor sizes and fire locations for the small firecell.

The ASET of the lower floors of the large 8m, medium and small firecells containing open intermediate floors predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes and fire locations are illustrated in Figure 49, Figure 50 and Figure 51 respectively. Regardless of the intermediate floor and firecell sizes, the ASET of the lower floors predicted by both FDS and BRANZFIRE, when a fire is located in the open area, are always greater than when a fire occurs under the intermediate floor. The figures also show that the ASET of the lower floors predicted by BRANZFIRE are always less than FDS when a fire occurs in the open area. However when a fire is located under the intermediate floor, the ASET predicted by BRANZFIRE are not always less than that of FDS.

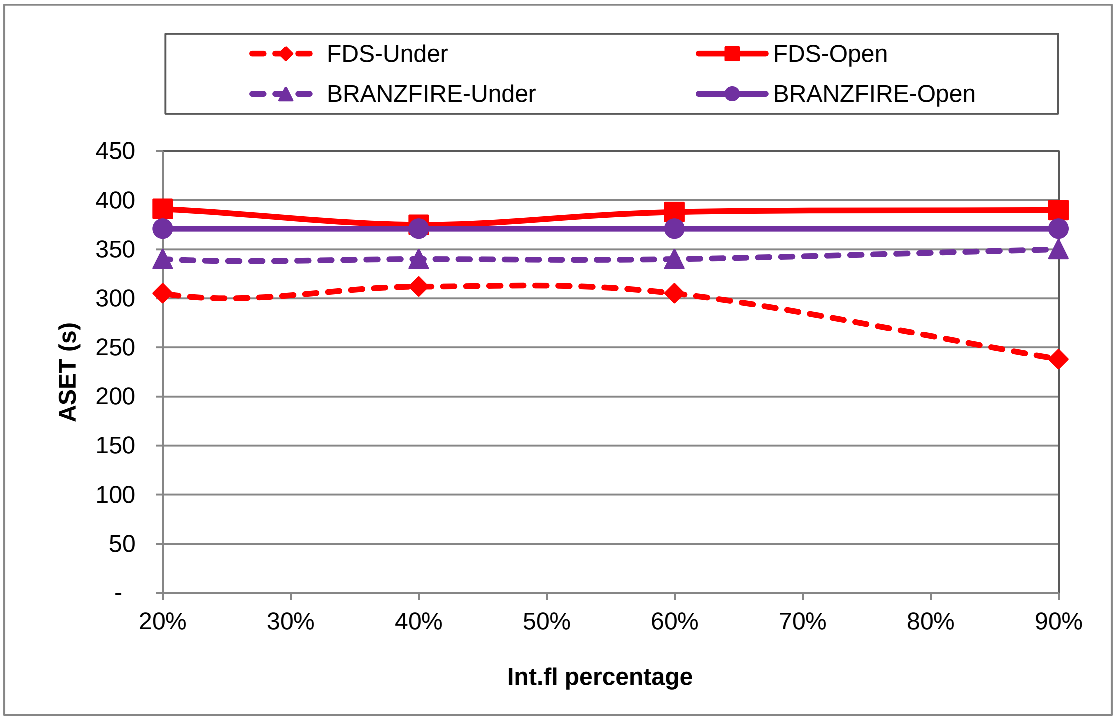


Figure 49: ASET of the lower floors by the variation of fire locations for the large 8m firecell.

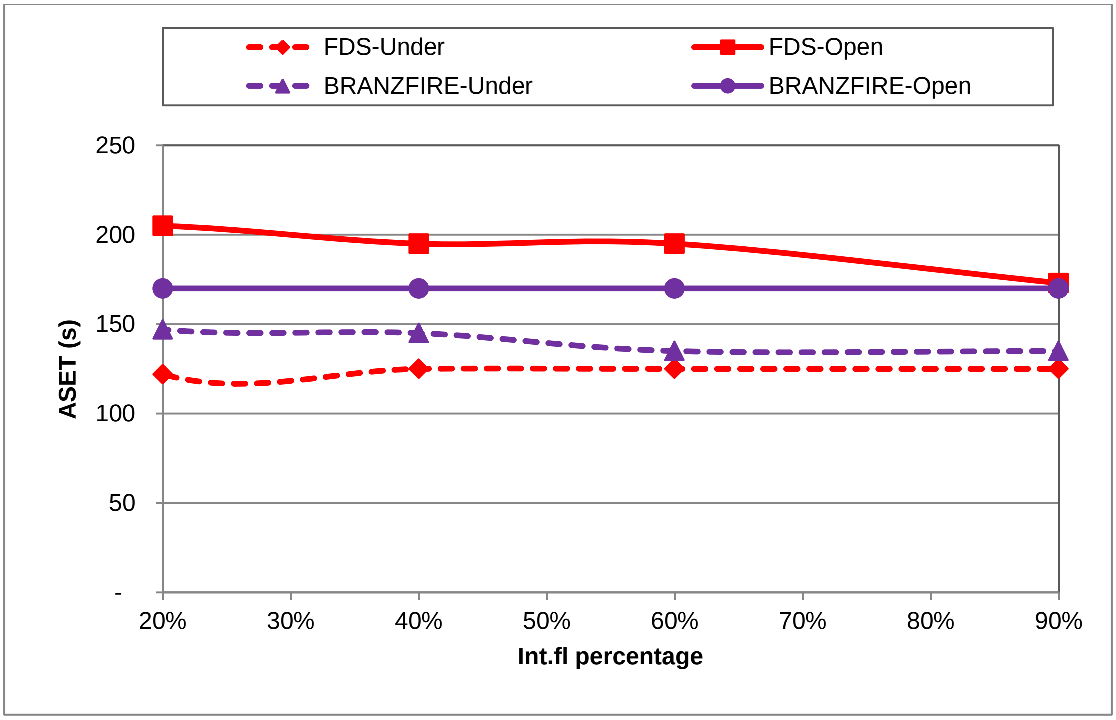


Figure 50: ASET of the lower floors by the variation of fire locations for the medium firecell.

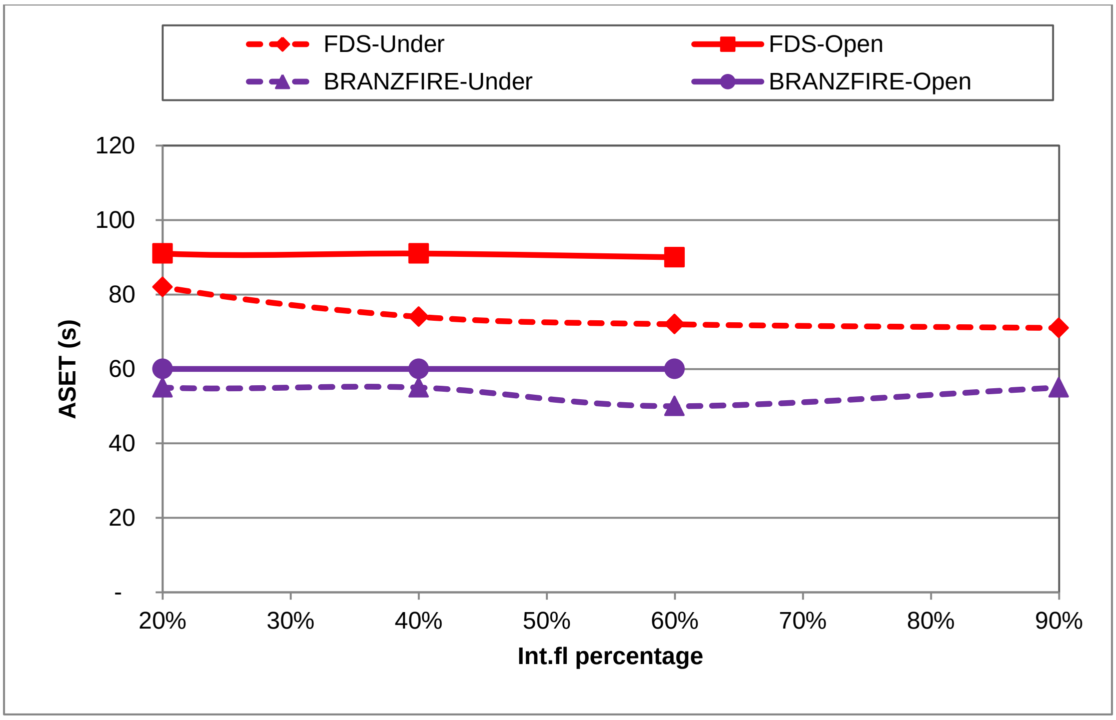


Figure 51: ASET of the lower floors by the variation of fire locations for the small firecell.

5.5.5 *Firecells containing open intermediate floors with different height*

In the previous sections, the large firecell was modelled with the intermediate floor height of 5 m. In order to investigate how the height of the intermediate floor effects the ASET, the large firecell with ceiling height of 8 m was modelled with the intermediate floor height of 3 m and the results then compared with the intermediate floor height of 5 m.

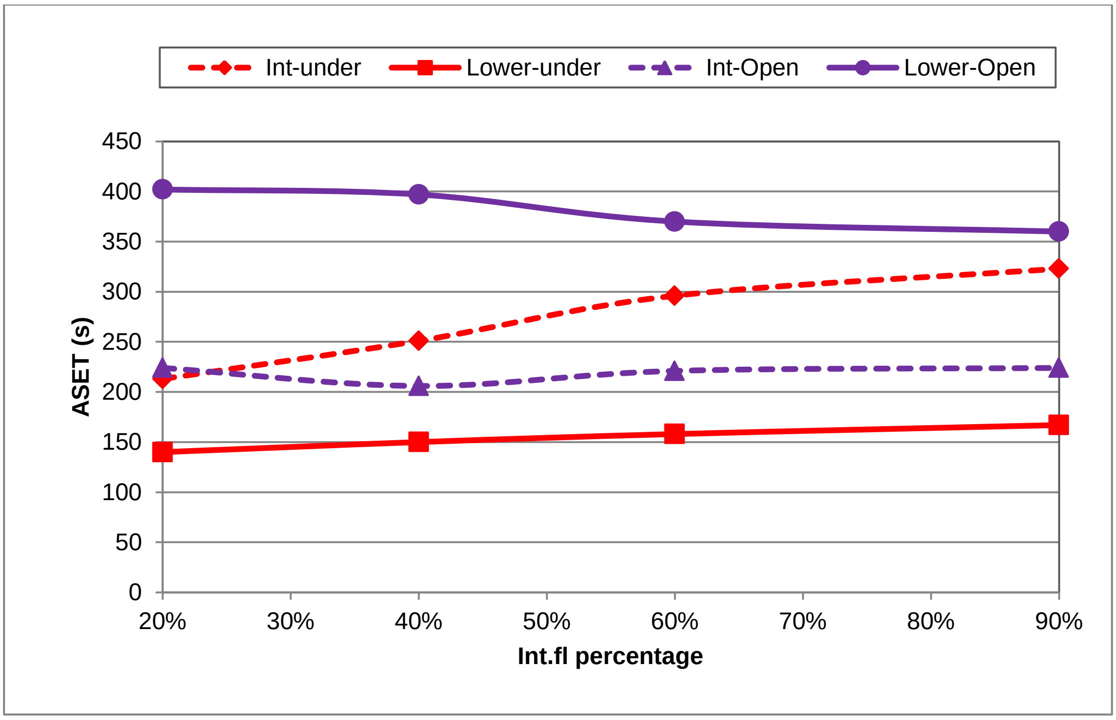


Figure 52: ASET of the intermediate and lower floors of large 8m firecell predicted by FDS with an open intermediate floor height of 3 m by the variation of intermediate floor sizes.

The ASET of the intermediate and lower floors of the large firecell with a ceiling height of 8 m and intermediate floor height of 3 m predicted by FDS by the variation of fire locations and intermediate floor sizes are illustrated in Figure 52.

The figure shows that when a fire is located under the intermediate floor the ASET of the intermediate floor is always greater than the ASET of the lower floor. When the intermediate floor size increases, the ASET of the intermediate floor increases gradually while the ASET of the lower floor changes very little. When a fire occurs in the open area, the ASET of both intermediate and lower floors change very little and the ASET of the lower floor is always greater than that of the intermediate floor. The figure also indicates that the ASET of the lower floor when a fire is located under the intermediate floor is significantly less than that when a fire is in the open area. The ASET of the intermediate floor when a fire is under the intermediate floor is greater than when a fire is located in the open area.

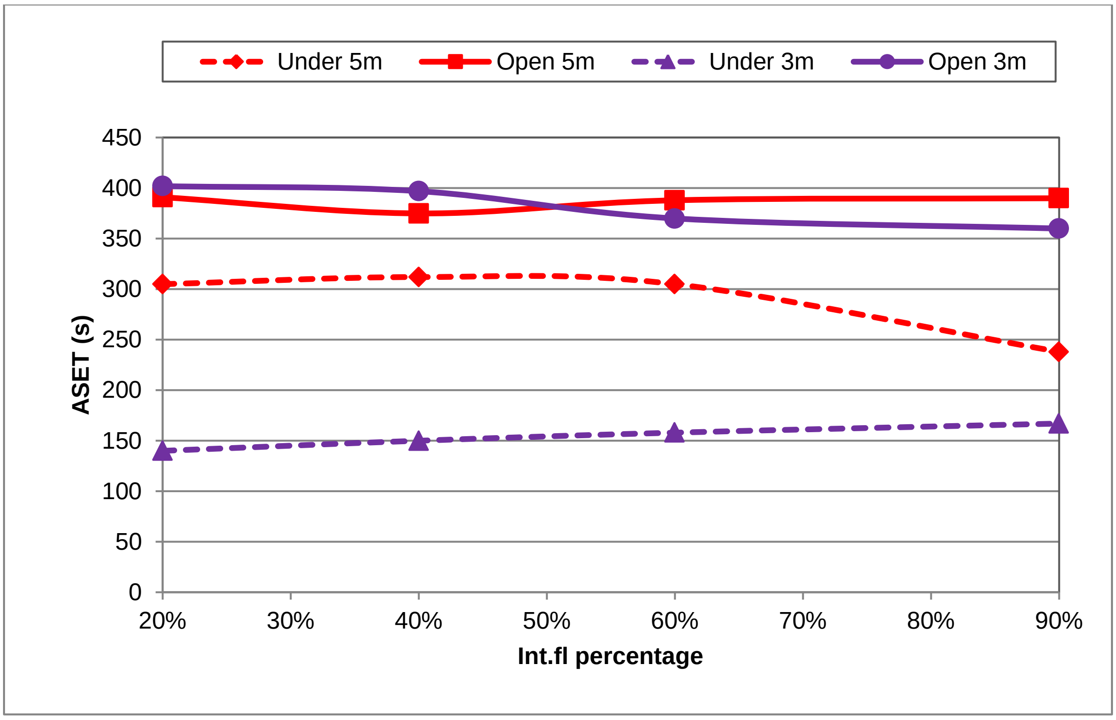


Figure 53: ASET of the lower floors of large 8m firecell predicted by FDS with an open intermediate floor height of 3 and 5 m by the variation of intermediate floor sizes.

The ASET predicted by FDS of the lower floors of the large 8m firecell, with the intermediate floor height of 3 m and 5 m, are plotted in Figure 53. When a fire is located in the open area, the ASET of the lower floor of the two firecells with different intermediate floor heights are very similar and change very little when the intermediate floor size increases. However, when a fire is under the intermediate floor, the ASET of the lower floor of the firecell with 3 m intermediate floor height is considerably less than that of the firecell with 5 m intermediate floor height as might be expected.

The ASET predicted by FDS of the intermediate floors of the large 8m firecell with the intermediate floor height of 3 m and 5 m are plotted in Figure 54. Regardless of the fire location, the ASET of the intermediate floor of the firecell with intermediate floor 3 m above the lower level is greater than that of the firecell with intermediate floor 5 m above the lower level.

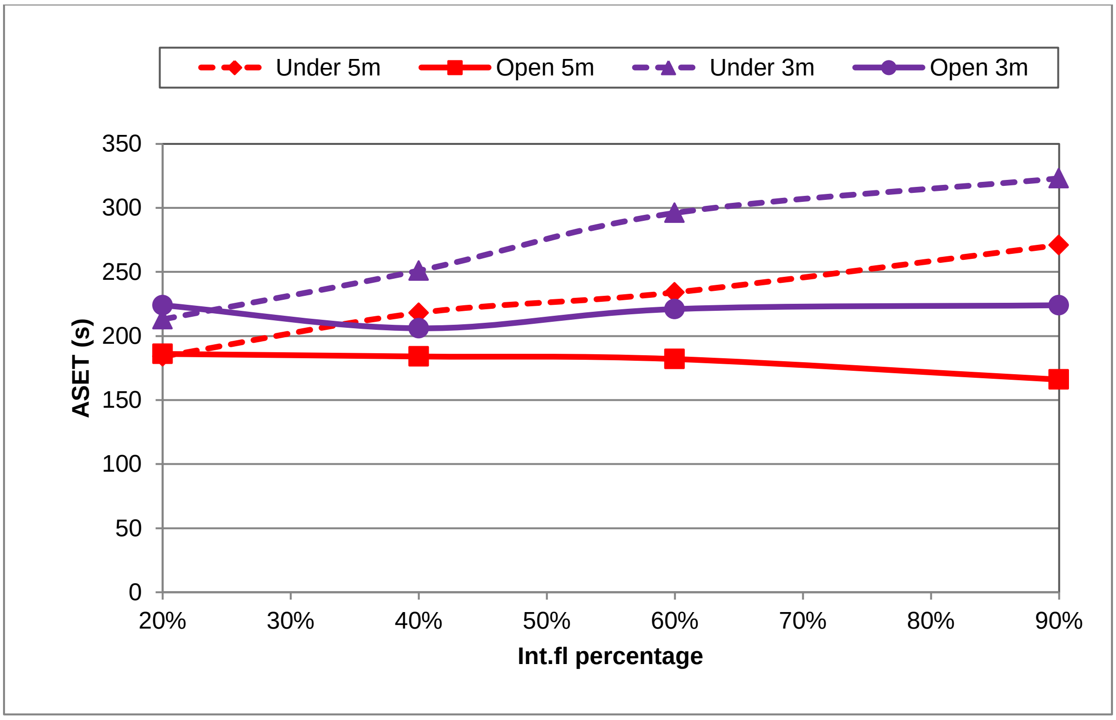


Figure 54: ASET of the intermediate floors of large 8m firecells predicted by FDS with an open intermediate floor at 3 and 5 m height by the variation of intermediate floor sizes.

In summary, the ASET of the intermediate and lower floors predicted by FDS of the large firecell with lower intermediate floor height (3 m) have very similar trends as the firecell with higher intermediate floor height (5 m). When a fire is located under the intermediate floor the ASET of the lower floor of the firecell with 3 m intermediate floor height is considerably less than that when a fire is in the open area. The ASET of the intermediate floor of the firecell with 3 m intermediate floor height is always greater than that of the firecell with 5 m intermediate floor height. When a fire is under the intermediate floor, the ASET of the lower floor of the firecell with lower intermediate floor height is significantly less than that of the firecell with higher intermediate floor height.

The ASET of both intermediate and lower floors predicted by FDS for the two firecells with different intermediate floor height are expected results which indicate that the model (FDS) is working appropriately.

5.5.6 *Closed intermediate floors*

Schematics of firecell containing closed intermediate floors with fires located under the intermediate floor and in the open area are shown in Figure 55 and Figure 56.

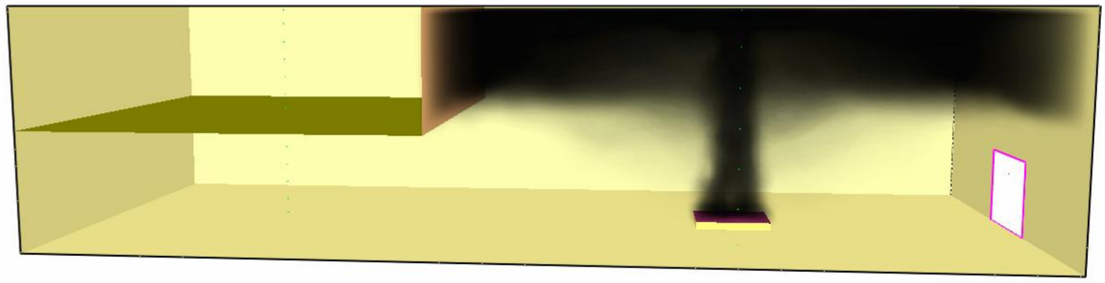


Figure 55: Firecell containing a closed intermediate floor with a fire located in the open area.

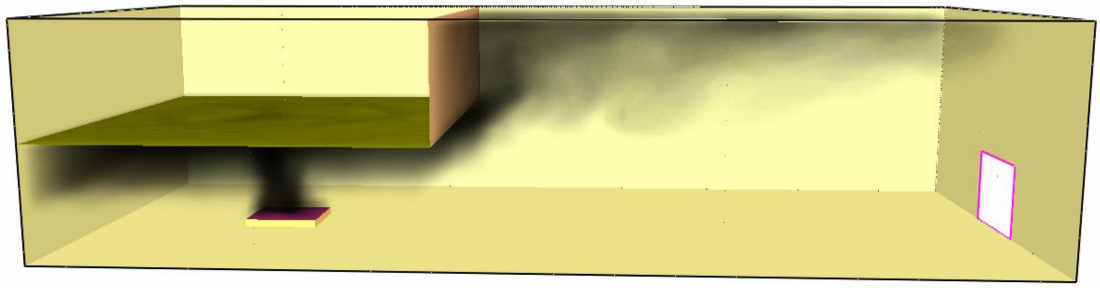


Figure 56: Firecell containing a closed intermediate floor with a fire located under the intermediate floor.

As stated earlier, because the intermediate floors are completely closed, they were not included in the FDS or BRANZFIRE modelling. In BRANZFIRE, the firecells were modelled as two virtual rooms connected to each other by a wall vent (see section 5.4.4). The ASET of intermediate floors were assumed to be the same as the ASET of the lower floors, as the occupants of the intermediate floors must escape via the lower floor. The small firecells were not modelled with 90% closed intermediate floors as the open area is very small (4 m^2) which is architecturally unrealistic. Therefore, only medium and large firecells were modelled with 90% closed intermediate floors.

For a given firecell containing closed intermediate floors, when the area of the intermediate floor increases then the open area decreases therefore the “smoke reservoir” volume declines , consequently the smoke filling time goes down. Because of the above reason, it is expected that when the area of the of the intermediate floor increases, the ASET of the firecell floor would decrease.

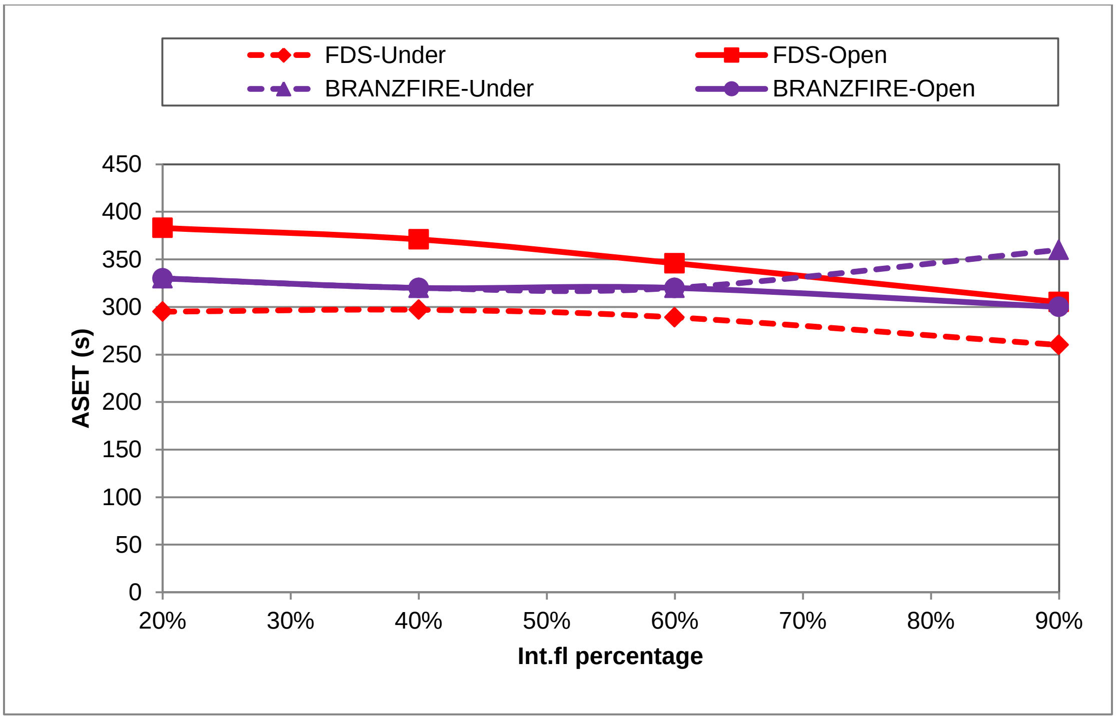


Figure 57: ASET of the lower floor of the large 8m firecell containing a closed intermediate floor predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes.

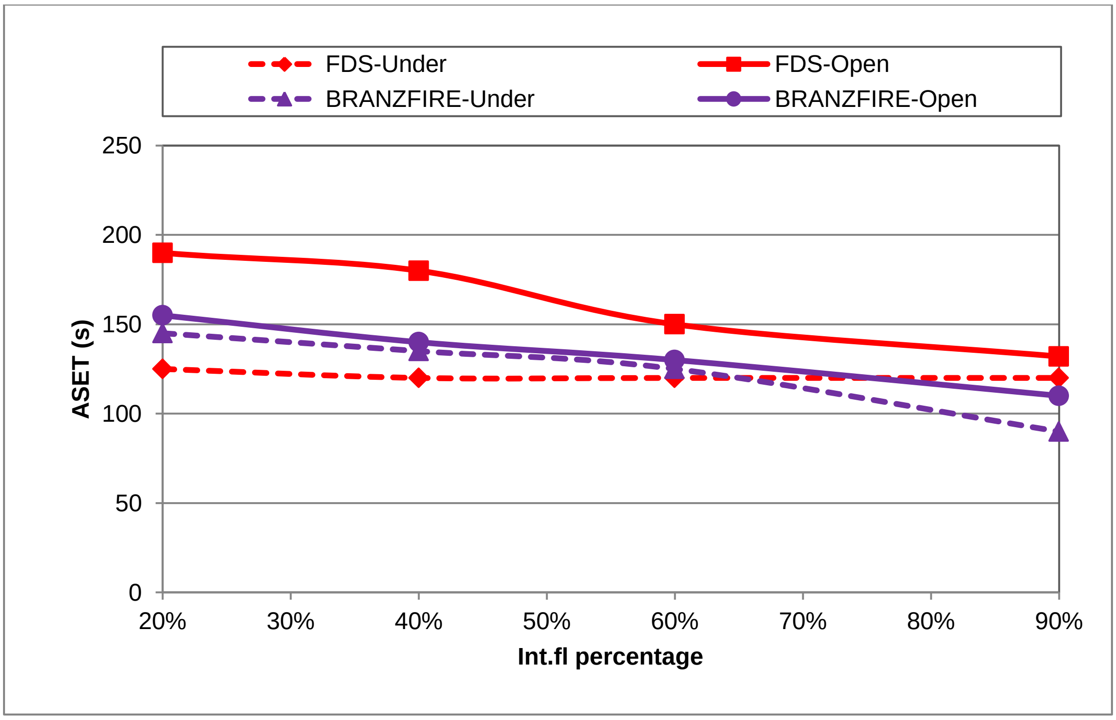


Figure 58: ASET of the lower floor of the medium firecell containing a closed intermediate floor predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes.

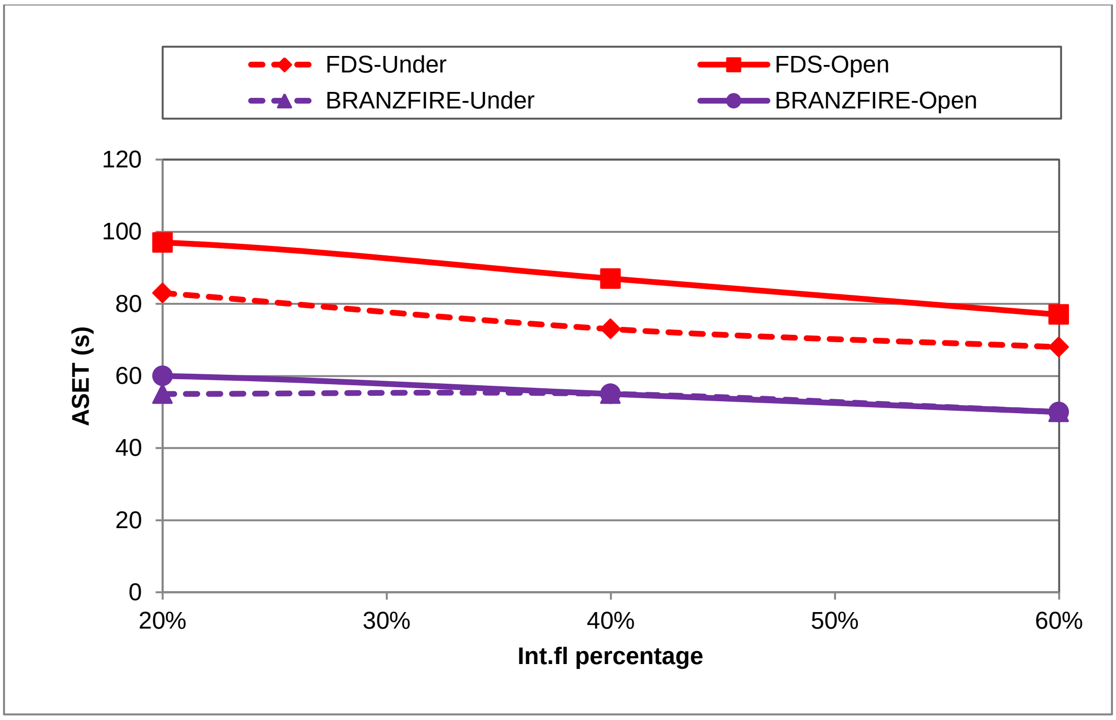


Figure 59: ASET of the lower floor of the small firecell containing a closed intermediate floor predicted by FDS and BRANZFIRE by the variation of intermediate floor sizes.

The ASET of the lower floors (same as ASET of intermediate floors) of the large 8m, medium and small firecells containing closed intermediate floors predicted by FDS and BRANZFIRE with a fast fire by the variation of intermediate floor and firecell sizes, and fire locations are plotted in Figure 57, Figure 58 and Figure 59.

In general, the ASET of the lower floors of all three firecell sizes predicted by both FDS and BRANZFIRE decrease slightly when the intermediate floor size increases. With the intermediate floor size range from 20% to 60%, the ASET of the lower floors predicted by FDS and BRANZFIRE, when a fire is located under the intermediate floor, are always less than that when a fire occurs in the open area. However, when the intermediate floor size exceeds 60% of the firecell floor, FDS still predicts that the ASET when a fire occurs in the open area are greater than that when a fire is located under the intermediate floors while BRANZFIRE gives the results in the opposite direction for the large firecell.

The analysis shows that the trend of ASET predicted by BRANZFIRE does not agree with that of FDS when the intermediate floor size exceeds 60% of the firecell floor, with a fire located under the intermediate floor: the ASET predicted by BRANZFIRE increases while that of FDS decreases. Therefore, BRANZFIRE is not suitable to simulate firecells containing large closed intermediate floors (greater than 60%) with a fire located under the intermediate floors.

Firecell	Small room		Medium room		Large room H= 8m	
Fire location	Under	Open	Under	Open	Under	Open
20%	34%	38%	-16%	18%	-12%	14%
40%	25%	37%	-13%	22%	-8%	14%
60%	26%	35%	-4%	13%	-11%	8%
90%	NA	NA	25%	17%	-27%	2%

Table 13: Differences of ASET predicted by FDS and BRANZFIRE with a fast fire by the variation of intermediate floor and firecell sizes.

The differences of ASET predicted by FDS and BRANZFIRE with a fast fire by the variation of the intermediate and lower floor sizes, and fire locations are shown in Table 13. The positive figures indicate that the ASET predicted by FDS are greater than that of BRANZFIRE and vice versa for the negative figures.

Regardless of the fire location and the intermediate floor size, the predictions of BRANZFIRE of ASET for the small firecell are always less than that of FDS which ranges from about 25% to 38% as shown in Table 13.

The table also shows that, for medium and large firecells, the ASET predicted by BRANZFIRE are not always less than that of FDS and depend on the fire locations. When a fire is located in the open area, the predictions of BRANZFIRE are less than that of FDS but when a fire occurs under the intermediate floor the ASET predicted by BRANZFIRE are not always less than with FDS.

Refer to Table A6 of Appendix A for the details of the ASET of the lower floors of the firecells containing closed intermediate floors predicted by FDS and BRANZFIRE with a fast fire by the variation of intermediate floor and firecell sizes, and fire locations.

Conclusions for modelling firecells containing closed intermediate floors:

- BRANZFIRE is not suitable to model the firecells containing large closed intermediate floors when a fire is located under the intermediate floor (exceeding 60% of the firecell floor in this research project).
- Regardless of the fire location and the intermediate floor size, BRANZFIRE predictions of ASET are always less than that of FDS for small firecells.
- For medium and large firecells, the ASET of the lower floors predicted by BRANZFIRE are always less than FDS when a fire is located in the open area, however, when a fire occurs under the intermediate floors, the ASET of the lower floors predicted by

BRANZFIRE are not always less than that of FDS. This is expected results as BRANZFIRE and zone models in general are more applicable to small rooms.

5.6 FDS modelling results with the ultra fast, moderate and slow fires

All analyses in the previous sections had been carried out with a fast fire. In order to investigate how the fire growth rate affects the ASET, the small, medium and large 8 m firecells were modelled in FDS with ultra fast, moderate and slow fires. Those firecell were modelled with an intermediate floor size of 0% (i.e. firecells without intermediate floor), 20% and 40% of the lower floor area. The details of the ASET of the firecells by the variation of fire locations, intermediate floor and firecell sizes with different fire growth rates are summarised in Table A7 of Appendix A.

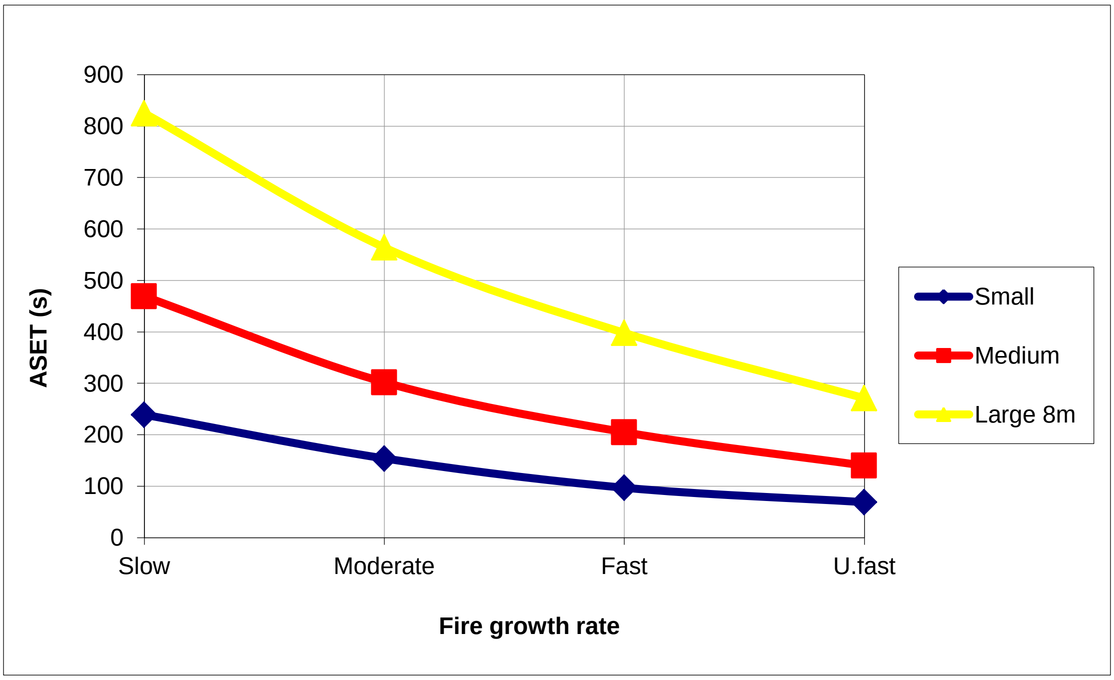


Figure 60: ASET of three studied firecells without intermediate floors predicted by FDS by the variation of fire growth rates.

The ASET of the small, medium and large 8m firecells without intermediate floors predicted by FDS by the variation of fire growth rates are plotted in Figure 60. The figure shows that the ASET of the firecells reduces when the fire growth rate increases as expected. The ASET decreases to approximately one third when the fire growth rate increases from slow to ultra fast for all firecell sizes.

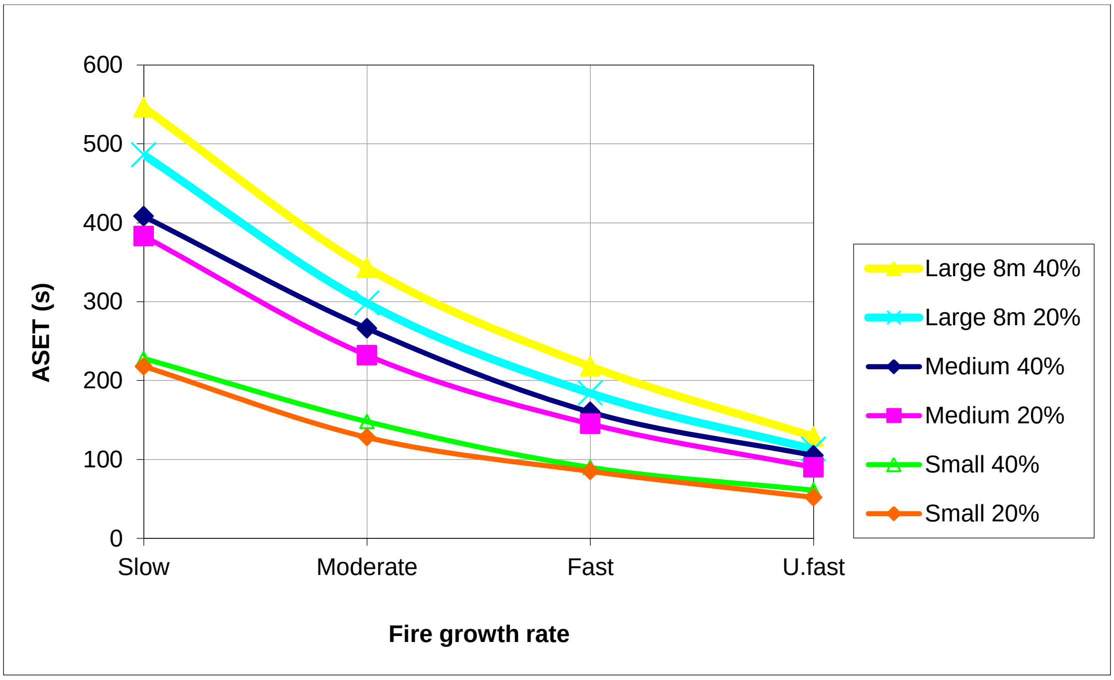


Figure 61: ASET of the intermediate floors predicted by FDS by the variation of fire growth rates for three firecell sizes with a fire located under the intermediate floor.

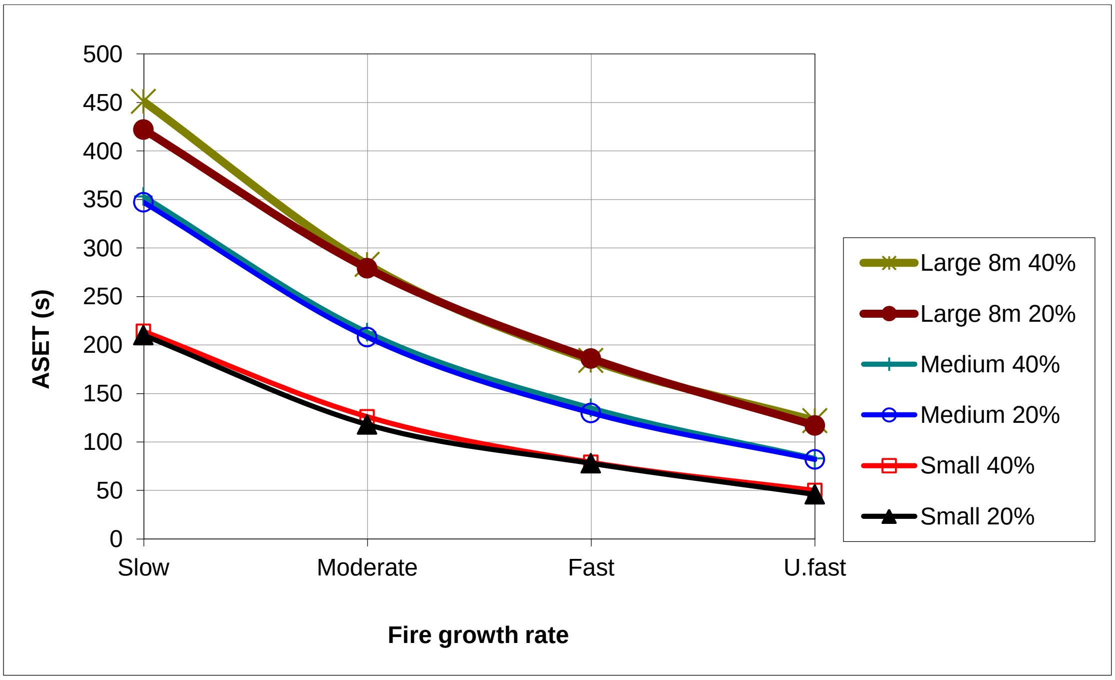


Figure 62: ASET of the intermediate floors predicted by FDS by the variation of fire growth rates for three firecell sizes with a fire located in the open area.

The ASET of the intermediate floors of the small, medium and large 8m firecells with intermediate floors of 20% and 40% predicted by FDS by the variation of fire growth rates are plotted in Figure 61 and Figure 62. Regardless of the fire location and intermediate floor size, the ASET of the intermediate floor decreases when the fire growth rate increases, as expected.

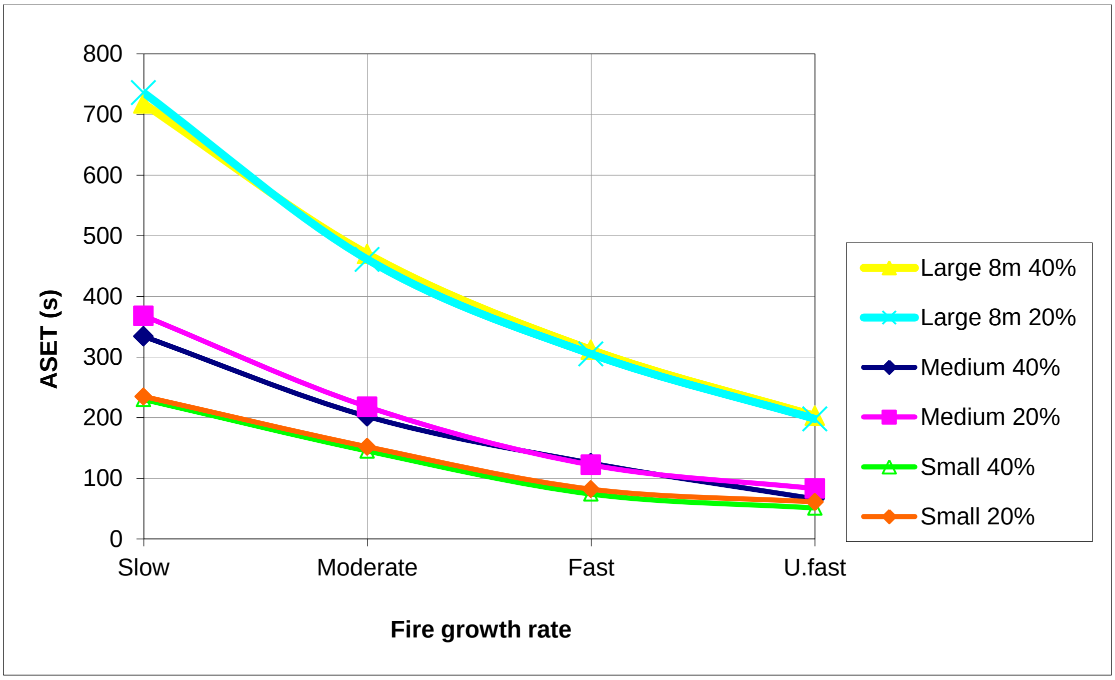


Figure 63: ASET of the lower floors predicted by FDS by the variation of fire growth rates for three firecell sizes with a fire located under the intermediate floor.

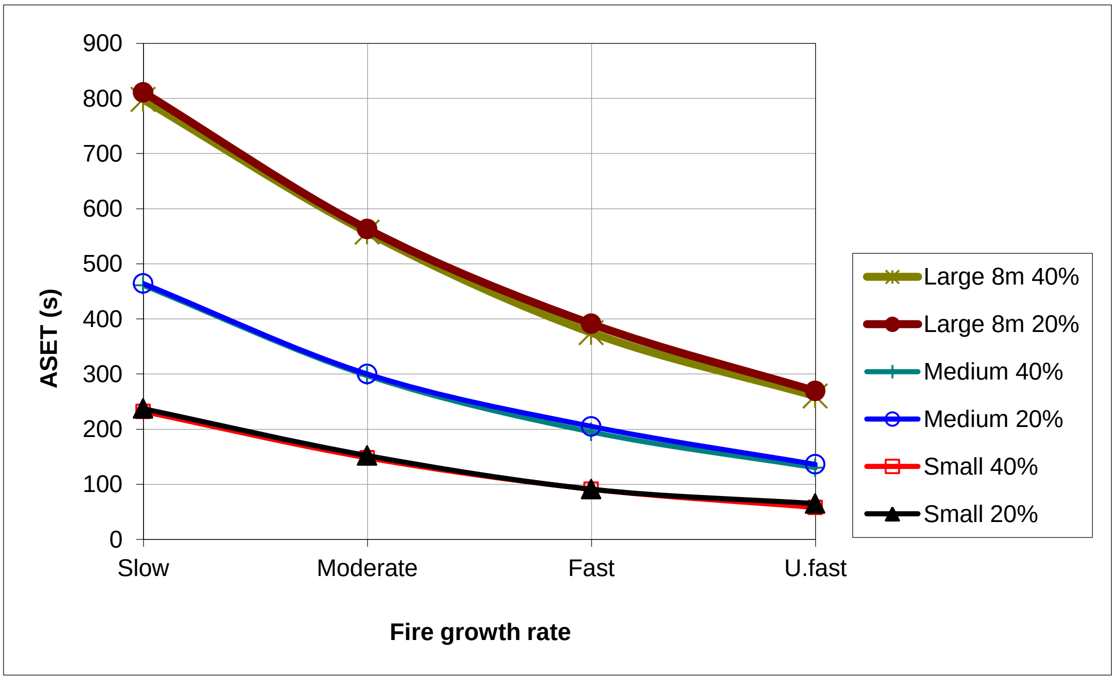


Figure 64: ASET of the lower floors predicted by FDS by the variation of fire growth rates for three firecell sizes with a fire located in the open area.

The ASET of the lower floors of the small, medium and large 8m firecells with intermediate floors of 20% and 40% predicted by FDS by the variation of fire growth rates are plotted in Figure 63 and Figure 64. The ASET of the lower floor decreases when the fire growth rate increases, regardless of the fire location and the intermediate floor size, as expected.

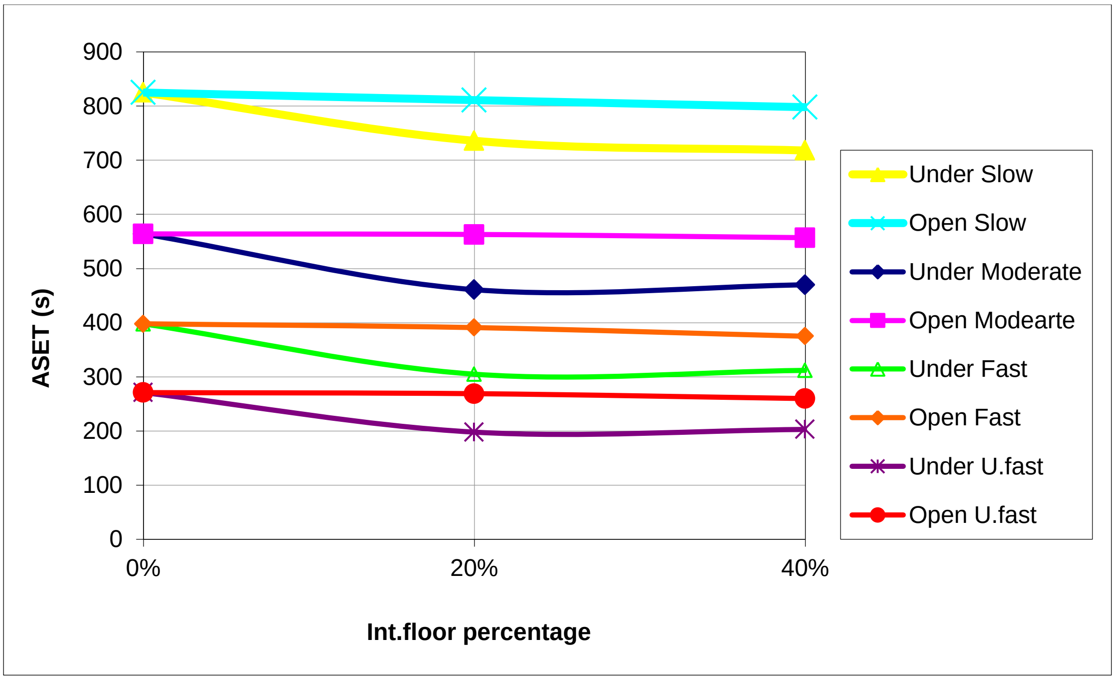


Figure 65: ASET of the lower floors predicted by FDS by the variation of intermediate floor sizes for large 8m firecell.

Figure 65 shows the ASET of the lower floors of the large 8m firecell predicted by FDS with slow, moderate, fast and ultra fast fires by the variation of intermediate floor sizes. Regardless of the fire location and fire growth rate, the ASET of the lower floor decreases when the intermediate floor size increases. The figure also illustrates that when a fire is located under the intermediate floor, the ASET of the lower floor is less than that when a fire is in the open area.

The ASET of the intermediate floors of the large 8m firecell containing an open intermediate floor predicted by FDS with slow, moderate, fast and ultra fast fires by the variation of intermediate floor sizes are presented in Figure 66. When the intermediate floor size increases, the ASET of the intermediate floor increases if a fire is located under the intermediate floor. However, the ASET of the intermediate floor changes very little when a fire is in the open area.

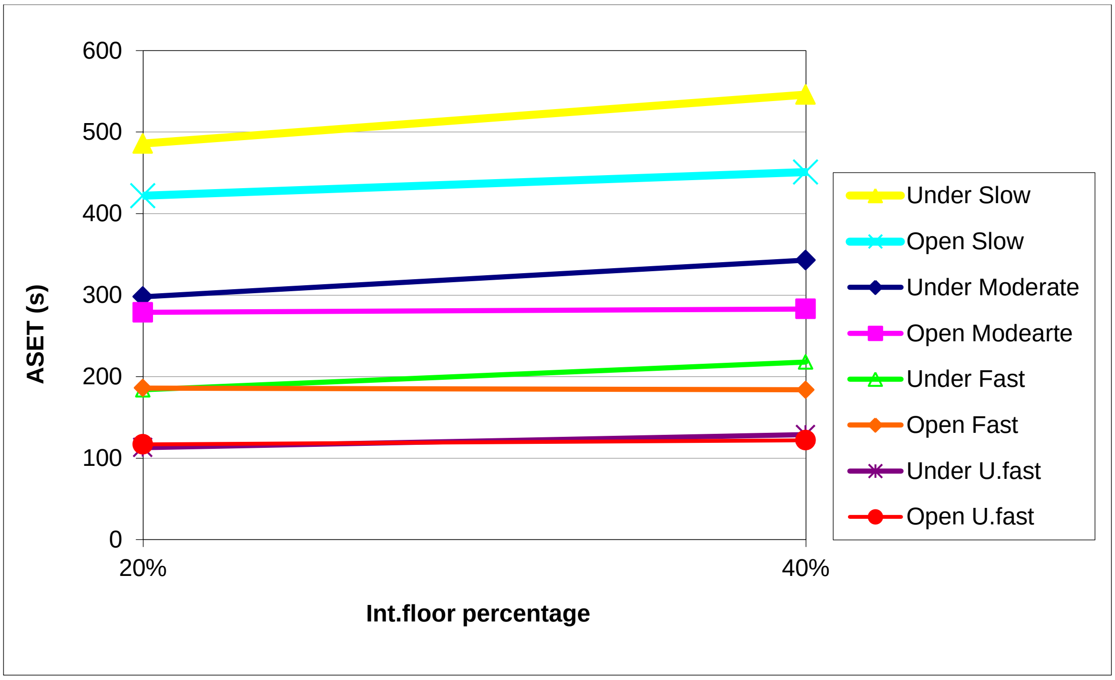


Figure 66: ASET of the intermediate floors predicted by FDS by the variation of intermediate floor sizes for large 8m firecell.

