# Sustainable Building Features And Fire Safety

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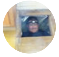

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# SUSTAINABLE BUILDING FEATURES AND FIRE SAFETY

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## ABSTRACT

It is often a challenge to design buildings to be more energy efficient and environmentally friendly. The impact of building features that meet this challenge on fire safety can be positive, neutral or negative. A list of common features of such buildings has been developed and their implications for fire safety investigated with the aid of an expert group. The most positive feature is distributed heating and cooling, which unlike central systems does not require the movement of large volumes of air and hence potentially smoke around a building in the event of a fire. Use of natural ventilation, commonly with atria and double skin facades allows for relatively unimpeded smoke transport in the event of a fire. Fire engineering design and fire safety mitigation measures such as natural draught and mechanical extract systems, for atria is well developed and understood. This is not the case for double skin facades. Computational Fluid Dynamics modelling of prototype buildings with a double skin façade has been carried out. Provided the vents to the double skin facade close in a fire, smoke spread via the double skin faced is prevented. The New Zealand Building Code, Framework for Fire Safety Design, C/VM2, and normal good practice, requires a robustness check, that is allowing for failure of one system such as that closing of vents to the inside of the building. In the event of such a failure the Fire Engineering design of a double skin facade, is unlikely to be successful unless a building is sprinklered. Other sustainable building features with less significant effects are also discussed.

## KEYWORDS:

Sustainable Buildings, Fire Safety, Fire Engineering, Fire Regulations, Energy Efficiency

## INTRODUCTION

There is a growing trend to construct green or sustainable buildings that have benefits environmentally through promoting recycling, energy efficiency and efficient use of resources. (Voss, Musall, 2012) However, a well-designed building must meet other design objectives such as usability, aesthetics, potential for redesign for alternative uses and safety. There are also statutory requirements that must be met. A building that does not meet all the design objectives is unlikely to be truly sustainable as it may quickly become obsolete or unfit for purpose, and substantially altered or demolished and replaced. Fire safety has and will continue to be an objective of building design. Despite advances in fire safety systems the objective of design for fire safety has remained the same for centuries, to reduce ignitions, warn occupants, supress fires and subdividing buildings to prevent rapid spread of fire. These methods can limit the use of recyclable and reusable materials, and restrict the layout of buildings to smaller spaces with implications for daylighting and natural ventilation (Krause, Grosshandler and Gritzo, 2012). This limitation can be extreme, in jurisdictions where highly restrictive, prescriptive fire codes limit design choices. This difficult with regulators is highlighted in a paper by Short, Whittle and Owarish (2006), in which the authors say “that natural ventilation systems are unlikely to proceed due to regulatory risk in the then current, UK 2006, environment”.

As the design of sustainable buildings is a recent and growing trend, research on the complementary topic of fire safety of sustainable building features is somewhat limited to date. In addition to the two papers mentioned above, the US National Association of State Fire Marshalls commissioned a project in this area resulting in a short book (Tidwell and Murphy 2010). The authors have a background in regulating fire safety and it focuses on potential problems rather than solutions. There are a number of papers about fire safety in houses, but many of the publications are generalised with reference to anecdotes. Several scoping studies have been published, notably Meacham, Poole, Echeverria & Cheng (2012), which includes a comprehensive list of sustainable building features and fire safety implications and qualitative risk analysis, but again focuses more on potential problems than solutions. BRE 2709 (2010), is focused more on the environmental costs of both fire and fire-fighting systems and Robbins (2012), is again a qualitative summary, but is more positive with an emphasis on how sustainability and fire safety concerns could be addressed together. There is also a summary of research need published by a group representing fire research laboratories (Krause, Grosshandler and Gritzo, 2012). These studies highlight a lack of information and a need for more case studies and research. The most detailed research on particular aspects of sustainable buildings has been published by Chow concentrating on atria (Chow & Chow, 2004) and double skin facades (Chow & Hung, 2006, Chow, Hung, Geo, Zou & Dong, 2007). These are both types of systems which allow for passive ventilation and environmental control, but also potentially allow for free passage of smoke between floors in buildings.

This study, by contrast focuses on assessing the sustainable features that predominate in buildings in New Zealand. It uses an expert group of fire engineers to rank common sustainable features in terms of both fire safety and the availability and design knowledge in regard to mitigating fire risks in these features. This list is not therefore exhaustive as is the case with Meacham, Poole, Echeverria & Cheng (2012). The biggest risk identified is double skin facades due to the lack of known mitigation measures. Further analysis of prototype buildings with double skin facades was carried out in the computational fluid dynamics (CFD) model, Fire Dynamics Simulator (FDS), (NIST, 2007).