The ASET of the intermediate and lower floors of the small and medium firecells containing open intermediate floors by the variation of intermediate floor sizes have the same trends as the large 8m firecell (Figure 65 and Figure 66). Refer to Figure A1 to Figure A4 of Appendix A for more details.

In summary, regardless of the fire location and intermediate floor size, the ASET of the intermediate and lower floors of the firecell containing open intermediate floors decreases when the fire growth rate increases. With all fire growth rates when the intermediate floor size increases, the ASET of the intermediate and lower floors change very little if a fire occurs in the open area. Regardless of fire growth rate, if a fire is located under the intermediate floor, the ASET of the intermediate floor increases while the ASET of the lower floors decreases when the intermediate floor size increases.

The ASET of both intermediate and lower floors predicted by FDS for three firecell sizes with slow, moderate, fast and ultra fast are expected results which indicate that the model (FDS) is working appropriately.

6. RSET MODELLING

The Fire Engineering Design Guide [30] states that the evacuation time (RSET) is a function of a number of constituent times such that:

$$t_{ev} = t_d + t_a + t_o + t_i + t_t + t_q \qquad (5)$$

Where:

t_d is the time from ignition until detection of the fire (by a building occupant or by an automatic detection system).

t_a is the time from detection until an alarm is sounded.

t_o is the time from alarm until the time occupants make a decision to respond (recognition time).

t_i is the time for occupants to investigate the fire, collect belongings, fight the fire (response time).

t_t is the travel time, being the actual time required to traverse the escape route until a place of safety is reached, including way-finding.

t_q is the queuing time at doorways or other obstructions.

The evacuation can be determined by the sum of the constituent times implies that each constituent is independent of one another. The term t_d depends upon the fire detection system in place and fire scenario and may be determined from computer fire growth and detector response models. The term t_a may vary between effectively zero (where the fire is detected by an automatic system triggering a general alarm on first detection) to several or many minutes (when for example, staged alarm systems are used or where there is no automatic detection) and should be obtained from knowledge of the alarm system or from knowledge of human behavior [32].

The terms t_o and t_i are more difficult to calculate so we can therefore group t_o and t_i into a component which represents the pre-movement time such that:

$$t_p = t_o + t_i \qquad (6)$$

and components t_t and t_q into an overall movement time such that:

$$t_m = t_t + t_q \qquad (7)$$

So the RSET can be expressed as

$$RSET = t_d + t_a + t_p + t_m \qquad (8)$$

The effect of pre-movement distributions on evacuation times has been studied by Spearpoint [50]. In this project, however, movement time and pre-movement time in equation (8) were assumed to be independent.

6.1 Detection time - t_d

As stated earlier, t_d depends upon the fire detection system in place and fire scenario and may be determined from computer fire growth and detector response models. In this project the heat and smoke detectors are assumed to be point type.

The detection time comprise of two components: response time (t_r) and transport time lag (t_l).

The response time (t_r) of the heat detector can be calculated using several tools such as FPETOOL, BRANZFIRE or FDS. In this project, the response time was calculated in the form of distribution so FPETOOL was chosen to calculate the response time.

The response time calculation procedure using FPETOOL is as follow [51]:

$$T_{D,t+\Delta t} = (T_{jet_{t+\Delta t}} - T_{D,t})(1 - e^{-1/\tau}) + (T_{jet_{t+\Delta t}} - T_{jet_t})\,\tau\left(e^{-1/\tau} + \frac{1}{\tau} - 1\right) \quad (9)$$

$$\tau = \frac{RTI}{\sqrt{v_{jet_t}}} \quad (10)$$

$$v_{jet_t} = 0.95\left(\frac{\dot{Q}}{h}\right)^{1/3} \quad \text{for } \frac{r}{h} \le 0.15 \quad (11)$$

$$v_{jet_t} = 0.2\frac{\dot{Q}^{1/3}h^{1/2}}{r^{5/6}} \quad \text{for } \frac{r}{h} > 0.15 \quad (12)$$

$$T_{jet_t} = T_\infty + \frac{16.9\dot{Q}^{2/3}}{h^{5/3}} \quad \text{for } \frac{r}{h} \le 0.18 \quad (13)$$

$$T_{jet_t} = T_\infty + \frac{5.38}{h}\left(\frac{\dot{Q}}{r}\right)^{2/3} \quad \text{for } \frac{r}{h} > 0.18 \quad (14)$$

The transport time lag (t_l) is given by [52]:

$$t_l = \frac{1.4r + 0.2z}{(0.0278\ \alpha h)^{1/5}} \qquad (15)$$

Simulation of smoke detector activation follows procedures identified for heat detector, except that the smoke detector has small response thermal index (resulting in an almost instantaneous response time). The smoke detector activates when the ceiling jet temperature at the radial location of the smoke detector attains the activation temperature. An activation temperature of 13°C above the initial detector temperature (ambient temperature) is assumed [51].

Nam. S [53] had measured RTI for heat detectors for various models using bench-scale tests and found that for rated temperature of 57°C the measured RTI ranges from about 20 to 120 $(m.s)^{0.5}$.

Therefore, in this research project, detector characteristics are chosen for assessment purpose as follows:

- Heat detector: activation temperature of 57°C, RTI = 30 $(m.s)^{0.5}$ which are based on the work by Nam [53] as described above.
- Smoke detector: activation temperature of 33°C, RTI =1 $(m.s)^{0.5}$ with an assumption of the ambient temperature of 20°C.

<u>Distribution of radial distance of smoke detector from the vertical axis of the fire:</u>

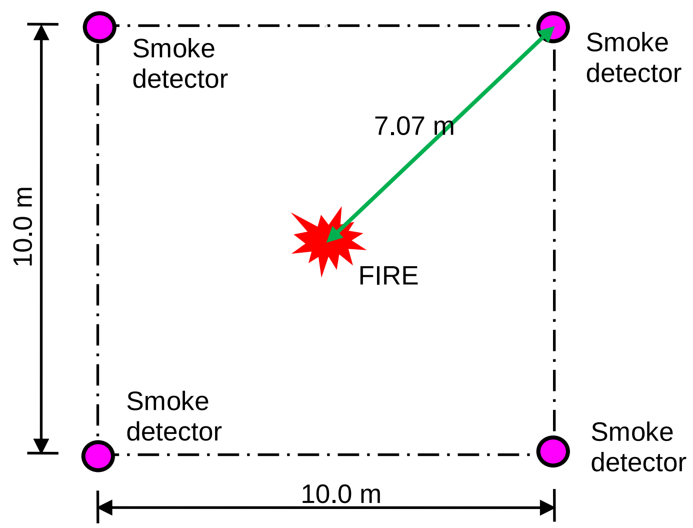


Figure 67: Point type smoke detectors spacing and fire location

Smoke detectors are installed to NZS 4512:2003 with maximum spacing of 10 m [54] so the worst case scenario of smoke detector location is shown in Figure 67. The maximum and minimum radial distances of smoke detector from the fire are 7.07 m and 0.0 m respectively.

The distribution of the radial distance of smoke detector from the vertical axis of the fire was numerically determined and presented as follows:

For a smoke detector as shown in Figure 68, the radial distance to the fire r, is calculated by the following equation:

$$r = \sqrt{x^2 + y^2} \qquad (16)$$

Where x and y are the distances from the fire to the axis y and x respectively. The x and y values for smoke detectors range from 0 to 5.0 m as illustrated in Figure 68. In this project, a step of 0.1 m for x and y was used to assess the distribution of the radial distance to the fire r and spreadsheet with best fit function of @RISK [55] was used to calculate the fitted distribution for the radial distance to the fire r.

The radial distance to the vertical axis of the fire is presented by triangular distribution with the mean value of 3.86 m and the most likely value of 4.56 m as shown in Figure 69.

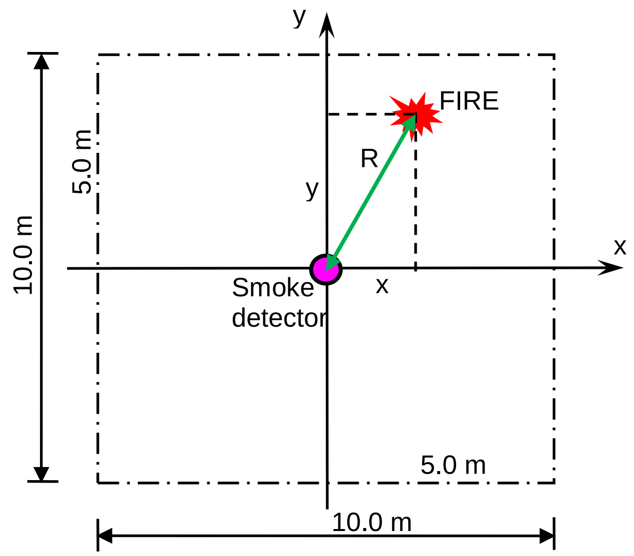


Figure 68: Determining the radial distance of smoke detector from the vertical axis of the fire.

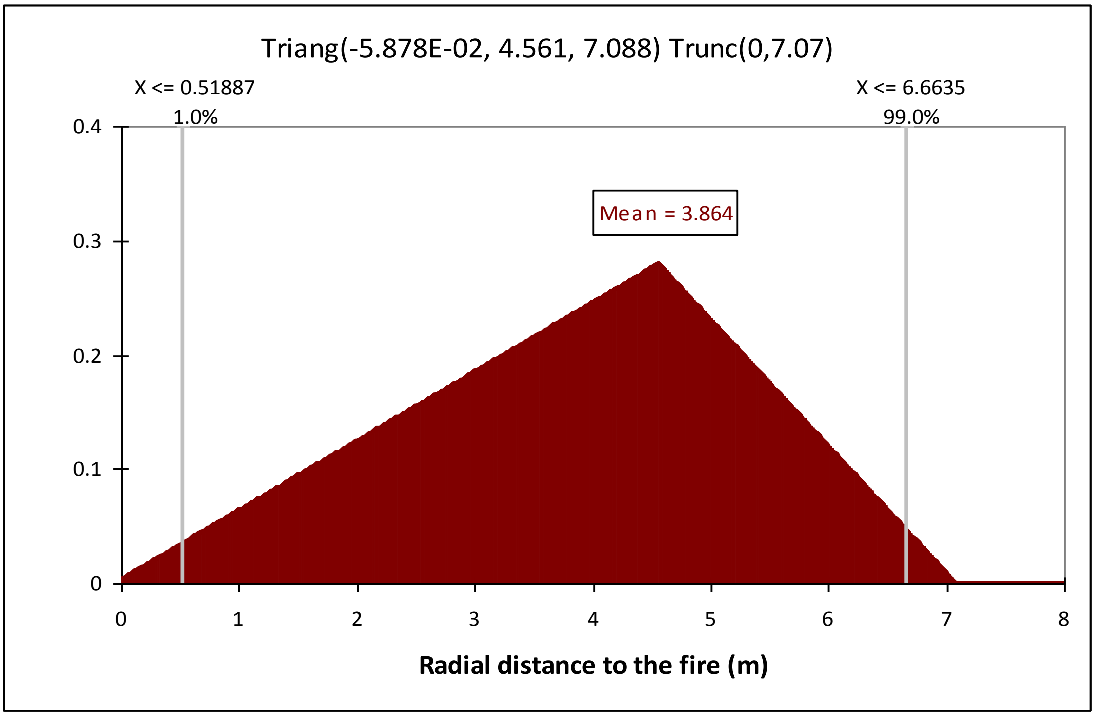


Figure 69: Radial distance of smoke detector from the vertical axis of the fire.

<u>Distribution of radial distance of heat detector from the vertical axis of the fire:</u>

Similar to smoke detectors, heat detectors are installed in accordance with NZS 4512:2003 with maximum spacing of 6.0 m and not less than one detector for 30 square metres [54] so the worst case scenario of smoke detector location is illustrated in Figure 70. The maximum and minimum radial distances of smoke detector from the fire are 3.9 m and 0.0 m respectively.

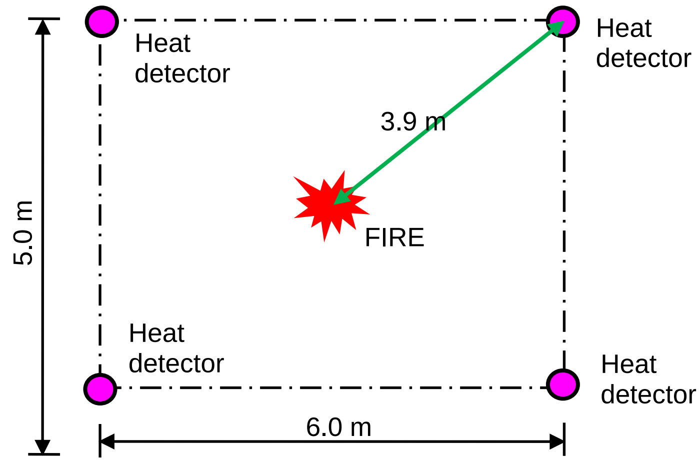


Figure 70: Point type heat detectors spacing and fire location

The same procedure that was used to calculate the distribution of the radial distance to the fire from a smoke detector was carried out to determine the distribution of the radial distance to the fire from a heat detector. The radial distance to the fire is illustrated by triangular distribution with the mean value of 2.13 m and the most likely value of 2.50 m as shown in Figure 71.

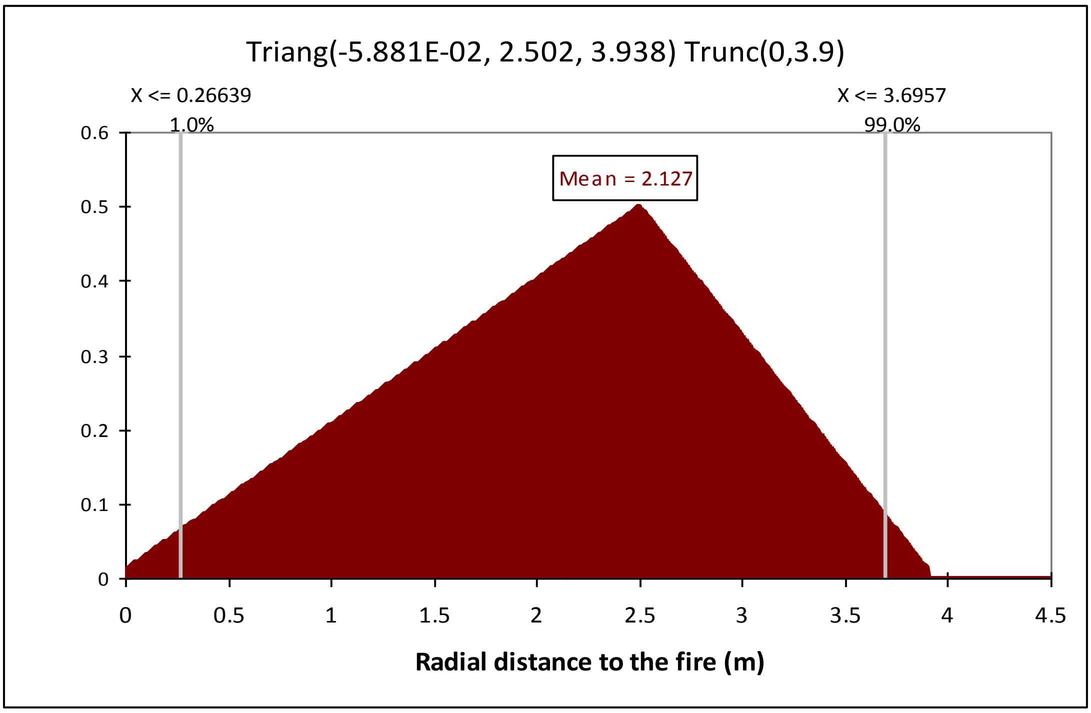


Figure 71: Radial distance of heat detector from the vertical axis of the fire

Detection time also varies with ceiling height from fire base, therefore, for a given firecell containing intermediate floors, the detection time was assessed in two scenarios depending on the fire locations: under the intermediate floor and in the open area.

Some small and medium firecells studied in this project with low occupant load are only required to be fitted with a manual fire alarm system (type 2) by C/AS1 (see section 4.4 of this report). The detection of a fire relies on occupants. It is expected that a fire would be visible and detected by occupants when it reaches a HRR of 50 kW which correspond to the time of 33 seconds of a “t” squared fire with fast growth rate. The distribution of manual detection time for fast fire therefore was assumed to be normal distribution with mean value of 33 seconds, and standard deviation of 10 seconds was assumed.

Detection times and the fitted distribution of each scenario were simulated by @RISK. The distributions of detection time by variation of detection methods and ceiling heights are summarised in Table 14. The ceiling heights of 3 and 5 m represent the scenarios when a fire occurs under the intermediate floors of the small or medium and large firecells respectively. The ceiling height of 6 m represents the scenarios when a fire occurs in the open area of the small or medium firecells while the ceiling heights of 8, 10 and 12 m are for the scenarios when a fire occurs in the open area of the large firecells.

Detector	Ceiling height (m)	Distribution type	Mean (s)	ST. Dev (s)	Min (s)	Most (s)	Max (s)
Smoke	3.0	Triang	57.2	-	15.5	68.6	87.4
	5.0	Triang	75.4	-	27.2	88.5	110.4
	6.0	Triang	83.9	-	33.2	97.0	121.5
	8.0	Triang	100.7	-	45.9	113.6	142.7
	10.0	Triang	117.3	-	59.7	129.3	163.0
	12.0	Triang	125.5	-	90.4	93.6	192.7
Heat	3.0	Triang	98.3	-	43.5	114.5	137.2
	5.0	Triang	126.9	-	67.5	140.7	172.7
	6.0	Triang	140.9	-	80.4	152.5	189.7
	8.0	Triang	163.0	-	129.9	131.0	228.4
	10.0	Triang	195.7	-	165.7	166.7	254.7
	12.0	Triang	230.4	-	203.4	204.6	283.3
Manual	NA	Normal	33.0	10.0	-	-	-

Table 14: Summary of detection time distributions for a fast fire

6.2 Alarm time - t_a

Alarm time (t_a) can vary from effectively zero to several minutes or be very long and unpredictable.

The British provisional standard *PD 7974-part 6, 2004* [32] categorises fire alarm system equipped to buildings into three levels and suggests the alarm time as follows:

- Level A1 alarm system: Automatic detection throughout the building, activating an immediate general alarm to occupants of all affected parts of the building: Alarm time (t_a) is effectively zero.
- Level A2 (two stage) alarm system: Automatic detection throughout the building providing a pre-alarm to management or security, with a manually activated general warning system sounding throughout affected occupied areas and a general alarm after a fixed delay if the pre-alarm is not cancelled: Alarm time (t_a) is taken as time out delay (usually two or five minutes).
- Level A3 alarm system: Local automatic detection and alarm only near the location of the fire or no automatic detection, with a manually activated general warning system

sounding throughout all affected occupied areas: Alarm time (t_a) is likely to be long and unpredictable.

For comparative analysis in this project the alarm time was taken to be zero.

6.3 Pre-movement time - t_p

Pre-movement time consists of two components: recognition (t_0) and response (t_i) as presented in equation (6).

6.3.1 *Recognition*

This consists of a period after an alarm or other cue is evident but before occupants of a building begin to respond. During the recognition period, occupants continue with the activities engaged in before the alarm or cue, such as working, shopping or sitting. The length of the recognition period can be extremely variable, depending upon factors such as the types of building, the nature of the occupants and the building alarm and management system [32].

In single enclosure buildings that are well managed, the recognition period is likely to be short. In multi-enclosure buildings where occupants might be remote from the fire (especially those with a sleeping risk such as hotels, residential homes and hostels), the recognition times can vary considerably. The recognition time ends when the occupants have accepted that there is a need to respond [32].

6.3.2 *Response*

This consists of a period after occupants recognise the alarms or cues, and begin to respond to them, but before they begin the travel phase of evacuation (where necessary). As with the recognition period, this may range from a few seconds to many minutes, depending upon the circumstances [32].

During the response process, occupants cease their normal activities and engage in a variety of activities related to the developing emergency. At the end of the response process, each occupant will have decided either to remain in the same enclosure or to begin evacuation. For simple evaluations, a single figure such as the average or slowest response time might be taken for each group of occupants. For more complex evaluations, response times may be assigned to each individual occupant [32].

Pre-movement times can vary considerably for different individuals or groups of individuals both within an enclosure and in different enclosures within the same building. The distribution of pre-movement times depends upon a range of factors including the occupants proximity to and knowledge of the fire as afforded by the architecture of the setting, the warning system and management systems. A range of factors can be taken into account in order to estimate pre-movement time. The principal ones are as follows [32]:

- Building parameters:
  - occupancy use: floor plans, layout and dimensions; contents; warning system; fire safety management emergency procedures;
  - occupant status: occupant numbers and location; occupant characteristics – age and health status; occupant activities; occupant condition;
  - fire simulation dynamics.
- Building condition and fire location:
  - visibility of smoke or fire;
  - exposure to fire effluent or heat;
  - fire alarm status and type.
- Other warnings or cues (e.g. from management or other occupants).

MacLennan et al. [56] suggest that a Weibull distribution is the most suitable way in which to describe the probability distribution of pre-movement times, they also note that other distributions may be equally appropriate. Spearpoint [50] used triangular distribution to assess the effect of pre-movement distributions on evacuation times.

According to *PD 7974-part 6, 2004* [32], pre-movement distributions consist of two phases: the time from alarm to the movement of the first few occupants to begin their travel phase and the subsequent distribution of times for the population of occupants to begin their travel phase. Once the first few occupants begin to move, pre-movement distributions tend to follow approximately log-normal distributions, with a rapid increase in the number of occupants starting to move soon after the beginning of the distribution and a long tail until the last few occupants move.

The pre-movement times of the firecells in this project have been taken from *PD 7974-part 6, 2004* [32] and shown in Table 15. The distributions of the pre-movement times are plotted in Figure 72, Figure 73 and Figure 74.

Firecell	Distribution type	First occupant (1st percentile)	Occupant distribution (99th percentile)
Small CS, CL, WL, WM	Lognormal	30	60
Medium CS, CL, WL, WM Large WL, WM	Lognormal	30	180
Large CS, CL	Lognormal	90	300

Table 15: Pre-movement times (second)

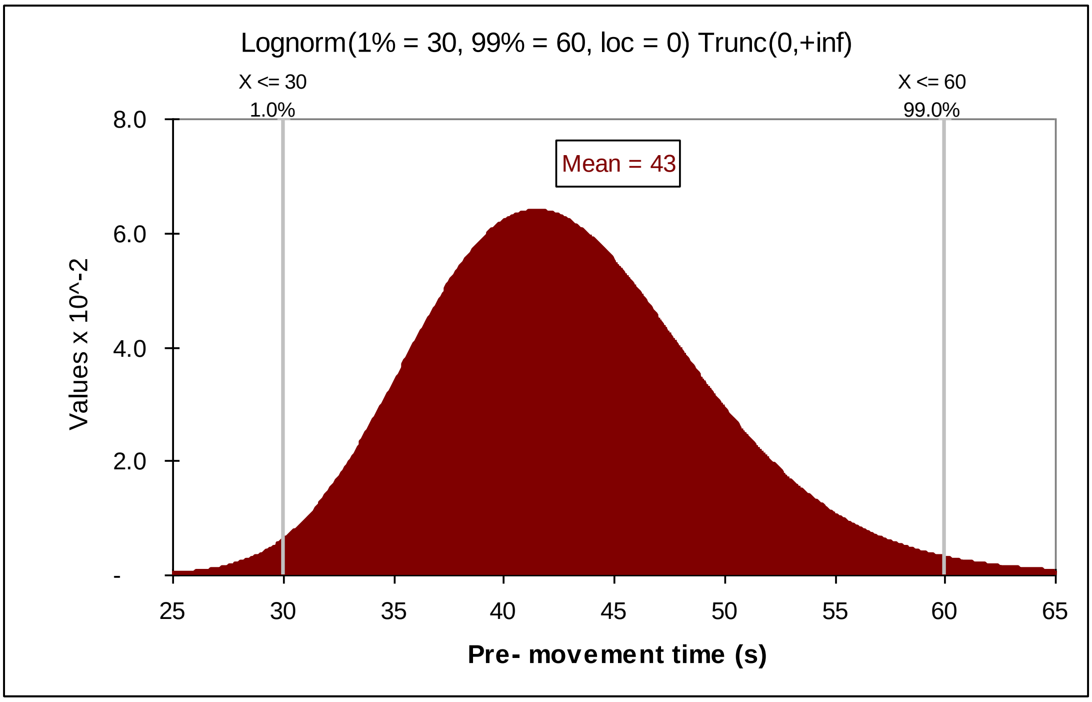


Figure 72: Distribution of pre-movement time for small firecells

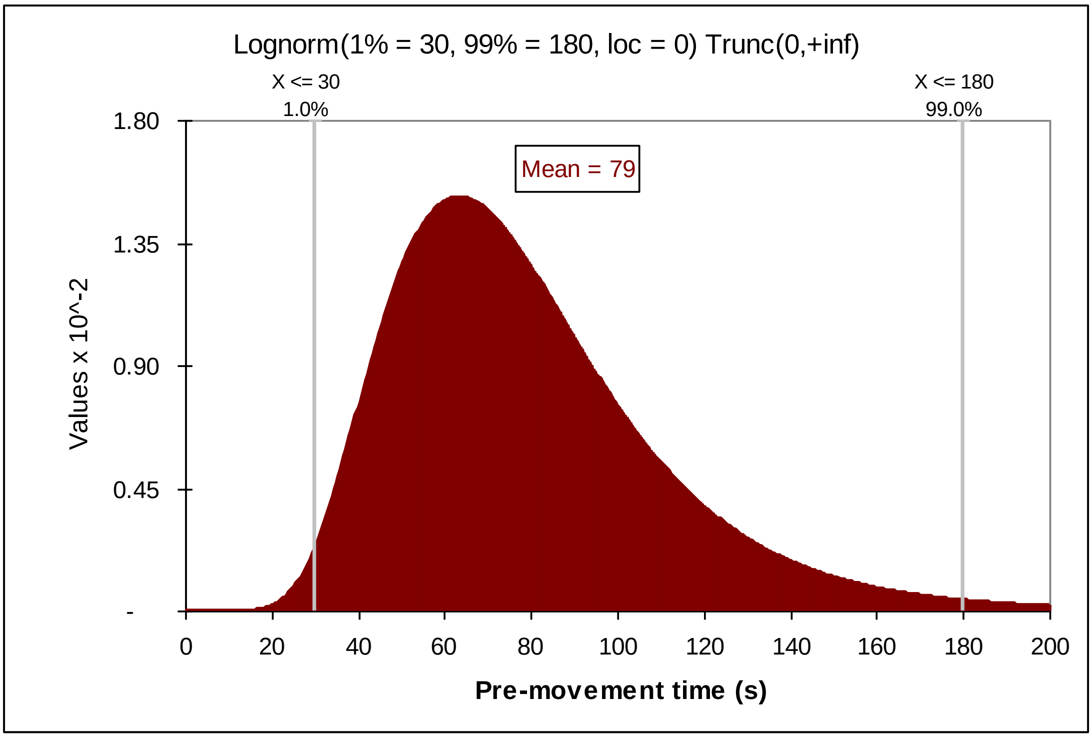


Figure 73: Distribution of pre-movement time for medium firecells

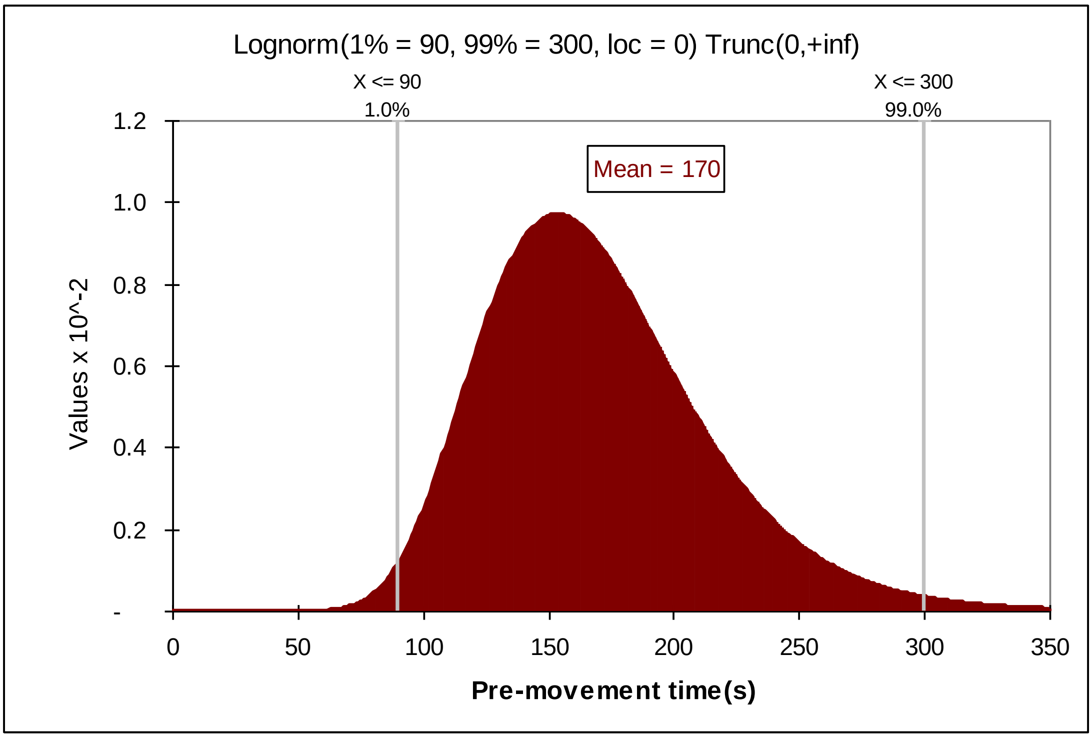


Figure 74: Distribution of pre-movement time for large firecells

6.4 Movement time - t_m

6.4.1 *Simulation tool_SIMULEX*

Simulex [57] is a computer package for PCs which is often used to obtain evacuation times of many people from large, geometrically complex building structures. Simulex allows the user to create a pseudo 3-D model of a building by using a number of Computer-aided design (CAD)-designed floor plans, connected by staircases. Building plans are imported from CAD tools and occupants are placed graphically on the floor plans. The user specifies exits from the building and stairs are used to connect different floor levels. The user defines 'final' external exits just outside the building, and Simulex will automatically calculate all travel distances and routes throughout the building space. Occupants are 'placed' into the building, either one-by-one or as groups. When the building population has been defined, and the potential routes calculated, then a simulation can be carried out. The algorithms for the movement of individuals are based on real-life data, collected by using computer-based techniques for the analysis of human movement, observed in real-life footage [57].

In Simulex, an occupant is represented by three circles and they are: the larger circle in the middle represents the torso and two smaller circles represent the shoulders. The movement parameters have allowed the model to simulate a realistic crowd movement. These features are such as normal unimpeded walking speed, reduction of walking speed due to the proximity of other occupants, overtaking, sidestepping and body twisting. The model also allows for a distribution of pre-movement times (termed response time in Simulex) to be applied to the occupants. Three type of distributions; random, normal and triangular with the mean and deviation of the distribution can be defined by the user.

6.4.2 *Building layouts, furniture and other obstructions*

Building layouts and occupant density have been described in Chapter 4 of this report.

Furniture and other obstructions within the firecells are represented by rectangles in the floor plans. The rectangles with the size of 1.0 x 2.0 m, 1.0 x 2.0 m and 0.5 x1.5 m are located in the large rooms, medium rooms and small rooms respectively. Examples of the furniture arrangement in Simulex simulations are shown in Figure B1, Figure B2 and Figure B3 of Appendix B.

6.4.3 *SIMULEX simulation setting*

As stated previously, the SIMULEX model allows user to chose a distribution of pre-movement times (termed response time in SIMULEX) for occupants. Three type of distributions; random, normal and triangular with the mean and deviation of the distribution can be defined by the user. In this project, pre-movement times are chosen as suggestions of the British standard *PD 7974-part 6, 2004* [32] therefore, the pre-movement time was set zero.

The occupancy type will govern the distribution of body sizes that are assigned to the individuals in the group [57]. In this project, crowd activity (CS and CL) occupants were characterised as “commuters” while working activity (WL and WM) occupants were assigned as “office staff” in SIMULEX models as shown in Table 16.

The normal unimpeded walking velocity for each person was randomly chosen in the interval between 0.8 - 1.7 m/s by the program [57].

In the simulations, there was no staged evacuation and occupants were set to choose the closest available exit (default distance map setting).

Occupant Type	%'Average'	%'Male'	%'Female'	%'Child'
Office Staff	30	40	30	0
Commuters	30	30	30	10
Shoppers	30	20	30	20
School Children	10	10	10	70
Elderly	50	20	30	0
All Male	100	0	0	0
All Female	0	0	100	0
All Children	0	0	0	100

Table 16: Distribution of body types for different occupant groups [57]

6.4.4 *SIMULEX simulation results*

The movement time of the occupants of the intermediate floors is determined by the time the last occupant enters the staircase, whereas the movement time of the lower floors is the time the last occupant reaches the exit.

The movement times of the occupants simulated by SIMULEX for all three sizes of firecells containing intermediate floors, with the variation of intermediate floor sizes for both crowd activity and working activity, are shown in Figure 75, Figure 76 and Figure 77. For comparison, the movement times for the firecells without intermediate floors (equivalent firecells), that have the same occupant loads as firecells containing intermediate floors are also plotted in these figures.

In general, the movement time increases when the building size and intermediate floor sizes increase. The movement times for the equivalent firecells without intermediate floors are moderately less than that of the firecells containing intermediate floors. With a given building geometry, the occupant load has significant impact on the movement time as shown in these figures for different purpose groups. Regardless of the intermediate floor and firecell sizes, the movement time of the firecell with higher occupant load (CS or CL) is significantly greater than that of the firecell with lower occupant load (WL and WM) as might be expected. The figures also show that the movement time of the occupants of the intermediate floor is always less than that of the lower floor for all firecell and intermediate floor sizes.

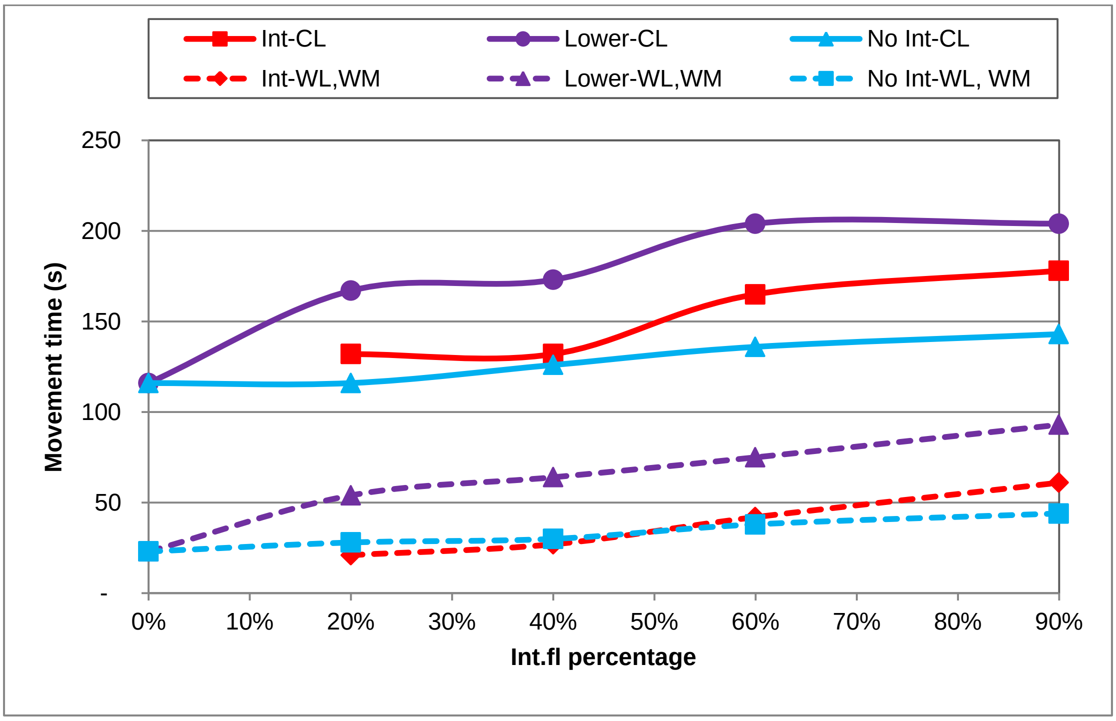


Figure 75: Movement times of the occupants of the large firecells containing intermediate floors over the variation of intermediate floor sizes and purpose groups.

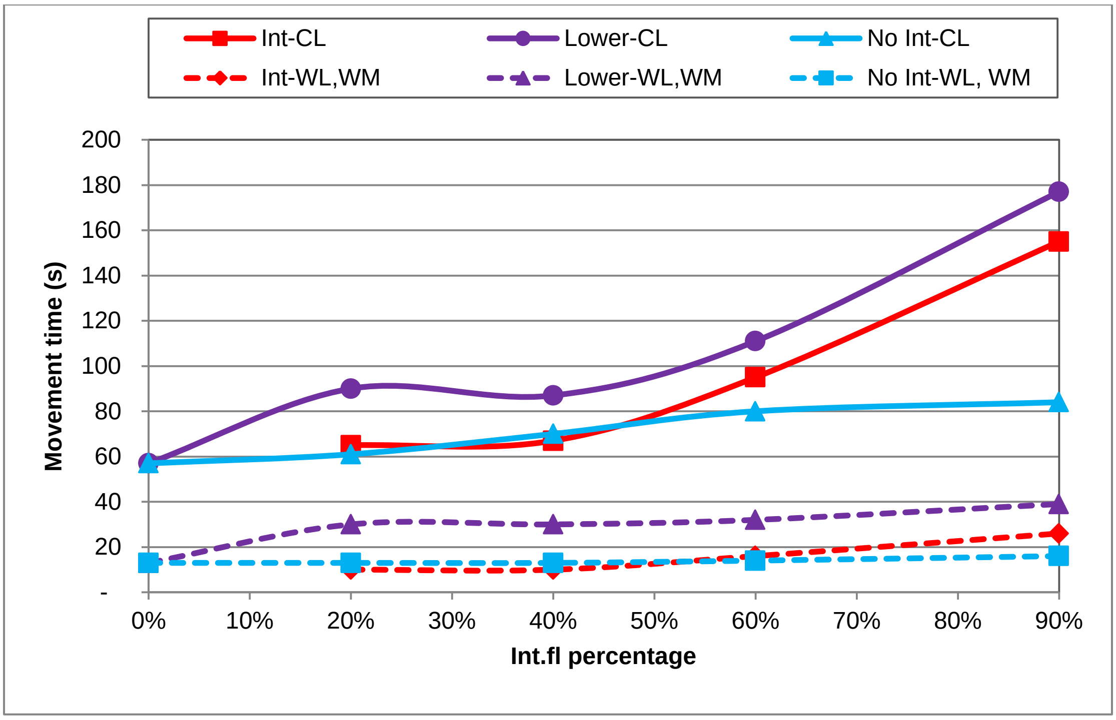


Figure 76: Movement times of the occupants of the medium firecells containing intermediate floors over the variation of intermediate floor sizes and purpose groups.

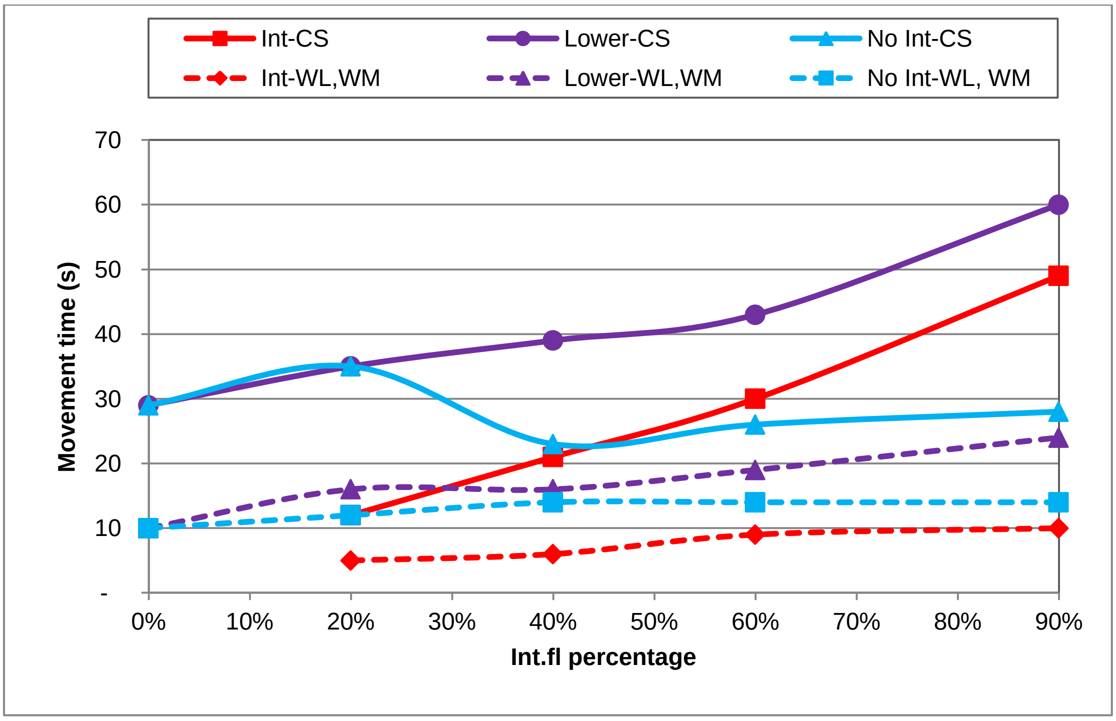


Figure 77: Movement times of the occupants of the small firecells containing intermediate floors over the variation of intermediate floor sizes and purpose groups.

As stated section 4.1 of this report, the unsprinklered firecells that are required more than one escape routes by C/AS1 were studied in both scenarios with and without a blocked exit on the lower floors. The studied firecells that are unsprinklered and require more than one exit are: small firecell in CS purpose group, medium firecells in purpose groups WL and WM and purpose group CL, and large firecell in purpose groups WL and WM (see section 4.4).

The movement times of the occupants of the large firecells containing intermediate floors in WL and WM purpose groups with and without a blocked exit are illustrated in Figure 78. When one exit on the lower floor is blocked the movement time of the occupants of both intermediate and lower floors increases significantly.

The impact of the blocked exit on the movement time for the small and medium firecells are similar to that of the large firecells analysed above (Figure 78). The graphs of the movement time of the small and medium firecells with a blocked exit are in Appendix C (Figure C1, Figure C2 and Figure C3).

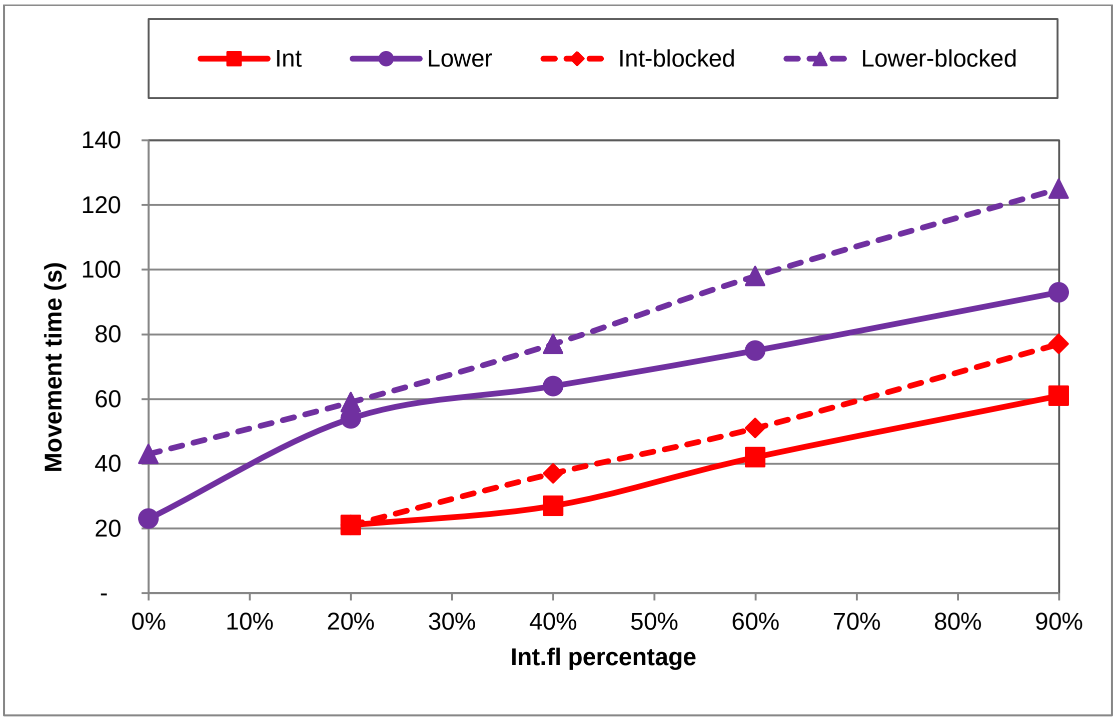


Figure 78: Movement times of the occupants of the large firecell in WL and WM purpose groups containing intermediate floors over the variation of intermediate floor sizes with and without a blocked exit.

The rate at which the movement time in unsprinklered firecells with a blocked exit increases depends upon the location of the blocked exit. In this project, the exit on the lower floor that is closest to the occupants on the intermediate floors was blocked which is the worst likely scenario.

The details of the movement times of the occupants calculated by SIMULEX for all studied firecells with and without intermediate floors over the variation of intermediate floor sizes can be found in Table C1, Table C2 and Table C3 of Appendix C.

7. FACTOR OF SAFETY ANALYSIS

7.1 Determining factor of safety

For all spaces in a building, the time taken to evacuate the space, referred to as required safe egress time (RSET), must be less than the time for the environment in that space to become life-threatening, referred to as available safe egress time (ASET). Factor of safety (FoS) is defined by the ratio of ASET and RSET.

In this research project, the ASETs were calculated by fire models: FDS and BRANZFIRE and the RSET were calculated by equation (5) as presented in Chapters 5 and 6 of this report.

The ASET analysis has shown that BRANZFIRE is not suitable to model a firecell containing large intermediate floors (open or closed). To be consistent in the FoS analysis, the ASET predicted by FDS were used to calculate FoS.

The RSET were calculated using equation (5), in which detection time and pre-movement time were presented in the form of distributions instead of single figures. The FoS therefore were presented as distributions. In this research project, the analysis of FoS were based on the 1st percentile which means 99 percent of the occupants would evacuate achieving that FoS.

Figure 79 shows an example of FoS presented by distribution in which the mean value of FoS is 1.05 and the 1st percentile and 99th percentile are 0.76 and 1.38 respectively. In this example, all occupants would evacuate with an average FoS of 1.05, with a FoS of 1.38 only 1% of occupants would escape and at the time required for 99% of occupants to escape the FoS is 0.76.

A factor of safety greater than unity is required to account for uncertainties in calculating the likely evacuation and tenability times, difficulties in way finding, and other unforeseen circumstances. The FoS selected may vary depending on occupant characteristics (e.g. age, disability, sleeping or active occupancies), presence of suppression systems, and building size or complexity [30]. A factor of safety of less than unity means occupants would not have enough time to escape before the environment in the space becomes life-threatening. The Fire Engineering Design Guide [30] recommends a FoS of not less than 2.0 for fire safety design.

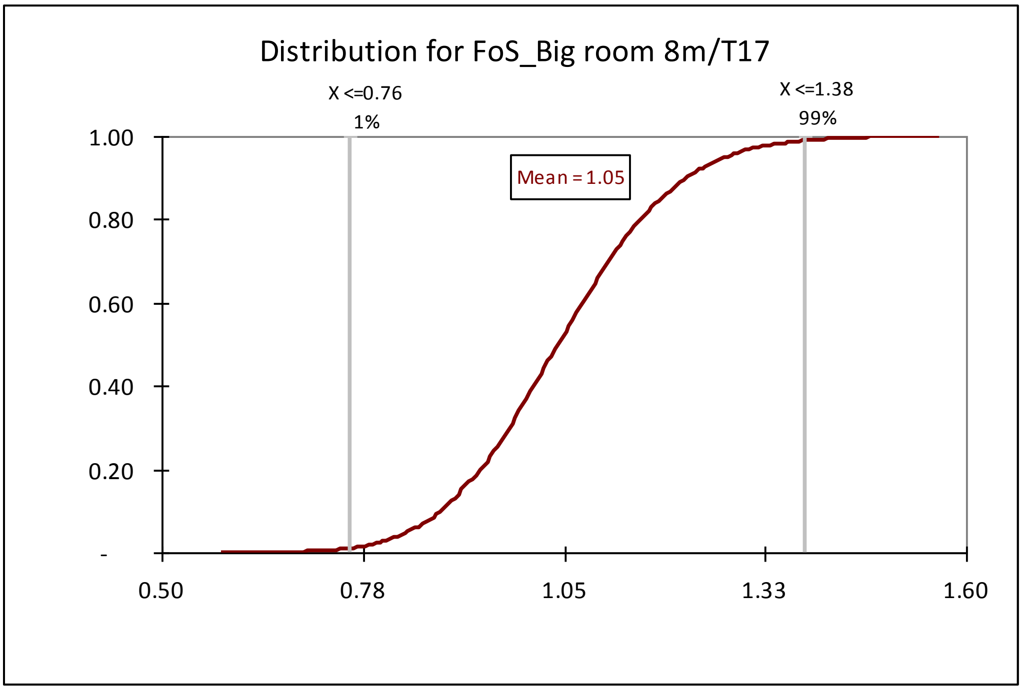


Figure 79: Distribution of FoS

7.2 Factor of safety of firecells without intermediate floors

The occupant loads of the firecells without intermediate floors (equivalent firecells) that have the same occupant load as the firecells containing intermediate floors in different firecell sizes and purpose groups are shown in Table 17. For example, the occupant loads of the large equivalent firecells in purpose groups WL and WM that are the same as the occupant loads of the firecells containing intermediate floors of 0%, 20%, 40%, 60% and 90% are 30, 50, 70, 90, and 120 people respectively.

Occ.load	Small		Medium		Large 8,10,12m	
	WL, WM	CS	WL, WM	CL	WL, WM	CL
O.load of equivalent firecell same as firecell with 0% Int.fl	2	40	8	250	30	1000
O.load of equivalent firecell same as firecell with 20% Int.fl	3	48	13	300	50	1200
O.load of equivalent firecell same as firecell with 40% Int.fl	4	56	18	350	70	1400
O.load of equivalent firecell same as firecell with 60% Int.fl	5	64	23	400	90	1600
O.load of equivalent firecell same as firecell with 90% Int.fl	6	76	31	475	120	1900

Table 17: Occupant loads of the equivalent firecells (without intermediate floors).

The FoS of the equivalent firecells that have the same occupant loads as the firecells containing intermediate floors with three different firecell sizes in different purpose groups are shown in Figure 80. The FoS of the equivalent firecells in WL and WM purpose groups are in solid lines while the FoS of equivalent firecells in CS or CL purpose groups are illustrated by the dashed lines. The FoS ranges from about 0.50 to nearly 1.20 and decreases slightly when the occupant load increases for all firecell sizes and purpose groups. The FoS of the equivalent firecell with lower occupant load (purpose groups WL and WM) is always greater than that of the same size firecell with higher occupant load (CS or CL). The FoS of the large equivalent firecells with ceiling heights of 10 and 12 m have the same trend but are always greater than the FoS of the large equivalent firecell with a ceiling height of 8 m as shown in Figure 81 and Figure 82.

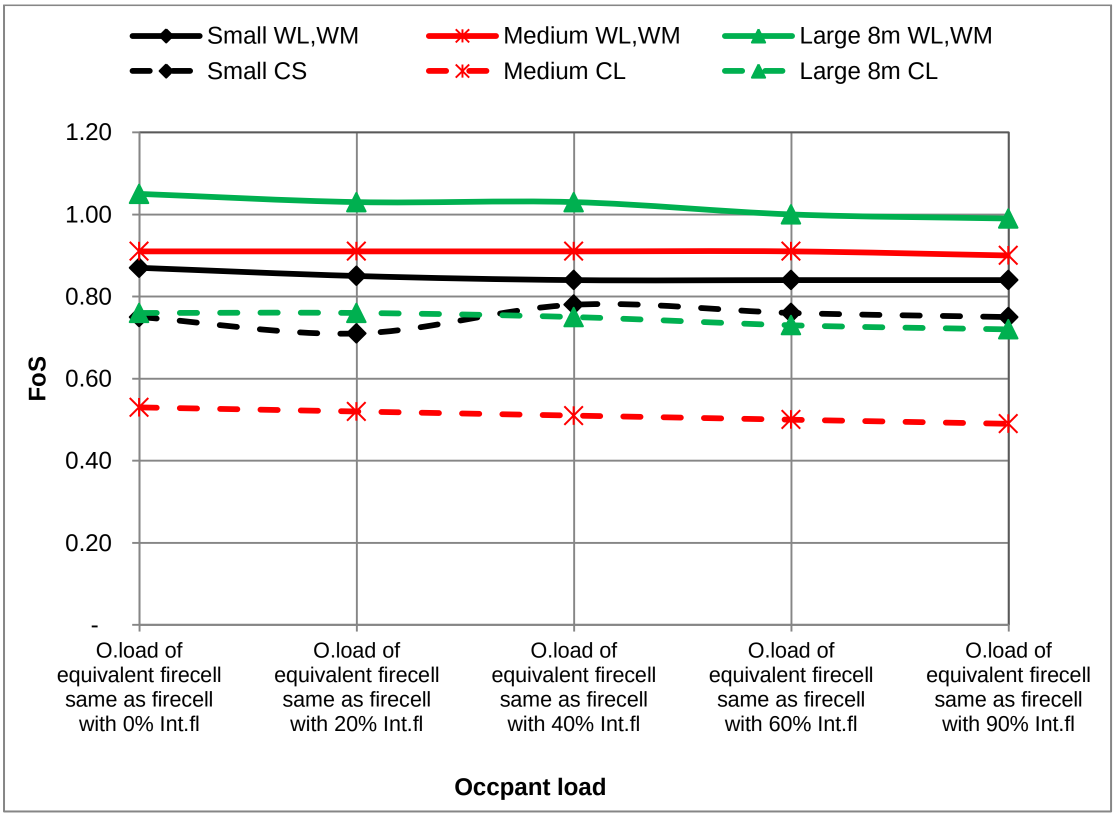


Figure 80: FoS of the equivalent firecells by the variation of occupant loads for three firecell sizes in different purpose groups.

Figure 81 illustrates the FoS of the five equivalent firecells; small, medium and large with ceiling heights of 8, 10 and 12 m, in purpose groups WL and WM. Regardless of the occupant load, which vary corresponding to the occupant loads of the firecells containing intermediate floors, the larger the firecell floor area, the greater the FoS is. The figure also shows that the higher the ceiling, the greater the FoS is (three large firecells), as might be expected. The FoS starts at the value of nearly 0.9 for the small equivalent firecell increasing to approximately 1.20 for the large equivalent firecell with a ceiling height of 12m.

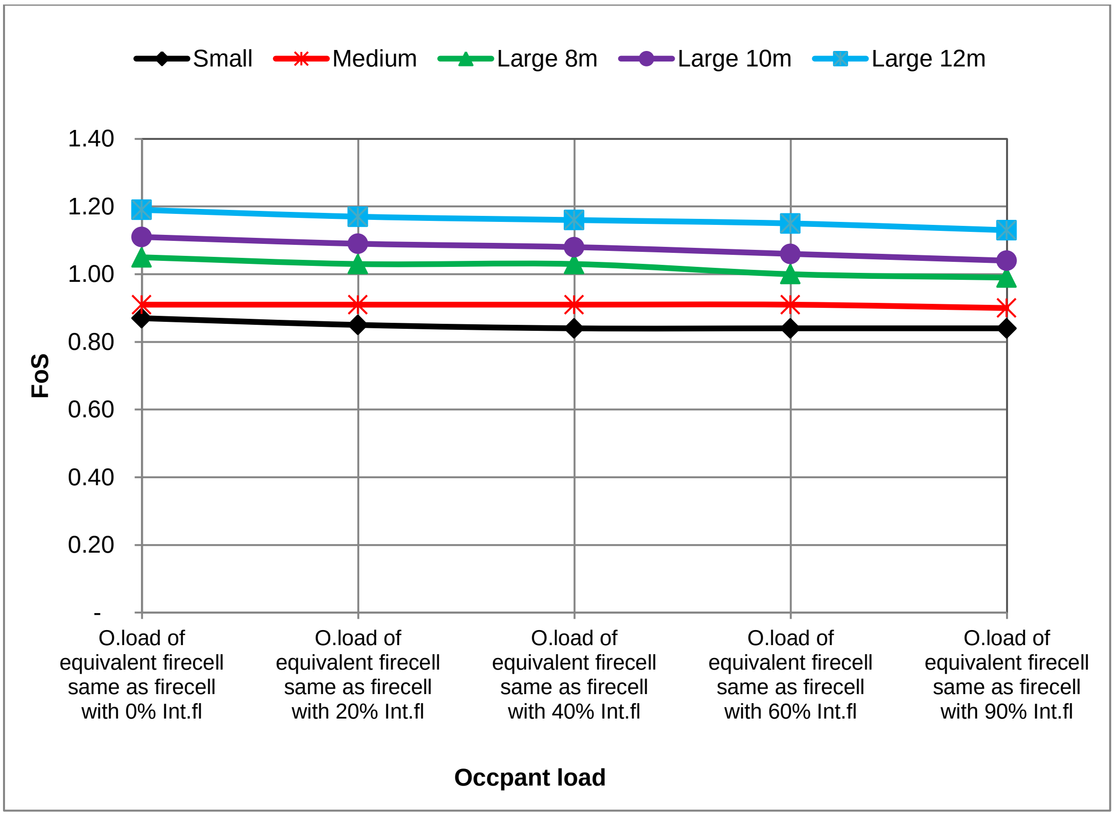


Figure 81: FoS of the equivalent firecells in purpose groups WL and WM by the variation of occupant loads.

The FoS of the five equivalent firecells; small, medium, and large 8, 10 and 12 m, in purpose groups CS or CL are illustrated in Figure 82. The FoS of these firecells are less than 1.0 with the value of approximately 0.50 and 0.90 for the medium and large equivalent firecells with 12 m of ceiling height respectively. Similar to the equivalent firecells in the WL and WM purpose groups, the equivalent firecells with the same floor areas but different ceiling heights (three large firecells) in CL purpose group, the higher the ceiling height the greater the ASET is, consequently the greater the FoS is. In firecells with the same ceiling height but different floor areas (small and medium equivalent firecells), the medium equivalent firecell has a lower FoS than that of a small equivalent firecell (Figure 82) because both firecells have similar detection times but the movement time of the medium equivalent firecell is significantly greater than that of the small equivalent firecell, which strongly governs the FoS.

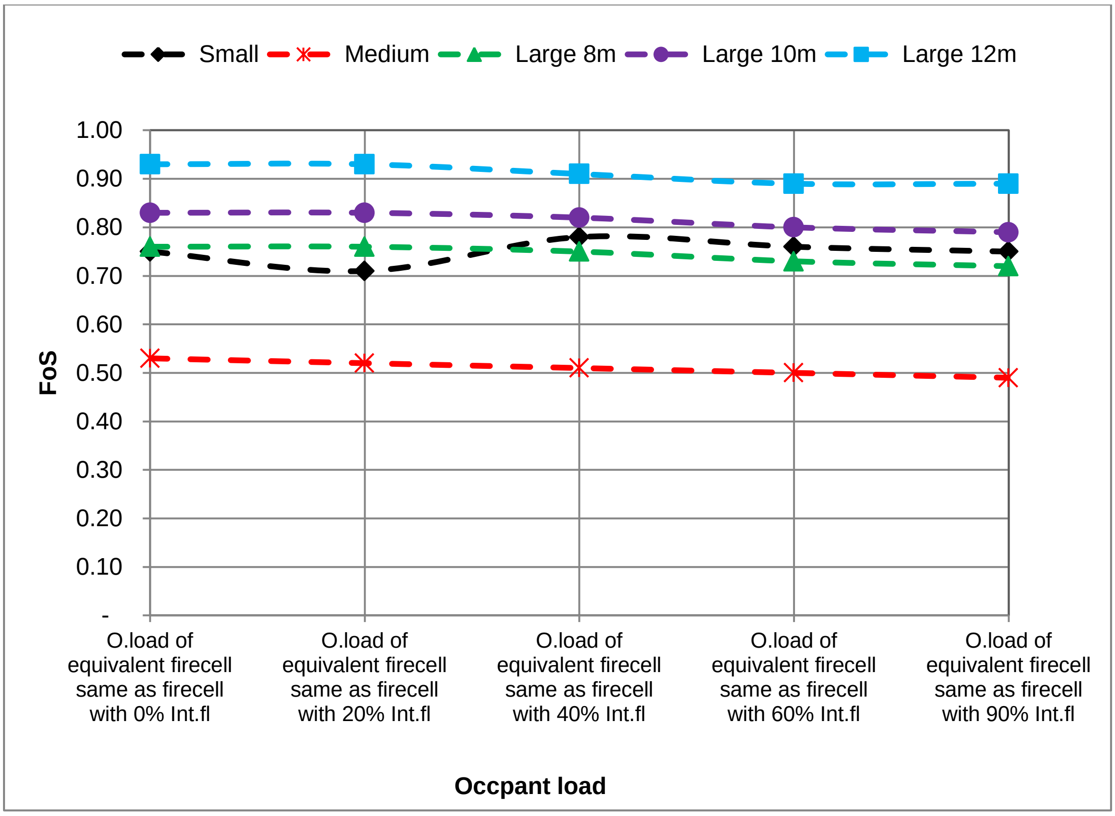


Figure 82: FoS of the equivalent firecells in purpose groups CS or CL by the variation of occupant loads.

The figures above (Figure 80, Figure 81 and Figure 82) show that none of the studied firecells without intermediate floors achieves a FoS of 2.0. In this research project, however, the firecells without intermediate floors designed to C/AS1 are assumed to be sufficiently ‘safe’. Therefore, the level of safety/risk of the firecells containing intermediate floors will be assessed by comparing the FoS of intermediate and lower floors with the FoS of firecells without intermediate floors.

7.3 Factor of safety of firecells containing intermediate floors

The FoS for three firecell sizes: small, medium, large with 8 m ceiling height with the variation of intermediate floor sizes and fire locations in different purpose groups are plotted in Figure 83 to Figure 88. For comparison, the FoS of the equivalent firecells without intermediate floors that have the same occupant loads and ceiling heights as the firecells containing intermediate floors are also plotted in these figures. The terms “under” and “open” used in the graphs are referred to the scenarios when a fire occurs under the intermediate floor and in the open area respectively.

The figures show that the FoS of the intermediate and lower floors have the same trends for all three firecell sizes in different purpose groups. In most scenarios, the FoS of the intermediate and lower floors are less than the FoS of the equivalent firecells without intermediate floors. This means the occupants of the firecells containing intermediate floors would have a higher risk level compared to the occupants of the equivalent firecells without intermediate floors.

For all intermediate floor, firecell sizes and purpose groups, the FoS of the intermediate floor when a fire occurs in the open area is always less than that of the lower floor. This means if a fire occurs in the open area, the occupants on the intermediate floors would have a higher level of risk than the occupants of the lower floors.

When a fire occurs under the intermediate floor, the FoS of the intermediate floor is greater than that of the lower floor in most scenarios. This means if a fire occurs under the intermediate floors, the occupants on the intermediate floors would have a lower level of risk than the occupants of the lower floors. However, if the occupants on the intermediate floors must escape via the lower floor (see section 4.1) then the level of risk of the occupants on the intermediate floors can be considered as the same as the occupants of the lower floor.

These figures (Figure 83 to Figure 88) also indicate that the FoS of the lower floor, when a fire is located under the intermediate floor, is considerably less than that when a fire is in the open area for all intermediate floor and firecell sizes and purpose groups. This means the occupants of the flower floors would have significantly less time to evacuate when a fire occurs under the intermediate floors compared to when a fire occurs in the open area.

Regardless of intermediate floor, firecell sizes and purpose group, the FoS of the intermediate floor, when a fire is located under the intermediate floor, is always greater than that when a fire occurs in the open area. This means the occupants on the intermediate floors would have more time to escape when a fire occurs under the intermediate floor than when a fire is in the open area. However, the occupants on the intermediate floors must travel via the lower floor so the risk level of the occupants depends on the FoS of the lower floor, and also depends on whether they must exit via the open or under intermediate floors area.

The FoS of the intermediate and lower floors decreases when the intermediate floor size increases except for FoS of the intermediate floor when the fire is under the intermediate floor. When a fire occurs under the intermediate floor, the FoS of the intermediate increases as the intermediate floor size increases, however, the level of risk of the occupants on the intermediate floors can be considered as the same as the occupants of the lower floor as analysed above. Therefore it is reasonable to say that the level of risk of the occupants of the firecells containing intermediate floors would increase when the intermediate floor size increases.

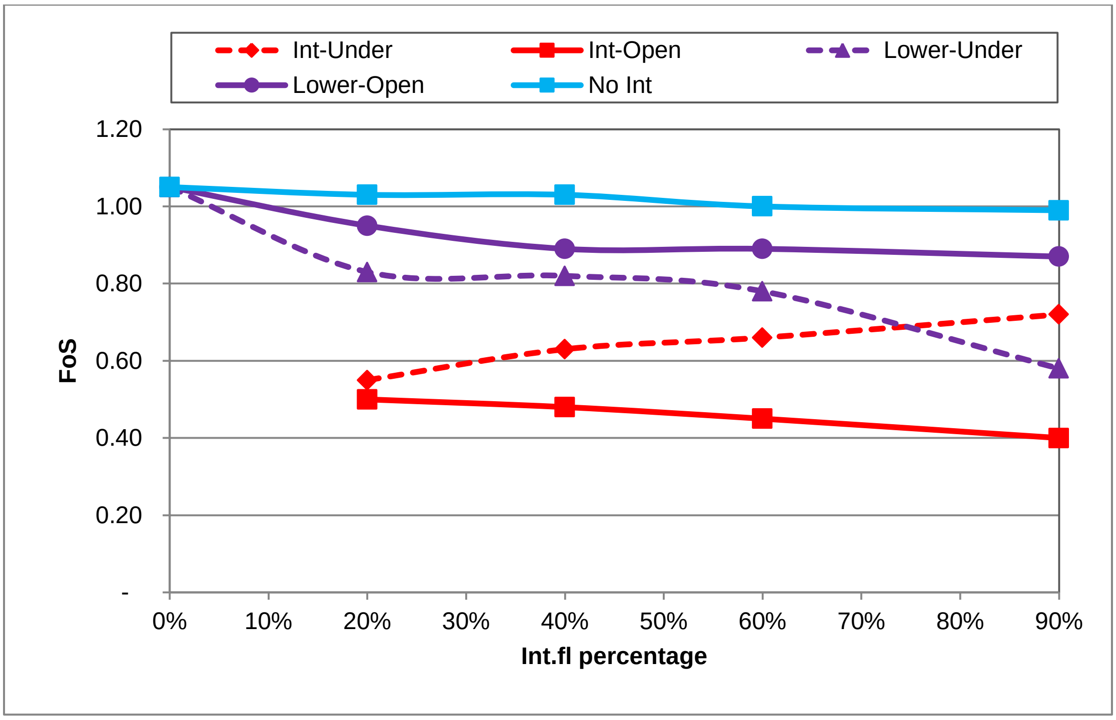


Figure 83: FoS of the large 8m firecells in WL and WM purpose groups over the variation of intermediate floor sizes and fire locations.

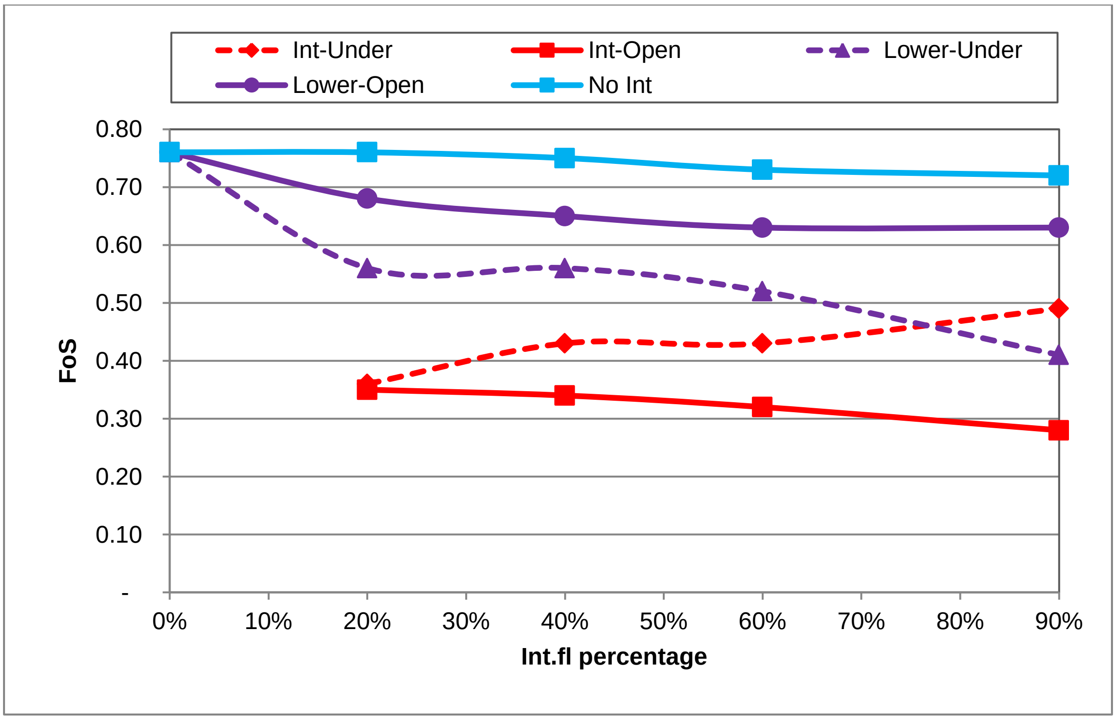


Figure 84: FoS of the large 8m firecells in CL purpose group over the variation of intermediate floor sizes and fire locations.

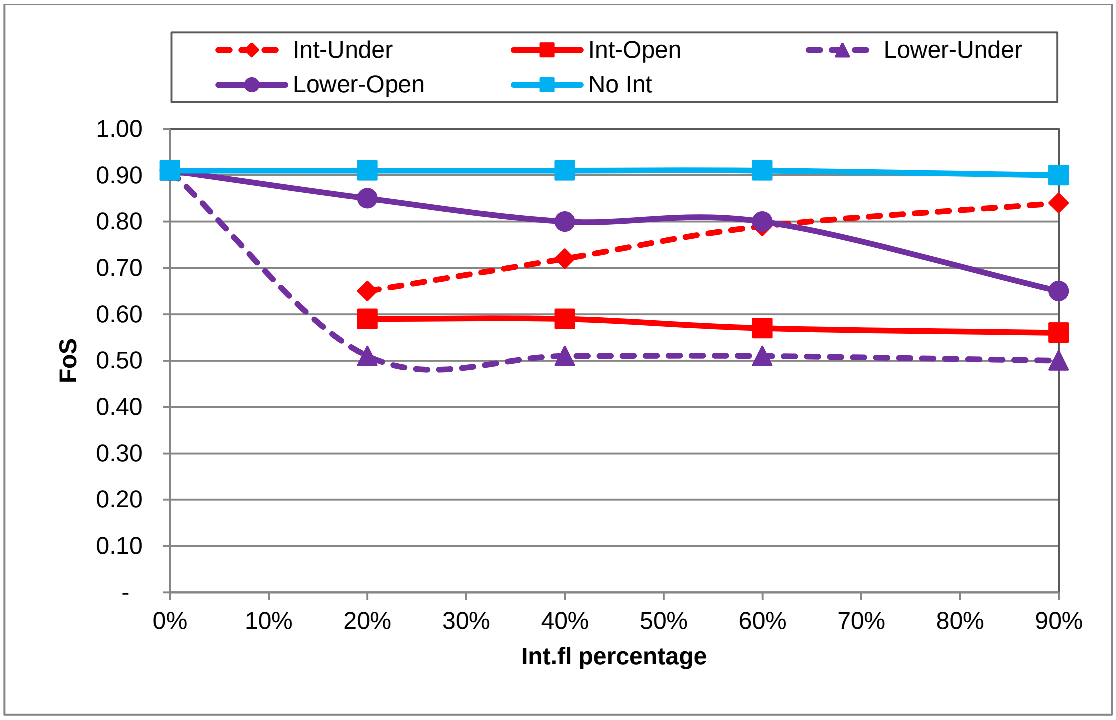


Figure 85: FoS of the medium firecells in WL and WM purpose groups over the variation of intermediate floor sizes and fire locations.

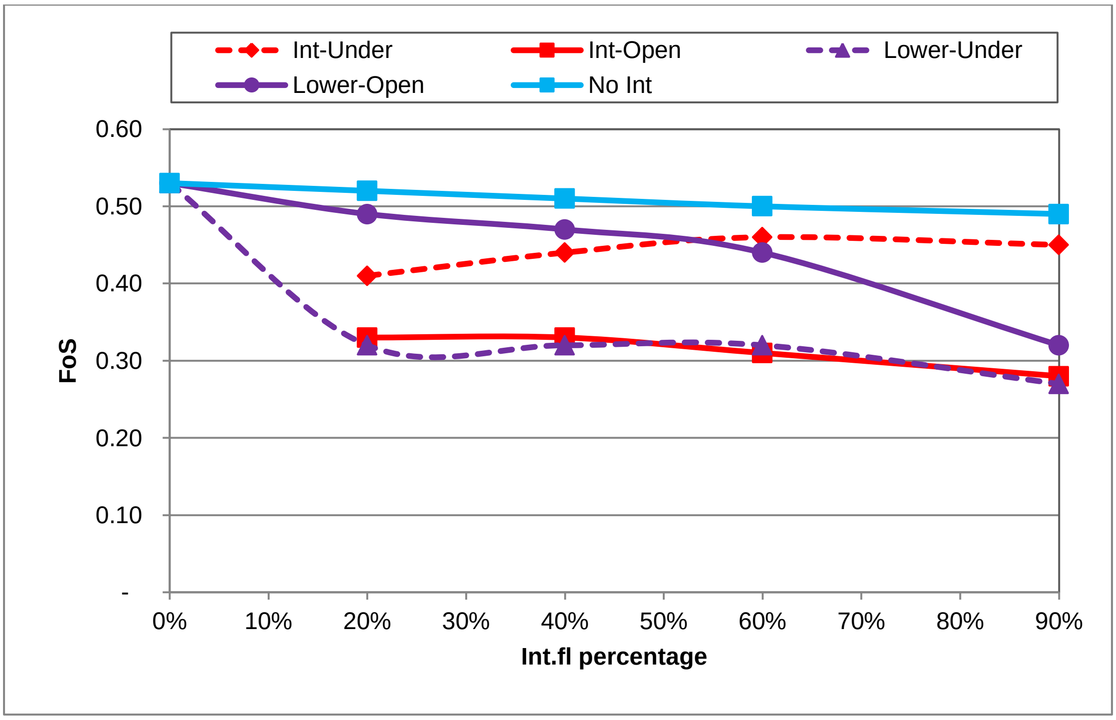


Figure 86: FoS of the medium firecells in CL purpose group over the variation of intermediate floor sizes and fire locations.

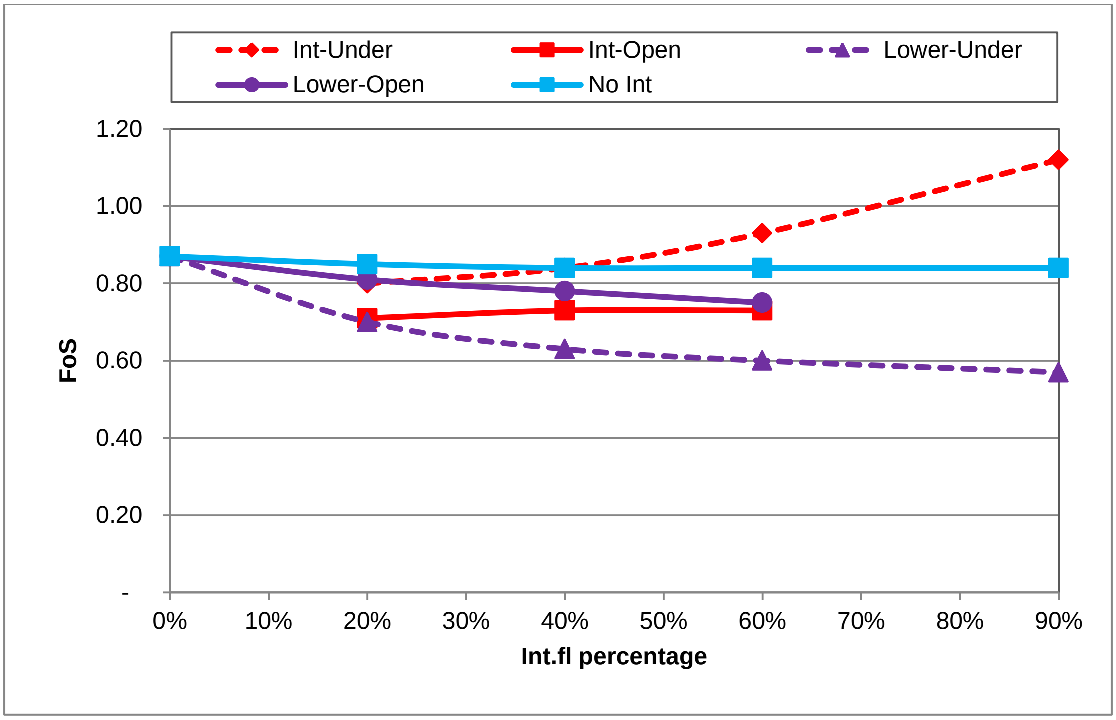


Figure 87: FoS of the small firecells in WL and WM purpose groups over the variation of intermediate floor sizes and fire locations.

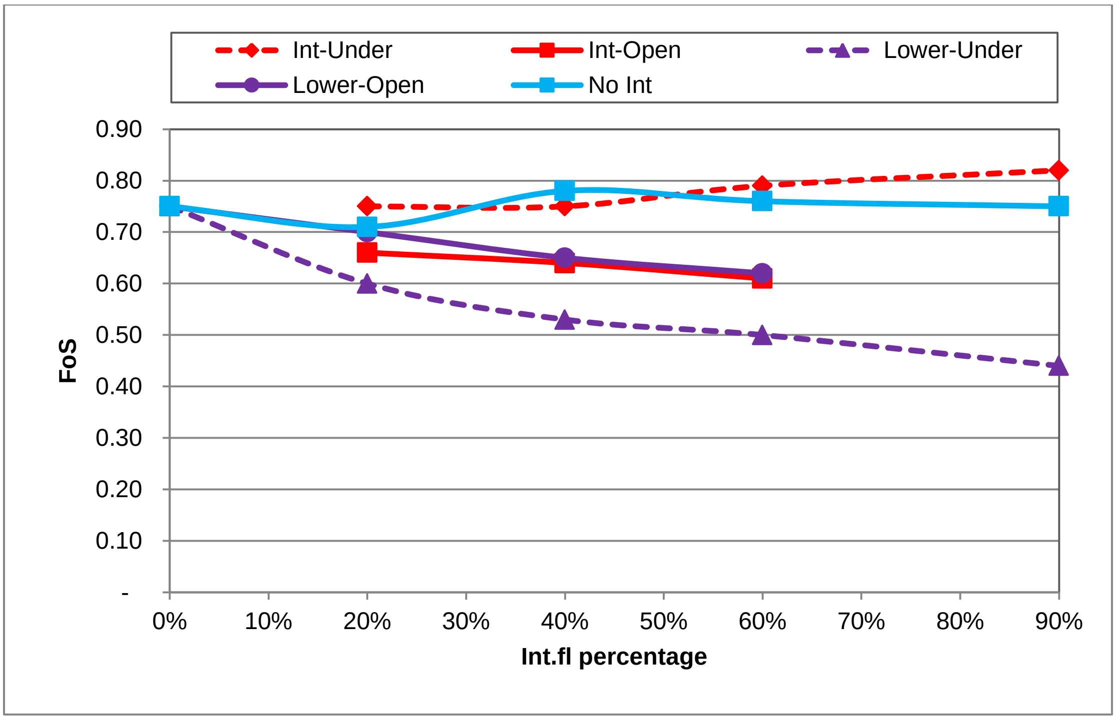


Figure 88: FoS of the small firecells in CS purpose group over the variation of intermediate floor sizes and fire locations.

In summary, the occupants of the firecell containing intermediate floors would have a higher level of risk compared to the occupants of the equivalent firecell without intermediate floors. When a fire occurs in the open area, occupants on the intermediate floors would have a higher level of risk than the occupants of the lower floor but when a fire is located under the intermediate floor, the level of risk to the occupants on the intermediate floors can be considered as the same as the occupant of the lower floor. The level of risk to the occupants of the firecells containing intermediate floors would increase when the intermediate floor size increases. However, there are no clear cut-off points at which a higher level of fire safety precaution is desirable. The scenario when a fire is located under the intermediate floor can be considered as the worst scenario in terms of fire location in designing fire safety for a fire cell containing intermediate floors. Location of the exits is very important in fire safety design but it becomes much more critical for a firecell containing intermediate floors.

The details of the FoS for all studied firecells can be found in Table D1 to Table D5 of Appendix D.

7.4 Effect of occupant load

Each studied firecell size in this project was assessed with different purpose groups; working (WL and WM) and crowd (CS or CL) which have different occupant densities as described in section 4.3 of this report. The effect of purpose group (occupant load) on the safety level of the occupants was assessed by comparing the FoS of each firecell size in two different purpose groups in the same graph.

The FoS of the intermediate and lower floors of the large 8m firecells containing intermediate floors with different occupant loads (purpose groups) by the variation of intermediate floor sizes are presented in Figure 89 and Figure 90.

Figure 89 shows the FoS of the intermediate floors of the large 8m firecells containing intermediate floors in different purpose groups WL and WM, and CL by the variation of intermediate floor sizes and fire locations. If a fire occurs under the intermediate floor, the FoS of the intermediate floors increase when the intermediate floor size increases. The FoS of the intermediate floors decrease when the intermediate floor size increases if a fire is in the open area, however the FoS of the intermediate floor of the firecell with lower occupant load (WL and WM) is significantly greater than that of the firecell with higher occupant load (CL).

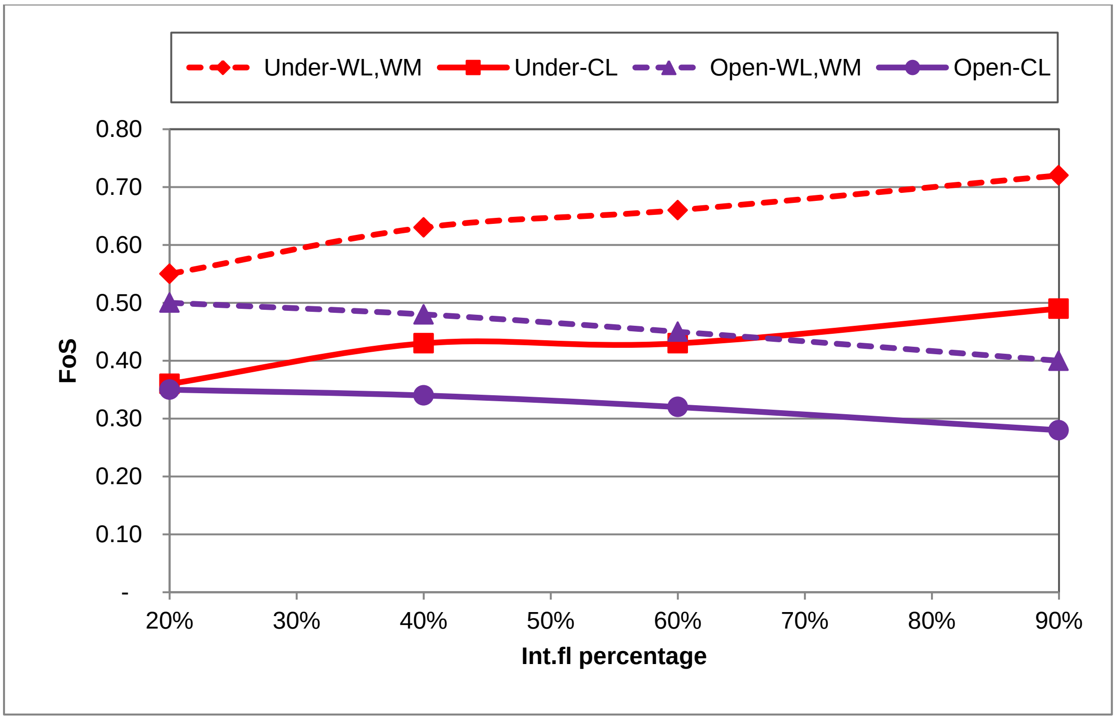


Figure 89: FoS of the intermediate floors of the large 8m firecells by the variation of intermediate floor sizes and purpose groups.

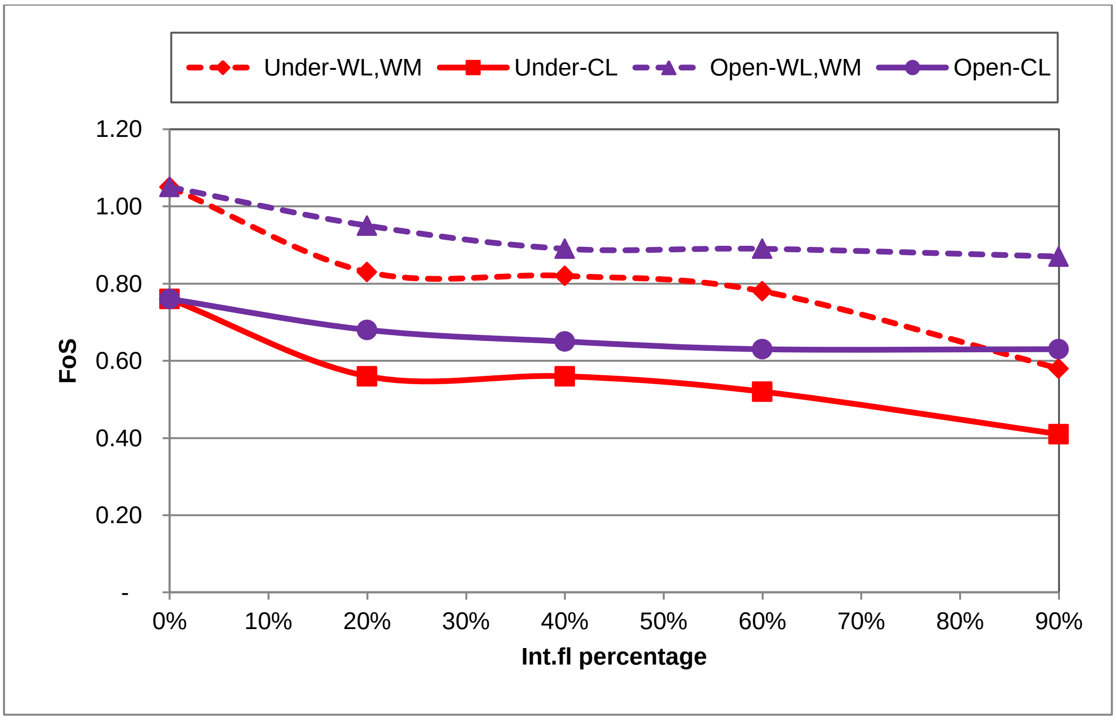


Figure 90: FoS of the lower floors of the large 8m firecells by the variation of intermediate floor sizes and purpose groups.

The FoS of the lower floors of the large 8m firecells containing intermediate floors in different purpose groups WL and WM, and CL over the variation of intermediate floor sizes and fire locations are illustrated in Figure 90. With the same fire location, the FoS of the lower floors decrease as the intermediate floor size increases but the FoS of the lower floor of the firecell with higher occupant load (CL) is considerably less than that of the firecell with lower occupant load (WL and WM).

The analysis of the effect of the occupant load on the FoS of the intermediate and lower floors above is for the large firecells with ceiling height of 8m however, all other studied firecells have the same trends as these firecells (Figure 89 and Figure 90). Refer to Figure D1 to Figure D8 of Appendix D for more graphs of the FoS for the small, medium, large 10 m and large 12 m firecells.

In summary, the occupant load has a significant impact on the FoS of the occupants of both intermediate and lower floors, therefore, occupant load should be considered in conjunction with the size of intermediate floors in designing fire systems for a firecell containing intermediate floors.

7.5 Effect of ceiling height

In general, the higher the ceiling height the greater the smoke reservoir is therefore, the smoke filling time (ASET) will increase. However, the higher the fire plume the more air will be entrained into the plume which will result in more smoke entrainment to fill the smoke reservoir. The more air entrainment into the plume will reduce the soot concentration of the smoke production, the visibility therefore will be higher. The detection time of the automatic fire alarm system depends on the ceiling height, the higher the ceiling height the longer the detection time is, consequently, the greater the RSET is.

In this project, the large firecells were studied with three different firecell ceiling heights: 8 m, 10 m and 12 m to investigate the effect of the ceiling height on the safety level of the occupants. The FoS of the large firecells with ceiling height of 8 m, 10 m and 12 m in purpose groups WL and WM, and CL over the variation of intermediate floor sizes in two fire locations are plotted in Figure 91 to Figure 94.

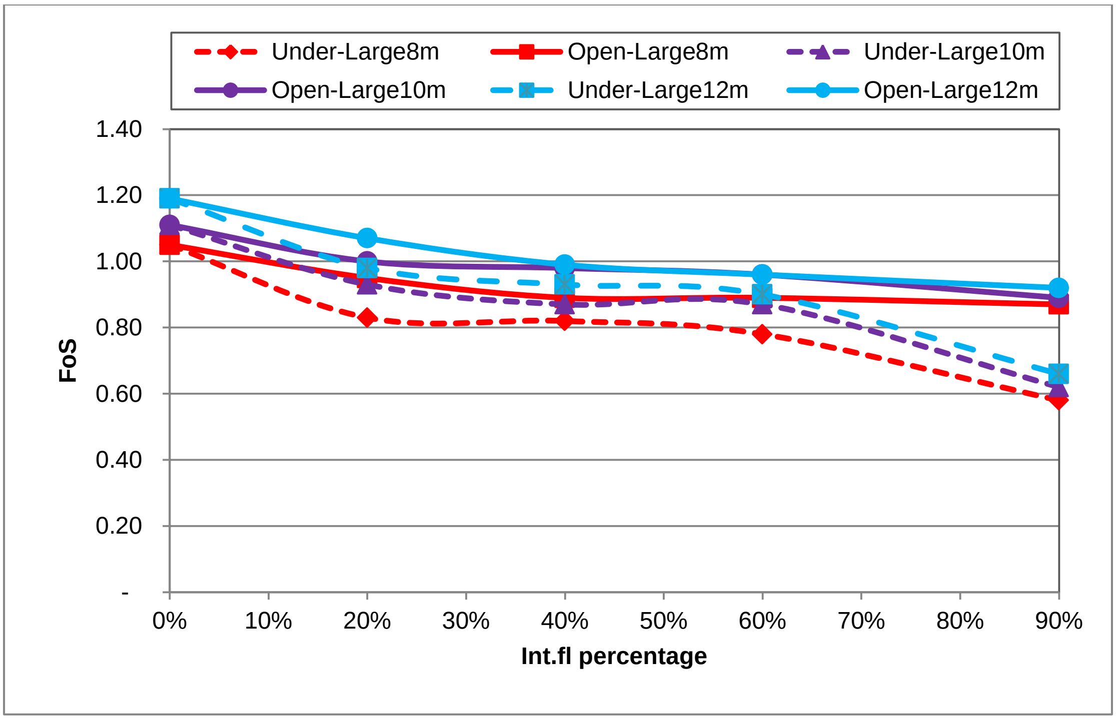


Figure 91: FoS of the lower floors of the large firecells in WL and WM purpose groups with different ceiling height by the variation of intermediate floor sizes.

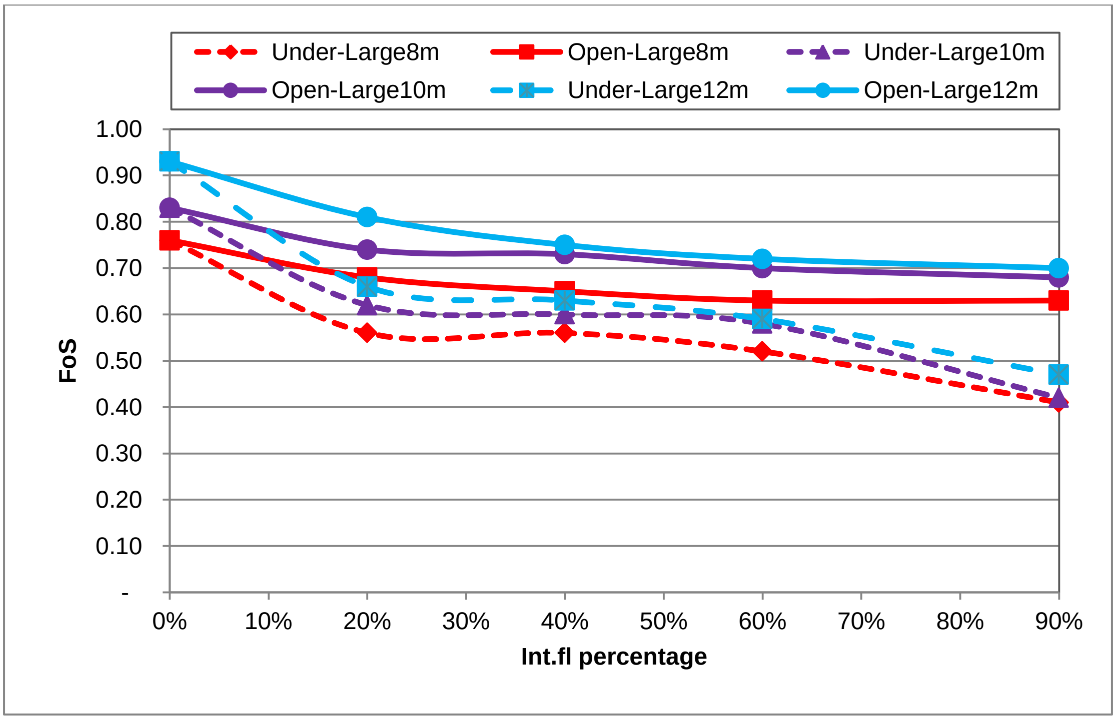


Figure 92: FoS of the lower floors of the large firecells in CL purpose group with different ceiling height by the variation of intermediate floor sizes.

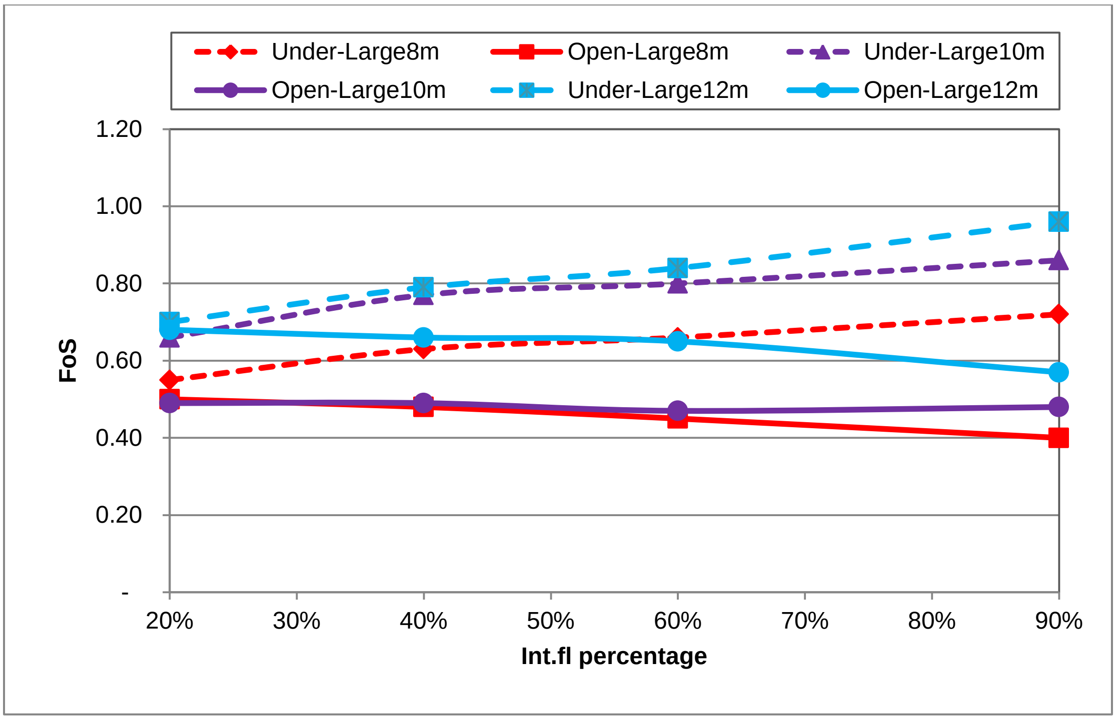


Figure 93: FoS of the intermediate floors of the large firecells in WL and WM purpose groups with different ceiling height by the variation of intermediate floor sizes.

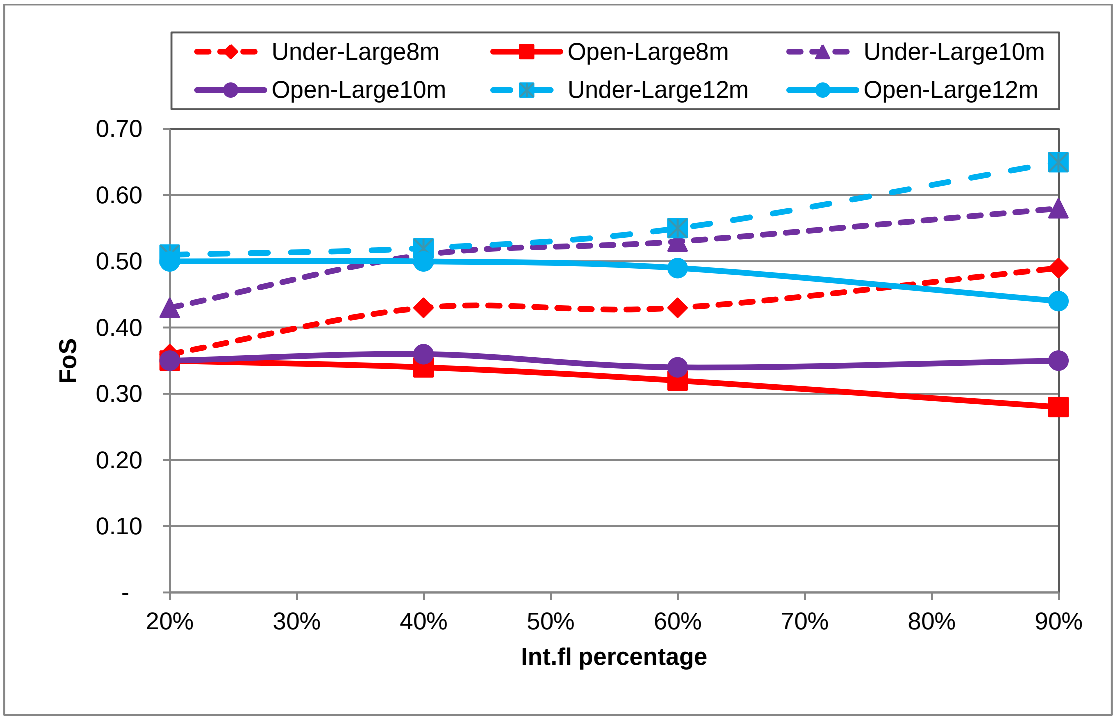


Figure 94: FoS of the intermediate floors of the large firecells in CL purpose group with different ceiling height by the variation of intermediate floor sizes.

The figures show that the large firecells with the same floor areas but different ceiling heights have the same trends in FoS of both intermediate and lower floors. The FoS of the lower floors decrease when the intermediate floor size increases. When a fire occurs under the intermediate floor, the FoS of the intermediate floors increase when the intermediate floor size increases and the FoS of the intermediate floors decrease when the intermediate floor size increases if a fire occurs in the open area. However the higher the ceiling height the greater the FoS of both intermediate and lower floors is, regardless of the intermediate floor size, fire location and purpose group.

In summary, the ceiling height of the firecell has a moderate impact on the safety level of occupants in the firecell containing intermediate floors. With the same floor area, the higher the ceiling height the greater the safety level of the occupants is.

7.6 Effect of fire alarm system

According to clauses 4.5.17, 6.21.5 and 6.21.6 of C/AS1 [7], all firecells containing intermediate floors that are not limited area intermediate floors must have a smoke control system installed which is activated by smoke detectors. The definition of limited area intermediate floor is presented in clause 6.21.5 and 6.21.6 of C/AS1 [7]. The firecells containing intermediate floors with an area that exceeds 20% for closed and 40% for open intermediate floors therefore must have smoke detectors installed throughout.

C/AS1 does not require automatic fire alarm systems in the small (all purpose groups) and medium firecells (WL and WM) studied in this project (see section 4.4). The detection of a fire relies on occupants so it is not easy to quantify the difference in FoS when smoke detectors are installed. For the large firecells in the CL purpose group studied, smoke detectors are required by C/AS1 so the detection type does not change when a smoke control system is installed.

The medium firecells with purpose group CL and the large firecells with purpose groups WL and WM studied in this project are only required to have heat detectors as a part of FSPs by C/AS1. These firecells therefore were studied in two scenarios; with and without the changing of heat detectors to smoke detectors when the intermediate floor area exceeds the above limit to investigate the impact of fire detection systems on the FoS.

Figure 95 to Figure 98 illustrate the FoS of the intermediate and lower floors of the firecells containing open intermediate floors when the heat detectors are replaced by smoke detectors, as the intermediate floor’s area exceed 40%. The FoS of both intermediate floor and lower floors increase when heat detectors are replaced by smoke detectors regardless of the firecell size and fire location. The rate at which the FoS of both intermediate and lower floors increase ranges from about 10% to nearly 20% when heat detectors are replaced by smoke detectors.

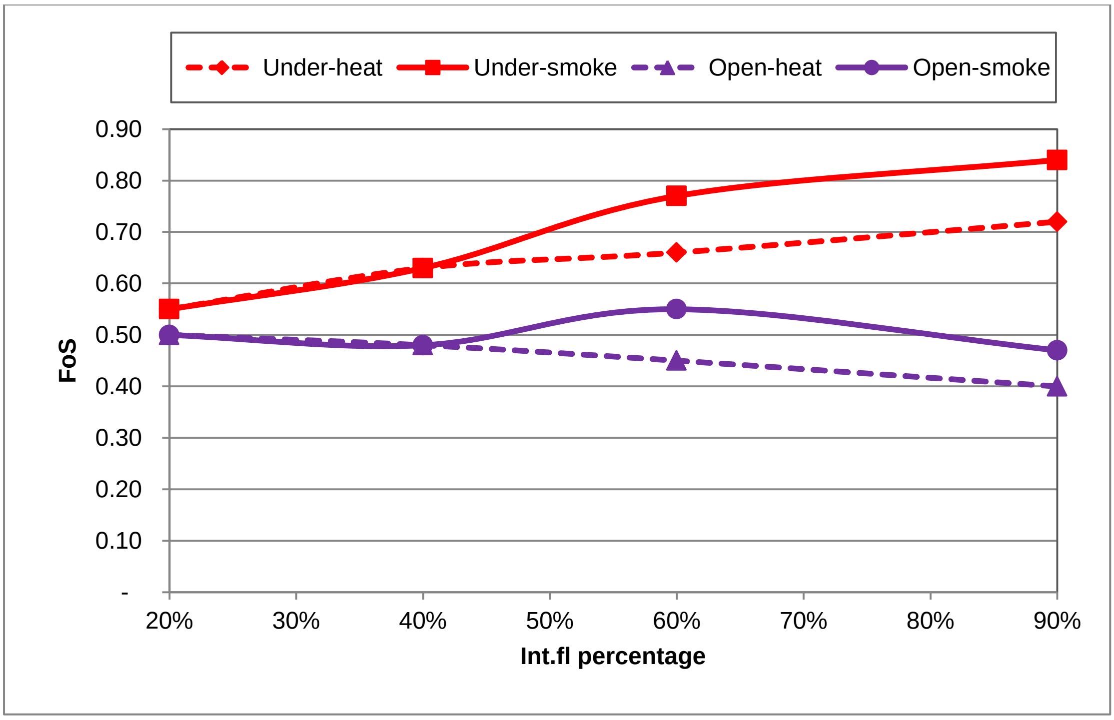


Figure 95: Comparison of FoS of the intermediate floors of the large 8m firecells in WL and WM purpose groups with different fire alarm systems.