## IDENTIFYING COMMON FEATURES OF SUSTAINABLE BUILDINGS.

Fifty-four commercial NZ green rated buildings were identified as being certified by the New Zealand Green Building Council (NZGBC, 2012), between 2007, the start of the scheme, and May 2012. Information on fifty of these buildings was accessed from a variety of written and online sources to determine the types of sustainable features they utilised. Information on four buildings was not available. The results are shown in table 1 below:

**Table 1 : Common Sustainable Features in Commercial Buildings.**

| **Number of Features Used in NZGBC certified Green Buildings** | | |
|---|---|---|
| **Building Features** | **Total** | **Percentage** |
| Sustainably Sourced Materials | 50 | 100% |
| Recyclable Materials | 50 | 100% |
| Rainwater Harvesting System | 50 | 100% |
| Lower Energy Mechanical Ventilation System | 20 | 40% |
| Atrium | 19 | 38% |
| Double Skin Facade | 7 | 14% |
| Green Roof | 6 | 12% |
| Local Power Generation | 6 | 12% |
| Storage Area for Recyclables | 4 | 8% |

These are broad classifications. Lower energy ventilation systems include heating, ventilation and air-conditioning (HVAC) systems with localised heating and localised cooling such as chiller beams, zoned control of heating and cooling, variable air volume and variable air flow systems. Local power generation can be of many types, with the most common being solar panel, and wind turbines.

## INITIAL QUALITATIVE ASSESSMENT AND DISCUSSION

Sustainably sourced and recyclable materials may have a positive, neutral or negative impact on fire safety. This impact depends on their susceptibility to ignition and their effect on rates of fire spread, smoke development, toxicity of combustion products and structural performance in fire compared with less sustainable alternatives. Many natural products are organic compounds, and all organic compounds are flammable. Some may require fire retardant treatments which tend to be more toxic after the material is burning, and also in situ. However some natural products perform better in terms of fire safety than alternatives, for example wool and cotton compared with many synthetic fabrics, and heavy timber structures compared with lightweight or unprotected steel structures. A type of material whose first known installation was in 1948 (http://www.eoearth.org/view/article/51cbef047896bb431f69bdc9/) that is nearing commercial application and may be utilised in sustainable buildings is phase change materials (PCMs), (Sharma, Tyagi, Chen & Buddhi, 2007). These materials usually have low melting points and are used to store heat with the latent heat of the phase change from solid to liquid providing higher density energy storage. Although relatively uncommon to date their use may increase, if draw-backs with them are overcome, notably common types of PCMs, paraffin wax, and organic fatty acids are both highly flammable.

Rainwater harvesting requires the storage of water that also has the potential to be used for firefighting. However fire-fighting water must always be available, so some part of the volume of stored water needs to be permanently stored and is not therefore normally available. Water stored on roofs has the same implication in terms of the effect of its mass on the buildings structure as green roofs. Recycled water is precluded from use in fire-fighting as distributing water that may contain microbes and other contaminants in aerosol form may lead to infection of personnel and other contamination.

Techniques to reduce energy consumption of mechanical ventilation systems are generally of benefit to fire safety. These techniques often involve only heating or cooling of areas of the building as needed or distributing heating and cooling to local zones. Both of these techniques result in less air being distributed around a building, as volumes of air flow required for ventilation are much lower than those required for heating and cooling. Any system that distributes air around the building will also distribute smoke from a fire, and even if the system is turned off smoke spread is possible through ducting and fixed vents driven by buoyancy. Localised heating and cooling, with lower air flow volumes therefore results in less potential for smoke spread via the ventilation system. Zoned systems can be designed to have the mutual benefit of reducing energy consumption by only ventilating, cooling and heating areas that are used, but can also be used for zoned smoke control, that helps confine smoke to the immediate area of a fire using airflow and differential pressures. With a system with controllable supply and/or extract air dampers, the fire floor or area can be negatively pressurised by extracting air from that area only and supplying air only to all other areas. This prevents or minimises smoke spread to other areas, giving more time to escape and reducing smoke damage to contents and building materials.

A common cause of extensive damage to property in even a small fire is corrosive acids from products of combustion such as hydrogen cyanide or sulphur compounds dissolving in water, either from sprinkler spray or as a product of combustion. These acids have a particularly severe effect on electronic equipment. Reducing property damage has an obvious benefit for sustainability as smoke damaged property will not need to be cleaned, repaired or discarded and replaced.

Atriums are a vertical space linking floors in a building. They may be enclosed with glazing, or open to some or all floors. An atrium precludes dividing the floors of a building with fire separations, so all atriums permit fire spread between floors. An open atrium permits the ready passage of smoke between floors and may substantially reduce the amount of time occupants have to escape from upper floors without having to escape through smoke, as the rate of smoke entrainment into a fire plume increases rapidly with height and more so when smoke spills into an atrium from under balconies. A glazed atrium may allow fire to spread between floors if the glazing fails in an uncontrolled fire or due to localised flame impingement on the glazing.