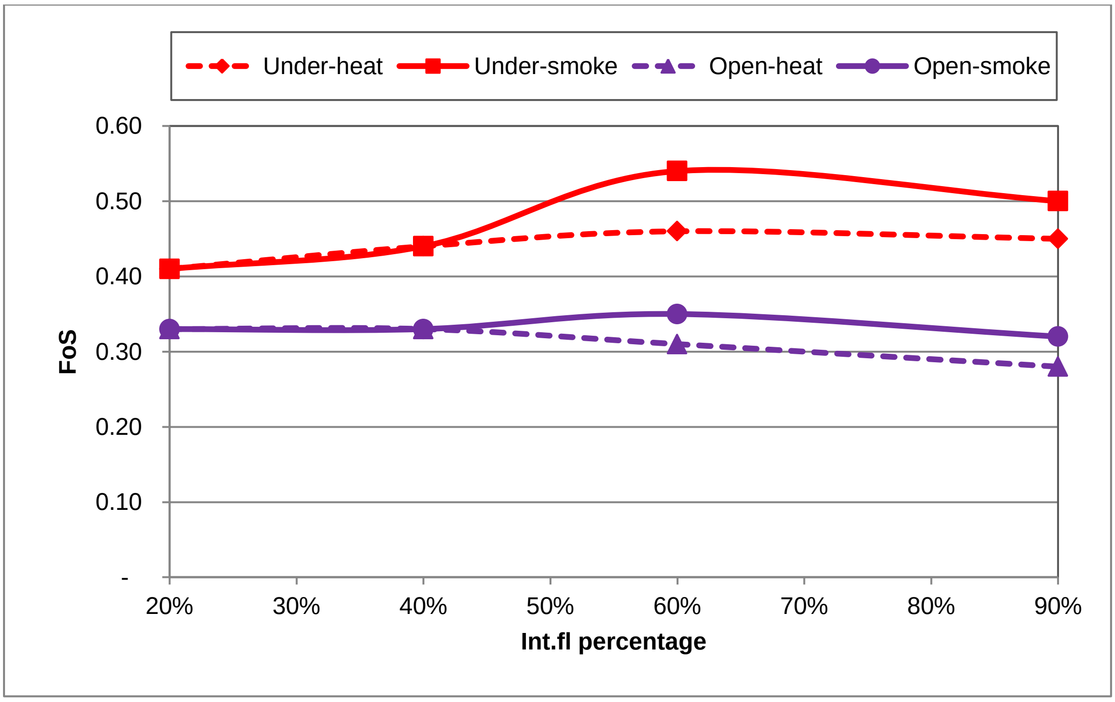


Figure 96: Comparison of FoS of the intermediate floors of the medium firecells in CL purpose group with different fire alarm systems.

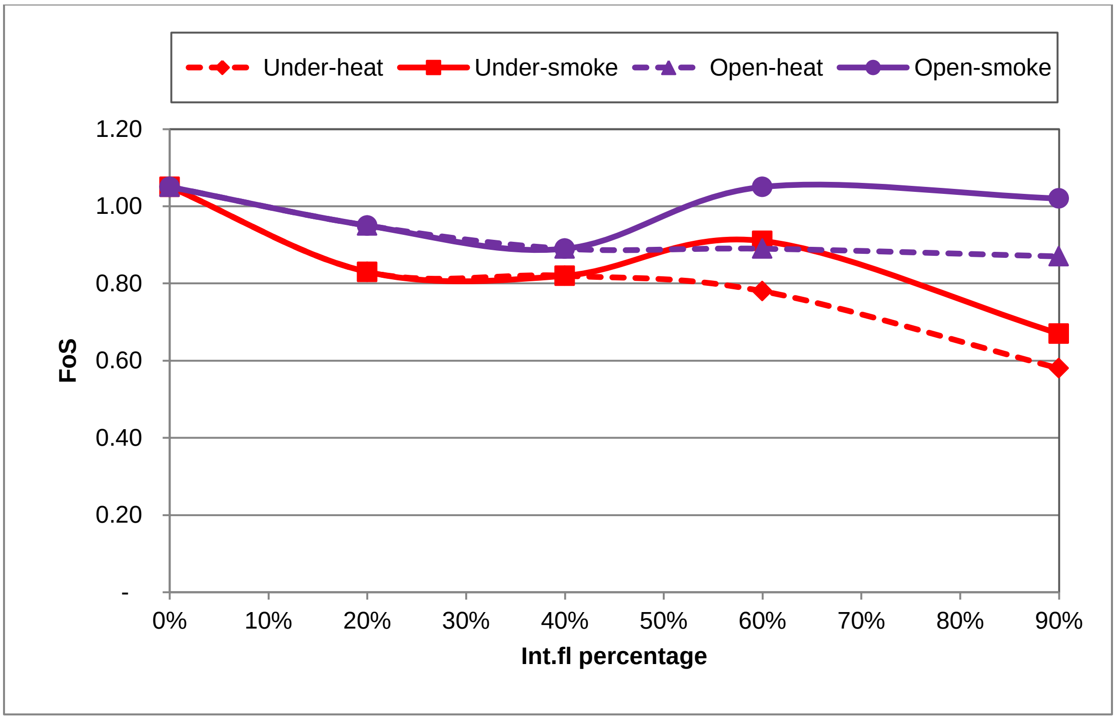


Figure 97: Comparison of FoS of the lower floors of the large 8m firecells in WL and WM purpose groups with different fire alarm systems.

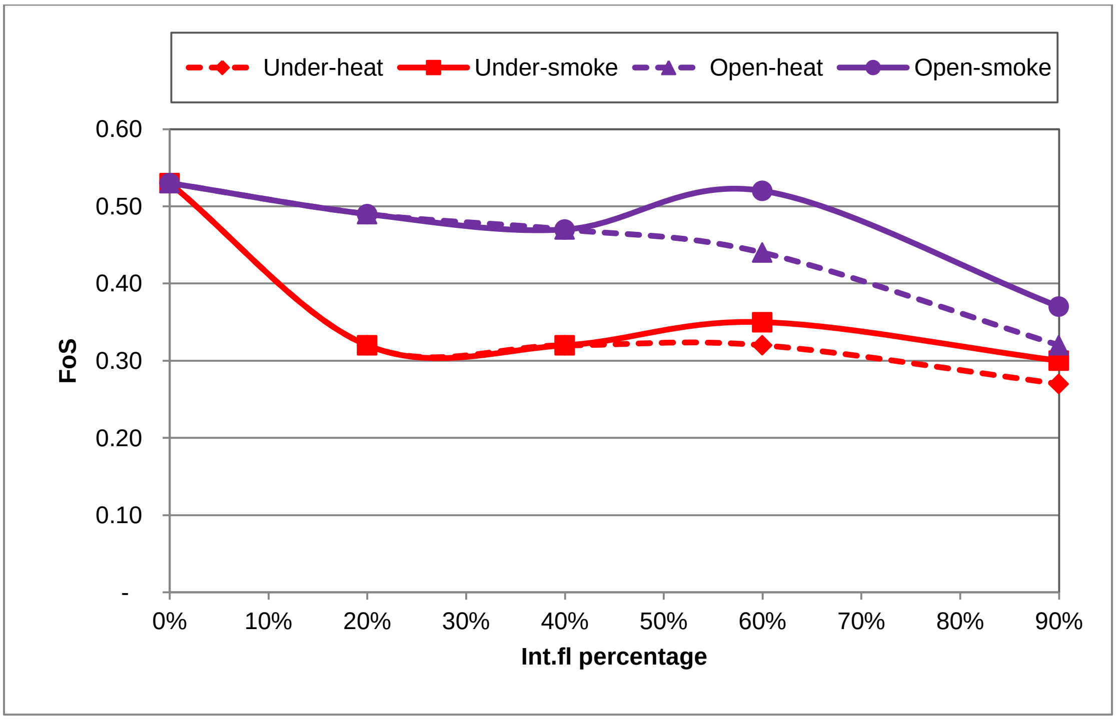


Figure 98: Comparison of FoS of the lower floors of the medium firecells in CL purpose group with different fire alarm systems.

The analysis above indicates that the type of detection has a moderate impact on the level of safety of the occupants in the firecells containing intermediate floors. Smoke detection provides a moderately higher safety level than heat detectors for occupants in the firecells containing intermediate floors.

7.7 Effect of blocked exits for unsprinklered firecells

The requirements for unusable escape routes are stated in Clause 3.3.2.b) of C/AS1: "*Except where dead ends and single escape routes are permitted, in unsprinklered firecells the total required width shall still be available should one of the escape routes be unusable due to the location of the fire or any other reason*."

As mentioned in section 4.1, no additional escape routes were provided to the unsprinklered firecells but each escape route was sized to ensure that the remaining unblocked escape routes of the firecells provide the required total width. The studied firecells that are unsprinklered and require more than one exit are: small firecell in CS purpose group, medium firecells in both purpose groups WL and WM, and CL, and large firecell in WL and WM purpose groups (see section 4.4). These firecells therefore were studied in two scenarios; with and without a blocked exit on the lower floor to investigate the impact of blocked exits on the safety level of the occupants of the firecells containing intermediate floors.

The effect of blocked exits on the safety level of the occupants of the firecells containing intermediate floors was assessed by comparing the FoS of the same firecell with and without a blocked exit in the same graph.

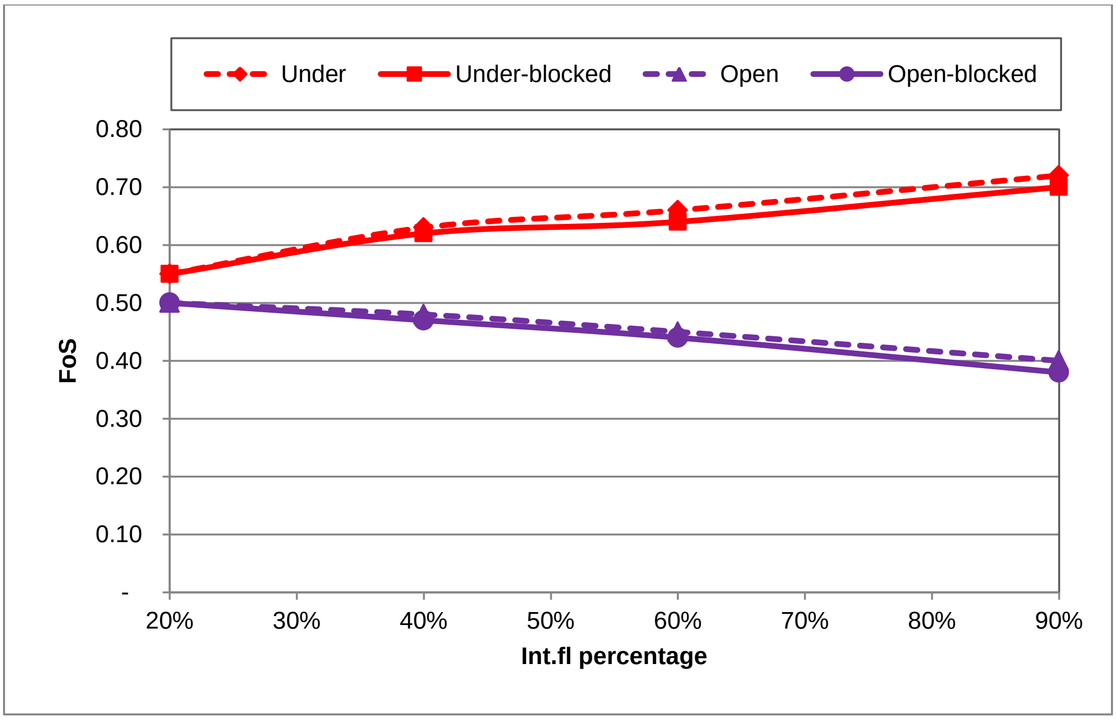


Figure 99: FoS of the intermediate floor of the large 8m firecell in WL and WM purpose groups by the variation of intermediate floor sizes with and without a blocked exit.

Figure 99 shows the FoS of intermediate floors of the large 8m firecell containing intermediate floors in WL and WM purpose groups with the variation of intermediate sizes in two scenarios: with and without a blocked exit. The FoS of the intermediate floors are almost unchanged regardless of the intermediate floor size and fire location. This means a blocked exit on the lower floor would have very little impact on the level of safety of the occupants of the intermediate floors of the unsprinklered firecells.

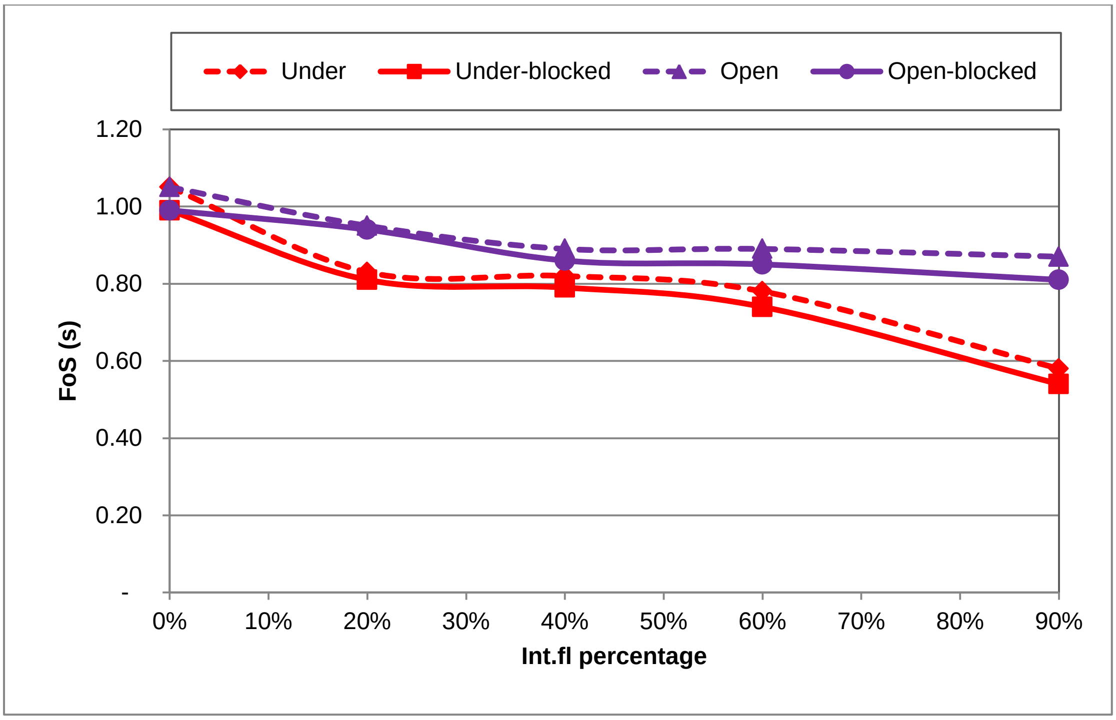


Figure 100: FoS of the lower floor of the large 8m firecell in WL and WM purpose groups by the variation of intermediate floor sizes with and without a blocked exit.

The FoS of lower floors of the large 8m firecell containing intermediate floors in WL and WM purpose groups, with the variation of intermediate sizes in two scenarios: with and without a blocked exit are shown in Figure 100. The FoS of lower floors of the firecell without a blocked exit is always greater than that of the firecell with a blocked exit. The difference of FoS between the two scenarios (with and without a blocked exit) is within 10%. This means the safety level of the occupants of the lower floors of the unsprinklered firecells containing intermediate floors would be affected when an exit on the lower floor was blocked but the effect would not be significant.

The analysis of the effect of blocked exits on the FoS of the intermediate and lower floors above is for the large firecell with ceiling height of 8m in purpose groups WL and WM, however, all other studied firecells that are unsprinklered and required more than one exit have very similar trends as this firecell (Figure 99 and Figure 100). Refer to Figure D9 to

Figure D14 of Appendix D for more graphs of the FoS for other studied firecells in both scenarios; with and without a blocked exit.

The analysis indicates that when there is a blocked exit on the lower floor, the risk level of the occupants in the unsprinklered firecell containing intermediate floors would always be higher than when no exit is blocked. However, the effect of the blocked exits on the safety level of the occupants would not be significant when the remaining unblocked exits of the firecells provide the total width required by C/AS1.

7.8 Effect of intermediate floor height

To investigate how the intermediate floor height affect the FoS of the intermediate and lower floors, the large firecell with 8 m ceiling height was analysed with 3 m intermediate floor height, the results were then compared with the large firecell 8m with intermediate floor height of 5 m (which had been analysed in the previous section).

The FoS of the intermediate and lower floors of the large 8m firecell with different intermediate floor height (3 and 5 m) by the variation of intermediate floor sizes are plotted in Figure 101 to Figure 104.

Figure 101 and Figure 102 illustrate the FoS of the lower floors of the large 8m firecell with different intermediate floor heights by the variation of intermediate floor sizes for purpose groups WL and WM, and CL. The FoS of the firecells containing intermediate floors is always less than that of the equivalent firecell without intermediate floors. Regardless of the fire location, purpose group and intermediate floor height, the FoS of the lower floor, if a fire is in the open area, is greater than if a fire is located under the intermediate floor. When a fire occurs in the open area, the FoS of the two firecells with different intermediate floor heights are very similar and decrease when the intermediate floor size increases. This means intermediate floor height would not have much of an effect on the occupants on the lower floor if a fire occurs in the open area.

If a fire is located under the intermediate floor, the FoS of the lower floor of the firecell with 5 m intermediate floor height decreases gradually when the intermediate floor size increases, while the FoS of the lower floor of the firecell with 3 m intermediate floor height changes very little. However, the FoS of the lower floor of the firecell with 3 m intermediate floor height is significantly less than that of the firecell with 5 m intermediate floor height. This means the occupants on the lower floor of the firecell with lower intermediate floor height would have a much higher level of risk than the occupants of the firecell with a higher intermediate floor height.

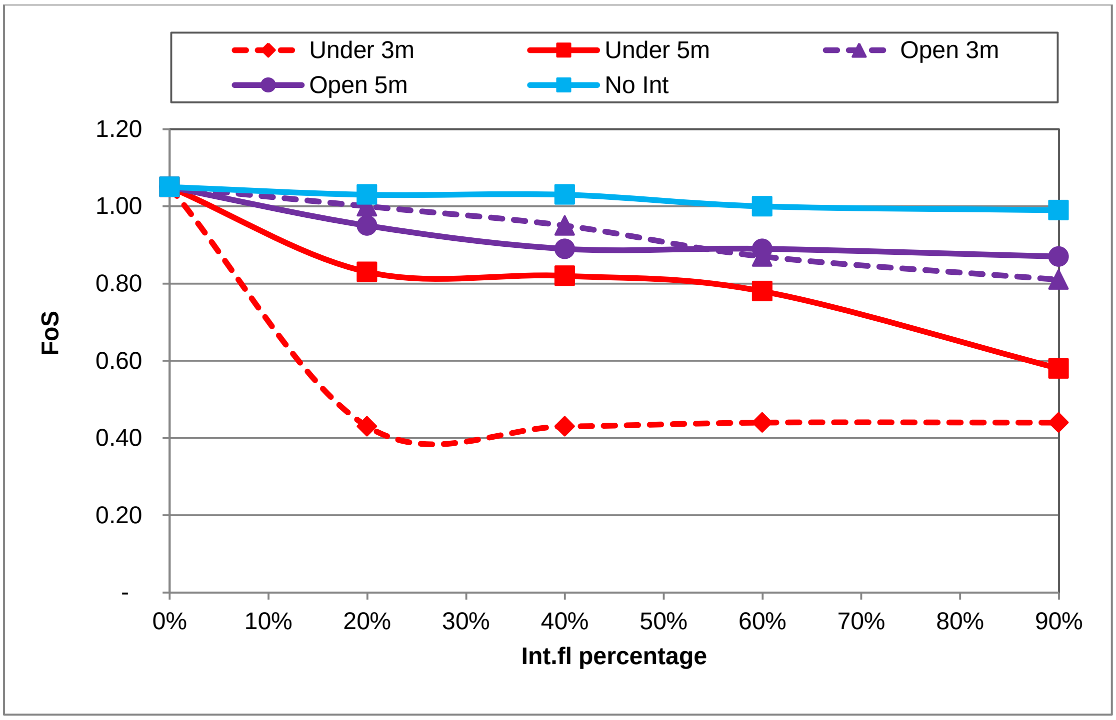


Figure 101: Comparison of FoS of the lower floors the large 8m firecells in WL and WM purpose groups containing open intermediate floors at 3 and 5 m in height with the variation of intermediate floor sizes.

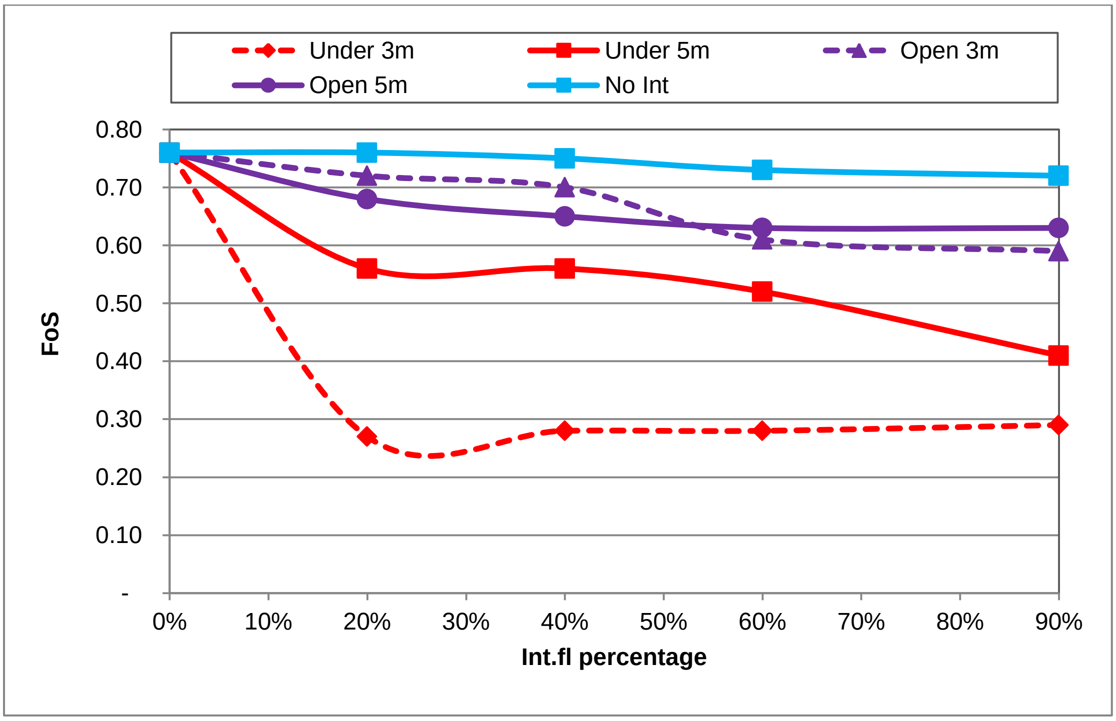


Figure 102: Comparison of FoS of the lower floors of the large 8m firecells in CL purpose group containing open intermediate floors at 3 and 5 m in height with the variation of intermediate floor sizes.

Figure 103 and Figure 104 show the FoS of the intermediate floors of the large 8m firecell with different intermediate floor height by the variation of intermediate floor sizes for purpose groups WL and WM, and CL. The FoS of the intermediate floors of the two firecells with different intermediate floor height have very similar trends. Regardless of the fire location, purpose group and intermediate floor height, the FoS of the intermediate floor of the firecell with a higher intermediate floor is less than that of the firecell with a lower intermediate floor. This means the occupants on the intermediate floor of the firecell with a lower intermediate floor height would have a lower level of risk than the occupants on the intermediate floor of the firecell with a higher intermediate floor height. However, the occupant on the intermediate floor must escape via the lower floor so the level of risk of the occupants on the intermediate floors also depends upon the FoS of the lower floor.

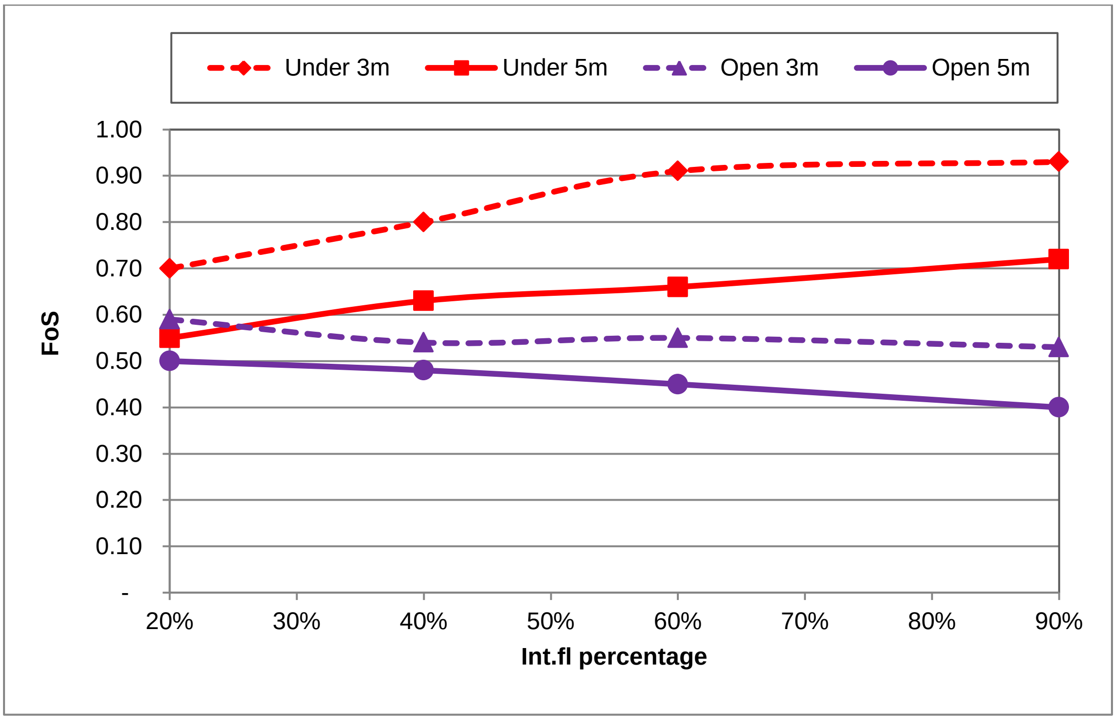


Figure 103: Comparison of FoS of the intermediate floors the large 8m firecells in WL and WM purpose groups containing open intermediate floors at 3 and 5 m in height with the variation of intermediate floor sizes.

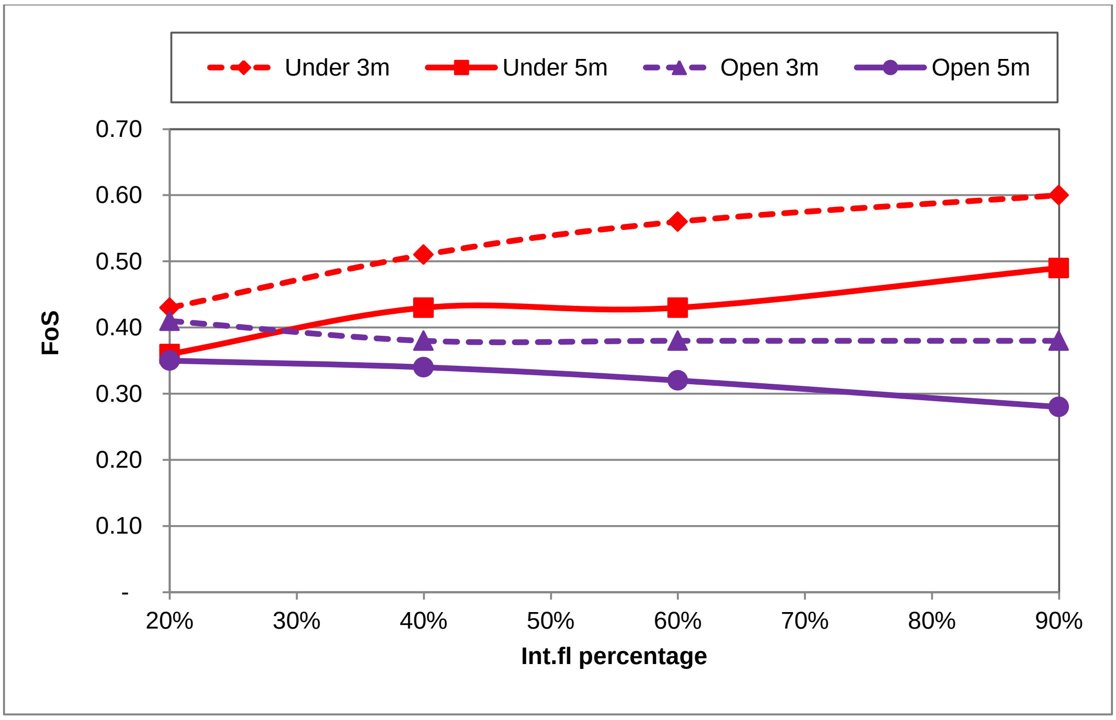


Figure 104: Comparison of FoS of the intermediate floors of the large 8m firecells in CL purpose group containing open intermediate floors at 3 and 5 m in height with the variation of intermediate floor sizes.

In summary, when a fire occurs under the intermediate floor, the intermediate floor height has a significant impact on the level of risk of the occupants on the lower floor: the lower the intermediate floor height the higher the level of risk of the occupants is. However, the occupants on the lower floor would be affected very little by the intermediate floor height if a fire is in the open area. Regardless of the fire location, the occupants on the intermediate floor of the firecell with a higher intermediate floor would have a higher level of risk than the firecell with a lower intermediate floor height.

7.9 Effect of fire growth rate

For a given firecell, when the fire growth rate increases, the ASET of both intermediate and lower floors decreases as shown in section 5.6. This means occupants would have less time to evacuate when the fire growth rate increases. However, the faster the fire growth rate the earlier the fire would be detected, consequently the RSET would decrease. In order to investigate how the fire growth rate affects the level of safety of the occupants, the small, medium and large 8 m firecells containing open intermediate floors ranging from 0% to 40% were also assessed with ultra fast, moderate and slow fires. The terms “Eq-WL,WM”, “Eq-CS” and “Eq-CL” used in the graphs are referred to the equivalent firecells without intermediate floors in WL and WM ,and CS or CL purpose groups respectively.

Figure 105 and Figure 106 illustrate the FoS of the lower floors of the small firecells with open intermediate floors over the variation of fire growth rates. For comparison, the FoS of the equivalent firecells without intermediate floors that have the same occupant loads as the firecells containing intermediate floors are also plotted in these figures. Regardless of the fire location, intermediate floor size and purpose group, the FoS of the lower floor decreases when the fire growth rate increases. In both scenarios when a fire occurs under the intermediate floor and in the open area, the FoS the lower floor of the firecell containing intermediate floors is less than that of the equivalent firecell without intermediate floors. The FoS of the lower floors of the firecells in WL and WM purpose groups are greater than that of the firecell in CS purpose group. The figures also show that the rates at which the FoS of the lower floors in all scenarios decline are very similar.

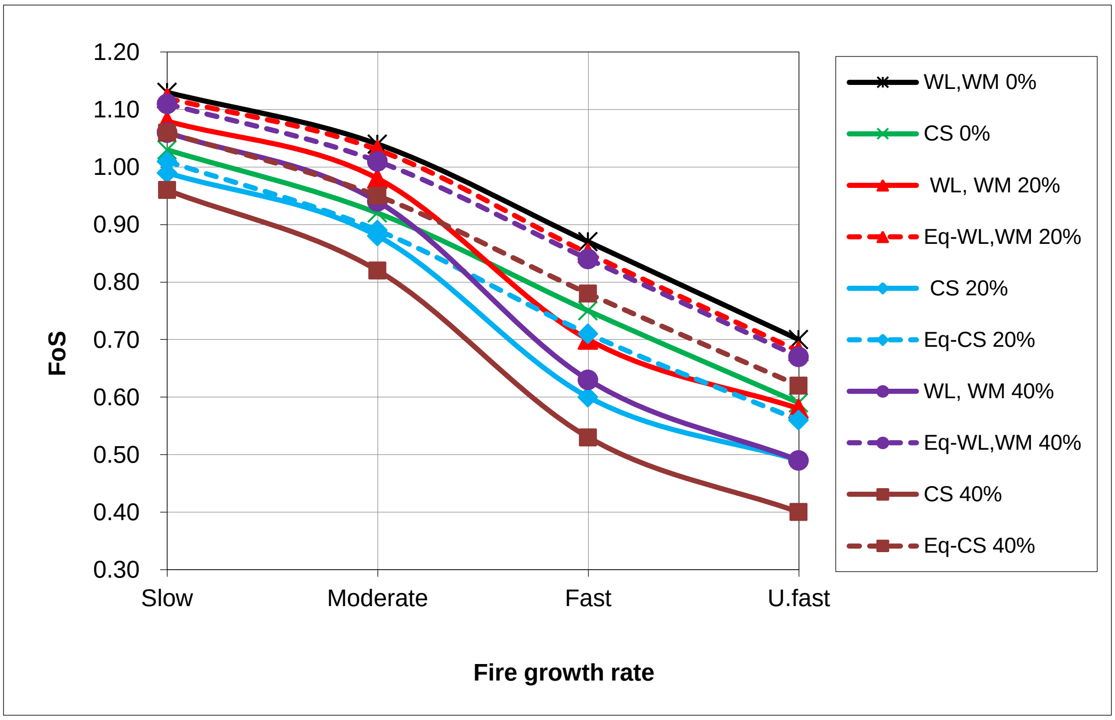


Figure 105: FoS of the lower floors by the variation of fire growth rates for small firecells with a fire located under the intermediate floor.

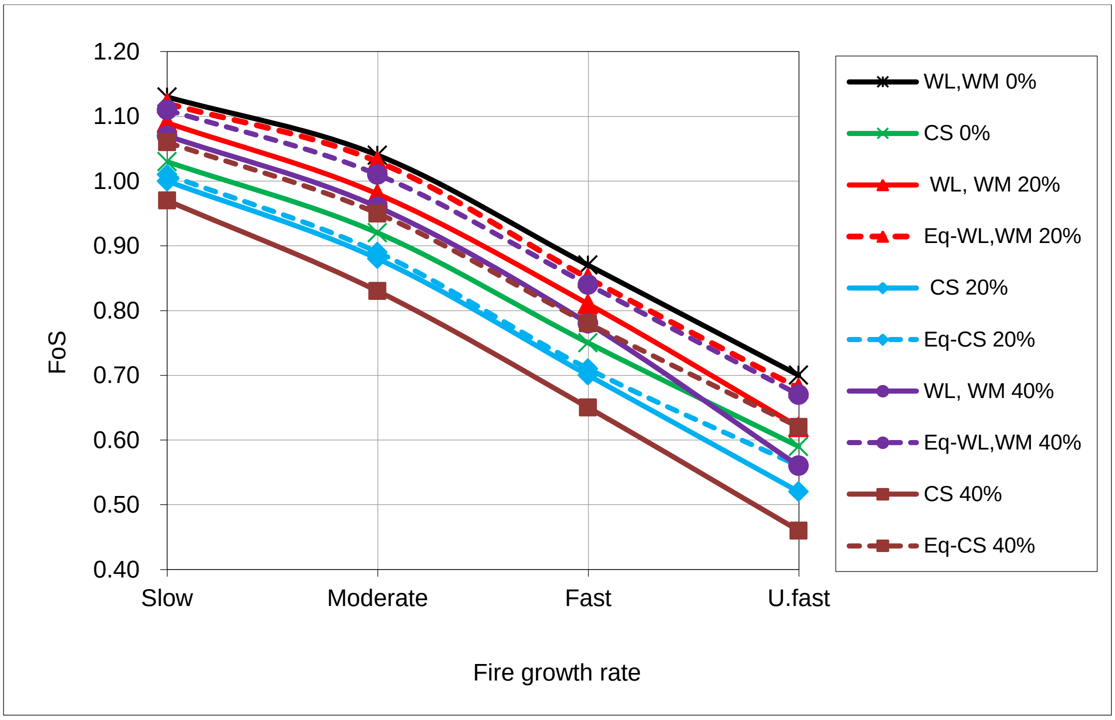


Figure 106: FoS of the lower floors by the variation of fire growth rates for small firecells with a fire located in the open area.

The FoS of the lower floors of the medium firecells with and without open intermediate floors over the variation of fire growth rates are presented in Figure 107 and Figure 108. Similar to the small firecells, regardless of the fire location, intermediate floor size and purpose group, the FoS of the lower floors of the medium firecell decreases when the fire growth rate increases. The FoS the lower floor of the firecell containing intermediate floors is less than that of the equivalent firecell without intermediate floors in all scenarios. The figures also show that the FoS of the lower floors of the firecells in WL and WM purpose groups are greater than that of the firecell in CL purpose group. The rates at which the FoS of the lower floors in WL and WM purpose groups decline are considerably greater than that of the firecells in CL purpose group.

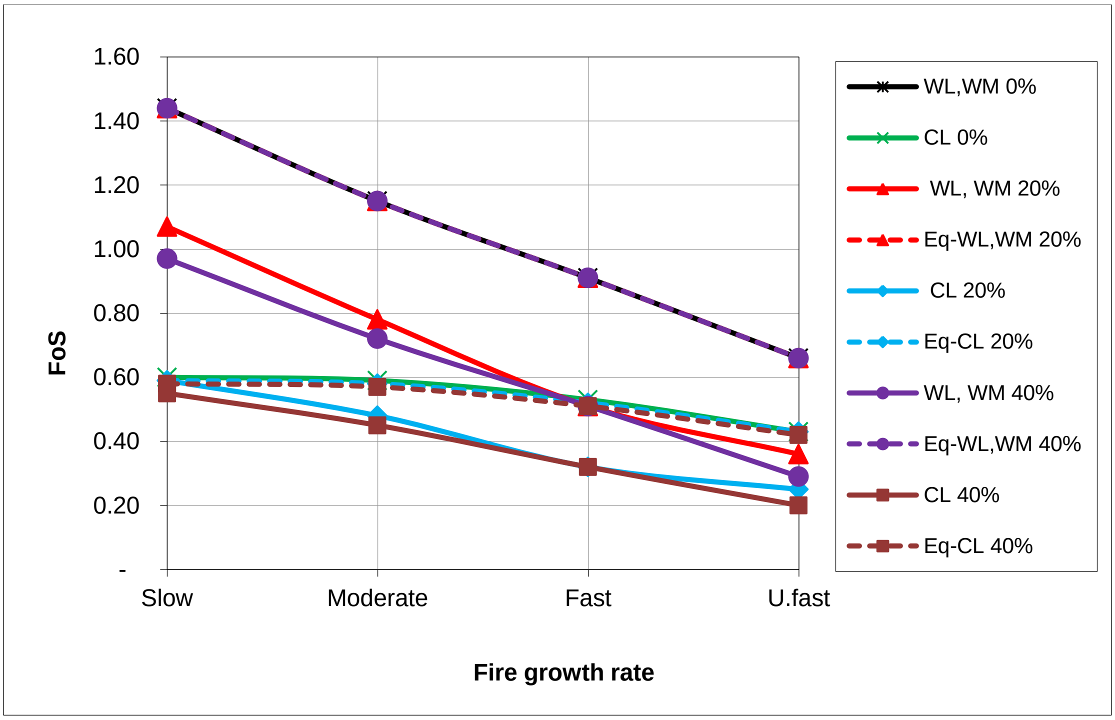


Figure 107: FoS of the lower floors by the variation of fire growth rates for medium firecells with a fire located under the intermediate floor.

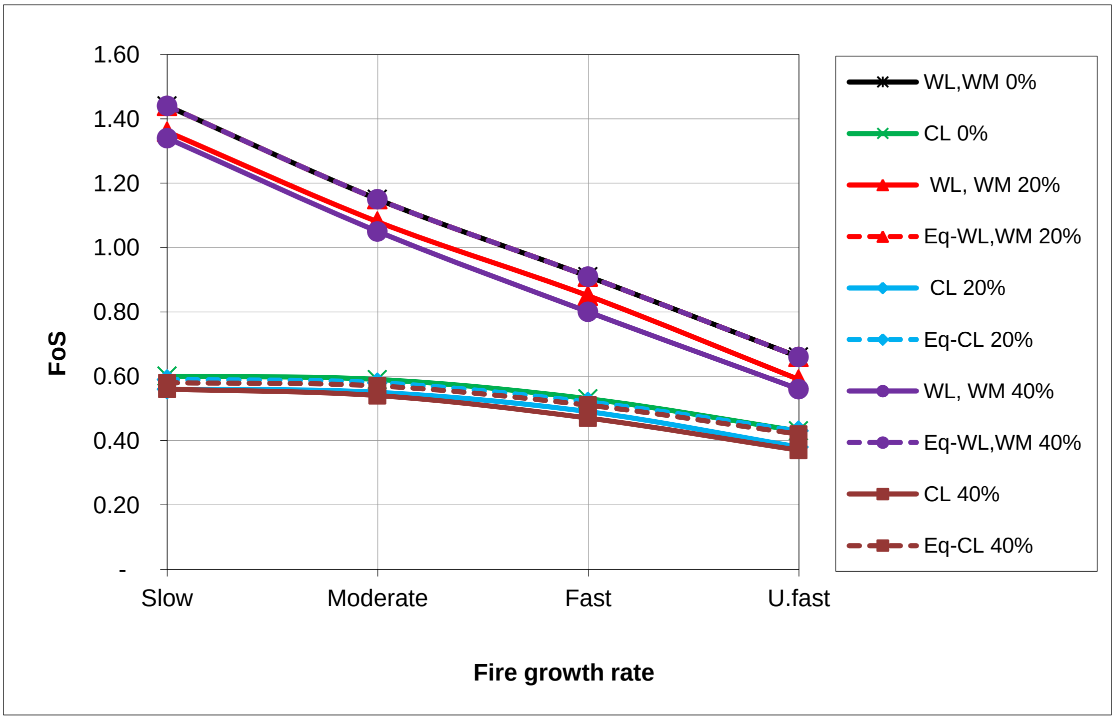


Figure 108: FoS of the lower floors by the variation of fire growth rates for medium firecells with a fire located in the open area.

Figure 109 shows the FoS of the lower floors of the large 8m firecells with and without open intermediate floors when a fire is under the intermediate floor over the variation of fire growth rates. Apart from the equivalent firecells without intermediate floors in WL and WM purpose groups, the FoS of the lower floors of other scenarios decreases when the fire growth rate increases. The FoS of the equivalent firecells without intermediate floors in WL and WM purpose groups increases slightly when the fire growth rate increases from slow to moderate then it starts to decrease as the fire growth rate continues to increase to fast and ultra fast. The detection times in the large 8m equivalent firecells without intermediate floors in WL and WM purpose groups are too long which strongly dominates the FoS of the slow and moderate fires while in other scenarios the FoS are governed by pre-movement times. Consequently the trend of FoS of the large 8m equivalent firecells without intermediate floors in WL and WM purpose groups are slightly different from others.

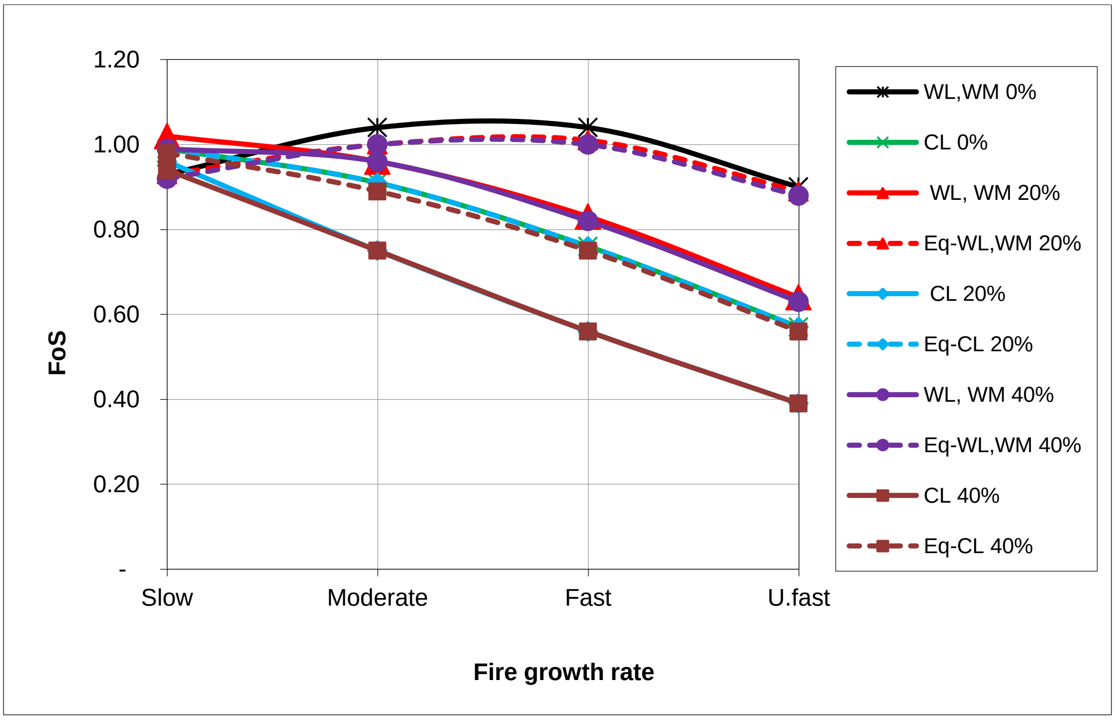


Figure 109: FoS of the lower floors by the variation of fire growth rates for large 8m firecells with a fire located under the intermediate floor.

The FoS of the lower floors of the large 8m firecells with and without intermediate floors when a fire occurs in the open area over the variation of fire growth rates are shown in Figure 110. For the firecells in CL purpose group, the FoS of the lower floor decreases when the fire growth rate increases regardless of the intermediate floor size. The FoS of the firecells with and without intermediate floors in WL and WM purpose groups when a fire is in the open area, increases slightly when the fire growth rate increases from slow to moderate then decrease as the fire growth rate continues to increase to fast and ultra fast. The detection times in the large 8m firecells with and without intermediate floors in WL and WM purpose groups when a fire occurs in the open area are too long which strongly dominates the FoS for the slow and moderate fires. While in CL purpose group the FoS are governed by pre-movement times, consequently the trend of FoS of the large 8m firecells with and without intermediate floors in purpose groups WL and WM are slightly different from purpose group CL.

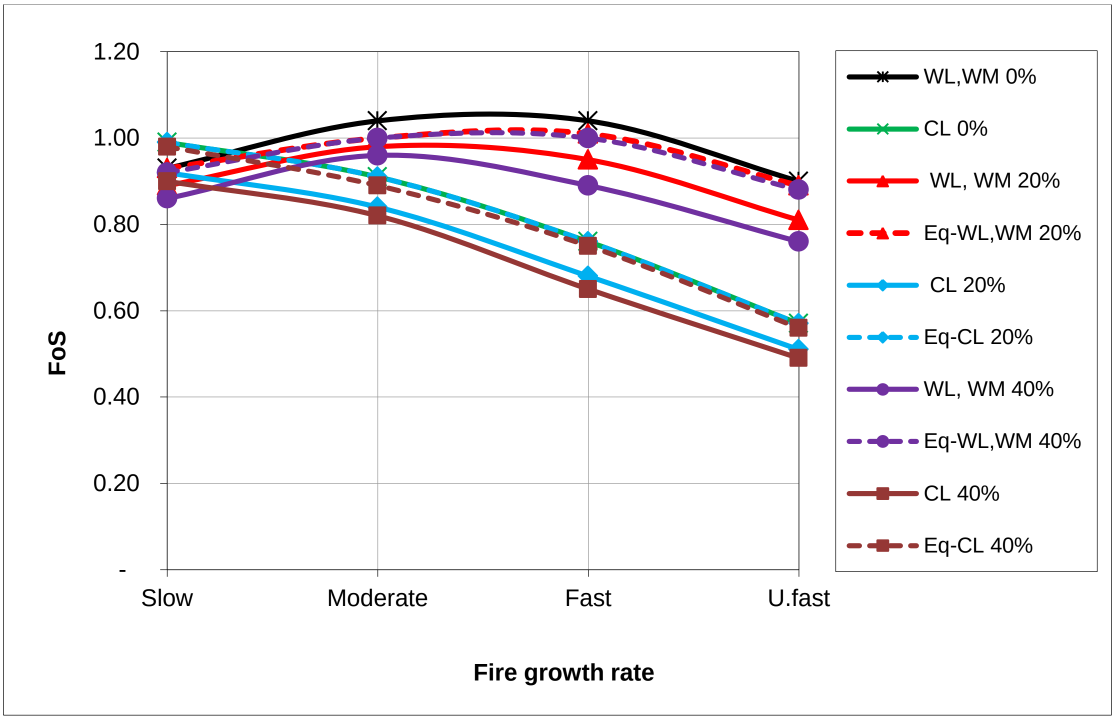


Figure 110: FoS of the lower floors by the variation of fire growth rates for large 8m firecells with a fire located in the open area.

Figure 111 and Figure 112 illustrate the FoS of the intermediate floors of the small and medium firecells containing open intermediate floors over the variation of fire growth rates. Regardless of the fire location, intermediate floor size and purpose group, the FoS of the intermediate floor decreases when the fire growth rate increases. The FoS of the intermediate floor of the firecell in WL and WM purpose groups is greater than that of the firecell in CS or CL purpose groups. The figures also show that the rates at which the FoS of the intermediate floors of the small firecells in all scenarios decline are very similar while the decline rates of the FoS of the medium firecells in WL and WM purpose groups are considerably higher than that of the firecells in CS or CL purpose groups.

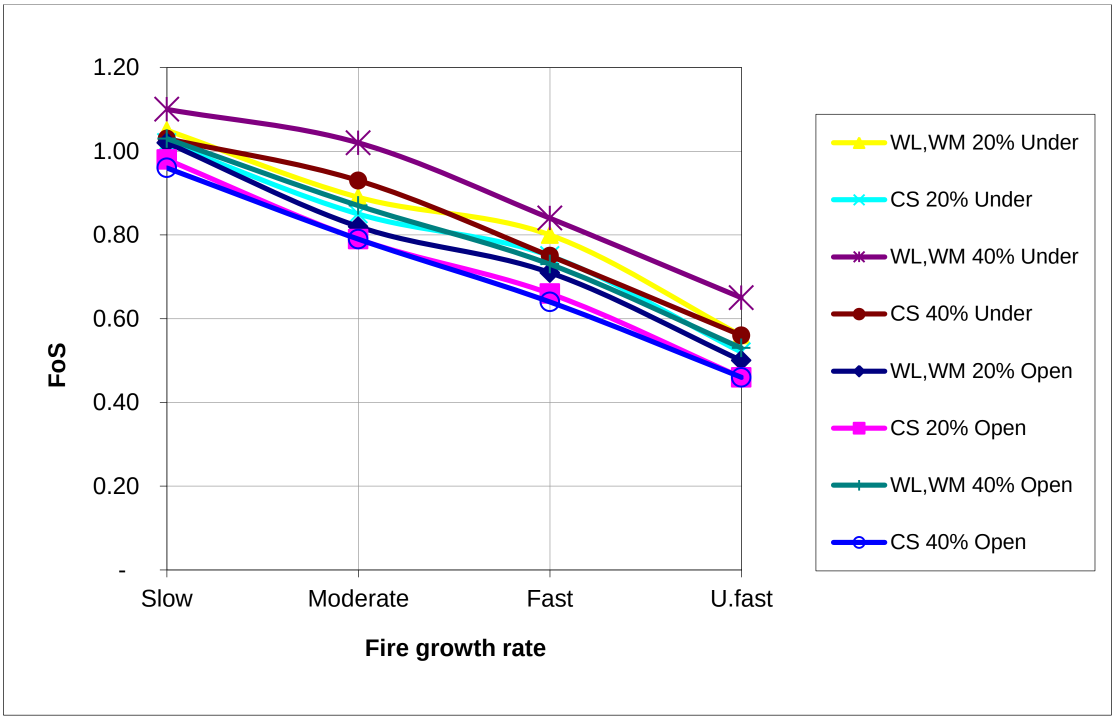


Figure 111: FoS of the intermediate floors by the variation of fire growth rates for small firecells.

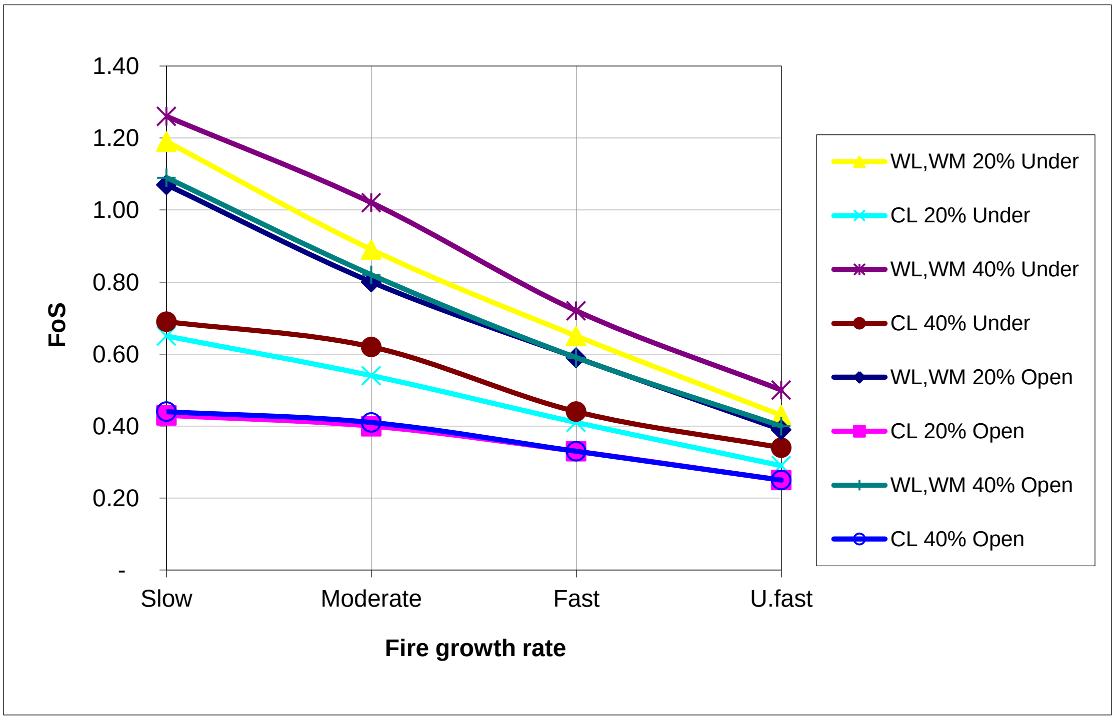


Figure 112: FoS of the intermediate floors by the variation of fire growth rates for medium firecells.

The FoS of the open intermediate floors of the large 8m firecell when a fire occurs under the intermediate floor by the variation of fire growth rates are shown in Figure 113. Regardless of the intermediate floor size and purpose group, the FoS of the intermediate floor decreases when the fire growth rate increases. The figure also indicates that the FoS of the intermediate floor of the firecell in WL and WM purpose groups is greater than that of the firecell in CL purpose group.

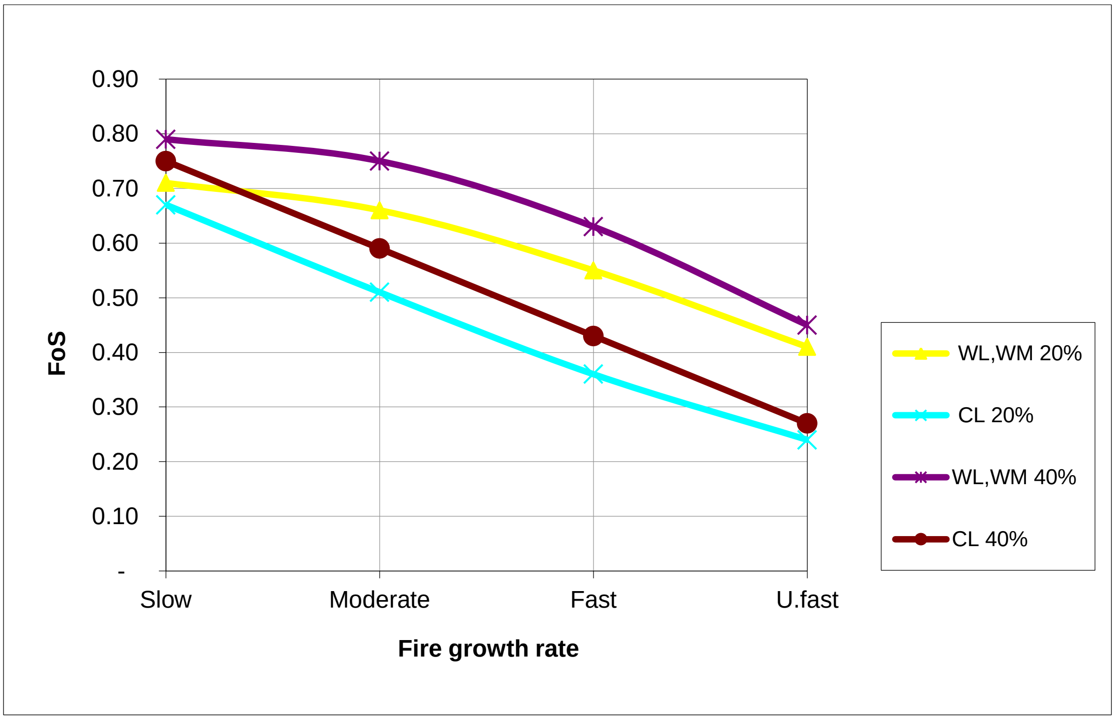


Figure 113: FoS of the intermediate floors by the variation of fire growth rates for large 8m firecells with a fire located under the intermediate floor.

Figure 114 illustrates the FoS of the open intermediate floor of the large 8m firecell when a fire is in the open area by the variation of fire growth rates. For firecells in CL purpose group, the FoS of the intermediate floor decreases when the fire growth rate increases regardless of the intermediate floor size. The FoS of the intermediate floor of the firecells in WL and WM purpose groups however increases very little when the fire growth rate increases from slow to moderate, then decreases as the fire growth rate continues to increase to fast and ultra fast. With a slow fire, the FoS of the intermediate floor of the firecell in WL and WM purpose groups is slightly less than that of the firecell in CL purpose group while with other fires the FoS of the intermediate floor of the firecell in WL and WM purpose groups is greater than that of the firecell in CL purpose group. The detection times in the large 8m firecell containing intermediate floors in WL and WM purpose groups, when a fire is in the open area, are too long which strongly dominates the FoS for the slow and moderate fires. While in CL purpose group the FoS are governed by pre-movement times, consequently the trend of FoS of the large 8m firecell containing intermediate floors in WL and WM purpose groups is slightly different from purpose group CL.

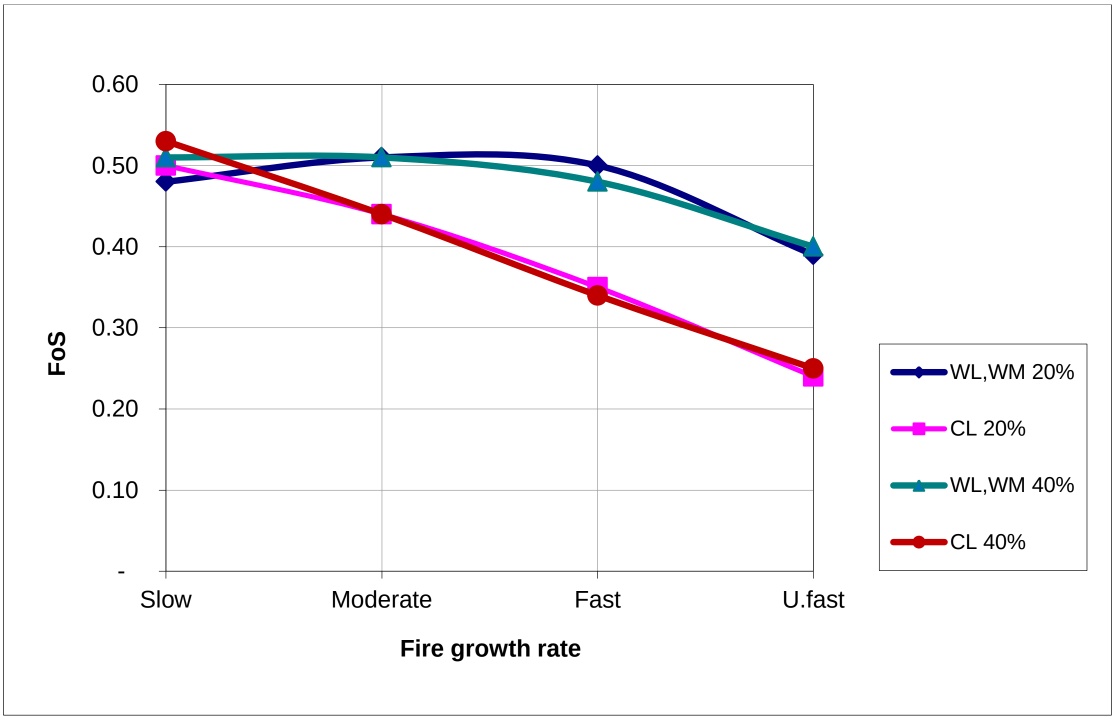


Figure 114: FoS of the intermediate floors by the variation of fire growth rates for large 8m firecells with a fire located in the open area.

Figure 115 and Figure 116 show the FoS of the lower floors of the medium firecells with different purpose groups, fire locations and fire growth rates by the variation of intermediate floor sizes. The figures indicate that regardless of the fire location, purpose group and fire growth rate, the FoS of the lower floor decreases when the intermediate floor size increases.

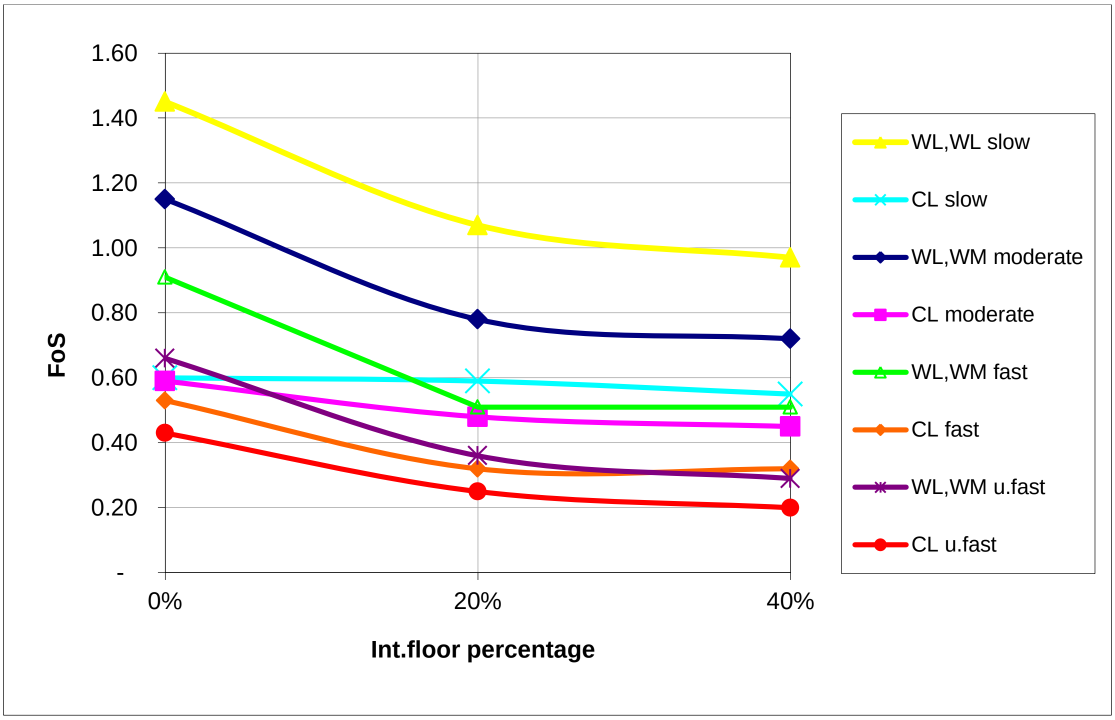


Figure 115: FoS of the lower floors by the variation of intermediate floor sizes for medium firecells with a fire located under the intermediate floor.

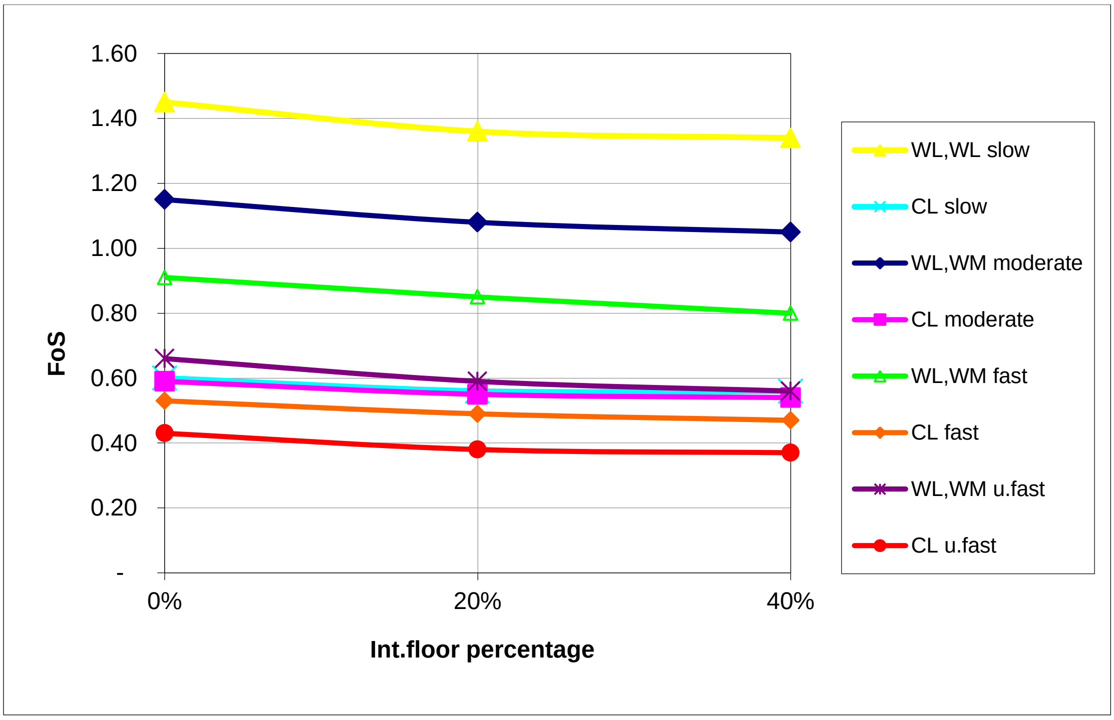


Figure 116: FoS of the lower floors by the variation of intermediate floor sizes for medium firecells with a fire located in the open area.

Figure 117 illustrates the FoS of intermediate floors of medium firecells with different purpose groups and fire growth rates when a fire is located under the intermediate floor by the variation of intermediate floor sizes. The FoS of the intermediate floor increases slightly when the intermediate floor size increases for all scenarios.

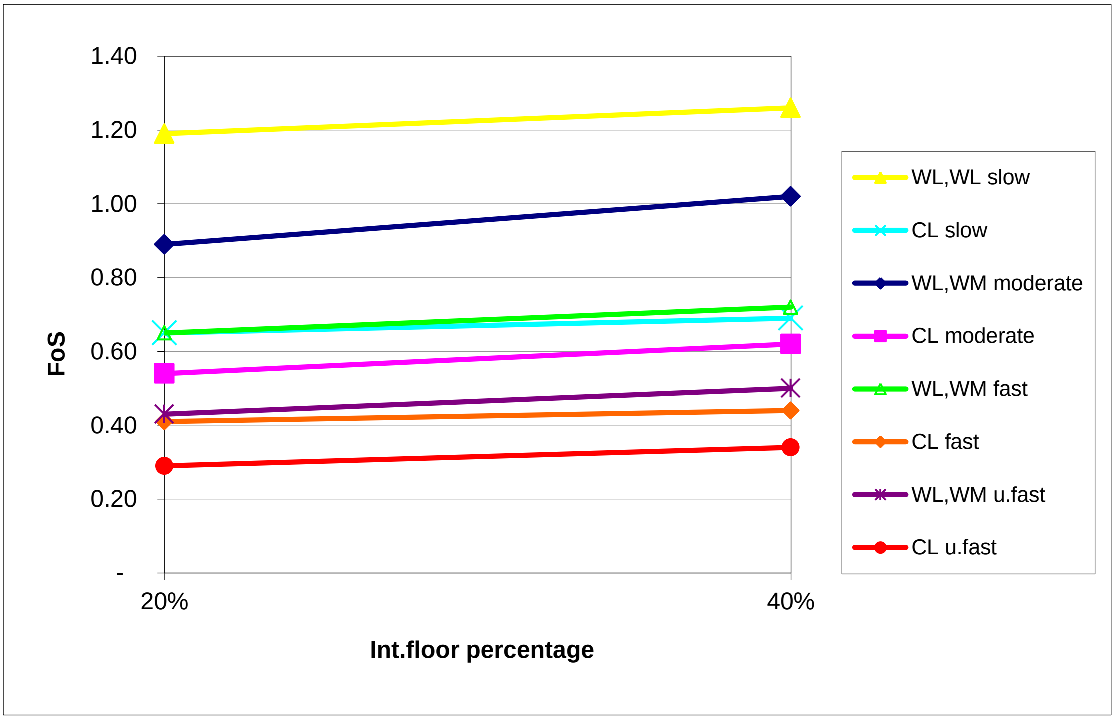


Figure 117: FoS of the intermediate floors by the variation of intermediate floor sizes for medium firecells with a fire located under the intermediate floor.

The FoS of intermediate floors of medium firecells with different purpose groups and fire growth rates with a fire in the open area by the variation of intermediate floor sizes are illustrated in Figure 118. Regardless of the purpose group and fire growth rate, the FoS of the lower floor changes very little when the intermediate floor size increases.

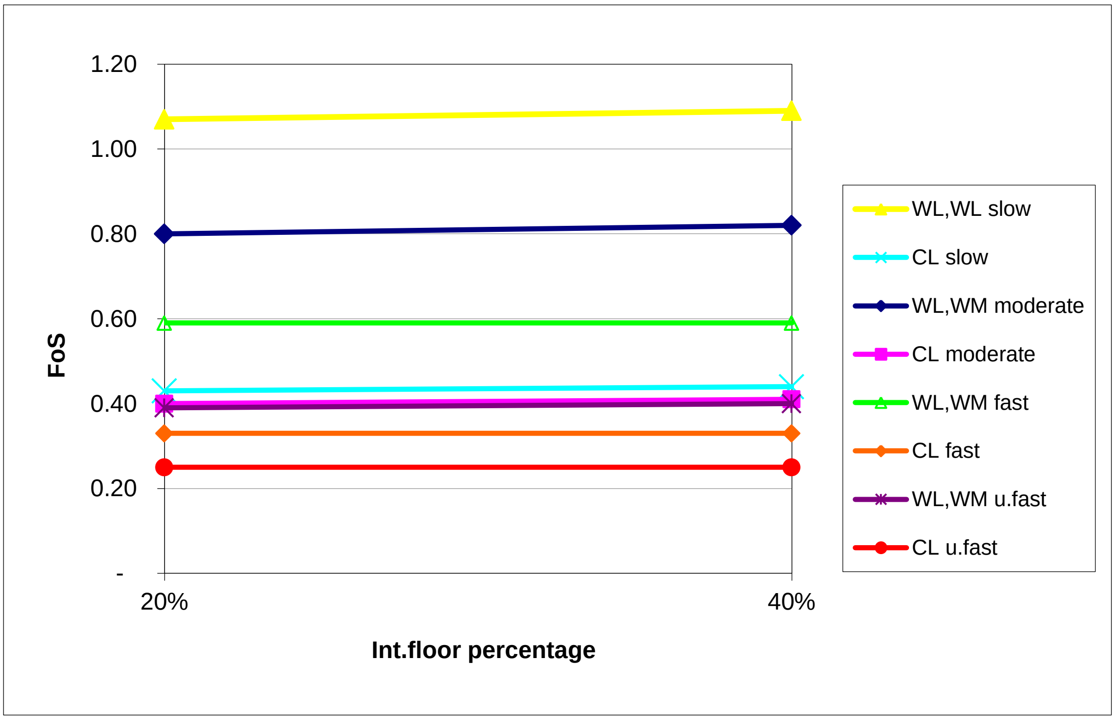


Figure 118: FoS of the intermediate floors by the variation of intermediate floor sizes for medium firecells with a fire located in the open area.

The analysis of the FoS of the intermediate and lower floors by the variation of intermediate floor sizes are for the medium firecells, however, the small and large 8m firecells have the same trends as the medium firecells (Figure 115 to Figure 118). Refer to Figure D15 to Figure D22 of Appendix D for more graphs of the FoS for the small and large 8m firecells.

<u>Summary of the effect of fire growth rates on the FoS:</u>

- Regardless of the purpose group, fire location, intermediate floor and firecell sizes, the FoS of the intermediate and lower floors of the firecell containing open intermediate floor decreases when the fire growth rate increases.
- When the intermediate floor size increases, the FoS of the lower floor decreases in all scenarios.
- When the intermediate floor size increases, the FoS of the intermediate floor increases if a fire occurs under the intermediate floor while the FoS of the intermediate floor changes very little when a fire is located in the open area.

7.10 Closed intermediate floors with fast fires

Because the occupants on the intermediate floor escape via the lower floor, the FoS of the closed intermediate floor was therefore assessed as the FoS of the lower floor.

The FoS of the lower floors of the firecells containing closed intermediate floors by the variation of intermediate floors sizes, fire locations and purpose groups are plotted in Figure 119 to Figure 121.

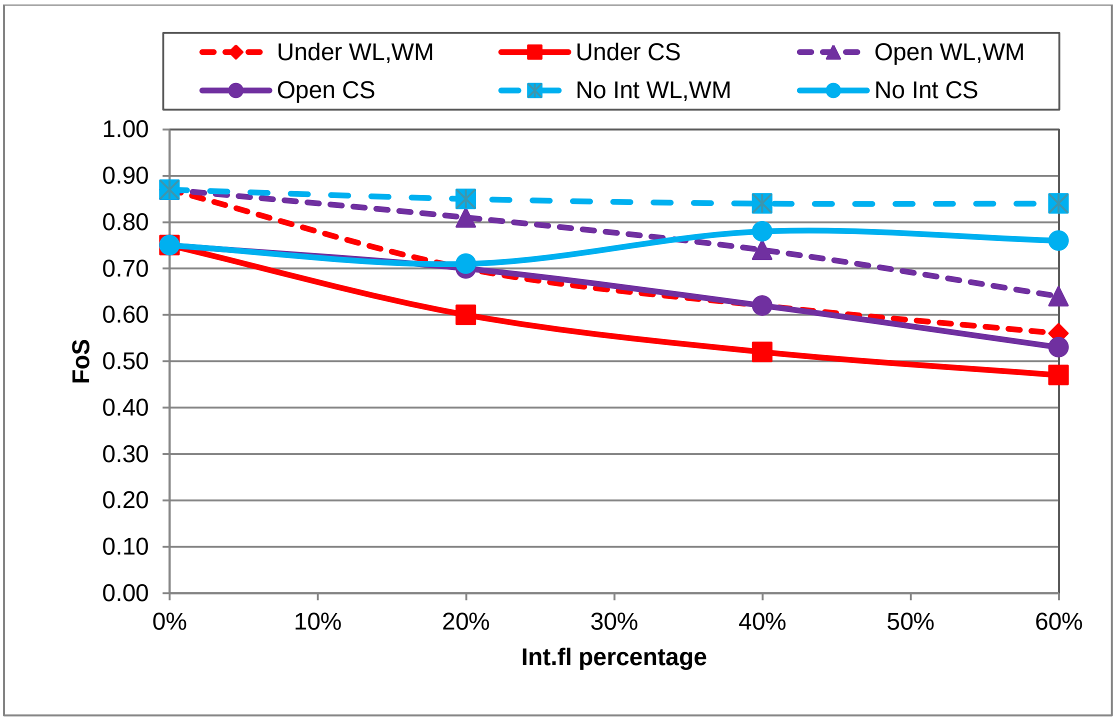


Figure 119: FoS of the lower floor of the small firecells containing closed intermediate floors with the variation of intermediate floor sizes, fire locations and purpose groups.

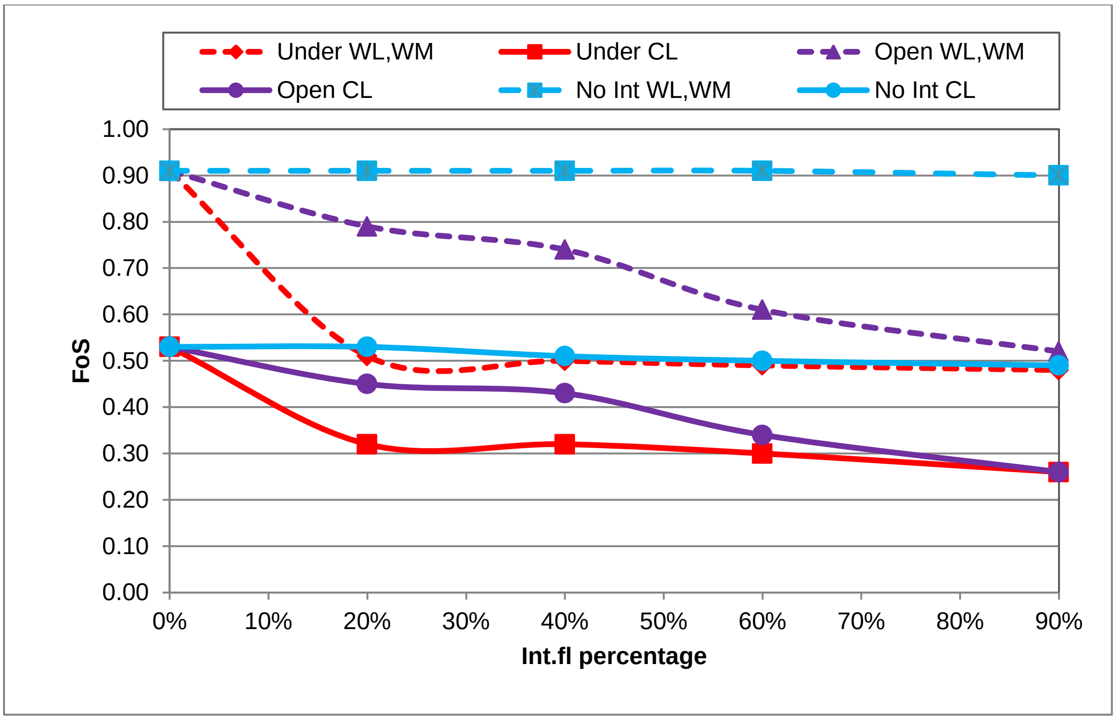


Figure 120: FoS of the lower floor of the medium firecells containing closed intermediate floors with the variation of intermediate floor sizes, fire locations and purpose groups.

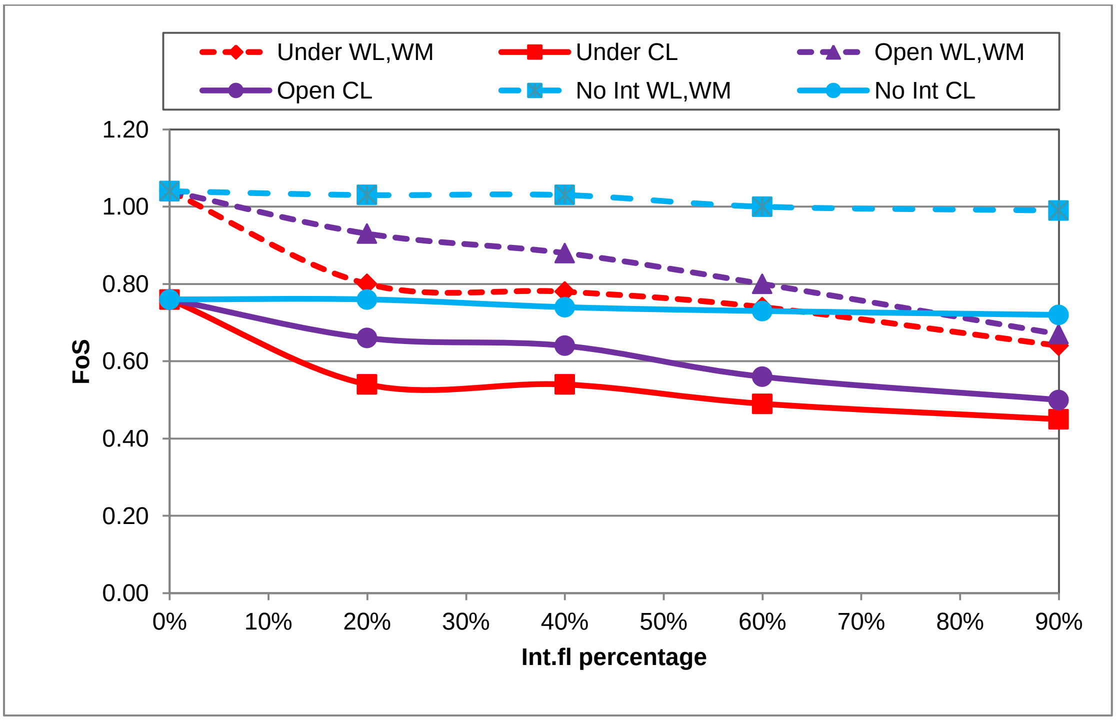


Figure 121: FoS of the lower floor of the large 8m firecells containing closed intermediate floors with the variation of intermediate floor sizes, fire locations and purpose groups.

Figure 119 to Figure 121 show that the FoS of the lower floors of the firecells containing closed intermediate floors are less than unity and range from about 0.3 to nearly 0.9. The scenario in which the FoS is greater than 1.0 (Figure 121) is the large equivalent firecell without intermediate floors in WL and WM purpose groups. In general, the FoS decreases when the intermediate floor size increases. When the intermediate floor size of the small firecell in purpose group CS increases from 20% to 40% the FoS increases because with an intermediate floor of 20% of the lower floor, the firecell was assessed with a single escape route as the conditions for a single escape route are met. However, with an intermediate floor of 40% of the lower floor, two escape routes are required [7], consequently the FoS increases but it starts to decrease when the intermediate floor size continues to increase. Regardless of the fire location and purpose group the FoS of the lower floor of firecells containing intermediate floors are always less than that of the equivalent firecells without intermediate floors. The FoS of the lower floors when a fire is located in the open area are slightly greater than when a fire occurs under the intermediate floor. The figure also illustrates that the FoS of the lower floor of the firecell with a high occupant load (CS or CL) is less than that of the same firecell with a low occupant load (WL and WM) as would be expected.

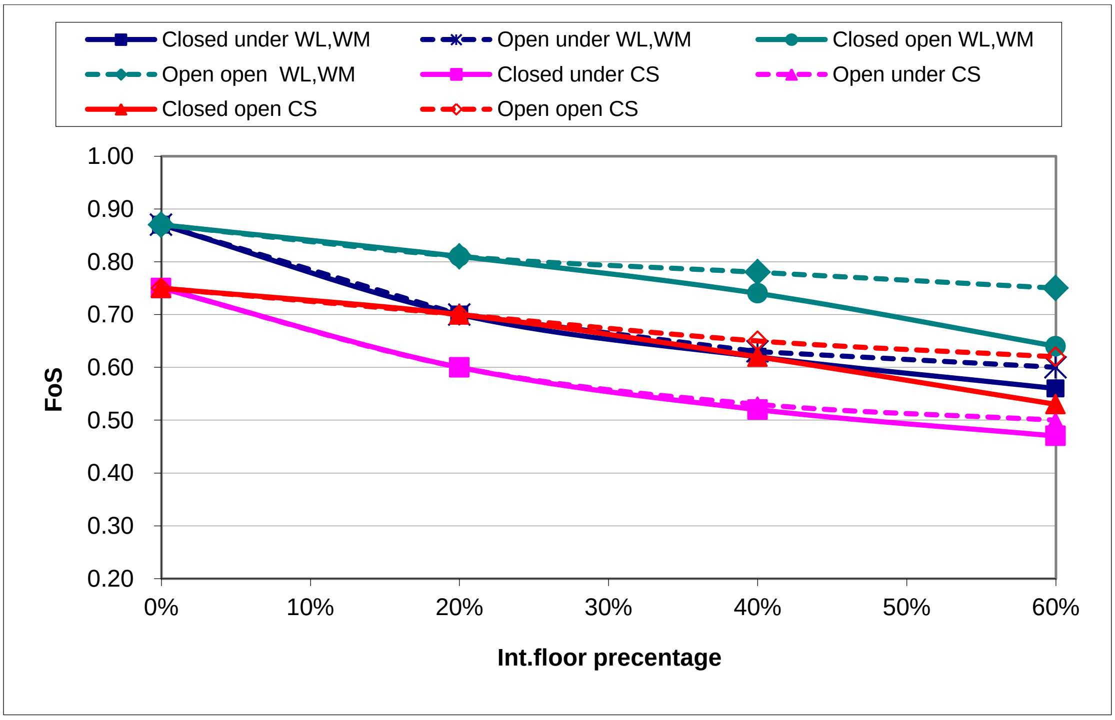


Figure 122: Comparison of FoS of the lower floor of the small firecells containing closed and open intermediate floors.

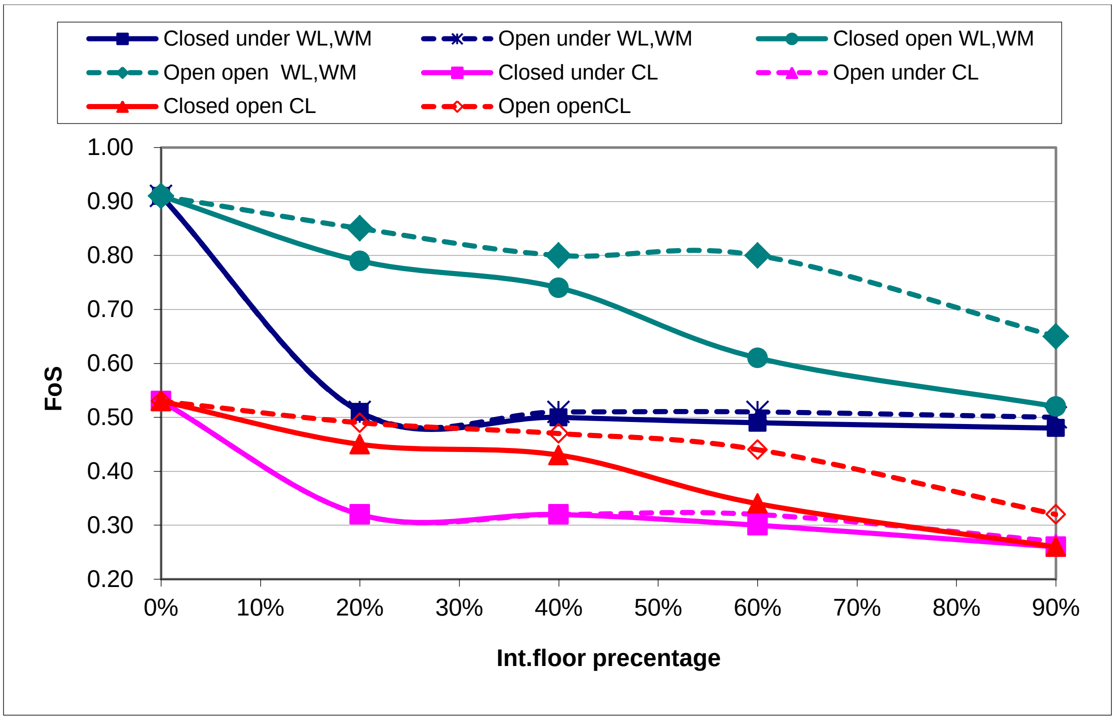


Figure 123: Comparison of FoS of the lower floor of the medium firecells containing closed and open intermediate floors.

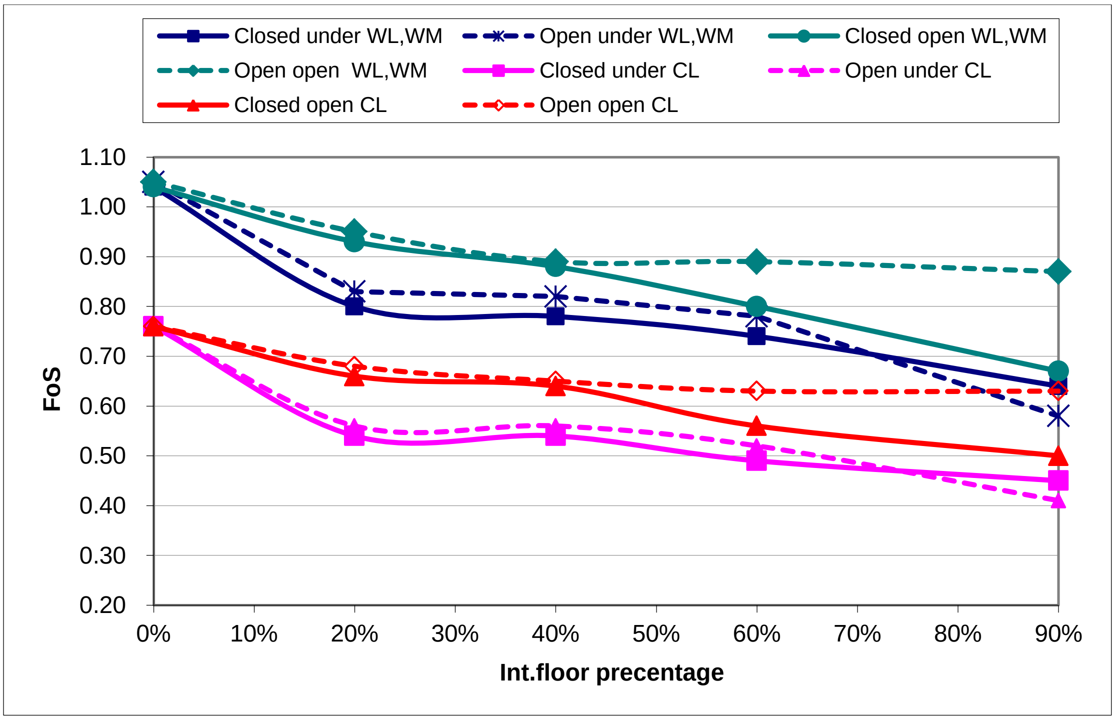


Figure 124: Comparison of FoS of the lower floor of the large 8m firecells containing closed and open intermediate floors.

The FoS of the lower floor of the firecells containing closed intermediate floors with the variation of intermediate floor sizes, fire locations and purpose groups are plotted along with the FoS of the lower floor of the firecells containing open intermediate floors in Figure 122 to Figure 124. The figures show that the FoS of the lower floor of the firecells containing closed intermediate floors have the same trends as the FoS of the lower floor of the firecells containing open intermediate floors: regardless of the fire location and purpose group, the FoS decrease when the intermediate floor size increases. The figures also indicate that the FoS of the lower floor of the firecell containing closed intermediate floors are slightly less than the FoS of the lower floor of the firecells containing open intermediate floors.

The details of the FoS of the studied firecells containing closed intermediate floors are in Table D6 of Appendix D.

Summary of the analysis of the FoS of firecells containing closed intermediate floors:

- The FoS of the lower floor of the firecells containing closed intermediate floors have the same trends as the FoS of the lower floor of the firecells containing open intermediate floors.
- For all fire locations and purpose groups, the FoS decreases when the intermediate floor size increases.
- The FoS of the lower floor of the firecell containing closed intermediate floors is slightly less than the FoS of the lower floor of the same size firecells containing open intermediate floors.
- The FoS of the lower floors when a fire is located in the open area are slightly greater than when a fire is under the intermediate floor.
- The FoS of the lower floor of the firecell with a high occupant load (CS or CL) is less than that of the same firecell with a low occupant load (WL and WM).

7.11 Overall Factor of Safety of firecells containing intermediate floors

In the analysis above, the safety/risk level of the occupants was assessed separately for the occupants of the intermediate floors and the occupants of the lower floors in two separate scenarios of fire location. In order to compare the overall safety/risk level of all occupants of the firecells containing intermediate floors, with the level of safety of the occupants of the equivalent firecells without intermediate floors, an overall factor of safety was developed so there is a single number for FoS that can be compared with the FoS of a single floor firecell.

The overall factor of safety of a firecell containing intermediate floors is calculated as a weighted average according to the following equation:

$$FoS_{overall} = \underbrace{\left[\left(\frac{A_u}{A_{tt}}\right)\left(\frac{N_{int}}{N_{tt}}\right)\left(FoS^{u}_{int}\right)\right]}_{\text{term 1}} + \underbrace{\left[\left(\frac{A_u}{A_{tt}}\right)\left(\frac{N_{low}}{N_{tt}}\right)\left(FoS^{u}_{low}\right)\right]}_{\text{term 2}} + \underbrace{\left[\left(\frac{A_o}{A_{tt}}\right)\left(\frac{N_{int}}{N_{tt}}\right)\left(FoS^{o}_{int}\right)\right]}_{\text{term 3}} + \underbrace{\left[\left(\frac{A_o}{A_{tt}}\right)\left(\frac{N_{low}}{N_{tt}}\right)\left(FoS^{o}_{low}\right)\right]}_{\text{term 4}} \quad (17)$$

Where:

A_u	Area under the intermediate floor (m^2)
A_o	Area of the open area on the lower floor (m^2)
A_{tt}	Total area of firecell (m^2)
FoS^{u}_{int}	Factor of safety of the intermediate floor when a fire is under the intermediate floor
FoS^{u}_{low}	Factor of safety of the lower floor when a fire is under the intermediate floor
FoS^{o}_{int}	Factor of safety of the intermediate floor when a fire is in the open area.
FoS^{o}_{low}	Factor of safety of the lower floor when a fire is in the open area
N_{int}	Occupant load of the intermediate floor (person)
N_{low}	Occupant load of the lower floor (person)
N_{tt}	Total occupant load of the firecell (person)

In equation (17), term 1, term 2, term 3 and term 4 represent the average weighted factor of safety of the intermediate and lower floors when a fire is under the intermediate floor and when a fire occurs in the open area respectively.

There are three components in each term: probability of fire occurring in the area (under the intermediate floor or open area) assuming the probability of a fire in all areas is the same and hence is simply proportional to the area of part of the firecell; proportion of occupant load of the floor (intermediate or lower); and factor of safety of the occupants of that floor with a fire in the area. For example in the first term:

- $\left(\frac{A_u}{A_{tt}}\right)$ is the probability of a fire occurring under the intermediate floor.

- $\left(\frac{N_{int}}{N_{tt}}\right)$ is the proportion of occupant load of the intermediate floor.
- (FoS^{u}_{int}) is the factor of safety of an intermediate floor when a fire is under the intermediate floor.

As mentioned earlier (section 5.2.2), the scenario of a fire occurring on the intermediate floor is not included in this project, therefore it is not included in the equation (17).

Figure 125 illustrates the overall FoS of studied firecells containing intermediate floors and FoS of the equivalent firecells without intermediate floors with the same occupant loads over the variation of occupant loads. In general, the overall FoS of the firecells containing intermediate floors is always less than the FoS of the equivalent firecells without intermediate floors having the same occupant loads regardless of the intermediate floor and firecell sizes, fire locations and occupant load. This means the occupants of the firecells containing intermediate floors would always have a lower level of safety than occupants of the equivalent firecells without intermediate floors. For the studied firecells in this project, the differences of FoS for the firecells containing intermediate floors and the overall FoS for the equivalent firecells without intermediate floors varies from 10% to 60%. The overall FoS of the firecell containing intermediate floors ranges from about 0.35 to under 0.8 while the FoS of the equivalent firecells without intermediate floors ranges from 0.45 to approximately 1.10.

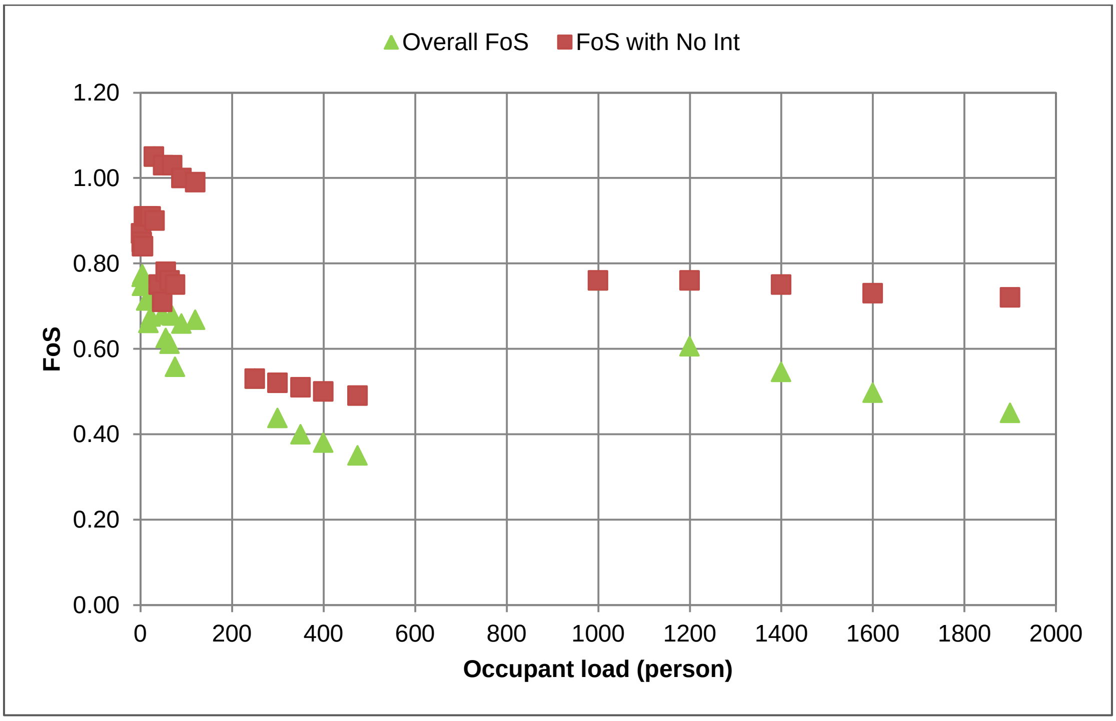


Figure 125: Overall FoS of firecells having intermediate floors and FoS of the equivalent firecells without intermediate floor by the variation of occupant loads.

As shown in Chapter 5 and 6, the ASET of the large firecells with and without intermediate floors are significantly greater than that of the medium firecells, while the RSET of the large firecells with and without intermediate floors in purpose group CL with the occupant load of 1000 or more are moderately greater than that of the medium firecells in purpose group CL with the occupant load from about 250 to 500. The ASET strongly dominates the FoS, therefore, there is a moderate increase in the overall FoS of the firecells having intermediate floors and FoS of the equivalent firecells without intermediate floors when the occupant load increases from about 500 to 1000 people as shown in Figure 125.

7.12 Conclusions of the FoS analysis

- In most scenarios, the FoS of both intermediate and lower floors are less than that of the equivalent firecell without intermediate floors. The overall FoS of the firecells containing intermediate floors is always less than the FoS of the equivalent firecells without intermediate floors and the differences in FoS range from 10% to 60%. This means the occupants of the firecell containing intermediate floors would have a higher level of risk compared to the occupants of the equivalent firecell without intermediate floors.
- The level of risk of occupants of the firecell containing intermediate floors increases as the intermediate floor size increases, however, there are no clear cut-off points at which a higher level of fire safety precaution is desirable. The cut-off points in C/AS1 of 20% for a closed intermediate floor and 40% for an open intermediate floor are not justified by this analysis.
- When a fire occurs in the open area, occupants on the intermediate floors would have a higher level of risk than the occupants of the lower floor but when a fire is located under the intermediate floor, the level of risk of the occupants on the intermediate floors can be considered as the same as the occupants of the lower floor.
- The scenario when a fire is located under the intermediate floor can be considered as the worst scenario in terms of fire location in designing fire safety for a firecell containing intermediate floors. Location of the exits is very important in fire safety design but it becomes much more critical for a firecell containing intermediate floors. The majority of exits from the lower floor should not be located under intermediate floors.
- Occupant load has a significant impact on the safety level of occupants of both intermediate and lower floors, therefore, occupant load should be considered in conjunction with the size of intermediate floors in specifying fire systems for a firecell containing intermediate floors.

- The type of fire detection has a moderate impact on the safety level of the occupants in the firecell containing intermediate floors. Smoke detection provides a moderately higher safety level than heat detectors for occupants in the firecell containing intermediate floors.
- The ceiling height of the firecell has a moderate impact on the risk level of occupants in the firecell containing intermediate floors. With the same floor area, the higher the ceiling height, the greater the safety level of the occupants is, as would be expected.
- For a given unsprinklered firecell containing intermediate floors, when there is a blocked exit on the lower floor, the risk level of the occupants would always be higher than when no exit is blocked. However, the effect of the blocked exits on the safety level of the occupants would not be significant when the remaining unblocked exits of the firecells provide the total width required by C/AS1.
- The occupants on the intermediate floor of a firecell with higher intermediate floor have a higher level of risk than a firecell with lower intermediate floor height.
- The FoS of the intermediate and lower floors of the firecell containing an open intermediate floor decreases when the fire growth rate increases. This means when the fire growth rate increases, the level of risk to occupants of the firecell containing intermediate floors increases.
- The FoS of the intermediate and lower floors of the firecell containing closed intermediate floors in which the occupants of the intermediate floors must escape via the lower floors, are slightly less than the FoS of the lower floor of the same size firecell containing open intermediate floors.

8. DISCUSSIONS AND RECOMMENDATIONS

The level of risk inherent in intermediate floors has been investigated. The analysis shows that the overall the FoS of the firecells containing intermediate floors is always less than the FoS of the equivalent firecells without intermediate floors with the same occupant loads. This means the occupants of the firecells containing intermediate floors would have a higher level of risk than the occupants of the equivalent firecells without intermediate floors. The analysis also indicates that the level of risk of the occupants of the firecells containing intermediate floors increases as the intermediate floor size increases but there are no clear cut-off points at which a higher level of fire safety precaution is desirable. The analysis points out that the fire safety requirements for firecells containing intermediate floors in the current C/AS1 may not have a rational basis as described in option 1 below.

There are number of options to consider in changing the requirements for firecells containing intermediate floors as follows:

- Option 1 is to keep the requirements for intermediate floors the same as they are currently in C/AS1.
- Option 2 is to ban the construction of intermediate floors.
- Option 3 is to ignore the intermediate floors, a firecell containing intermediate floors would be treated as a single level firecell that has the same occupant load and escape height.
- Option 4 is to set out the limitation on the area of the intermediate floors. The intermediate floor where the area exceeds the limitation would be treated as a storey and not an intermediate floor.
- Option 5 is to develop a verification method for designing fire safety for intermediate floors.
- Option 6 is to use a specific fire engineering design for designing fire safety for intermediate floors.
- Option 7 is to develop a new set of FSPs for intermediate floors which are based on the occupant load of the intermediate floor and not the area of the intermediate floor.

The advantages and disadvantages and/or the analysis of each option are discussed in more detail in the following sections.

8.1 Option 1: Keep the requirements for intermediate floors the same as they are currently in C/AS1.

The fire safety requirements for firecells containing intermediate floors of the current C/AS1 have been reviewed in section 3.3. In this option, all the fire safety requirements for firecells containing intermediate floors will stay the same as they are in the current C/AS1.

The current Acceptable Solution C/AS1 has been used in New Zealand for nearly ten years with several amendments so people (designers, Building Consent Authorities etc.) are very familiar with it. Any significant change to C/AS1 would take time for designers and Building Consent Authorities to get used to it. This option is the simplest solution because designers and Building Consent Authorities would not have to do anything other than what they are currently doing.

According to C/AS1, firecells containing limited area intermediate floors require the same fire safety precautions as single level firecells having the same total occupant load and escape height and all firecells containing intermediate floors that are not limited area intermediate floors must have a smoke control system. The cut-off points at which the limited area intermediate floors are defined as 20% for a closed intermediate floor and 40% for an open intermediate floor. The analysis in this project has shown that the level of risk to the occupants of the fircells containing intermediate floors increases as the intermediate floor size increases but there are no clear cut-off points at which a higher level of fire safety precaution is desirable.

In some scenarios studied in this project, the level of safety of the occupants of both intermediate and lower floors of the firecells containing limited area intermediate floors are about 50% of the level of safety of the equivalent firecells without intermediate floors having the same occupant load and escape height. However, according to C/AS1 above firecells (with and without intermediate floors) require the same Fire Safety Precautions.

As described in section 1.1, in some cases, the requirements can be less when there are more people on an intermediate floor of the buildings designed to C/AS1.

In some instances, it is possible to interpret the requirements of C/AS1 in such a way to, or where there is unusual combinations of building design and features, produce designs that have a lower level of safety than other buildings, and lower than the authors of C/AS1 are thought to have intended as discussed in section 1.1.

Above discussions have pointed out some advantages of this option, however, the disadvantages of the option are significant compared to advantages therefore this option is not recommended.

8.2 Option 2: Ban the construction of intermediate floors.

The analysis in this project shows that the risk level of the occupants of the firecells containing intermediate floors is higher than occupants of the equivalent firecells without intermediate floors and it increases when the intermediate floor size increases. So should intermediate floors be totally banned?

If intermediate floors are totally banned, it would make the Acceptable Solution much simpler and easier to use. However, intermediate floors are desirable architectural features of buildings which can be found in many types of buildings, such as warehouses, factories, churches, halls, theatres, shopping malls, offices and many more. How could theatres and shopping malls be designed without intermediate floors?

The other major disadvantage of prohibition of building intermediate floors is it would also have an effect on existing buildings that contain intermediate floors. Section 112 (alterations to existing buildings), section 115 (Code compliance requirements: change of use), section 116 (Code compliance requirements: extension of life) and section 116A (Code compliance requirements: subdivision) of the Building Act 2004 [11] require upgrading of building to current code levels when an alteration, a change of use, an extension of life or a subdivision of an existing building occurs.

The prohibition of building intermediate floors might be a good option in terms of fire safety design for buildings. However, fire safety is only one aspect of a building design which cannot dominate the whole design of a building. This option therefore is not recommended.