Double skin facades (DSF) are a system of glazing with a large cavity between two sets of glazing, typically with a cavity of between 0.5 and 2.0m wide. These are most often used for natural ventilation with automatically operable louvers or windows on the outer glazing to outside in various arrangements, and operable louvers or windows on the inner glazing to inside. They allow greater control of ingress of noise from outside, and operation of the ventilation in strong winds without compromising the flow of fresh air into the occupied zones. They are similar to atria in that they allow for the passage of smoke when the interior louvers are open, and in the later stages of the fire, the glass may break permitting passage of fire between floors, leading to greater property loss.

Green roofs are essentially gardens on the top of roofs. These add substantially mass to the top of a building as do rainwater or recycled water tanks if located on the roof. The materials used in these may be flammable, and they are likely to prevent the use of the fire-fighting technique of venting fires by removing roof cladding. A less obvious implication is that by adding a long term load to the building, the structural design of the building for fire safety is more onerous. Most building codes throughout the world require the building to be designed for gravity or normal loads with a large margin of safety (an overload), and then assume that as the probability of a fire and an overload at the same time is low. It is therefore reasonable in design to assume a reduced gravity load in conjunction with a fire condition. The reduced load is calculated by removing the factor of safety from the permanent (dead) loads, and using a factor of safety of less than one for the moveable (live) loads. The load from a green roof should be treated as a permanent load, so the reduced gravity load in a building with a green roof will be significantly higher than that for a building without. With such a high reduced gravity load, it is more likely the structural design of the entire building is governed by the fire load condition rather than the normal condition, and to a greater extent, so the provision of a green roof may have a more substantial impact on the structural design of a building due to the fire loading than the normal design would suggest.

Localised power generation is most commonly provided by photovoltaic cells (PV or solar panels) and wind turbines. These have issues in terms of structural load on buildings, and photovoltaic cells can cause access problems for fire-fighters. Unlike a mains electricity supply, or generators which can readily be isolated when a fire service attends a building, localised generation still produces current unless stopped from operating. Wind turbines are designed to depower by “feathering” the blades so the force of wind upon them is minimised, and the blades then allowed to freely rotate. Stopping the operation of PV panels is more complicated as the AC power output from the inverter needs to be shut off near the inverter, and then every individual panel circuit needs to be shut down. Even when the panel circuit is broken the panels will be energised if there is short circuit across them and there is incident light upon them. The panels should be capable of being isolated from the fire service access point to the building, unlike the photovoltaic panel fire on the Target store in Bakersfield California, on April 5, 2009 where the only way to isolate the panels was to open 56 fuses in the combiner box on the roof (http://nfpa.typepad.com/files/target-fire-report-09apr29.pdf).

A storage area for recyclables must be managed well to prevent ignitions and though should be given to fire rating this area. If materials placed there are not controlled, there is some potential for reactive substances to be stored together with potential for ignition and then rapid fire spread through combustible recyclables.

## EXPERT RANKING

As there is little experience and literature in regard to the real fire safety hazard of sustainable building features, an expert panel of fire engineers was formed to assess the fire safety hazard, risk and state of the art in potential mitigation measures for sustainable building features. An invitation was distributed by the Society of Fire Protection Engineers New Zealand Chapter and five fire engineers took part in the panel. This panel were sent questionnaires and then interviewed in person. The purpose of this type of research is not to find average responses but to form a consensus on the issues. A panel of five is sufficient to identify most issues, with increasing the panel size above this of little or no significant benefit (Turner, Lewis, & Nielsen 2006). The panel of experts provided a background to the issues that were faced in their experience and provided opinions or suggestions to eliminate, avoid, and manage risks as follows:-.

1. Identifying features' issues concerning fire safety.
2. Identifying mitigation measures for the fire safety issues identified
3. Rating and ranking the fire risk severity level of the features, taking into account both (1) and (2).

A table of the common features identified in the review of NZGBC buildings was given to the panel to rate and rank fire safety. The fire safety concerns were subdivided into the categories from the requirements of the New Zealand Building Code Clauses C2 – C6, that is:-

| | |
|---|---|
| C2 | Prevention of fire occurring |
| C3 | Fire affecting areas beyond the fire source |
| C4 | Movement to place of safety |
| C5 | Access and safety for firefighting operations |
| C6 | Structural stability (during fire) |

The fire engineers were asked to rate and rank the top five features that are considered as a high risk and questions were asked according to their choice. The interviews were analysed using the grounded theory method which includes three stages of analysis:

1. Open coding.

Open coding is a process of constant comparison, memoing, categories, sub-categories, and themes. The transcripts are broken to sentences, categories and paragraphs which then are collected and sorted under different categories. At this stage, all data are initially examined and no extraneous information is removed to allow the analyst to spot patterns. The main categories are identified through their densities of information which are referred to as 'core categories' (Jones & Alony, 2011).