8.3 Option 3: Ignore intermediate floors; a firecell containing intermediate floors would be treated as a single level firecell.

In this option, the firecells containing intermediate floors would require the same Fire Safety Precautions (FSPs) as single level firecells having the same total occupant load and escape height, regardless of the firecell and intermediate floor sizes.

This option is simple as all requirements for firecells containing intermediate floor could be covered in C/AS1 because there is no involvement of an alternative solution so it is very straight forward for designers to apply in designing fire safety for firecells containing intermediate floors as well as Building Consent Authorities in processing building consents.

The level of risk of the occupants of the firecells containing intermediate floors has been analysed in Chapter 7 of this report. The analysis has compared the FoS of the firecell containing intermediate floors with a single level firecell having the same total occupant load and escape height. The FoS of the firecells containing intermediate floors decrease when the intermediate floor size increases but the FoS of the intermediate and lower floors of the fircells containing intermediate floor are always less than that of the equivalent firecells without intermediate floors. Especially in some scenarios the FoS of the intermediate and firecell floors are nearly 50% of the FoS of the equivalent firecell without intermediate floors, regardless of intermediate floor size. This means the occupants of the firecells containing intermediate floors could have a much higher level of risk than the occupants of the equivalent firecells without intermediate floors. Therefore if the firecells containing intermediate floors are treated as single level firecells, the level of risk of occupants of the firecells containing intermediate floors would be underestimated.

As discussed above, there are some advantages of this option however the occupants of the firecells containing intermediate floors could have a much higher level of risk than the occupants of the equivalent firecell without intermediate floors. Therefore, this option is not recommended.

8.4 Option 4: Limit area for intermediate floors

As mentioned in Chapter 3 of this report, in overseas prescriptive requirements [1-4] and in the New Zealand prescriptive requirements prior to 1991 [5, 6], the total aggregate area of the mezzanines (intermediate floors) are limited but it varies with country. If the total aggregate area of the mezzanine exceeds the limited area, the mezzanine then is considered as a storey (firecell) and all requirements for a separate firecell are applied.

In USA [1], the aggregate area of mezzanines located within a room is limited at one-third of the open area of the room in which the mezzanines are located. In Canada [2], the aggregate area of mezzanines does not exceed 40% of the open area of the room in which they are located. In Australia [4], the aggregate area of mezzanines located within a room is less than 200 square metres or less than one-third of the floor area of the room, whichever is the lesser. In UK [3], the total aggregate area of all the galleries (intermediate floors) in any one space is less than half of the area of that space.

Prior to 1991, in the NZS1900, Chapter 5, Fire Resisting Construction and Means of Egress [5], the area of the mezzanine did not exceed one-third of the area of the fire compartment in which it occurs.

The aggregate area of intermediate floors (mezzanines) was also limited at one-third of the lower floor for two-floor buildings in the NZBC, Approved Documents for Fire Safety C2, C3, C4 prior to 2001 [6]. The intermediate floor was not treated as a storey but a smoke control was required if the area of intermediate floor exceeds one-third of the lower floor.

In the current C/AS1 [7], total aggregate area of the intermediate floors at which the firecell containing intermediate floors requires the same FSPs as a single level firecell having the same total occupant load and escape height is limited at 20% and 40% for closed and open intermediate floors respectively. However, intermediate floor size is unlimited when a smoke control system is provided.

The analysis in this project has shown that the level of risk to the occupants of the fircells containing intermediate floors increases as the intermediate floor size increases, however, there are no clear cut-off points at which a higher level of fire safety precaution should be provided or the intermediate floor should be treated as a separate firecell.

In addition, the number of people on the intermediate floors who are subject to a hazard, relate to risk but the area limits do not necessarily relate to risk. For example, the consequence if a fire occurs in a firecell containing an intermediate floor with 50 people on the intermediate floor would be more severe than the same firecell with five people on the intermediate floor, hence the level of risk to the occupants of the firecell with 50 people on the intermediate floor would be higher than that of the same firecell with five people on the intermediate floor.

Based on the analysis in this project, it is very hard to determine a single figure rationally at which the intermediate floor size should be limited. This is a very good option to consider but difficult to achieve rationally, therefore, this option is not recommended.

8.5 Option 5: A verification method for designing fire safety for intermediate floors

Currently in New Zealand there are two means for designing a building to meet the fire safety requirements of the building code: *Acceptable Solution* C/AS1 and *alternative solution*. One of the objectives of this project is to propose an outline for a verification method for designing fire safety for intermediate floors.

A *verification method* for designing fire safety for intermediate floors would bring many benefits not only for building owners and designers but also for Building Consent Authorities and the New Zealand Fire Service. The verification method would contribute other means to comply with the building code for fire safety design. The *verification method* would bring much more flexibility for designers in designing fire safety for intermediate floors. The building consent process would be faster if a *verification method* or *acceptable solution* is used instead of an *alternative solution* in designing fire safety for buildings. The New Zealand Fire Service would not have to review the fire safety design if the *verification method* is used.

The analysis in this project shows that the risk level to the occupants of the firecells containing intermediate floors is higher than occupants of the equivalent firecells without intermediate floors and it increases when the intermediate floor size or the fire growth rate increases. However, there are too many variables in designing fire safety for firecells containing intermediate floors. The fire safety of the firecells containing intermediate floors depends upon the intermediate and firecell floor's area, the heights of the firecell and intermediate floor ceilings, occupant loads of the firecell and intermediate floors. The fire safety of the firecells containing intermediate floors also depend on the escape routes, active fire protection, such as heat, smoke detectors, sprinklers and smoke control systems, passive protection: fire rated doors, walls and ceilings. Therefore, it is very difficult to develop a rational verification method for designing fire safety for firecells containing intermediate floors.

There would be many advantages of having a *verification method* for designing fire safety for firecells containing intermediate floors as discussed above. This option is very good to consider but it is very difficult to achieve rationally so this option is not recommended.

8.6 Option 6: Alternative solution for firecells containing intermediate floors.

In this option, all clauses of intermediate floors in C/AS1 would be taken out and an alternative solution must be used for any fire safety design of firecells containing intermediate floors.

An *alternative solution* or specific engineering (performance based) design is described in the Building Code handbook as being an alternative to the *Acceptable Solutions*, accreditation, or to a *verification method*. *Alternative solutions* can be based on tests and research, calculation from first principles, or substitution of one element with another.

In general, specific fire engineering design provides more design flexibility than C/AS1. In addition, specific fire engineering design may provide a more economical solution than designs prepared to C/AS1.

However the use of alternative designs that deviate from C/AS1 in designing fire safety can cause difficulties to obtain a building consent. There are several reasons why an alternative design may not receive a building consent. The first reason is designer's skill which result in the design not being adequate, or the design is adequate but the design documentation is incomplete. The second reason is when a design or a part of a design is based on engineering judgment because there is limited or no data available. Lastly, the design fails to obtain a building consent because it is being compared to C/AS1 instead of the performance criteria set out by the Building Code and Building Consent Authorities often treat C/AS1 as the only means to comply with the Building Code. This does not imply that the Acceptable Solution C/AS1 does not reflect the criteria of the Building Code but it indicates that C/AS1 cannot possibly cover for all buildings. The other disadvantage of using alternative solution is while the *Acceptable Solution* can be easily used by architects or non-fire engineers, an *alternative solution* requires a qualified fire engineer who is not always available in many small or medium design firms.

The advantages and disadvantages of using an *alternative solution* in designing fire safety for buildings in general, or for firecells containing intermediate floors in particular, have been discussed above. While other options for designing fire safety for firecells containing intermediate floors are not recommended as analysed above, the use of *alternative solution* for designing fire safety for firecells containing intermediate floors is an option that is always available.

8.7 Option 7: Proposed FSPs based on occupant load on intermediate floors

8.7.1 *Introduction*

The main objective of the New Zealand Building Code is life safety, to ensure that buildings provide occupants with a sufficient level of safety. NZBC is a performance based code which allows for specific design or the use of more prescriptive compliance documents for fire safety. Therefore, two firecells with the same occupant load; one containing intermediate floors and the other without intermediate floors might be expected to be designed to ensure that the occupants of both firecells have a similar level of safety.

In the current C/AS1 [7], the FSPs of an intermediate floor are based on the firecells in which it is located and the area of the intermediate floor. A new set of requirements for intermediate floors which are based on the occupant load of the intermediate floor will be developed in this section.

8.7.2 *Analysis*

In this section, the number of occupants of the intermediate floors of the firecells containing intermediate floors to which the firecells have a similar level of safety with the equivalent firecells without intermediate floors at the cut off points set out by the current C/AS1 were determined.

Total occupant load	Required Fire Safety Precautions	Short Description
≤ 100	Type 2	Manual call points
101 to 500	Type 3	Automatic heat detection
501 to 1000	Type 4	Automatic smoke detection
> 1000	Type 7	Automatic smoke detection and sprinklers

Table 18: Summary of required FSPs for two floor buildings.

The FSPs for two-floor buildings without intermediate floors required by the current C/AS1 are summarised in Table 18. The table contains only requirement for detection and sprinkler systems, for other requirements see Table 4.1/1 to 4.1/4 of C/AS1 which are appended in Appendix E. The cut-off points in terms of occupant load for two-floor buildings without intermediate floors at which the required FSPs have been increased as set out by C/AS1 are 100, 500 and 1000 people which corresponds to the requirement of Type 2, Type 3, Type 4 and Type 7 respectively.

The comparison of the overall FoS of firecells containing intermediate floors and FoS of the equivalent firecells without intermediate floors having the same occupant load has been carried out in section 7.11. To establish a relationship between the number of occupants on the intermediate floors of the firecells containing intermediate floors and the number of occupants of the equivalent firecells without intermediate floors, a set of the overall FoS of the firecells having intermediate floors over the variation of the occupant load of the intermediate floors and FoS of the equivalent firecells without intermediate floors over the variation of total occupant load up to 1000 is assessed as shown in Figure 126.

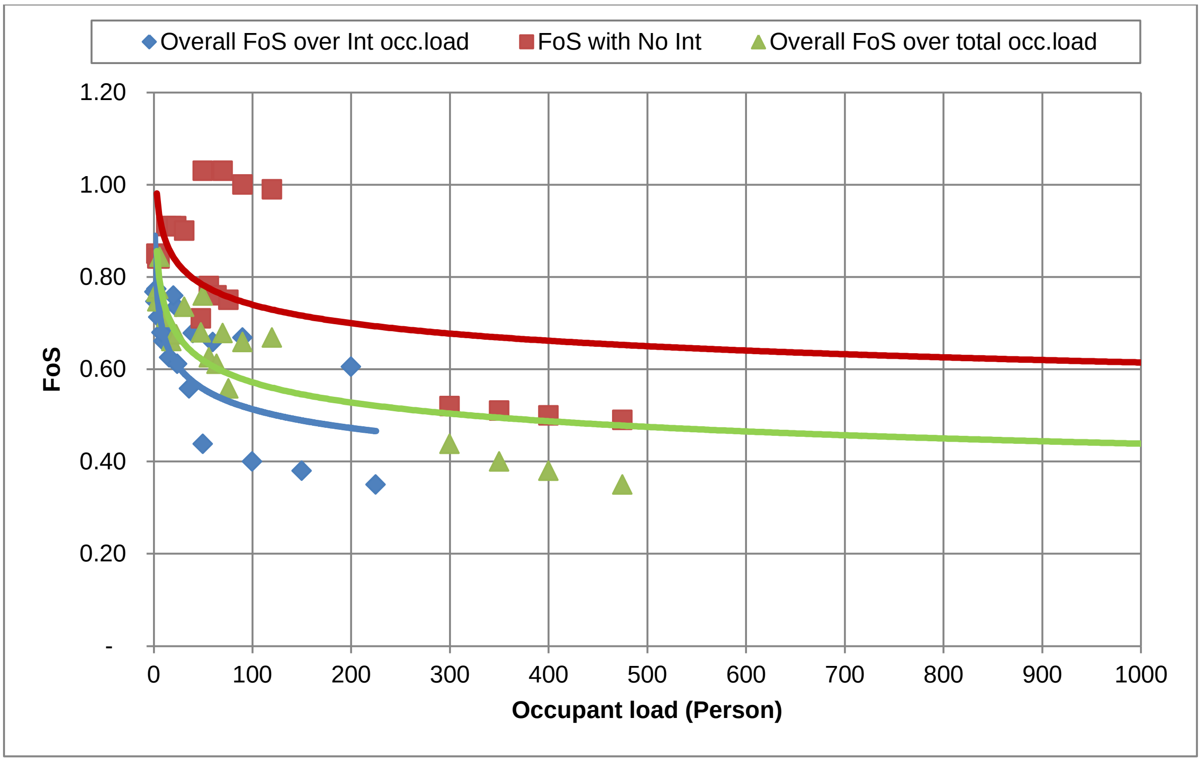


Figure 126: Overall FoS of firecells containing intermediate floors over the variation of occupant load of intermediate floor and total occupant load, and FoS of the equivalent firecells without intermediate floors over the variation of total occupant load.

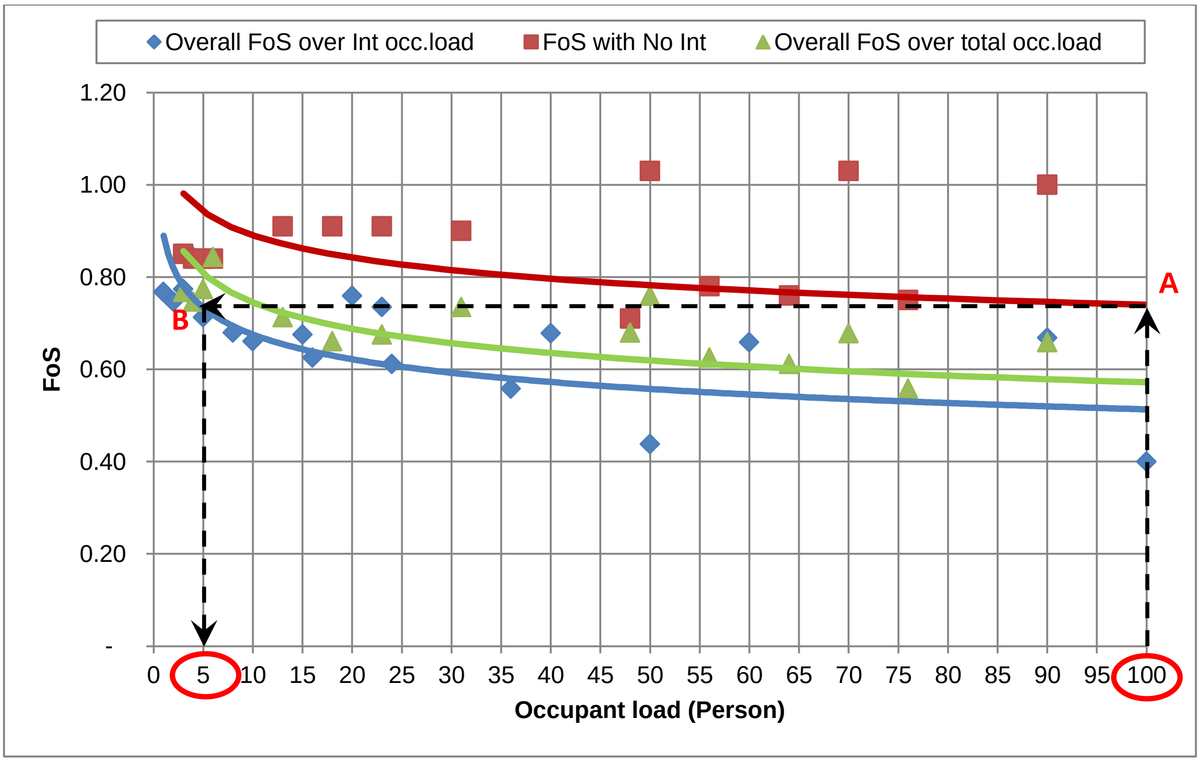


Figure 127: Overall FoS of firecells containing intermediate floors over the variation of occupant load of intermediate floor and total occupant load, and FoS of the equivalent firecells without intermediate floors over the variation of total occupant load. (Enlargement of Figure 126)

The limit of occupant load of 1000 people is chosen in this assessment because firecells that have occupant loads exceeding 1000 people require Type 7 by C/AS1. Therefore, the overall FoS of the firecells containing intermediate floors and FoS of the firecells without intermediate floors are considered to be equal.

The best-fit curves are plotted for the overall FoS of the firecells containing intermediate floors and FoS of the equivalent firecells without intermediate floors as illustrated in Figure 126. The best-fit curve of the FoS of the equivalent firecells without intermediate floors is in red. The green curve is for the overall FoS of the firecells having intermediate floors over the variation of the total occupant load and the best-fit curve for the overall FoS of the firecells having intermediate floors over the variation of the occupant load on the intermediate floors is in blue.

The number of occupants on the intermediate floors of the firecells containing intermediate floors to which the firecells have the overall FoS as the same as the FoS of the equivalent firecells without intermediate floors at three cut-off points (100, 500 and 1000 people) were determined as shown in Figure 126. Figure 127, Figure 128 and Figure 129 are enlargements of Figure 126.

Figure 127 shows the process of determining the number of occupants on the intermediate floors of the firecell containing intermediate floors to which the firecell having intermediate floors has the overall FoS as the same as the FoS of the equivalent firecell without intermediate floors at the cut-off point of 100 people. The process details are illustrated by the black dashed arrows. First, a vertical black dashed arrow was drawn from the point of 100 on the x axis (horizontal axis) to the best-fit line of FoS of the equivalent firecells without intermediate floors (point A on the red line) to obtain the FoS of the equivalent firecell without intermediate floors with the occupant load of 100 people. Next, the overall FoS of the firecells containing intermediate floors that is the same as the FoS of the equivalent firecell without intermediate floors with the occupant load of 100 people was obtained by projecting a horizontal black dashed arrow from point A to the best-fit line of the overall FoS of the firecells having intermediate floors (point B on the blue line). Then the occupant load of five people on the intermediate floor of the firecell containing intermediate floors to which the firecell having intermediate floors has the overall FoS the same as the FoS of the equivalent firecell without intermediate floors at the cut-off point of 100 people was determined by drawing a vertical black dashed arrow from point B to the horizontal axis.

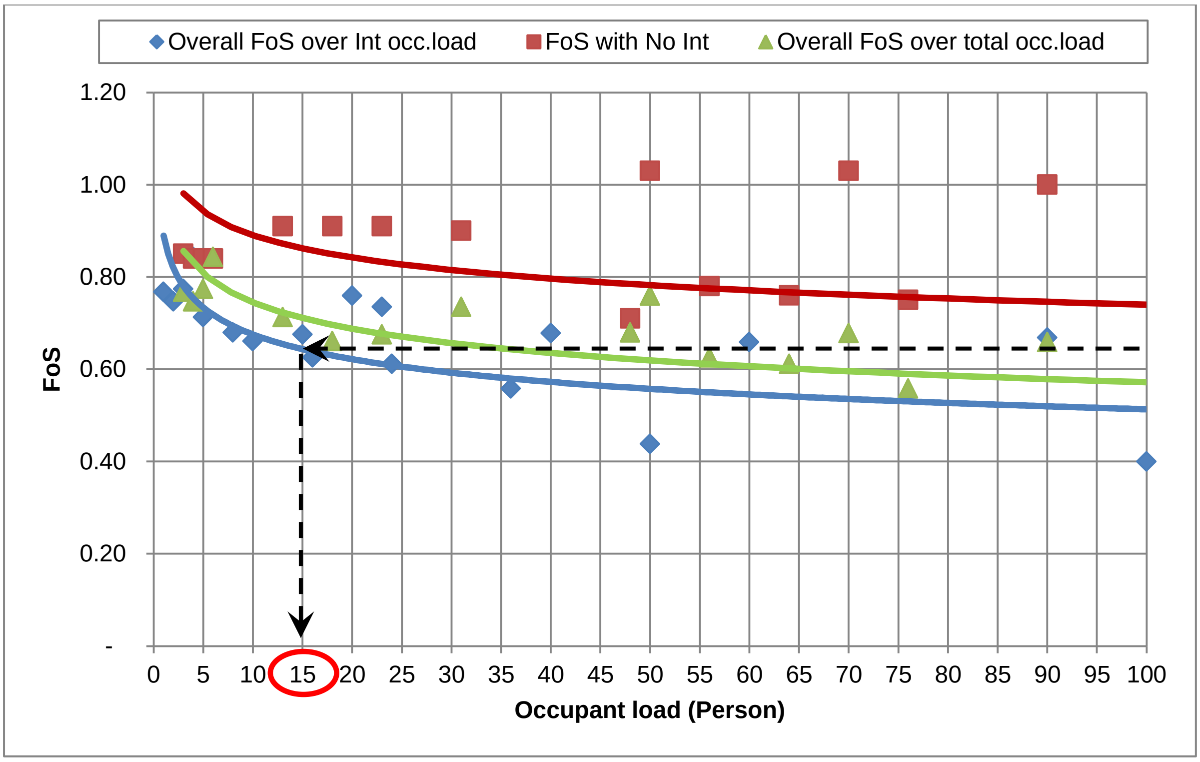


Figure 128: Overall FoS of firecells containing intermediate floors over the variation of occupant load of intermediate floor and total occupant load, and FoS of the equivalent firecells without intermediate floors over the variation of total occupant load. (Enlargement of Figure 126)

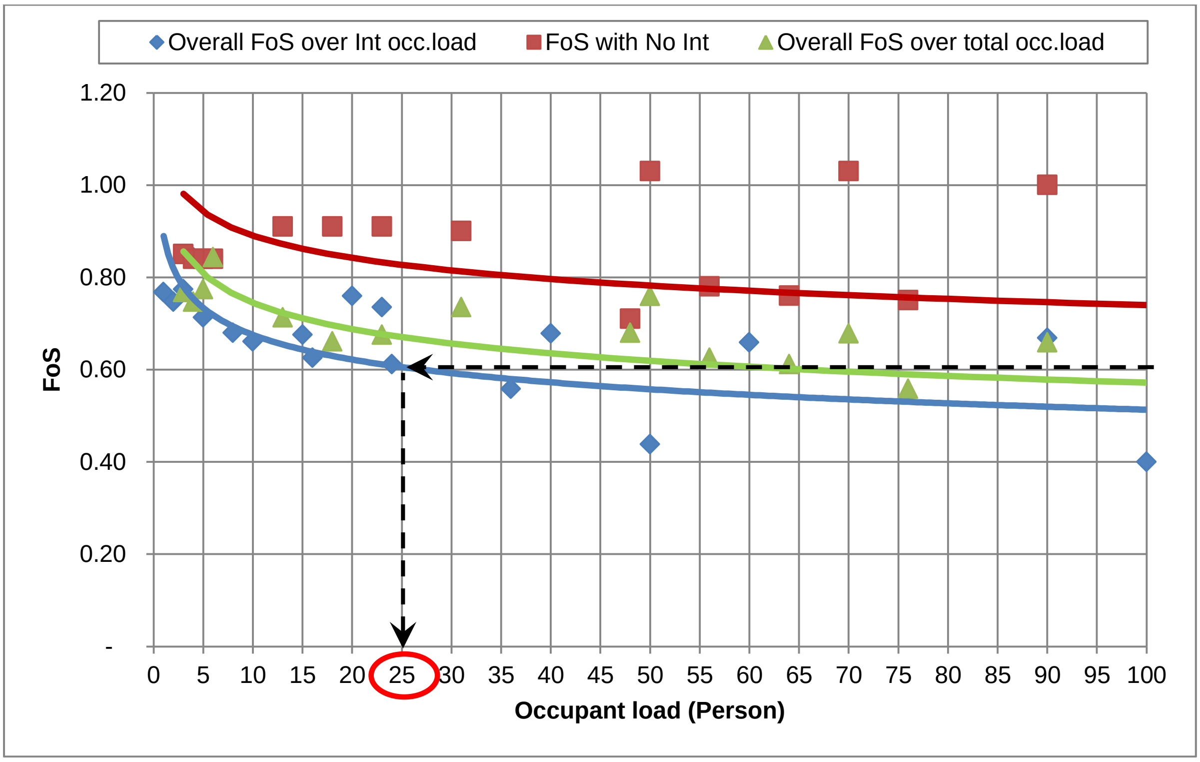


Figure 129: Overall FoS of firecells containing intermediate floors over the variation of occupant load of intermediate floor and total occupant load, and FoS of the equivalent firecells without intermediate floors over the variation of total occupant load. (Enlargement of Figure 126)

The same processes were carried out to determine the occupant loads of the firecells containing intermediate floors to which the firecells having intermediate floors have the overall FoS the same as the FoS of the equivalent firecells without intermediate floors at the cut-off points of 500 and 1000 people. The process details are illustrated in Figure 128 and Figure 129. The occupant loads of the intermediate floors of the firecells containing intermediate floors to which the firecells having intermediate floors have the overall FoS the same as the FoS of the equivalent firecells without intermediate floors at the cut-off points of 500 and 1000 people were determined at 15 and 25 people respectively.

Total occupant load of two-floor buildings	Occupant load of intermediate floor
100	5
500	15
1000	25

Table 19: Occupant loads of intermediate floors of firecells with intermediate floors at which the firecells have the same FoS with the equivalent firecells without intermediate floors at the cut off points: 100, 500 and 1000 people.

In summary, to achieve an overall FoS the same as the FoS of the equivalent firecells without intermediate floors with total occupant load of 100, 500 and 1000 people, the occupant loads of the intermediate floors of the firecells having intermediate floors are approximately 5, 15 and 25 respectively as summarised in Table 19.

8.7.3 *Proposed requirements for intermediate floors*

The analysis above shows that the occupants of the firecells having intermediate floors have a lower level of safety than occupants of the equivalent firecells without intermediate floors regardless of intermediate floor size. The analysis also points out that the level of safety of the occupants of the firecells having intermediate floors can be achieved as the level of safety of the equivalent firecells without intermediate floors by providing the FSPs for intermediate floors that are determined rationally based on occupant load of the intermediate floors and not the intermediate floor size.

The proposed changes in the requirements for intermediate floors of firecells containing intermediate floors are as follows:

- Introduce definitions for open and closed intermediate floors.
- Delete the term “limited area intermediate floor”.

- Delete or amend all clauses related to “limited area intermediate floor”.
- Introduce new clauses and tables for Fire Safety Precautions for intermediate floors.

In this section, the texts that are reproduced from the current C/AS1 are presented in italics and the proposed clauses are underlined.

8.7.3.1 Proposed new definitions for open and closed intermediate floors and delete the term “limited area intermediate floor”

Intermediate floor is defined in the current C/AS1 [7] as “*Any upper floor within a firecell and which is not fire separated from the floor below. Upper floors within household units need not meet the specific fire safety requirements which apply to intermediate floors in all other situations*”.

In addition to the definition of an intermediate floor, the definitions for open and closed intermediate floors are proposed as follows:

> “An open intermediate floor is the intermediate floor that has an escape route which is exposed to smoke and hot gases from a floor below”

and

> “A closed intermediate floor is the intermediate floor that has an escape route which is protected from smoke and hot gases from any floor below until it reaches a final exit”

The open and closed intermediate floors are clearly distinguished in the proposed definitions. A “closed” intermediate floor that has an escape route which is not protected from smoke and hot gases from a floor below would be treated as an open intermediate floor as the occupants from the intermediate floor must escape via the lower floor.

In the current C/AS1, clauses 6.21.5 and 6.21.6 are:

6.21.5 A firecell with intermediate floors satisfying the following conditions may be treated as a single floor firecell and a smoke control system Type 10 or Type 11 is not required where:

> *a) The fire hazard category of the firecell is no greater than 3, and*
>
> *b) Where there are two or more separate intermediate floors, the levels of those floors above the firecell floor differ by no more than 1.0 m, and*
>
> *c) The total occupant load on all intermediate floors is not greater than 100, and*

d) The total area of the intermediate floors is no greater than allowed by Paragraph 6.21.6.

6.21.6 The total area of limited area intermediate floors within the firecell shall not exceed:

a) 20% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s) are enclosed or partitioned, or

b) 40% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s):

i) are completely open, or

ii) if enclosed or partitioned, a Type 4 or Type 7 alarm system with smoke detection is installed throughout the firecell.

Clauses 6.21.5 and 6.21.6 would be deleted as they would no longer be required.

8.7.3.2 Proposed new tables for Fire Safety Precautions for open and closed intermediate floors

Based on the required FSPs of the equivalent firecells without intermediate floors at the cut-off points, a new set of FSPs for open intermediate floors is proposed in the form of table similar to Table 4.1 of C/AS1 [7] as shown in Table 20. It should be noted that this table is not the final proposed FSPs for open intermediate floors as some alternative options of FSPs will be discussed in this section.

Occupant load of open intermediate floor	Proposed Fire Safety Precautions
≤ 5	Type 2
6 to 15	Type 3
16 to 25	Type 4
26 to 100	Type 7
> 100	Type 7 and Type 10 or 11

Table 20: Table of initial proposed FSPs for open intermediate floors.

The cut-off point of 100 people on intermediate floors to which a smoke control is required by the current C/AS1 would still be used in the proposal as illustrated in Table 20. Type 2, Type 3 Type 4 and Type 7 are the FSPs for intermediate floors with occupant loads not exceeding

5, 6 to 15, 16 to 25 and over 25 people respectively which are determined based on the required FSPs of the equivalent firecells without intermediate floors with the occupant load not exceeding 100, 101 to 500, 501 to 1000 and over 1000 respectively as analysed above. The proposed FSPs for intermediate floors with an occupant of over 100 people are Type 7 and a smoke control system Type 10 or 11.

Table 20 shows that when the occupant load of the intermediate floor changes from the range of 16 to 25 to the range of 26 to 100, there is a big increase in terms of FSPs; from Type 4 to Type 7. Therefore, some other options for the FSPs for intermediate floors with the occupant load between 26 to 100 people are proposed as discussed below.

New Zealand sprinkler systems are more reliable than those installed in other parts of the world. New Zealand claims a success rate of some 99.8% [58] for systems installed, while in USA, success rates can be quoted as low as 81% to 99% [59, 60]. In 2006, a report by Mears [61] showed that there are six recorded deaths from fire in sprinklered buildings in New Zealand. All these cases are deemed to be beyond the capability of a sprinkler system, as the deceased was in direct contact with flames.

The terms “sprinkler system” in those reports above is referred to both Type 6 and Type 7 in C/AS1. Therefore, it would be reasonable to replace Type 7 which is the proposed FSPs for intermediate floor with occupant load from 26 to 100 people in Table 20 by Type 6.

A smoke control system activated by smoke detectors (Type 10 or 11 and Type 4) is currently required for firecells having an intermediate floor that is not “limited area intermediate floor” in C/AS1. The proposed FSPs (Type 7 for intermediate floors with occupant load from 26 to 100) would have effect on existing buildings containing intermediate floors that have a smoke control system activated by smoke detectors (Type 10 or 11 and Type 4) because the Building Act 2004 [11] requires upgrading of building to current code levels when an alteration, a change of use, an extension of life or a subdivision of an existing building occurs.

In addition, the tenable conditions in a firecell containing intermediate floors with a smoke control system installed (Type 10 or 11 and Type 4) that is properly designed could be maintained during the evacuation of the occupants. The designed FoS of the occupants, say the FoS of 2.0 as suggested in literature [30], therefore could be achieved. Thus, a smoke control system activated by smoke detectors (Type 10 or 11 and Type 4) would be a good option for the proposed FSPs for intermediate floors where occupant load is from 26 to 100 people as in Table 20. This is a very reasonable option, especially for the transition period when the new FSPs for intermediate floors start being applied.

Therefore, the table of FSPs for open intermediate floors in which some alternative options of FSPs for occupant load from 26 to 100 is proposed as shown in Table 21.

Occupant load of open intermediate floor	Proposed Fire Safety Precautions
≤ 5	Type 2
6 to 15	Type 3
16 to 25	Type 4
26 to 100	Type 6 , or Type 4 and Type 10 or 11
> 100	Type 7 and Type 10 or 11

Table 21: Table of final proposed FSPs for open intermediate floors.

The analysis and proposal above (Table 21) are for open intermediate floors. The requirements for closed intermediate floors however can be proposed based on the proposed requirements for open intermediate floors.

As closed intermediate floors have smoke separated egress (see the proposed definition above), the occupants of the closed intermediate floors would not be exposed to smoke and hot gases until the smoke separations are breached. The occupants of the closed intermediate floors therefore would have a considerably high level of safety compared to the occupants of the open intermediate floors. A conservative approach would be applied to determine the occupant loads of the closed intermediate floors based on the occupant load of the open intermediate floors. The proposed FSPs for closed intermediate floors are shown in Table 22 in which the occupant loads of the closed intermediate floors are double that of the open intermediate floors for all scenarios with automatic fire alarm systems: Type 3, Type 4, Type 6 and Type 7. The number of occupants for the closed intermediate floors with Type 2 would not increase as shown in Table 22 because there is no automatic warning for the occupants of the intermediate floors.

The analysis shows that the ASET values for the intermediate and lower floors were dominated by the visibility criteria. As the occupants of the closed intermediate floors are protected from smoke and hot gases until the smoke separations are breached so the ASET of the closed intermediate floors would be significantly higher than that of the open intermediate floors. A smoke control system (Type 10 or 11) therefore would not be necessary for closed intermediate floors.

Occupant load of closed intermediate floor	Proposed Fire Safety Precautions
≤ 5	Type 2
6 to 30	Type 3
31 to 50	Type 4
51 to 200	Type 6
> 200	Type 7

Table 22: Table of proposed FSPs for closed intermediate floors.

The fire safety design for closed intermediate floors could be achieved by using a *verification method* in which the ASET could be calculated by using zone models such as BRANZFIRE. The methodology of using BRANZFIRE has been described in section 5.4 of this report. A very important assumption must be made in the BRANZFIRE modelling to determine the ASET of the closed intermediate floor; the ASET of a closed intermediate floor is determined by the time the smoke separations may be breached.

The AS 1530 Part 4 [62] sets out the insulation criterion failure for construction elements in a standard fire resistance test that is the temperature on the cold side of the test specimen exceeding an average increase of 140°C. Assume that a temperature drop of 40°C through any common wall assembly or glazing in early stages of a fire and the ambient temperature of 20^{o}C. The temperature at which the smoke separations may be breached therefore was chosen as 200°C (140+40+20). Hence, the ASET of a closed intermediate floor is determined by the time for the upper layer temperature of the lower floor reaches 200^{o}C.

8.7.3.3 Proposed addition clauses for Fire Safety Precautions for intermediate floors

A two-storey building with a small staircase opening that is the only opening which can be considered as a firecell containing an intermediate floor as discussed in section 1.1. There would be several solutions to avoid this disadvantage of using C/AS1, where designers can alter planning and reduce costs by designing in accordance with the prescriptive requirements of C/AS1 when this results in an overall lower level of safety rather than by designing for a reasonable performance level of fire safety. The first solution is to set the minimum size of the opening for intermediate floors. The second solution sets out the limitation on the opening size of intermediate floors but limitation would not apply for the intermediate floors with a low occupant load. The third option is to require smoke curtain or downstands for the open staircases while there is no additional requirement in the fourth solution. The details of these solutions are discussed as follows:

- Solution 1: Introduce an additional clause to set the minimum size of the opening for intermediate floors. This proposed clause would be based on the same principle as Clause 6.22.3 of C/AS1 in which the minimum separation requirement is set to prevent smoke spreading to the occupied spaces on sides of the atrium and allow the smoke plume to rise.

  6.22.3 The minimum horizontal separation between occupied spaces across the atrium shaft shall be:

  a) 4.0 m for sprinklered firecells, or

  b) 6.0 m for unsprinklered firecells. Between an occupied space and a wall or non-occupied space the separation may be reduced to 4.0 m.

  The additional suggested clause could be: "The horizontal opening between the intermediate floor and the lower floor must be at least 4 m by 4 m".

  This suggested clause could solve the problem above but the big disadvantage of this solution is that it would prevent having intermediate floors for small firecells. That leads to the second solution.

- Solution 2: This solution is similar to the first solution that limits the opening to a minimum of 4 m by 4 m but the limitation would not be placed on the intermediate floors with a low occupant load: the limitation of occupant load of five people or less is suggested based on the analysis in this project. This solution could also solve the problem above but still allows having intermediate floors for small firecells.

  The additional suggested clause could be: "The horizontal opening between the intermediate floor and the lower floor of a firecell with an occupant load on the intermediate floor greater than five people must be at least 4 m by 4 m".

- Solution 3: This solution would not set the limitation on the opening area. However, to prevent smoke spread to the opening staircase before the smoke layer of the lower floor drops to head level (2 m), the open staircase is required to have downstands or an automatic smoke curtain which drops to the maximum of 2 m above the lower floor level.

- Solution 4: In this solution, no additional requirement is proposed. This is the simplest solution however; the disadvantages are discussed in section 8.1 of this report.

Four solutions to deal with the problem of having a small stair opening that is the only opening are discussed above. The second solution in which the opening size is limited to minimum of 4 m by 4 m but this limitation would not be placed on the intermediate floors with an occupant load of five people or less is recommended. However, it is good practice to provide downstands or smoke curtains for open staircases as described above.

There would be more than one intermediate floor within a firecell but the limitation on the difference in the levels of these intermediate floors above the lower floor would be kept the same as it is currently in C/AS1. An additional clause is proposed:

> "Where there are two or more separate intermediate floors, the levels of those floors above the firecell floor must differ by no more than 1.0 m."

Where a firecell having more than one intermediate floor and the level of these floors differs by more than 1 m, the firecell may be treated as a *limited area atrium* or a specific engineering design may be required.

8.7.3.4 Proposed changes related to "limited area intermediate floor"

In addition to the new clauses and tables for FSPs for intermediate floors some clauses in C/AS1 would no longer be relevant and would be deleted or amended as follows:

Clause 4.5.17 of C/AS1 states "*Except for limited area intermediate floors meeting the provisions of Paragraphs 6.21.5 and 6.21.6, all firecells containing intermediate floors shall have a smoke control system*."

The proposed change for clause 4.5.17 is to delete the whole clause as clauses 6.21.5 and 6.21.6 were already proposed to be deleted, and firecells containing intermediate floors that require a smoke control system will be specified in the proposed tables for FSPs for intermediate floors.

Clause 4.5.18 of C/AS1 states "*Smoke control requirements for limited area atrium firecells are given in Paragraph 6.22. For all other firecells containing intermediate floors, except where Paragraph 4.5.17 applies, smoke control shall be by specific fire engineering design*".

There would be no "limited area intermediate floor" in the proposal so clause 4.5.18 is proposed to be amended as follows:

“Smoke control requirements for limited area atrium firecells are given in Paragraph 6.22. For all other firecells containing intermediate floors that require a smoke control by Table 21, smoke control shall be by specific fire engineering design*”.*

Clause 6.21.3 of C/AS1 states “*Except where permitted by Paragraphs 6.21.4 to 6.22.14, smoke control in firecells containing intermediate floors shall be by specific fire engineering design*”.

This clause (6.21.3) would be deleted as this requirement is already covered in the proposed amendment of clause 4.5.18.

Clause 6.21.4 of C/AS1 states “*These acceptable solutions for smoke control apply to firecells with intermediate floors which meet either of the following criteria*:

a) The firecell has limited area intermediate floors on one level complying with Paragraphs 6.21.5 and 6.21.6, or

b) The firecell is a limited area atrium meeting the requirements of Paragraphs 6.22.1 to 6.22.14.”

This clause (6.21.4) would be deleted in the proposal as “limited area intermediate floors” would no longer be available.

The provision of Clause 5.6.13 of C/AS1 requires a FHC4 firecell containing intermediate floors to be protected by sprinklers if the total aggregate area of the intermediate floors is greater than 35 m^2. In addition, in the proposal, a sprinkler system would be required when the occupant load of an intermediate floor exceeds 25 people. Therefore, there would be no restriction on the fire hazard category of the firecell having intermediate floors.

The summary of the proposed changes can be found in Appendix F.

8.7.3.5 Conclusion on the proposed requirements for intermediate floors

In conclusion, the proposed FSPs for intermediate floors in this option are rationally determined based on the occupant load of the intermediate floors and not the intermediate floor sizes. With the proposed FSPs, a firecell with lower occupant load would require lesser fire safety requirements than a firecell with higher occupant load regardless of intermediate floor size. Moreover, with the proposed FSPs for intermediate floors, the level of safety of the occupants of the firecells having intermediate floors would be very similar to the level of safety of the equivalent firecells without intermediate floors. Although, to apply this option many changes must be made to the current C/AS1, as analysed above, but the advantages of this option are significant, this option therefore, is strongly recommended.

8.8 Guidance for designers in designing fire safety for intermediate floors

BRANZFIRE can be used to model a firecell containing intermediate floors. However, it is necessity to use the virtual room methodology due to the natural geometry of the firecell containing intermediate floors. The analysis in this project has pointed that the fire location and type of intermediate floor are very critical in BRANZFIRE modelling.

- A firecell containing intermediate floors should not be modelled as two virtual rooms connected to each other by a virtual ceiling vent (Figure 24) as the virtual ceiling vent area is relatively large compared to the ceiling area.
- For a firecell containing closed intermediate floors, the intermediate floor can be neglected in the BRANZFIRE as it is completely closed. The firecell should be modelled as two virtual rooms connected to each other by a virtual wall vent (Figure 29).
- BRANZFIRE is not suitable to model the firecell containing large intermediate floors (closed and open) when a fire occurs under the intermediate floor (exceeding 60% of the firecell floor in this research project).
- A firecell containing open intermediate floors with a fire located under the intermediate floor can be modelled as three virtual rooms (Figure 25) connected to each other by virtual wall vents.
- A firecell containing open intermediate floors with a fire located in the open area should be modelled as a single room (Figure 26) and not three virtual rooms (Figure 25) connected to each other by virtual wall vents.
- The ASET of the firecells with no intermediate floors predicted by both FDS and BRANZFIRE are always greater than the ASET of the lower floors of firecells containing intermediate floors.
- When a fire is in the open area, BRANZFIRE predicts ASET for both intermediate and lower floors as being lower than FDS does regardless of the firecell and intermediate floor sizes.
- When a fire is located under the intermediate floor, BRANZFIRE predicts ASET for both intermediate and lower floors as being lower than FDS does for small firecells. For medium and large firecells, the ASET of the intermediate floors predicted by BRANZFIRE are less than that of FDS but the predictions of BRANZFIRE of ASET of the lower floors are slightly greater than the predictions of FDS.

- The intermediate floor height has significant impact on the ASET of the lower floor when a fire is under the intermediate floor: the lower the intermediate floor height, the smaller the ASET of the lower floor is.
- Regardless of the fire location and intermediate floor size, the ASET of the intermediate and lower floors of the firecell containing intermediate floors decrease when the fire growth rate increase.
- The scenario when a fire occurs under the intermediate floor can be considered as a worst scenario in term of fire location in designing fire safety for a firecell containing intermediate floor.
- Final exit locations:

  Buildings containing intermediate floors with exits located under the intermediate floor are very popular in practice: churches, halls, offices, theatres, warehouses. Some of those buildings have exits under intermediate floors as well as in the open area but because of a number of reasons many of them have exits that are located under the intermediate floors only.

  The analysis in this project indicates that the level of risk to the occupants of lower floors when a fire is located under the intermediate floor is considerably higher than when a fire is in the open area for all firecell sizes and purpose groups. This means the occupants in the firecell would have significantly less time to evacuate when a fire occurs under the intermediate floors compared to when a fire occurs in the open area. This scenario becomes much worse if the exits are located in the area under intermediate floors which may blocked by the fire.

  Location of the exits therefore is very critical in designing fire safety for firecells containing intermediate floors and the majority of exits from the lower floor should not be located under intermediate floors.

9. CONCLUSION

In conclusion, the analysis in this project showed that the overall level of safety of the occupants of the firecells containing intermediate floors is always less than that of the equivalent firecells without intermediate floors and the differences in FoS range from 10% to 60%. The analysis also showed that the safety level of the occupants of firecells having intermediate floors decreases as the intermediate floors size increases, however, there are no clear cut-off points at which a higher level of fire safety precaution should be provided. The cut-off points in the current C/AS1 of 20% for a closed intermediate floor and 40% for an open intermediate floor are therefore not justified by this analysis. Occupant load has significant impact on the level of safety of the occupants of the firecells containing intermediate floors. The higher the occupant load, the lower the level of safety is.

In addition to the current definition of an intermediate floor, the definitions for open and closed intermediate floors are proposed to which open and closed intermediate floors are clearly distinguished. The term "limited area intermediate floor" in the current C/AS1 is proposed be removed and all related clauses are proposed to be amended or deleted accordingly. A proposed new set of prescriptive fire safety requirements for intermediate floors has been developed based on the occupant load of intermediate floors and not the intermediate floor size in the form of a table similar to Table 4.1 of the current C/AS1. With the proposed FSPs, a firecell with lower occupant load would require lesser fire safety requirements than a firecell with higher occupant load regardless of intermediate floor size. Moreover, the proposed FSPs for intermediate floors would bring the level of safety of the occupants of the firecells containing intermediate floors to a similar level of safety of the equivalent firecells without intermediate floors.

The analysis of this project illustrated that it is very difficult to develop a rational *verification method* for designing fire safety for firecells containing intermediate floors.

Guidance for designers in designing fire safety for firecells containing intermediate floors in which the methods of modelling using BRANZFIRE and Fire Dynamics Simulator (FDS) are presented in detail, has been developed. The analysis showed that BRANZFIRE can be used to model a firecell containing intermediate floors. However, it is necessary to use the virtual room methodology due to the natural geometry of the firecell containing intermediate floors, and the fire location and type of intermediate floor are very critical in BRANZFIRE modelling. BRANZFIRE is not suitable to model the firecell containing large intermediate floors (open or closed) when a fire occurs under the intermediate floor. The analysis also pointed out that the location of the exits is critical in designing fire safety for firecells containing intermediate floors and majority of exits from the lower floor should not be located under intermediate floors.

Applying the proposed FSPs for intermediate floors which are based on the occupant load of the intermediate floors in designing fire safety for firecells containing intermediate floors is recommended by this study. In addition, the *alternative solution* is an option that is always available for designing fire safety for firecells having intermediate floors.

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11. APPENDICES

Appendix A: Tables and Figures of ASET predicted by FDS and BRANZFIRE

Table A1: ASET predicted by FDS and BRANZFIRE with a fast fire located under the intermediate floor for small and medium firecells containing open intermediate floors.

Firecell	Medium room				Small room			
Tool	FDS		BRANZFIRE		FDS		BRANZFIRE	
Floor	Int	Lower	Int	Lower	Int	Lower	Int	Lower
0%	NA	205	NA	170	NA	97	NA	60
20%	145	122	130	147	85	82	75	55
40%	160	125	140	145	90	74	80	55
60%	180	125	140	135	103	72	80	50
90%	200	125	130	135	124	71	80	55
99%	250	125	140	145	NA	NA	NA	NA

Table A2: ASET predicted by FDS and BRANZFIRE with a fast fire located under the intermediate floor for large firecells containing open intermediate floors.

Firecell	Large room H= 8m				Large room H= 10m				Large room H= 12m			
Tool	FDS		BRANZFIRE		FDS		BRANZFIRE		FDS		BRANZFIRE	
Floor	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower
0%	NA	398	NA	368	NA	449	NA	382	NA	519	NA	392
20%	184	305	160	340	221	341	165	350	233	359	180	360
40%	218	312	190	340	264	332	195	345	268	351	200	355
60%	234	305	210	340	288	341	210	345	300	350	215	352
90%	271	238	200	350	323	250	205	355	359	251	215	350
99%	446	188	230	300	538	188	250	310	650	188	250	310

Table A3: ASET predicted by FDS and BRANZFIRE with a fast fire located in the open area for small and medium firecells containing open intermediate floors.

Firecell	Medium room						Small room					
Tool	FDS		BRANZFIRE				FDS		BRANZFIRE			
			as 1 room		*as 3 rooms*				as 1 room		*as 3 rooms*	
Floor	Int	Lower	Int	Lower	*Int*	*Lower*	Int	Lower	Int	Lower	*Int*	*Lower*
0%	NA	205	NA	170	*NA*	*170*	NA	97	NA	60	*NA*	*60*
20%	130	205	75	170	*115*	*160*	78	91	51	60	*70*	*60*
40%	135	195	75	170	*120*	*150*	79	91	51	60	*70*	*60*
60%	130	195	75	170	*115*	*140*	80	90	51	60	*70*	*60*
90%	134	173	75	170	*95*	*140*	NA	NA	NA	NA	*NA*	*NA*

Table A4: ASET predicted by FDS and BRANZFIRE with a fast fire located in the open area for large 8m and 10m firecells containing open intermediate floors .

Firecell	Large room H= 8m						Large room H= 10m					
Tool	FDS		BRANZFIRE				FDS		BRANZFIRE			
			as 1 room		*as 3 rooms*				as 1 room		*as 3 rooms*	
Floor	Int	Lower	Int	Lower	*Int*	*Lower*	Int	Lower	Int	Lower	*Int*	*Lower*
0%	NA	398	NA	371	*NA*	*371*	NA	449	NA	383	*NA*	*383*
20%	186	391	117	371	*150*	*340*	191	437	141	383	*155*	*360*
40%	184	375	117	371	*150*	*330*	202	440	141	383	*165*	*350*
60%	182	388	117	371	*150*	*330*	202	440	141	383	*160*	*345*
90%	166	390	117	371	*130*	*340*	219	424	141	383	*140*	*350*

Table A5: ASET predicted by FDS and BRANZFIRE with a fast fire located in the open area for large 12m firecell containing open intermediate floors .

Firecell	Large room H= 12m					
Tool	FDS		BRANZFIRE			
			as 1 room		*as 3 rooms*	
Floor	Int	Lower	Int	Lower	*Int*	*Lower*
0%	NA	519	NA	393	*NA*	*393*
20%	295	497	176	393	*170*	*375*
40%	289	459	176	393	*175*	*365*
60%	298	467	176	393	*170*	*355*
90%	269	449	176	393	*160*	*355*

Table A6: ASET of lower floors predicted by FDS and BRANZFIRE with a fast fire for three firecell sizes containing closed intermediate floors.

Firecell	Small room				Medium room				Large room H= 8m			
Tool	FDS		BRANZFIRE		FDS		BRANZFIRE		FDS		BRANZFIRE	
Location	Under	Open	Under	Open	Under	Open	Under	Open	Under	Open	Under	Open
0%	NA	97	NA	60	NA	205	NA	170	NA	398	NA	371
20%	83	97	55	60	125	190	145	155	295	383	330	330
40%	73	87	55	55	120	180	135	140	297	371	320	320
60%	68	77	50	50	120	150	125	130	289	346	320	320
90%	NA	NA	NA	NA	120	132	90	110	260	305	330	300

Table A7: ASET predicted by FDS for three firecell sizes containing open intermediate floors with slow, moderate, fast and ultrafast fires.

Firecell	Small room				Medium room				Large room H= 8m				Fire growth rate
Location	Under		Open		Under		Open		Under		Open		
Floor	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower	Int	Lower	
0%	NA	239	NA	239	NA	469	NA	469	NA	825	NA	825	Slow
	NA	154	NA	154	NA	302	NA	302	NA	564	NA	564	Moderate
	NA	97	NA	97	NA	205	NA	205	NA	398	NA	398	Fast
	NA	69	NA	69	NA	140	NA	140	NA	271	NA	271	U.fast
20%	218	235	210	237	383	368	347	464	486	736	422	811	Slow
	128	152	118	152	232	218	208	300	298	461	279	563	Moderate
	85	82	78	91	145	122	130	205	184	305	186	391	Fast
	52	61	46	65	90	83	82	136	113	198	117	269	U.fast
40%	228	230	214	232	408	334	353	461	546	718	451	798	Slow
	148	145	126	148	266	202	213	297	343	470	283	557	Moderate
	90	74	79	91	160	125	135	195	218	312	184	375	Fast
	61	51	50	58	105	66	83	130	129	203	122	260	U.fast

Figure A1: ASET of the lower floor predicted by FDS for medium firecells containing open intermediate floors with different fire growth rates.

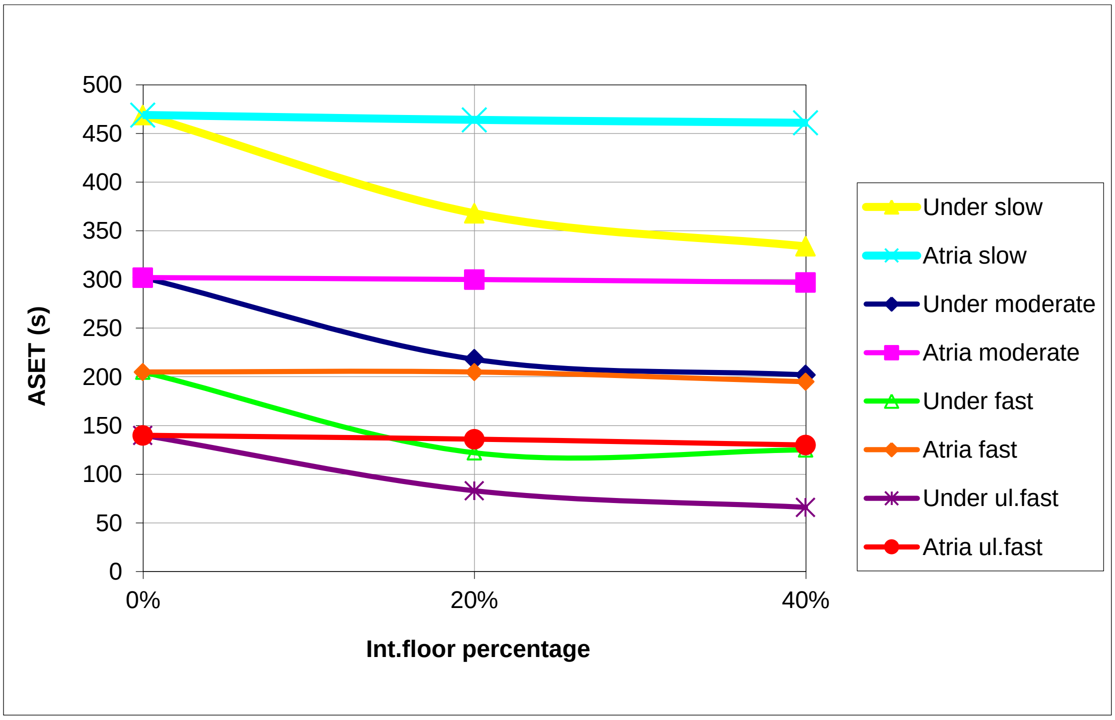


Figure A2: ASET of the lower floor predicted by FDS for small firecells containing open intermediate floors with different fire growth rates.

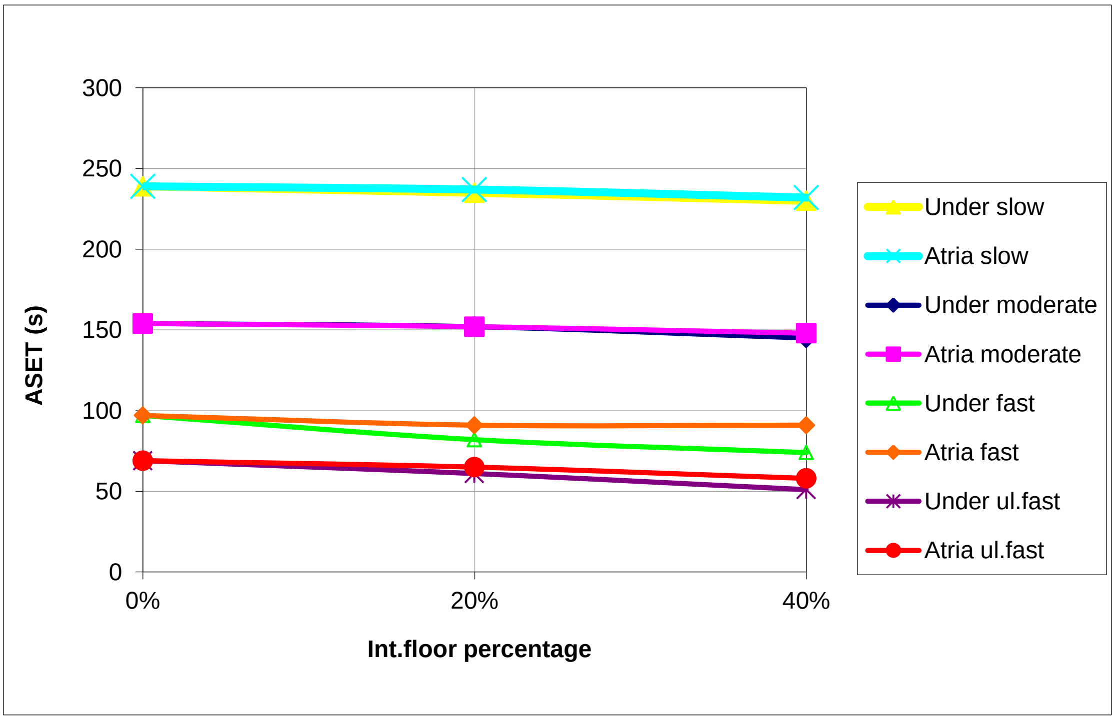


Figure A3: ASET of the intermediate floor predicted by FDS for medium firecells containing open intermediate floors with different fire growth rates.

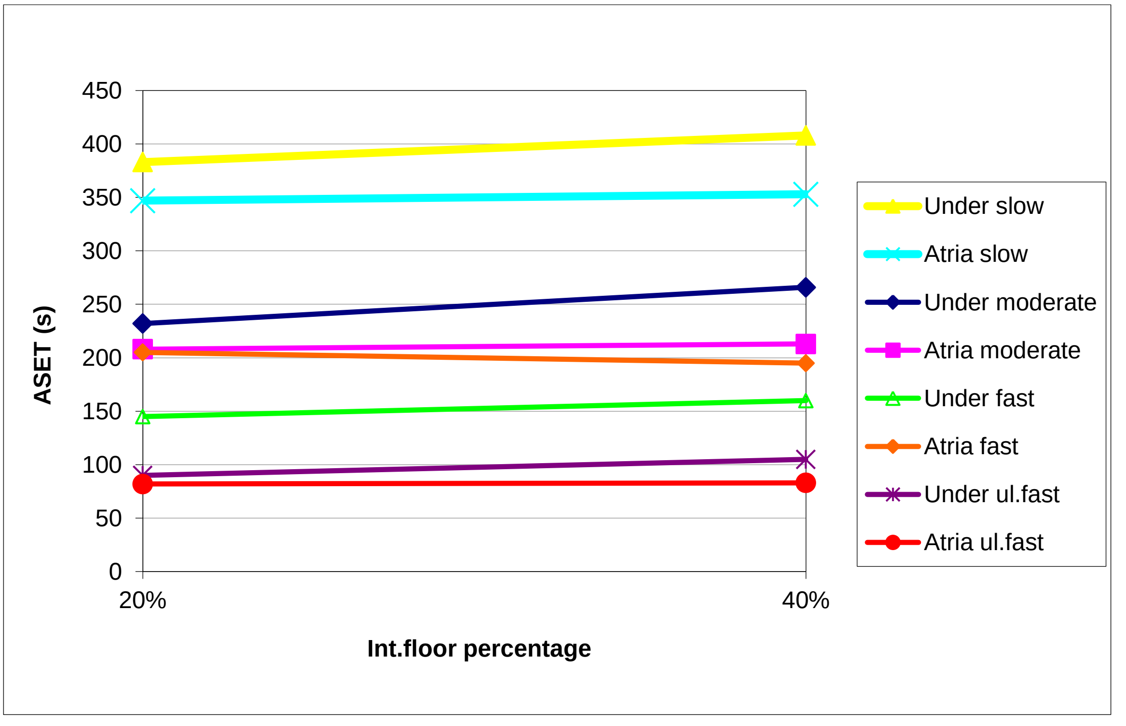
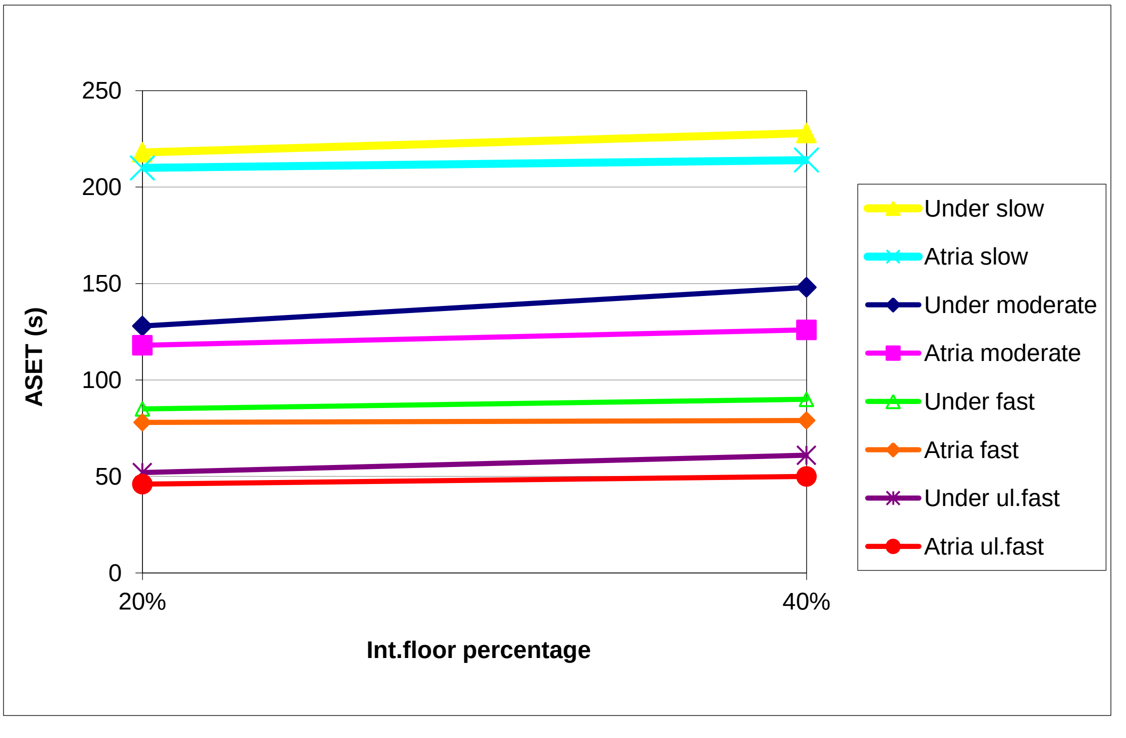


Figure A4: ASET of the intermediate floor predicted by FDS for small firecells containing open intermediate floors with different fire growth rates.



Appendix B: Examples of furniture arrangement in movement time simulations

Figure B1: Small firecell with 40% of intermediate floor

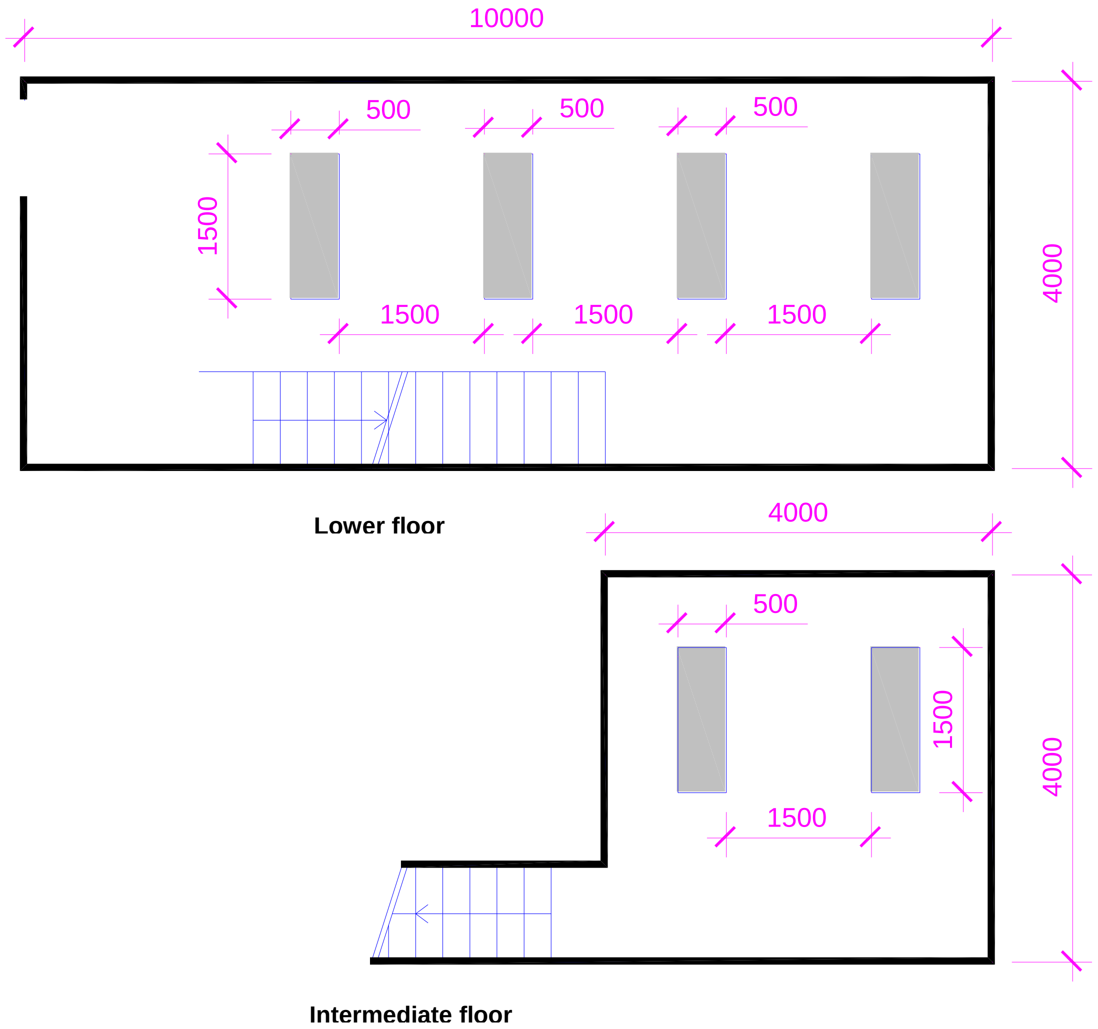
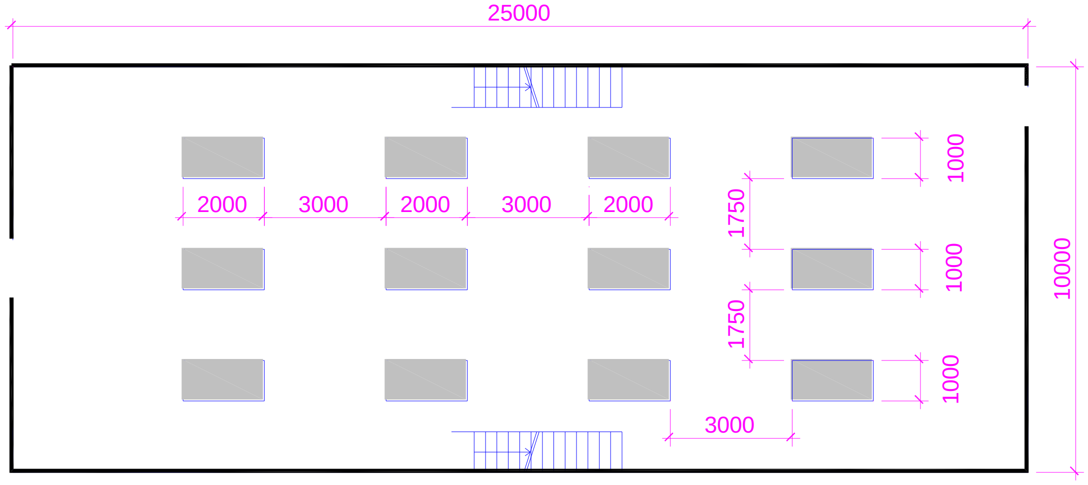
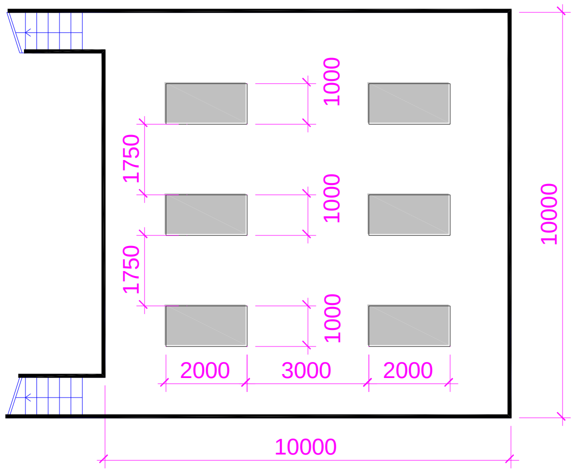


Figure B2: Medium firecell with 40% of intermediate floor

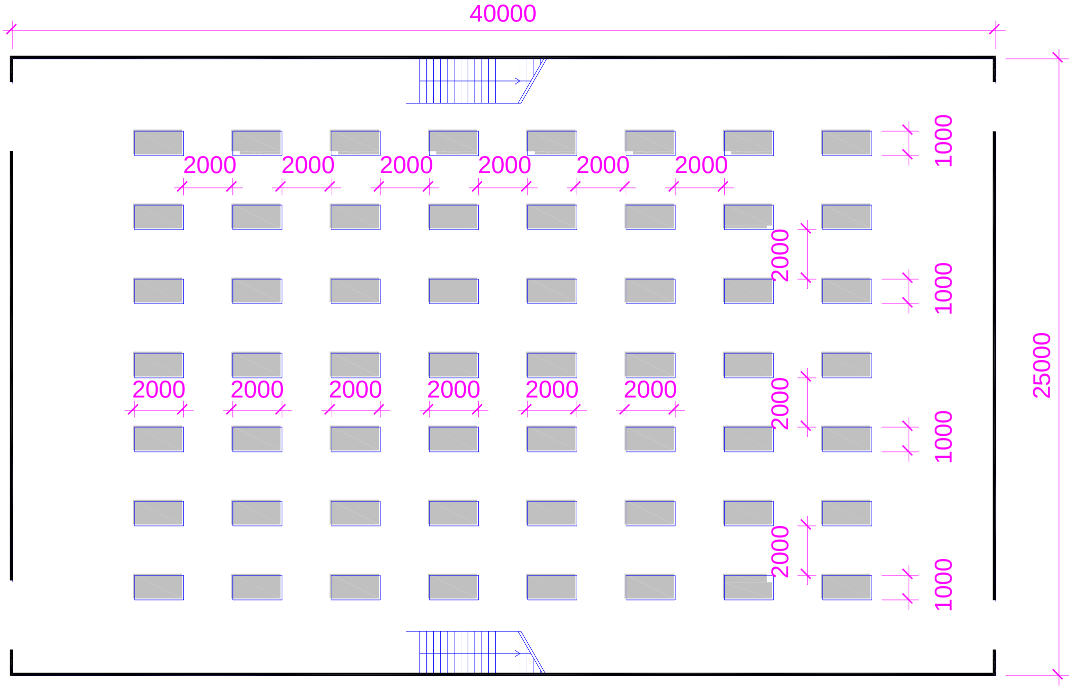


Lower floor

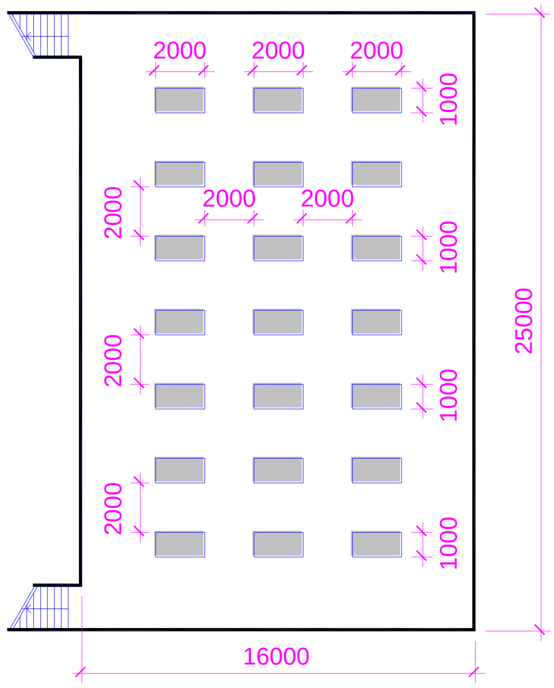


Intermediate floor

Figure B3: Large firecell with 40% of intermediate floor



Lower floor



Intermediate floor

Appendix C: Tables and Figures of movement times

Table C1: Movement times for small firecells in different purpose groups and intermediate floor sizes.

Purpose group	% of Int floor	Occ. Load (ppl)	No of exit	Blocked exit	No of staircase	Movement time (s)		
						Int	Lower	Firecell with no int.floor
CS	0%	40	1	0	0		29	-
	20%	48	1	0	1	12	35	35
	40%	56	*2*	*1*	*1*	*21*	*41*	*40*
			2	0	1	21	39	23
	60%	64	*2*	*1*	*1*	*30*	*52*	*43*
			2	0	1	30	43	26
	90%	76	*2*	*1*	*1*	*49*	*72*	*51*
			2	0	1	49	60	28
WL, WM	0%	2	1	0	0		10	-
	20%	3	1	0	1	5	16	12
	40%	4	1	0	1	6	16	14
	60%	5	1	0	1	9	19	14
	90%	6	1	0	1	10	24	14

Table C2: Movement times for large firecells in different purpose groups and intermediate floor sizes.

Purpose group	% of Int floor	Occ. Load (ppl)	No of exit	Blocked exit	No of staircase	Movement time (s)		
						Int	Lower	Firecell with no int.floor
CL	0%	1,000	3	0	2		116	-
	20%	1,200	4	0	2	132	167	116
	40%	1,400	4	0	2	132	173	126
	60%	1,600	4	0	3	165	207	136
	90%	1,900	4	0	3	172	204	143
WL, WM	0%	30	*2*	*1*	*2*		*43*	*-*
			2	0	2		23	-
	20%	50	*2*	*1*	*2*	*21*	*59*	*45*
			2	0	2	21	54	28
	40%	70	*2*	*1*	*2*	*37*	*77*	*53*
			2	0	2	27	64	30
	60%	90	*2*	*1*	*2*	*51*	*98*	*64*
			2	0	2	42	75	38
	90%	120	*2*	*1*	*2*	*77*	*125*	*84*
			2	0	2	61	93	44

Table C3: Movement times for medium firecells in different purpose groups and intermediate floor sizes.

Purpose group	% of Int floor	Occ. Load (ppl)	No of exit	Blocked exit	No of staircase	Movement time (s)		
						Int	Lower	Firecell with no int.floor
CL	0%	250	2	1	0		100	-
			2	0	0		57	-
	20%	300	2	1	1	65	120	109
			2	0	1	65	90	61
	40%	350	2	1	2	88	120	120
			2	0	2	67	87	70
	60%	400	2	1	2	108	137	126
			2	0	2	95	111	80
	90%	475	2	1	2	167	212	138
			2	0	2	155	177	84
WL, WM	0%	8	2	1	0		21	-
			2	0	0		13	-
	20%	13	2	1	1	10	30	23
			2	0	1	10	30	12
	40%	18	2	1	2	10	37	23
			2	0	2	10	30	13
	60%	23	2	1	2	17	47	25
			2	0	2	16	32	14
	90%	31	2	1	2	25	60	27
			2	0	2	26	39	16

Figure C1: Movement times of the occupants of the small firecell containing intermediate floors in CS purpose group with and without a blocked exit.

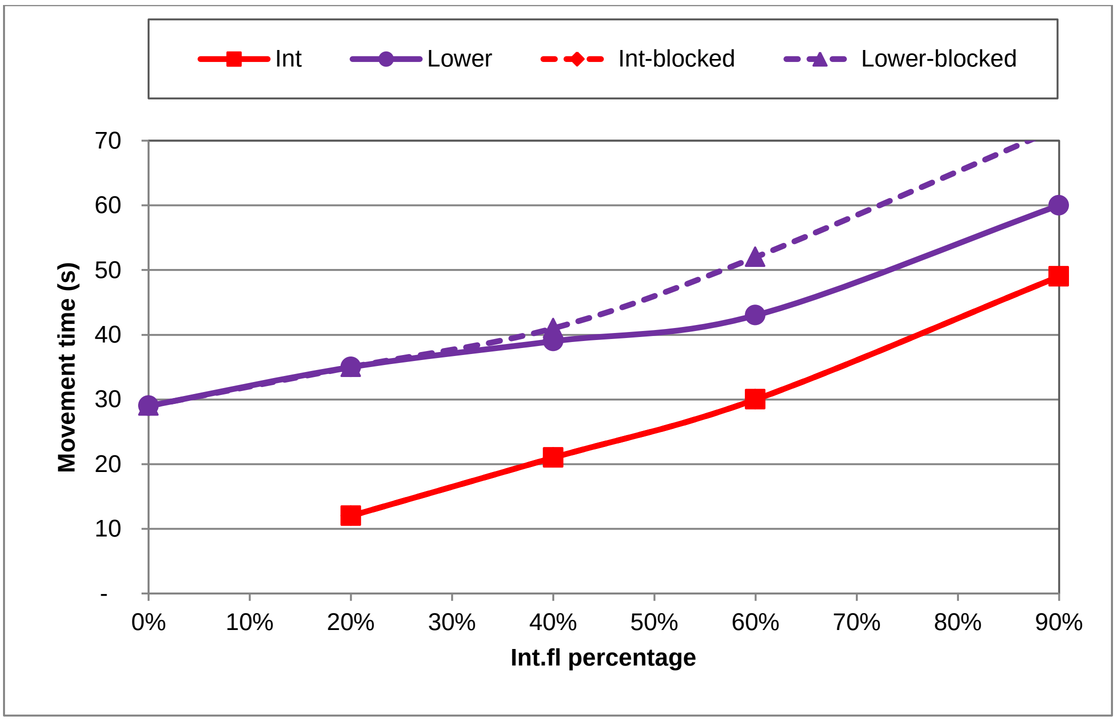


Figure C2: Movement times of the occupants of the medium firecell containing intermediate floors in CL purpose group with and without a blocked exit.

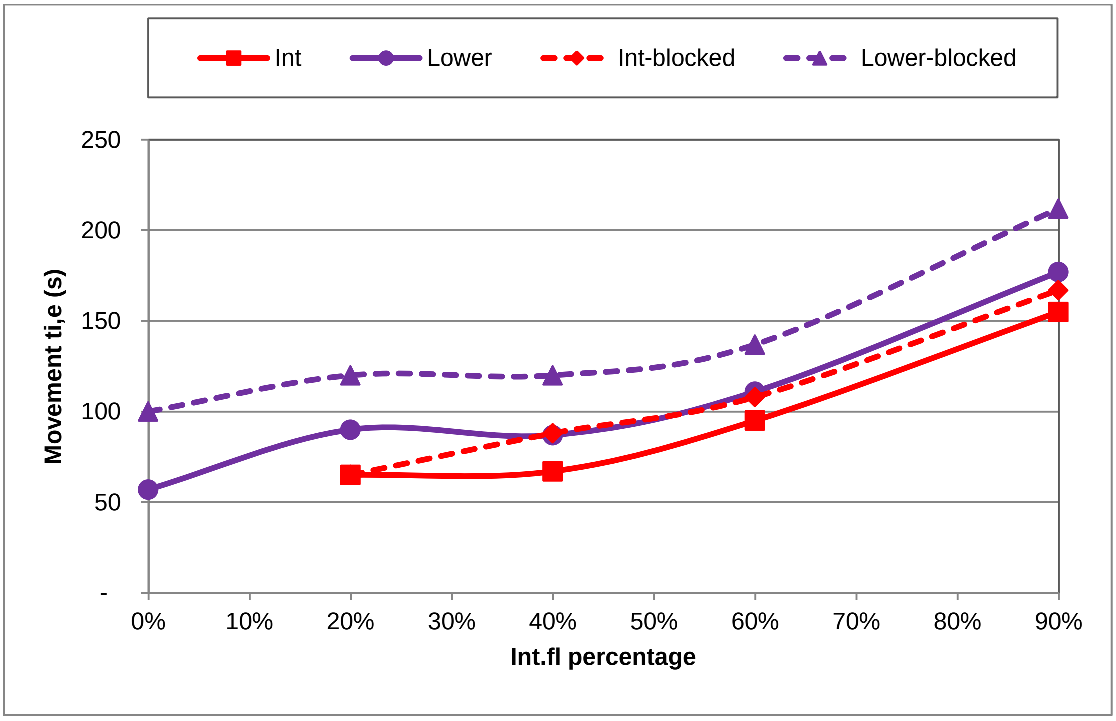
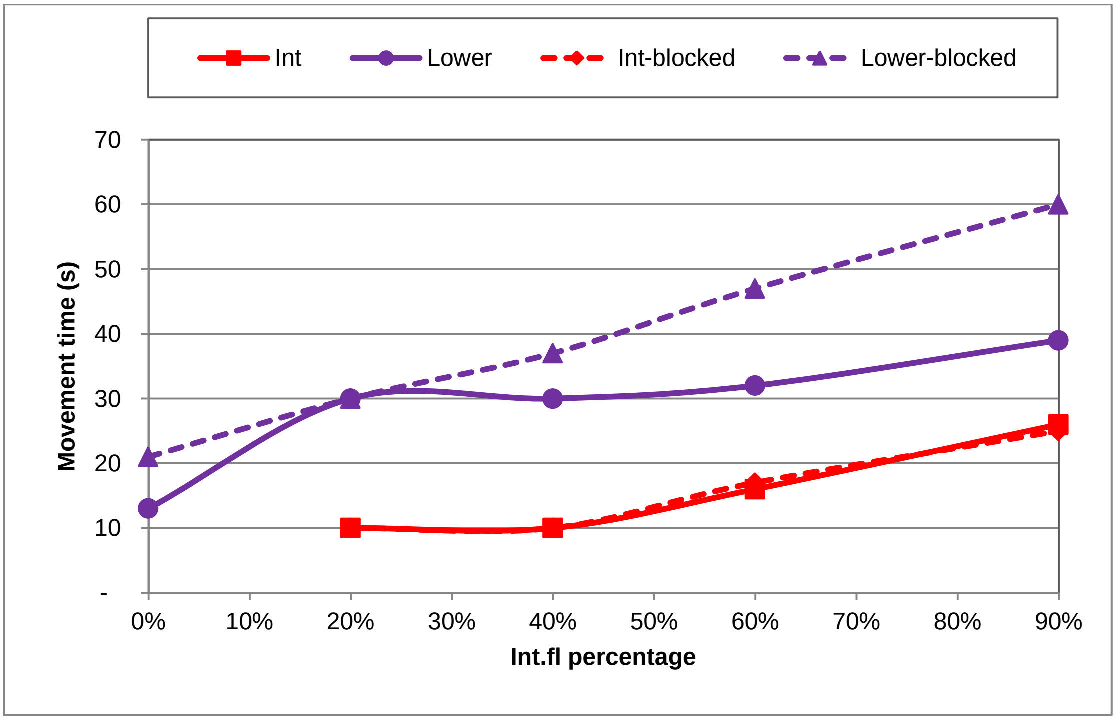


Figure C3: Movement times of the occupants of the medium firecell containing intermediate floors in WL and WM purpose groups with and without a blocked exit..



Appendix D: Tables and Figures of FoS

Table D1: FoS of small firecells containing open intermediate floors with different purpose groups and fire locations.

P. group	WL, WM					CS				
Fire location	Under		Open		*Firecell no Int*	Under		Open		*Firecell no Int*
Floor	Int	Lower	Int	Lower		Int	Lower	Int	Lower	
0%	NA	0.87	NA	0.87	*0.87*	NA	0.75	NA	0.75	*0.75*
20%	0.80	0.70	0.71	0.81	*0.85*	0.75	0.60	0.66	0.70	*0.71*
40%	0.84	0.63	0.73	0.78	*0.84*	0.75	0.53	0.64	0.65	*0.78*
60%	0.93	0.60	0.73	0.75	*0.84*	0.79	0.50	0.61	0.62	*0.76*
90%	1.12	0.57	NA	NA	*0.84*	0.82	0.44	NA	NA	*0.75*

Table D2: FoS of medium firecells containing open intermediate floors with different purpose groups and fire locations.

P. group	WL, WM					CL				
Fire location	Under		Open		*Firecell no Int*	Under		Open		*Firecell no Int*
Floor	Int	Lower	Int	Lower		Int	Lower	Int	Lower	
0%	NA	0.91	NA	0.91	*0.91*	NA	0.53	NA	0.53	*0.53*
20%	0.65	0.51	0.59	0.85	*0.91*	0.41	0.32	0.33	0.49	*0.52*
40%	0.72	0.51	0.59	0.80	*0.91*	0.44	0.32	0.33	0.47	*0.51*
60%	0.79	0.51	0.57	0.80	*0.91*	0.46	0.32	0.31	0.44	*0.50*
90%	0.84	0.50	0.56	0.65	*0.90*	0.45	0.27	0.28	0.32	*0.49*

Table D3: FoS of large 8m firecells containing open intermediate floors with different purpose groups and fire locations.

P. group	WL, WM					CL				
Fire location	Under		Open		*Firecell no Int*	Under		Open		*Firecell no Int*
Floor	Int	Lower	Int	Lower		Int	Lower	Int	Lower	
0%	NA	1.05	NA	1.05	*1.05*	NA	0.76	NA	0.76	*0.76*
20%	0.55	0.83	0.50	0.95	*1.03*	0.36	0.56	0.35	0.68	*0.76*
40%	0.63	0.82	0.48	0.89	*1.03*	0.43	0.56	0.34	0.65	*0.75*
60%	0.66	0.78	0.45	0.89	*1.00*	0.43	0.52	0.32	0.63	*0.73*
90%	0.72	0.58	0.40	0.87	*0.99*	0.49	0.41	0.28	0.63	*0.72*

Table D4 FoS of large 10m firecells containing open intermediate floors with different purpose groups and fire locations.

P. group	WL, WM					CL				
Fire location	Under		Open		*Firecell no Int*	Under		Open		*Firecell no Int*
Floor	Int	Lower	Int	Lower		Int	Lower	Int	Lower	
0%	NA	1.11	NA	1.11	*1.11*	NA	0.83	NA	0.83	*0.83*
20%	0.66	0.93	0.49	1.00	*1.09*	0.43	0.62	0.35	0.74	*0.83*
40%	0.77	0.87	0.49	0.98	*1.08*	0.51	0.60	0.36	0.73	*0.82*
60%	0.80	0.87	0.47	0.96	*1.06*	0.53	0.58	0.34	0.70	*0.80*
90%	0.86	0.62	0.48	0.89	*1.04*	0.58	0.42	0.35	0.68	*0.79*

Table D5: FoS of large 12m firecells containing open intermediate floors with different purpose groups and fire locations.

P. group	WL, WM					CL				
Fire location	Under		Open		*Firecell no Int*	Under		Open		*Firecell no Int*
Floor	Int	Lower	Int	Lower		Int	Lower	Int	Lower	
0%	NA	1.19	NA	1.19	*1.19*	NA	0.93	NA	0.93	*0.93*
20%	0.70	0.98	0.68	1.07	*1.17*	0.51	0.66	0.50	0.81	*0.93*
40%	0.79	0.93	0.66	0.99	*1.16*	0.52	0.63	0.50	0.75	*0.91*
60%	0.84	0.90	0.65	0.96	*1.15*	0.55	0.59	0.49	0.72	*0.89*
90%	0.96	0.66	0.57	0.92	*1.13*	0.65	0.47	0.44	0.70	*0.89*

Table D6: FoS of three studied firecells containing closed intermediate floors.

Fire cell	Small				Medium				Large 8m			
P. group	WL, WM		CS		WL, WM		CL		WL, WM		CL	
Fire location	Under	Open	Under	Open	Under	Open	Under	Open	Under	Open	Under	Open
0%	0.87	0.87	0.75	0.75	0.91	0.91	0.53	0.53	1.04	1.04	0.76	0.76
20%	0.70	0.81	0.60	0.70	0.51	0.79	0.32	0.45	0.80	0.93	0.54	0.66
40%	0.62	0.74	0.52	0.62	0.50	0.74	0.32	0.43	0.78	0.88	0.54	0.64
60%	0.56	0.64	0.47	0.53	0.49	0.61	0.30	0.34	0.74	0.80	0.49	0.56
90%	NA	NA	NA	NA	0.48	0.52	0.26	0.26	0.64	0.67	0.45	0.50

Figure D1: FoS of the intermediate floors of the small firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

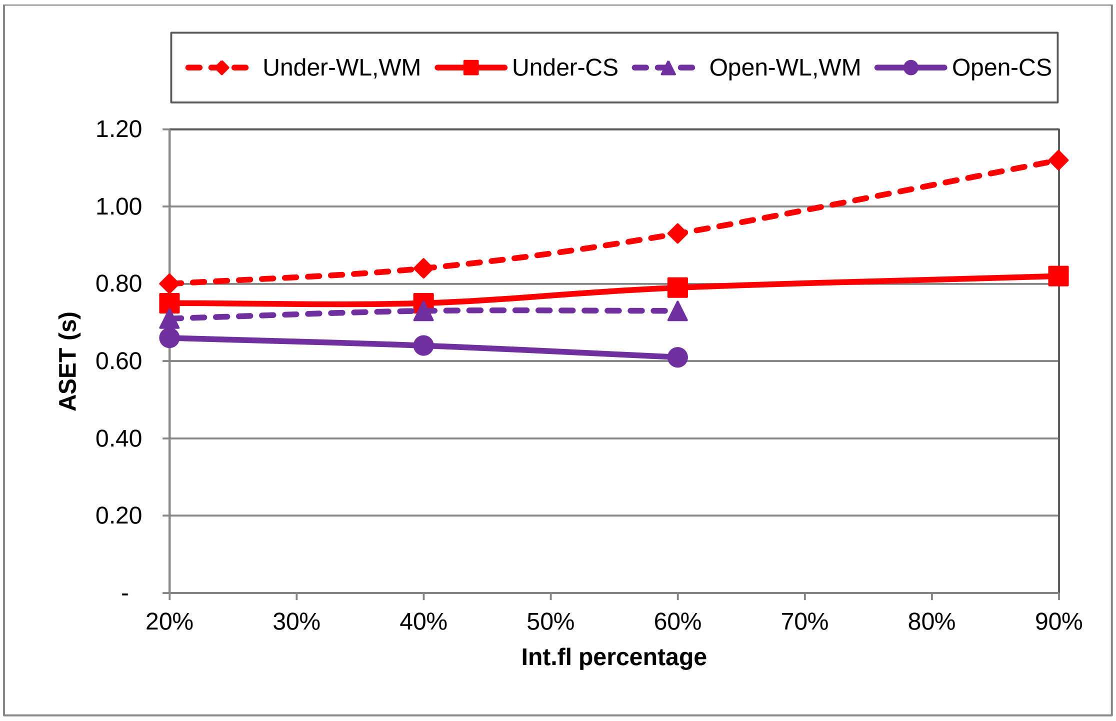


Figure D2 FoS of the lower floors of the small firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

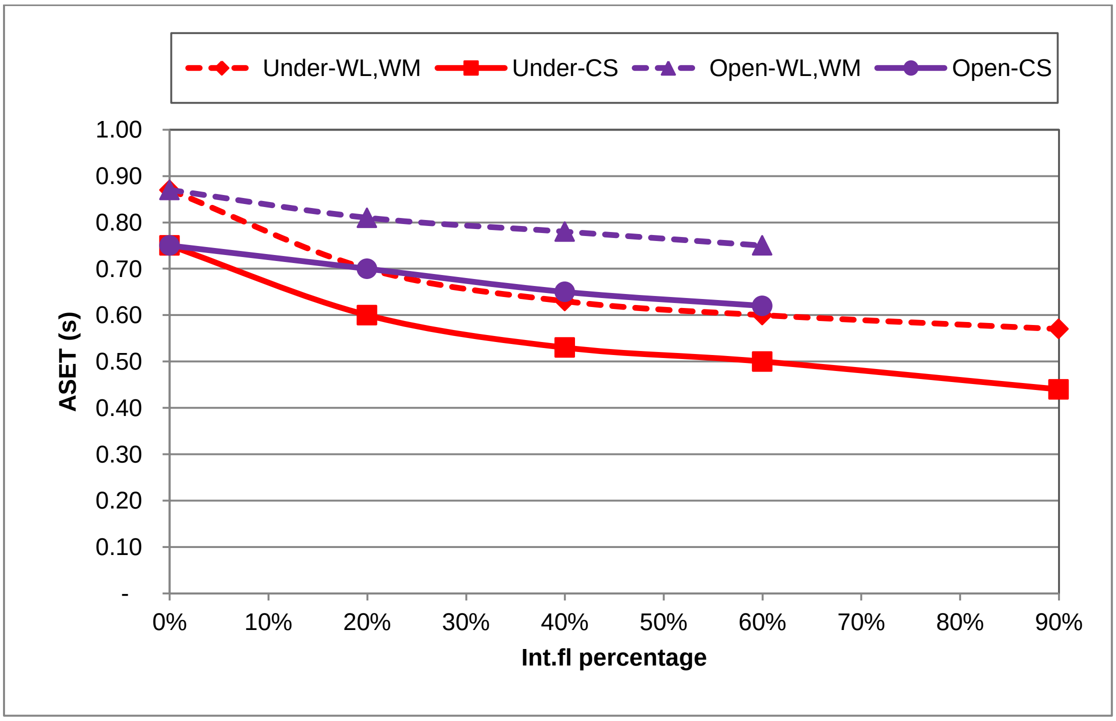


Figure D3: FoS of the intermediate floor of the medium firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

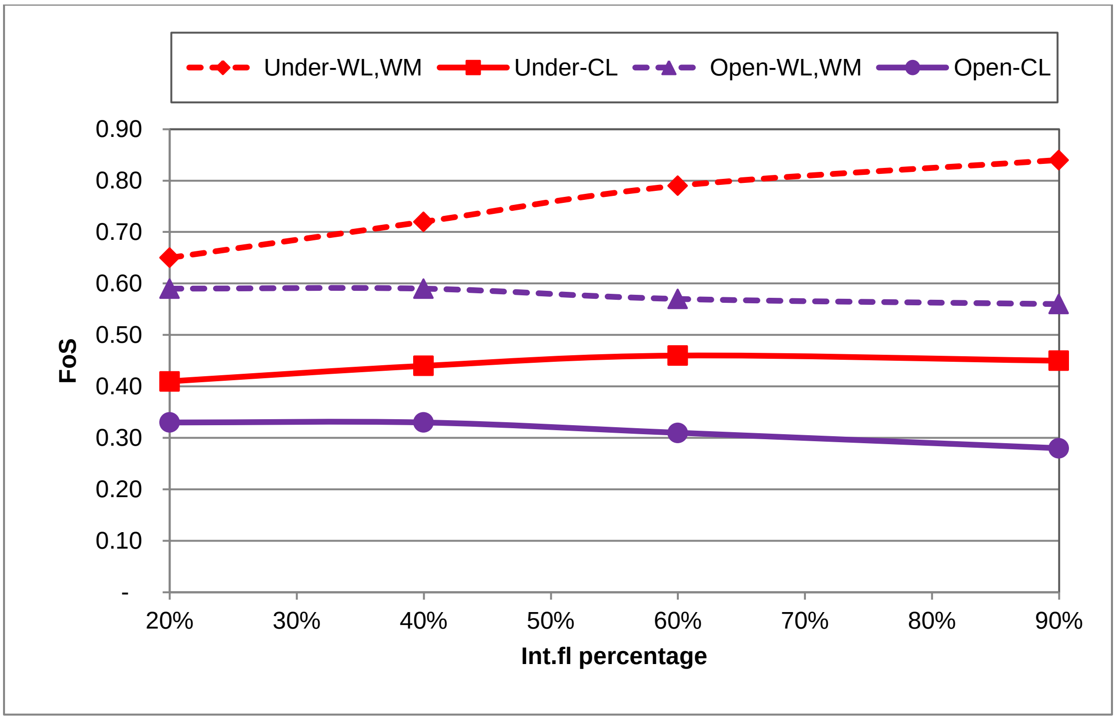


Figure D4: FoS of the lower floors of the medium firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

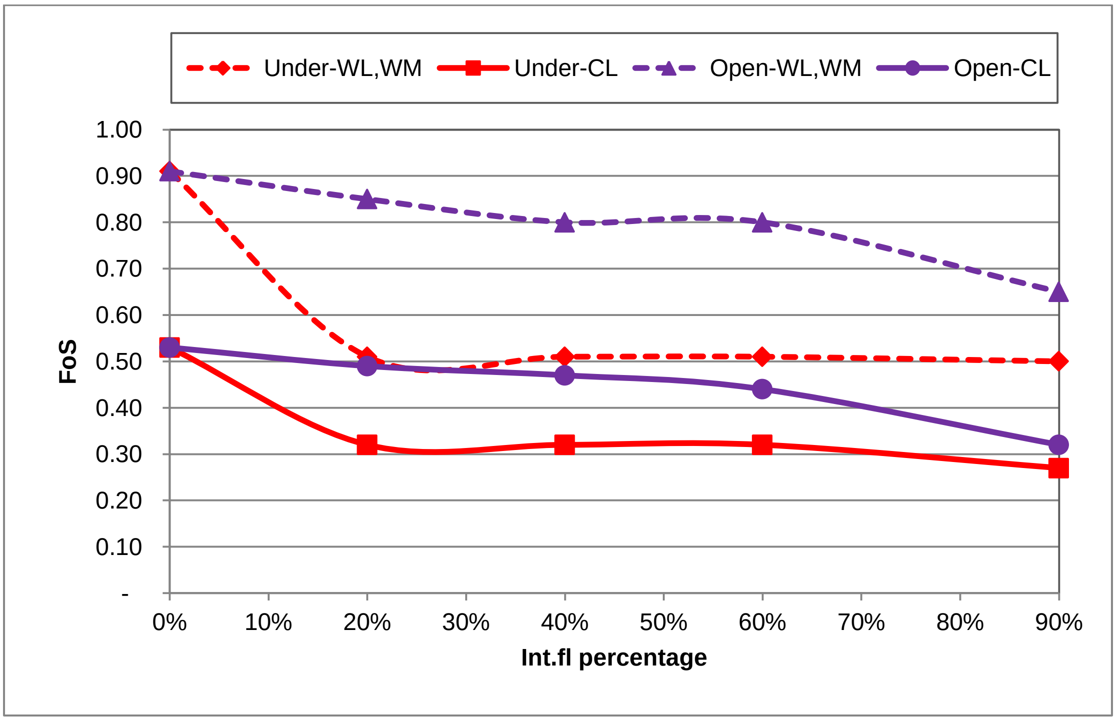


Figure D5: FoS of the intermediate floors of the large10m firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

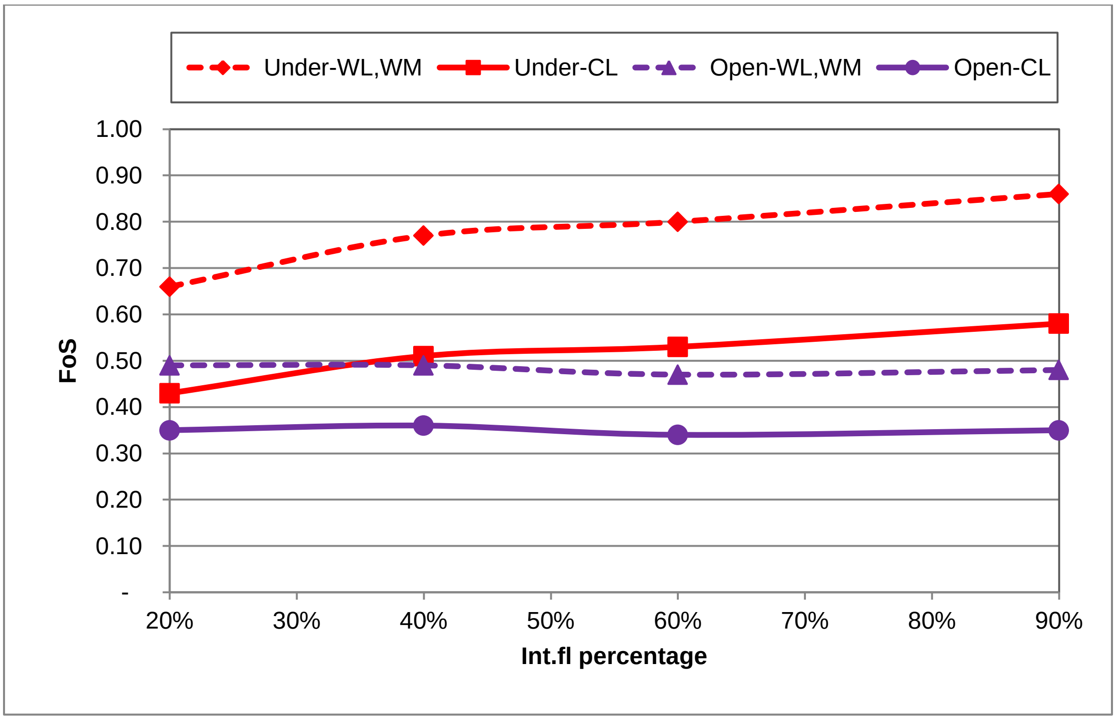


Figure D6: FoS of the lower floors of the large 10m firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

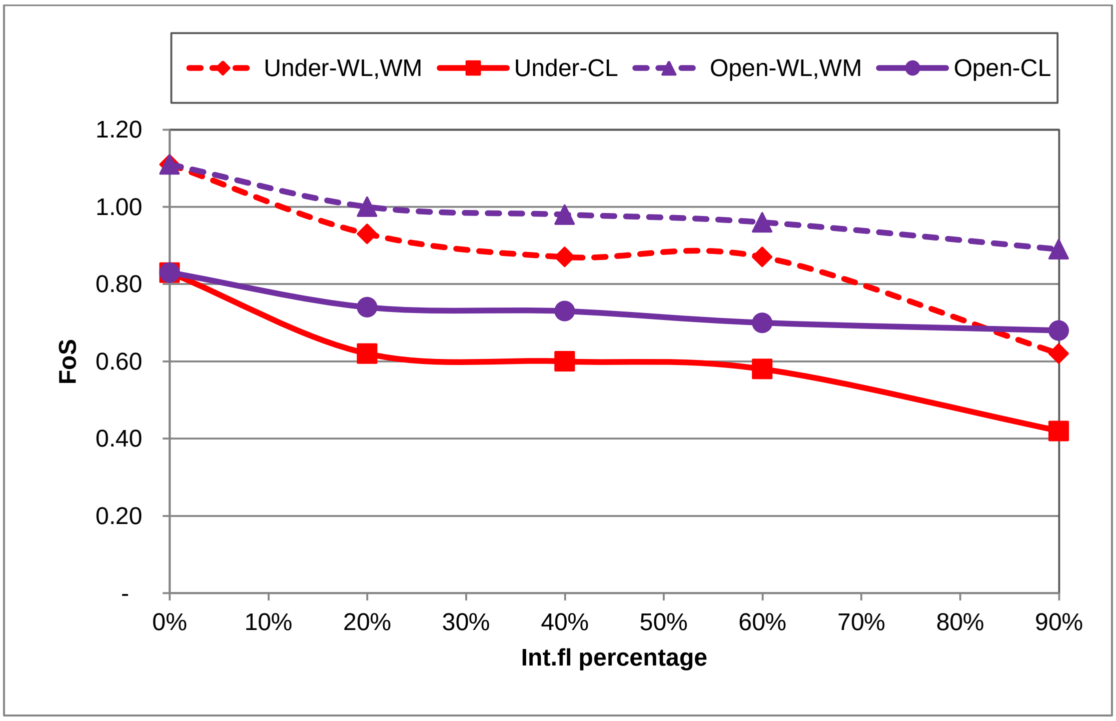


Figure D7: FoS of the intermediate floors of the large12m firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

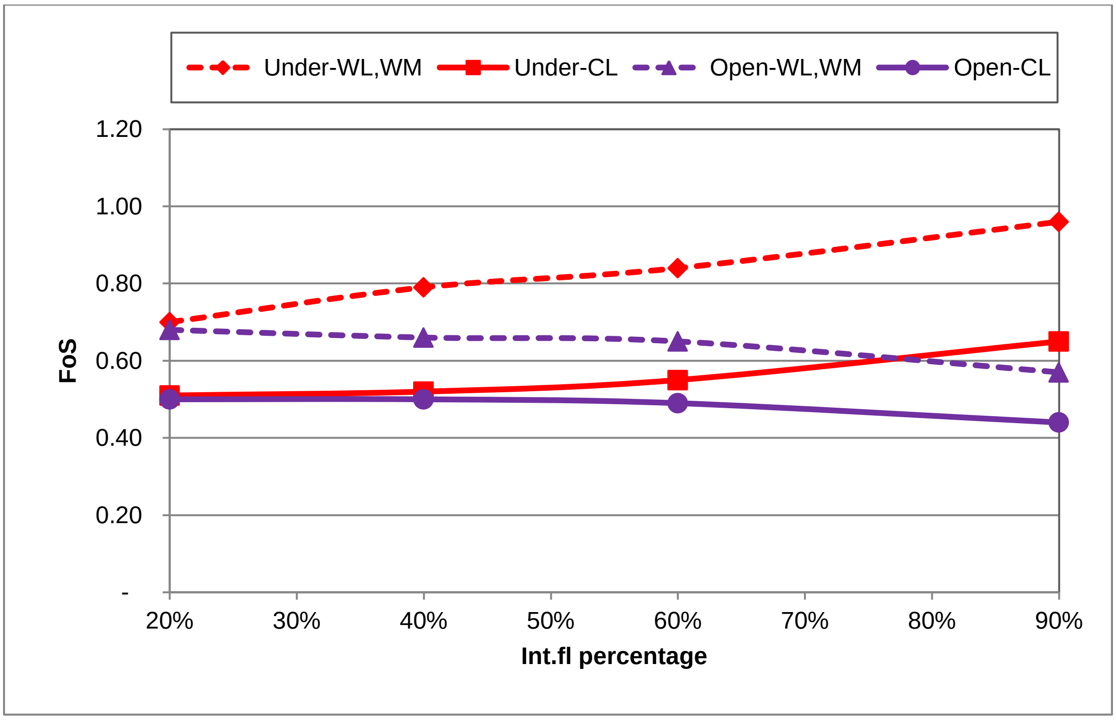


Figure D8: FoS of the lower floors of the large 12m firecells containing open intermediate floors by the variation of intermediate floor sizes and purpose groups.

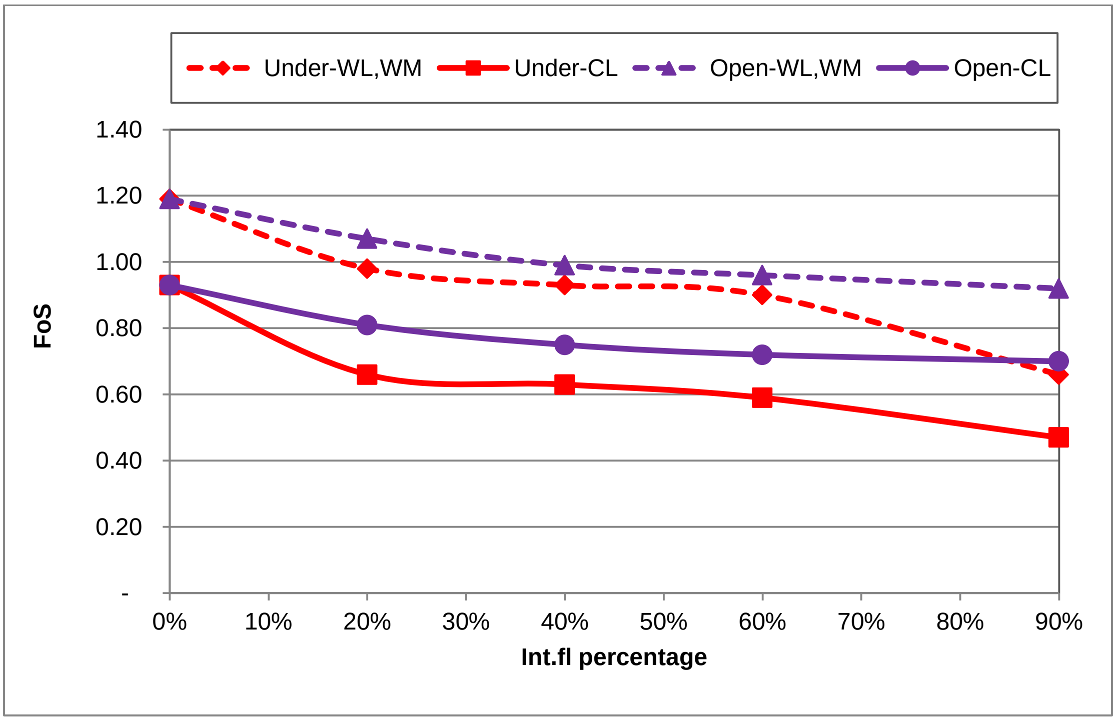


Figure D9: FoS of the intermediate floor of the small firecell containing open intermediate floors in CS purpose group by the variation of intermediate floor sizes with and without a blocked exit.

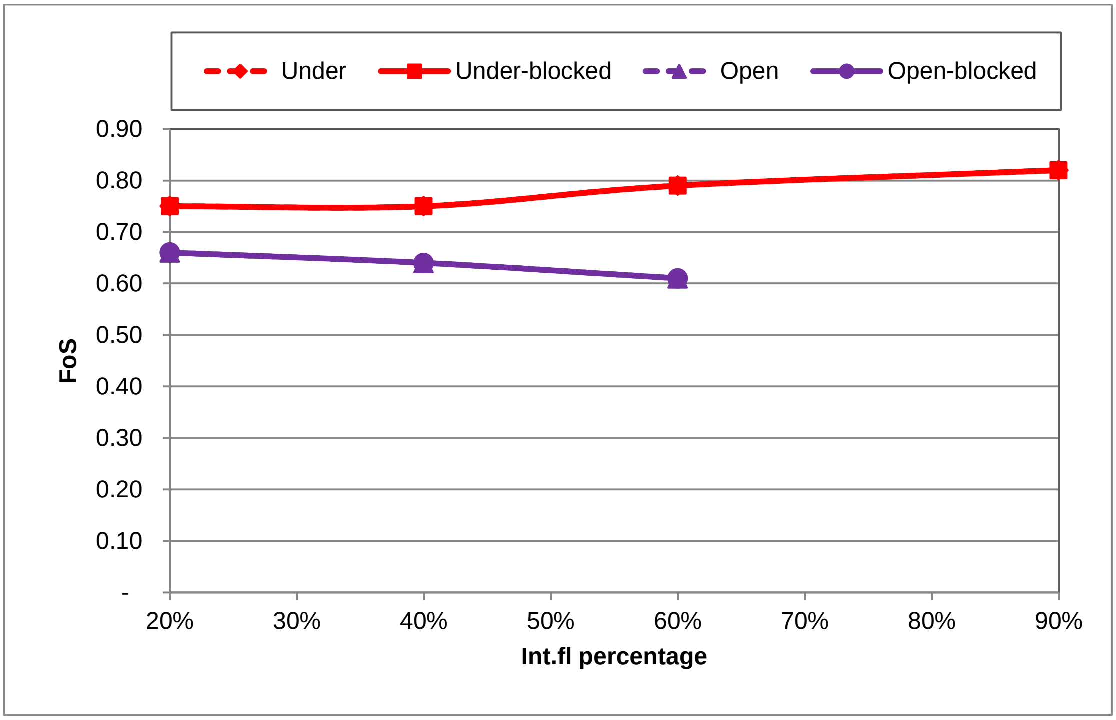


Figure D10: FoS of the lower floor of the small firecell containing open intermediate floors in CS purpose group by the variation of intermediate floor sizes with and without a blocked exit.

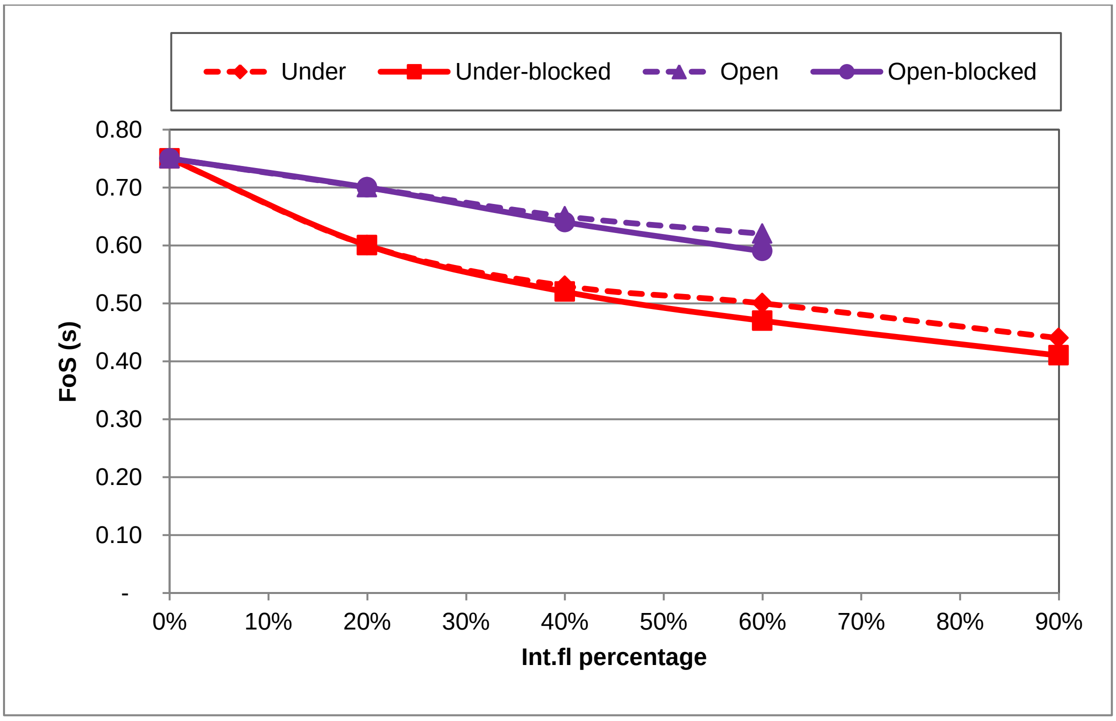


Figure D11: FoS of the intermediate floor of the medium firecell containing open intermediate floors in WL and WM purpose groups by the variation of intermediate floor sizes with and without a blocked exit.

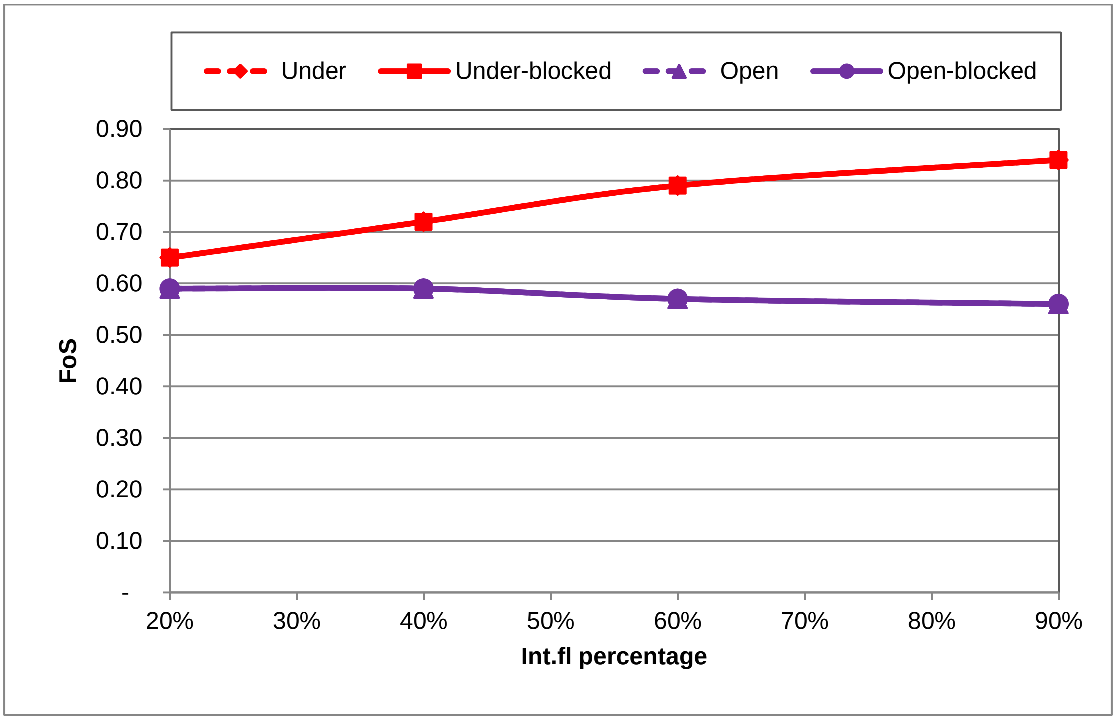


Figure D12: FoS of the lower floor of the medium firecell containing open intermediate floors in WL and WM purpose groups by the variation of intermediate floor sizes with and without a blocked exit.

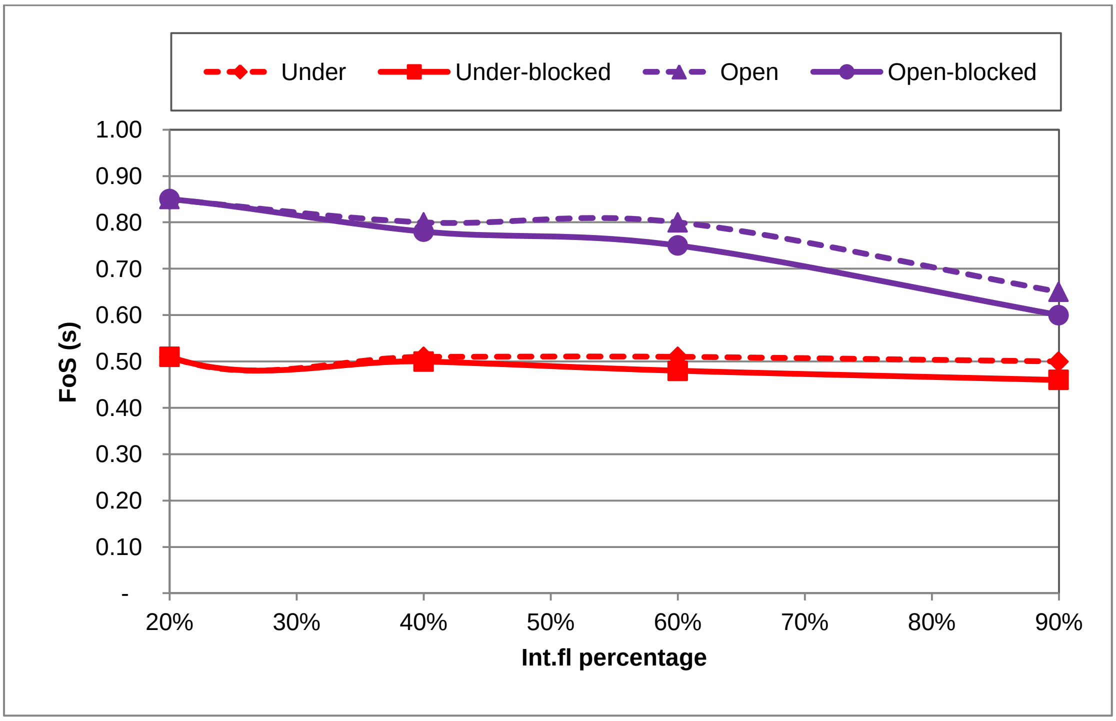


Figure D13: FoS of the intermediate floor of the medium firecell containing open intermediate floors in CL purpose group by the variation of intermediate floor sizes with and without a blocked exit.

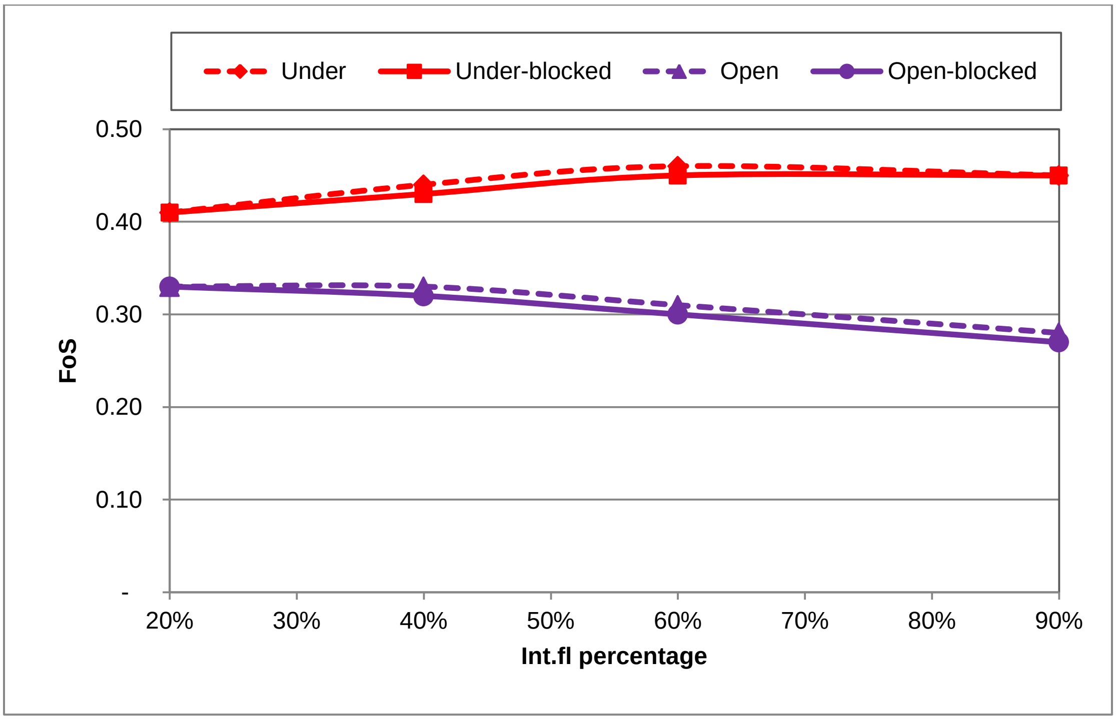


Figure D14: FoS of the lower floor of the medium firecell containing open intermediate floors in CL purpose group by the variation of intermediate floor sizes with and without a blocked exit.

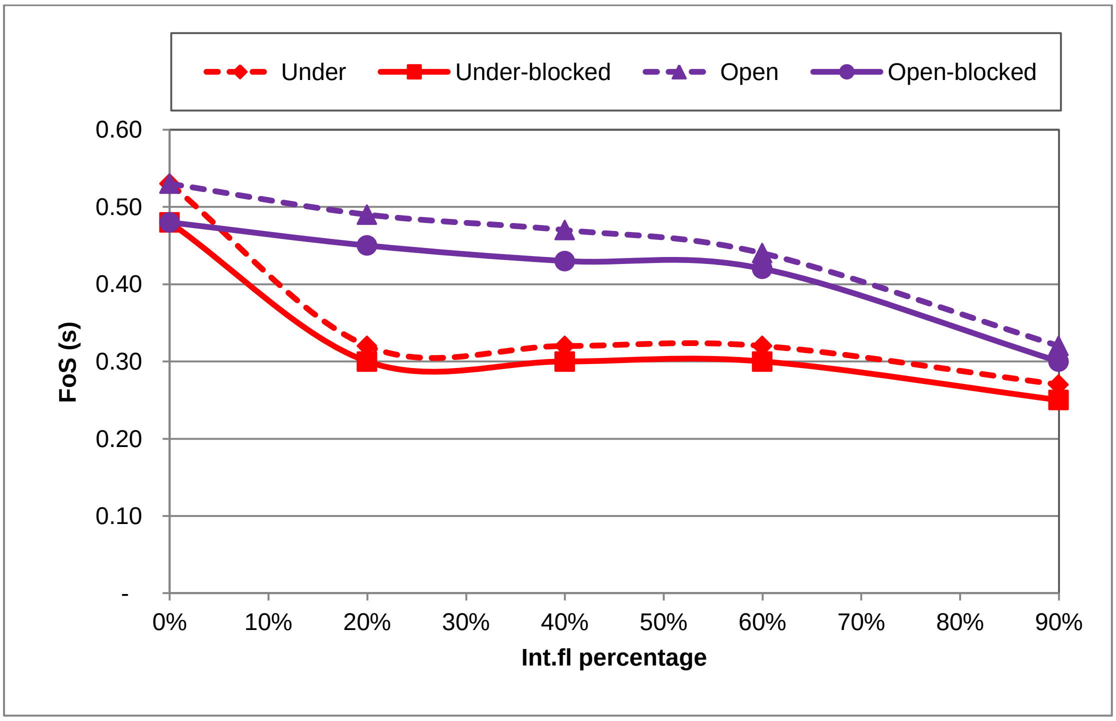


Figure D15: FoS of the lower floors by the variation of intermediate floor sizes for small firecells containing open intermediate floors with a fire is under intermediate floor.

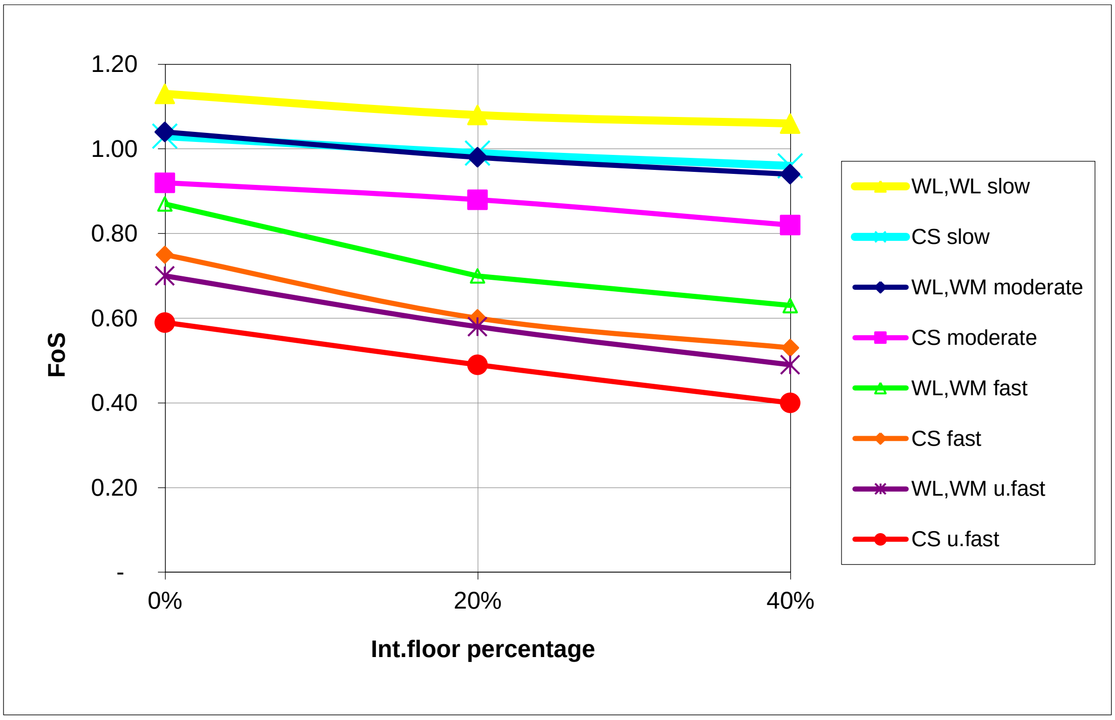


Figure D16: FoS of the lower floors by the variation of intermediate floor sizes for small firecells containing open intermediate floors with a fire is in the open area.

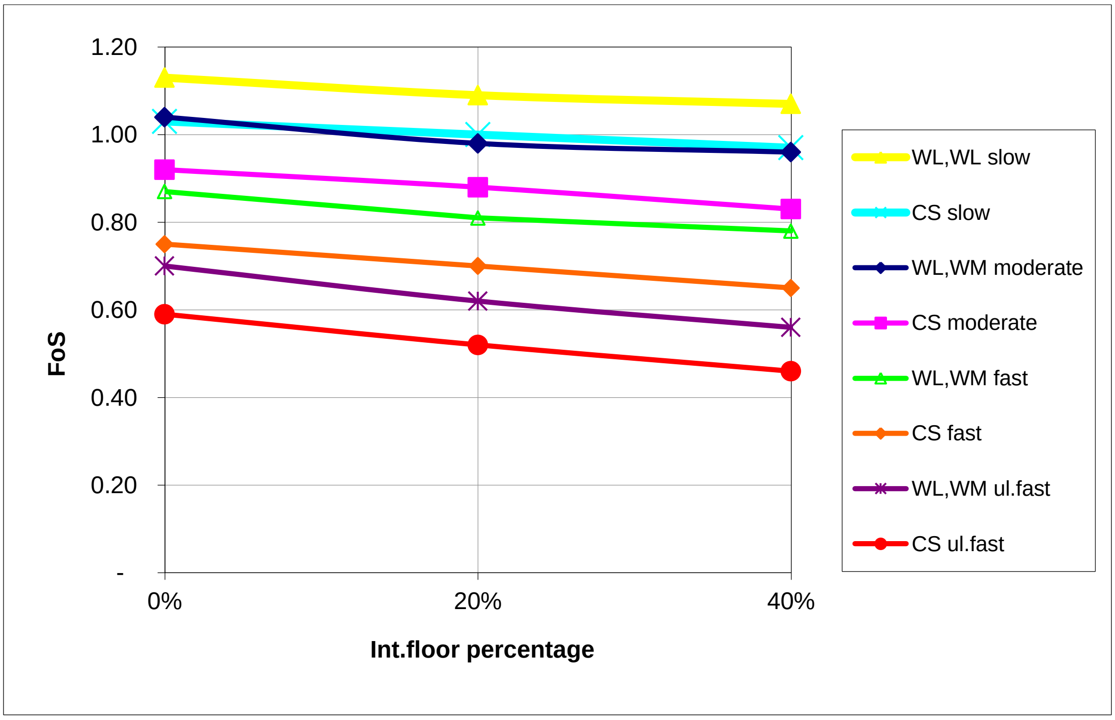


Figure D17: FoS of the intermediate floors by the variation of intermediate floor sizes for small firecells containing open intermediate floors with a fire is under intermediate floor.

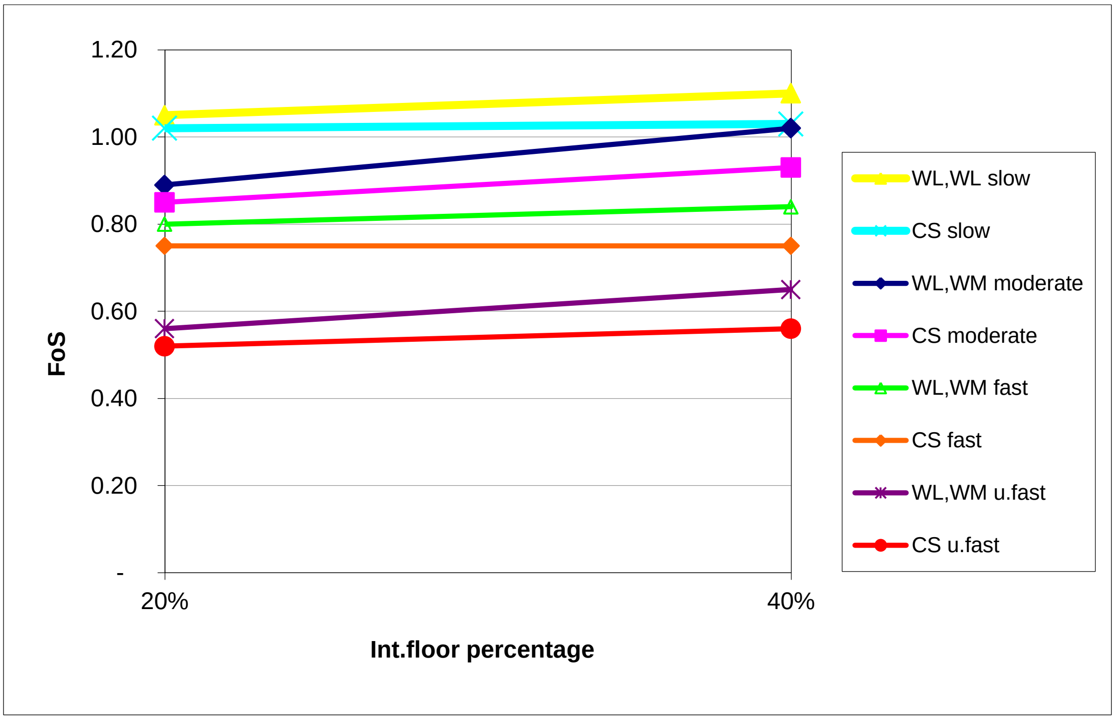


Figure D18: FoS of the intermediate floors by the variation of intermediate floor sizes for small firecells containing open intermediate floors with a fire is in the open area.

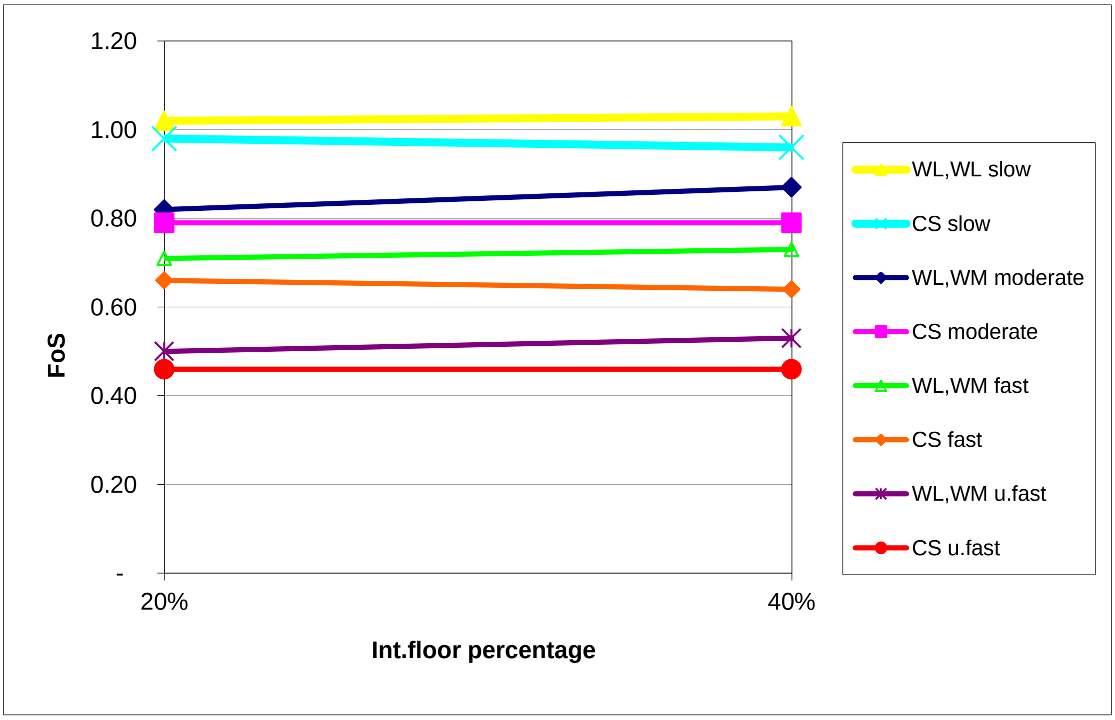


Figure D19: FoS of the lower floors by the variation of intermediate floor sizes for large 8m firecells containing open intermediate floors with a fire is under the intermediate floor.

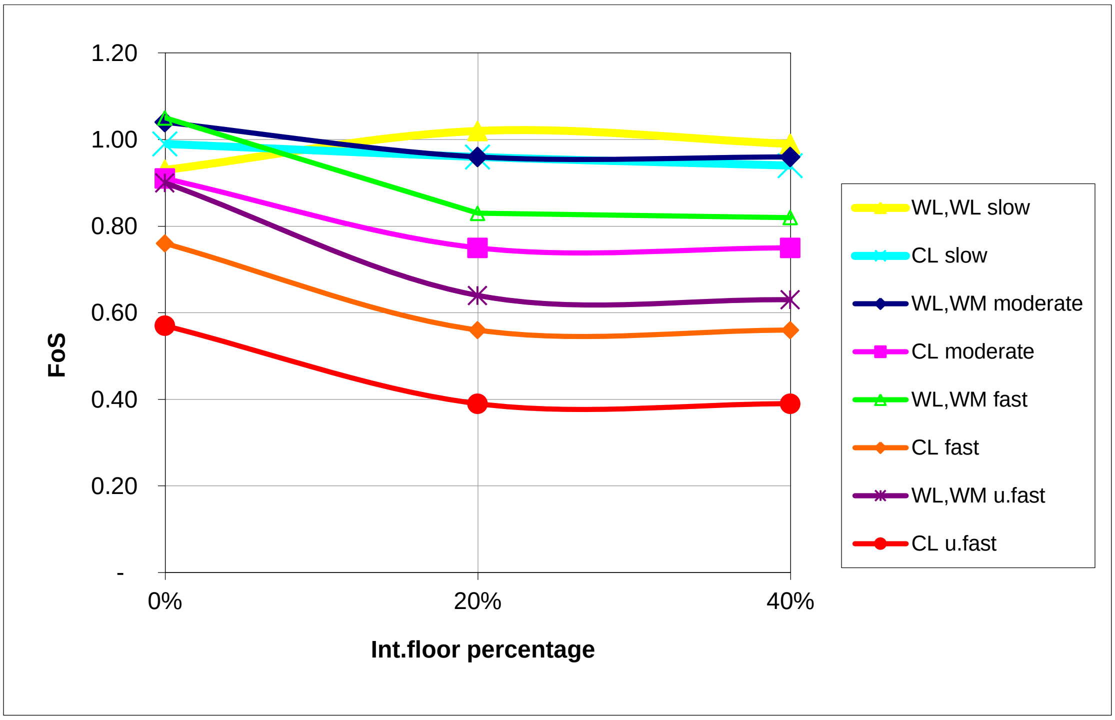


Figure D20: FoS of the lower floors by the variation of intermediate floor sizes for large 8m firecells containing open intermediate floors with a fire is in the open area.

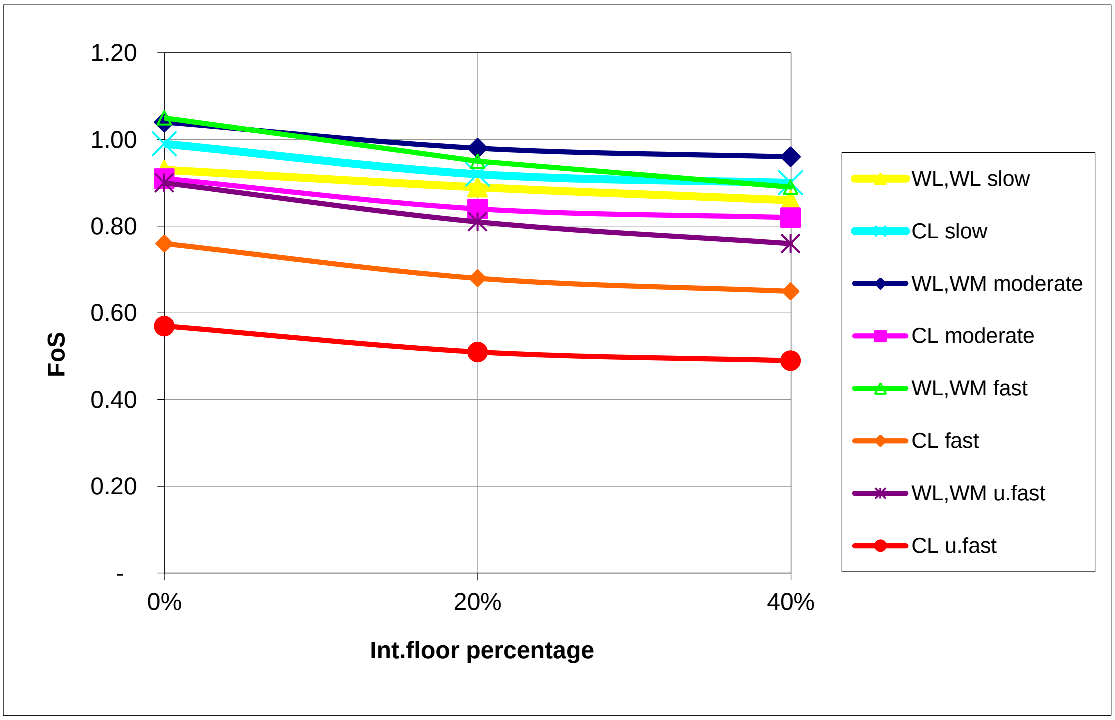


Figure D21: FoS of the intermediate floors by the variation of intermediate floor sizes for large 8m firecells containing open intermediate floors with a fire is under intermediate floor.

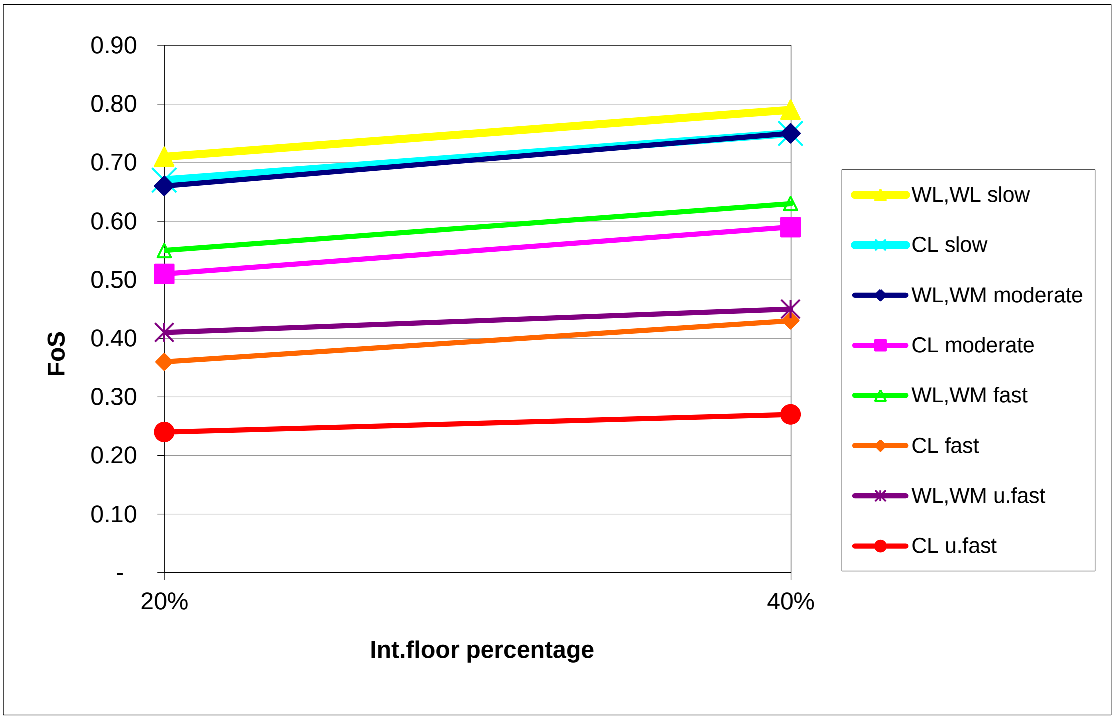
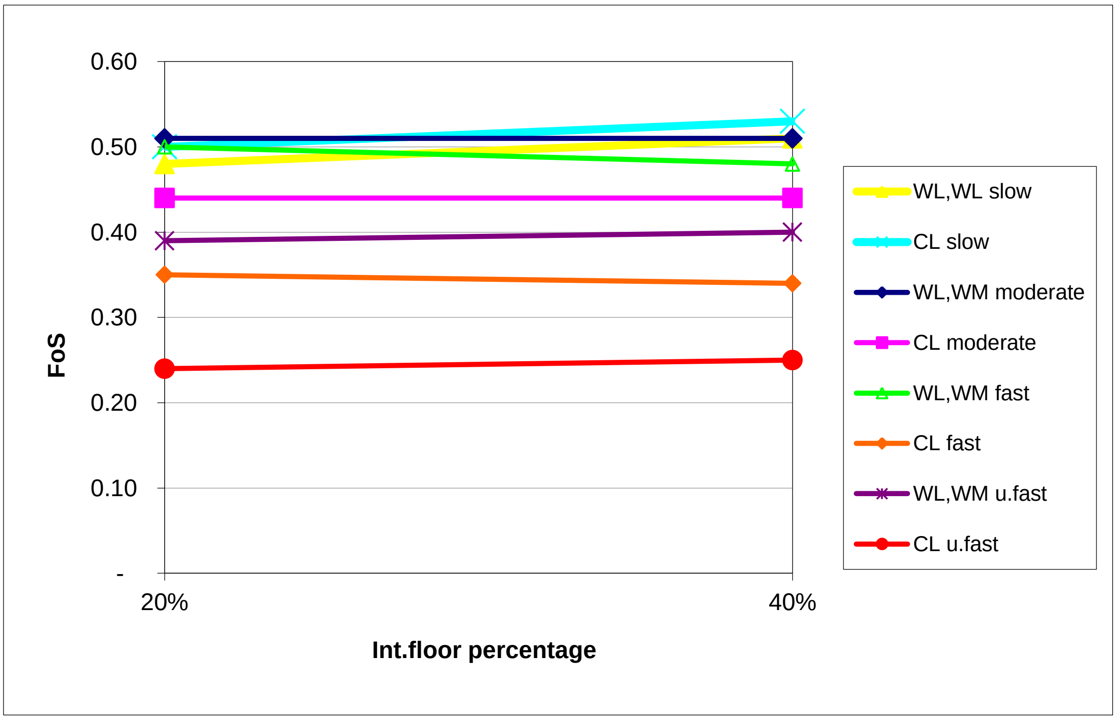


Figure D22: FoS of the intermediate floors by the variation of intermediate floor sizes for large8m firecells containing open intermediate floors with a fire is in the open area.



Appendix E: Fire Safety Precautions tables (Table 4.1/1 to 4.1/4 of /AS1)

Table 4.1: Fire Safety Precautions
Key to table references

Amend 5 Oct 2005 | Amend 4 Oct 2005 | Amend 5 Oct 2005

Part 3	Paragraphs 3.1.5, 3.13.1 and 3.19.2
Part 4	Paragraphs 4.3, 4.3.1, 4.3.3, 4.4.1, 4.5.2, 4.5.3, 4.5.4, 4.5.7, 4.5.8, 4.5.9, 4.5.10, 4.5.13, 4.5.14, 4.5.15, 4.5.19
Part 5	Paragraphs 5.5.1, 5.6.6, 5.6.8, 5.9.4 (c)
Part 6	Paragraphs 6.2.1, 6.4.1, 6.7.1, 6.8.1, 6.8.5, 6.8.6, 6.10.1, 6.11.1, 6.15.1, 6.19.9, 6.21.2, 6.23.1 (d), 6.23.2, 6.23.3
Part 8	Paragraphs 8.2.1, 8.2.2, 8.2.3
Appendix A	Paragraphs A1.1.1 and A1.1.2

Fire safety precautions

Amend 4 Oct 2005 | Amend 7 Nov 2008

Type	Description
1	Domestic smoke alarm system.
2	Manual fire alarm system.
3	Automatic fire alarm system with heat detectors and manual call points.
4	Automatic fire alarm system with smoke detectors and manual call points.
5	Automatic fire alarm system with modified smoke/heat detection and manual call points.
6	Automatic fire sprinkler system with manual call points.
7	Automatic fire sprinkler system with smoke detectors and manual call points.
8	Voice communication system.
9	Smoke control in air handling system.
10	Natural smoke venting.
11	Mechanical smoke extract.
12	No Type 12 currently specified.
13	Pressurisation of safe paths.
14	Fire hose reels.
15	Fire Service lift control.
16	Visibility in escape routes.
17	Emergency electrical power supply.
18	Fire hydrant system.
19	Refuge areas.
20.	Fire systems centre.

Special applications

Amend 4 Oct 2005 | Amend 7 Nov 2008

a Not required where:
- i) the *escape routes* serve an *occupant load* of no more than 50 in *purpose groups* CS (excluding *early childhood centres*), CM, WL, WM, WH and WF, or
- ii) the *escape routes* are for *purpose group* SA and serve no more than 10 beds, (or 20 beds for trampers huts, see Paragraph 6.20.6), or
- iii) exit doors from *purpose group* SA and SR *firecells* open directly onto a *safe place* or an external *safe path* (see Paragraph 3.14).

b Where only a single *escape route* is available, no less than a Type 4 alarm is required. See Paragraph 3.15.3 for situations where sprinklers are required.

c Required where Fire Service hose run distance, from the Fire Service vehicular access (see Paragraph 8.1.1) to any point on any floor, is greater than 75 m.

e The smoke detection element is Type 5 within *firecells* containing sleeping accommodation. (See Appendix A for description of Type 5.)

f A direct connection to the Fire Service is not required provided a telephone is installed and freely available at all times to enable 111 calls to be made.

Note:

The numbered references are more fully explained in Appendix A. Throughout Table 4.1 dark shading identifies where sprinklers are required.

Amend 7 Nov 2008

Table 4.1/1: Fire safety precautions for active purpose group firecells Occupant load 100

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)		4 m to <10 m		10 m to <25 m		25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CS	1	F0	F45		F45		F45		F30	F45	F45	F60
	2	F0	F60		F60		F60		F45	F45	F60	F90
	3	F0	F60		F60		F90		F45	F60	F60	F90
		2af 18c 16	2af 18c 16		3b 9 16 18c		4 9 16 18		6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM	2	F0	F60		F60		F60		F45	F45	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		2af 18c 16	2af 18c 16	6 18c 16	3b 9 16 18c	6 9 16 18c	3b 9 15 16 18	6 9 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F45		F45		F45		F30	F45	F45	F60
WM	2	F0	F60		F60		F60		F45	F45	F60	F90
WH	3	F0	F60		F60		F90		F45	F60	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		2af 18c 16	2af 18c 16	6 18c 16	3b 16 18c	6 16 18c	3b 15 16 18	6 15 16 18	6 15 16 18	6 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	4	F0	F30		F30		F45		F45	F60	F60	F90
		3af 18c 16	6 18c 16		6 16 18c		6 15 16 18		6 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column		1	2		3		4		5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Amend 7 Nov 2008
Amend 4 Oct 2005

Amend 5 Oct 2005

Amend 7 Nov 2008

Table 4.1/2: Fire safety precautions for active purpose group firecells Occupant load 101 to 500

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)		4 m to <10 m		10 m to <25 m		25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	1	F0	F45		F45		F45		F30	F45	F45	F60
(Note 7)	2	F0	F60		F60		F60		F45	F45	F60	F90
	3	F0	F60		F60		F90		F45	F60	F60	F90
		3f 16 18c	3f 16 18c		3b 9 16 18c		4 9 16 18		6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM	2	F0	F60		F60		F60		F45	F45	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		3f 16 18c	3f 16 18c	6 16 18c	3b 9 16 18c	6 9 16 18c	3b 9 15 16 18	6 9 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F45		F45		F45		F30	F45	F45	F60
WM	2	F0	F60		F60		F60		F45	F45	F60	F90
WH	3	F0	F60		F60		F90		F45	F60	F60	F90
(Note 5)	4	F0		F30		F30		F45	F45	F60	F60	F90
		3f 16 18c	3f 16 18c	6 16 18c	3b 16 18c	6 16 18c	3b 15 16 18	6 15 16 18	6 15 16 18	6 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	4	F0	F30		F30		F45		F45	F60	F60	F90
		3f 16 18c	6 16 18c		6 16 18c		6 15 16 18		6 15 16 18	6 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column		1	2		3		4		5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.
7. **CL:** For *firecells*, which are not cinemas or *theatres*, with *escape height* less than 4.0 m and *occupant load* not greater than 250, Type 2f is a permitted alternative to Type 3f.

Amend 7 Nov 2008

Amend 4 Nov 2008

Table 4.1/3: Fire safety precautions for active purpose group firecells Occupant load 501 to 1000

Amend 5 Oct 2005
Amend 7 Nov 2008

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)		4 m to <10 m		10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	1	F0	F45		F45		F30	F30	F45	F45	F60
	2	F0	F60		F60		F30	F45	F45	F60	F90
	3	F0	F60		F60		F45	F45	F60	F60	F90
		4 16 19c	4 16 19c		4 9 16 19c		7 9 16 19	7 9 13 15 16 19	7 9 13 15 16 19	7 9 13 15 16 19	7 9 13 15 16 17 18 19 20
CM	2	F0	F60		F60		F30	F45	F45	F60	F90
(Note 5)	4	F0		F30		F30	F45	F45	F60	F60	F90
		4 16 19c	4 16 19c	6 16 19c	4 9 16 19c	6 9 16 19c	7 9 15 16 19	7 9 13 15 16 19	7 9 13 15 16 19 20	7 9 13 15 16 19 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F45		F45		F30	F30	F45	F45	F60
WM	2	F0	F60		F60		F30	F45	F45	F60	F90
WH	3	F0	F60		F60		F45	F45	F60	F60	F90
(Note 5)	4	F0		F30		F30	F45	F45	F60	F60	F90
		4 16 19c	4 16 19c	6 16 19c	4 16 19c	6 16 19c	7 15 16 19	7 15 16 19	7 9 15 16 19	7 9 13 15 16 19	7 9 13 15 16 18 19 20
WF	4	F0	F30		F30		F45	F45	F60	F60	F90
		4 16 19c	6 16 19c		6 16 19c		7 15 16 19	7 15 16 19	7 9 13 15 16 19	7 9 13 15 16 19	7 9 13 15 16 18 19 20
Column		1	2		3		4	5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* an *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*. (Amend 4 Oct 2005)
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4. (Amend 7 Jun 2008)
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Amend 4 Oct 2005

Table 4.1/4: Fire safety precautions for active purpose group firecells Occupant load over 1000

Amend 7 Nov 2008

Purpose group	FHC	Escape height: 0 m (or single floor)	<4 m (or two floors)	4 m to <10 m	10 m to <25 m	25 m to <34 m	34 m to <46 m	46 m to <58 m	over 58 m
CL	1	F0	F30	F30	F30	F30	F45	F45	F60
	2	F0	F30	F30	F30	F45	F60	F60	F90
	3	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 9 16 18c	7 9 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 17 18 19 20
CM	2	F0	F30	F30	F30	F45	F45	F60	F90
(Note 5)	4	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 9 16 18c	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 20	7 9 13 15 16 18 20	7 9 13 15 16 17 18 19 20
WL	1	F0	F30	F30	F30	F30	F45	F45	F60
WM	2	F0	F30	F30	F30	F45	F45	F60	F90
WH	3	F0	F30	F30	F30	F45	F60	F60	F90
(Note 5)	4	F0	F30	F30	F30	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
WF	4	F0	F30	F30	F45	F45	F60	F60	F90
		7 16 18c	7 16 18c	7 16 18c	7 15 16 18	7 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18	7 9 13 15 16 18 19 20
Column		1	2	3	4	5	6	7	8

Notes:

1. **Use of table:** Refer to Paragraph 4.4 for instructions on using this table to determine the *fire safety precautions* in *firecells*.
2. **Adjoining firecells having a F0 rating:** Paragraph 6.2.1 requires adjoining *firecells* to be separated by *fire separations* with *FRR* no less than 30/30/30.
3. **Intermediate floors:** Where a *firecell* contains *intermediate floors* a *FRR* shall apply to the *intermediate floors* and supporting elements, and smoke control systems Type 9 and either Type 10 or Type 11, are required (see Paragraphs 4.5.16 to 4.5.18, 6.14.3 and 6.21.5 to 6.22.14).
4. **Car parking:** Refer to Paragraphs 6.10.3 to 6.10.6 for car parking provisions within *buildings*.
5. **Sprinklers:** Refer to Paragraphs 5.6.12 and 5.6.13 for concessions for *FHC* 4.
6. **Visibility in escape routes:** is specified in NZBC Clause F6.

Appendix F: Summary of proposed clauses

	Current clause	Proposed changes
1	Intermediate floor definition: Any upper floor within a firecell and which is not fire separated from the floor below. Upper floors within household units need not meet the specific fire safety requirements which apply to intermediate floors in all other situations.	No change.
2	NA	New definition for open intermediate floor: An open intermediate floor is the intermediate floor that has an escape route which is exposed to smoke and hot gases from a floor below. New definition for closed intermediate floor: A closed intermediate floor is the intermediate floor that has an escape route which is protected from smoke and hot gases from any floor below until it reaches a final exit
3	6.21.5: A firecell with intermediate floors satisfying the following conditions may be treated as a single floor firecell and a smoke control system Type 10 or Type 11 is not required where: a) The fire hazard category of the firecell is no greater than 3, and	Delete

	b) Where there are two or more separate intermediate floors, the levels of those floors above the firecell floor differ by no more than 1.0 m, and c) The total occupant load on all intermediate floors is not greater than 100, and d) The total area of the intermediate floors is no greater than allowed by Paragraph 6.21.6.	
4	6.21.6: The total area of limited area intermediate floors within the firecell shall not exceed: a) 20% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s) are enclosed or partitioned, or b) 40% of the area of the firecell floor, not including the area of the intermediate floor(s), where the intermediate floor(s): *i) are completely open, or* *ii) if enclosed or partitioned, a Type 4 or Type 7 alarm system with smoke detection is installed throughout the firecell.*	Delete
5	NA	New clause: The horizontal opening between the intermediate floor and the lower floor of a firecell with an occupant load on the intermediate floor greater than five people must be at least 4 m by 4 m.
6	NA	New clause: Where there are two or more

		separate intermediate floors, the levels of those floors above the firecell floor must differ by no more than 1.0 m.
7	4.5.17: Except for limited area intermediate floors meeting the provisions of Paragraphs 6.21.5 and 6.21.6, all firecells containing intermediate floors shall have a smoke control system	Delete
8	4.5.18: Smoke control requirements for limited area atrium firecells are given in Paragraph 6.22. For all other firecells containing intermediate floors, except where Paragraph 4.5.17 applies, smoke control shall be by specific fire engineering design.	Amend: Smoke control requirements for limited area atrium firecells are given in Paragraph 6.22. For all other firecells containing intermediate floors that require a smoke control by Table 21 (of this report), smoke control shall be by specific fire engineering design
9	6.21.3: Except where permitted by Paragraphs 6.21.4 to 6.22.14, smoke control in firecells containing intermediate floors shall be by specific fire engineering design.	Delete
10	6.21.4: These acceptable solutions for smoke control apply to firecells with intermediate floors which meet either of the following criteria: a) The firecell has limited area intermediate floors on one level complying with Paragraphs 6.21.5 and 6.21.6, or b) The firecell is a limited area atrium meeting the requirements of Paragraphs 6.22.1 to 6.22.14.	Delete