2. Selective coding.

Selective coding is more thorough and produces denser results than open coding although it follows the same process, but the process is more refined. Further, at this stage extraneous information is removed and information that explains the concepts and core categories are kept (Jones & Alony, 2011).

3. Theoretical coding.

Theoretical coding is sorting the categories with reference to the literature. This stage is putting the fractured information back together to allow a coherent flow of concepts and ideas. Then it allows the researcher to compare, contrast, and make connections to the literature regarding the theories and their justifications (Jones & Alony, 2011).

## RESULTS

A scoring system was established to determine which feature had the most impact on life safety according to the expert panel with the results for the five worst ranked features in terms of fire safety shown in Table 2. One of the panel declined to rank the features so only four individual results are shown.

The ranking is due to the summation of the individual ranking from each member of the panel. The features that are ranked as 1 are the worst, the number attributed to it was 5, 2 is 4, 3 is 3, 4 is 2, and 5 is 1. This means that if atrium was ranked 1 twice, 2 once then it was calculated as 2X5+1X4=14. The same scoring system was used to find the highest score meaning the worst perceived risk. DSF had the highest risk score, closely followed by atria and storage areas for recyclables. The panel believed that mitigation measures for atria, and storage of recyclables are well understood and readily implemented. There are potential fire safety issues and with double skin facades that are poorly researched and understood, as are potential mitigation measures, so it was decided to investigate double skin facades further.

**Table 2: Questionnaire results**.

| **Individual Ranking** | **Features** | | | | **Overall Ranking** | **Top 5 Features** | **Score** |
|---|---|---|---|---|---|---|---|
| | **Expert 1** | **Expert 2** | **Expert 3** | **Expert 4** | | | |
| 1 | Atrium | Atrium | Recyclables Storage | DSF | 1 | DSF | 15 |
| 2 | DSF | Recyclables Storage | Variable Air Volume | Atrium | 2 | Atrium | 14 |
| 3 | Recyclable Materials | Recyclable Materials | DSF | DSF | 3 | Recyclables Storage | 13 |
| 4 | Recyclables Storage | Recyclable Materials | Green Roof | Recyclables Storage | 4 | Materials | 8 |
| 5 | Variable Air Volume | Variable Air Volume | Rain Water Harvesting | PV Panels | 5 | VAV | 4 |

The main concern with DSF was smoke and fire spread through the cavity, with the main mitigation measure being closing of the internal vents in the event of fire. If the system does not close due to failure of the alarm signal through to the BMS (Building Management System), failure of the BMS to close the vents, or other failure such as that due to fire damage of the circuits or vents themselves, then smoke spreads to other floors and fire can spread to floors above. It was mentioned by a member of the panel, that with smoke spreading though the DSF it may be harder for the Fire Service to locate the seat of the fire, but another panel member stated “access for fire-fighting is positive” because there will be less smoke spread compared to an atrium.

Most of the panel mentioned that installing smoke extract would eliminate the risk of smoke spreading because the smoke is buoyant and the facade area is small. Hence, smoke extraction is effective and ensuring the cavity closes off in the event of fire would keep the fire and smoke trapped in the area of origin; further, the panel also mentioned that DSF is similar to atrium and it should be dealt with the same way in terms of risk and mitigation measures.

## DOUBLE SKIN FACADES

### Previous Research

Chow, Hung, Geo, Zou & Dong (2007) carried out full scale fire tests on double skin facades and determined that the width of the cavity is critical, as in narrower cavities the smoke adhered to the inner glass wall. Chow & Hung (2006) concluded that tempered glass would give more protection and a vertical spandrel of 900m m or more extending downwards from the floor would be beneficial. Deng, Hasemi and Yamada (2005) found in a model and CFD study that smoke would not enter a building if a DSF was vented in such a way that the cavity was at a lower pressure than the inside of the building, and so the DSF could be used for smoke control.

### Double Skin Façade Fire Performance Simulation

Seven out of the 50 green buildings in the sample contained either or both atria and double skin facade. The floor area and number of levels of these varied significantly, so gave little guidance on the appropriate scale for a prototype building to model in the Fire Dynamics Simulator program FDS (http://www.nist.gov/el/fire_research/fds_smokeview.cfm) . Two sizes of building were modelled, 60m by 60m and 30m by 30m, both with 3 levels. The inter-storey height is 3.0m, with a floor to ceiling height of 2.7m. The DSF connects the 3 floors on one external wall. Buildings with a DSF and atrium were not modelled, as this was outside the scope of this study. The smaller size building was used for most analysis, as the time required to run the simulation was significantly less, and any problems with smoke control will be more severe with a smaller building with less space for smoke to accumulate at the top of the DSF (Figure 1).. The larger building is of such a size that automatic sprinklers would almost certainly be installed, so running scenarios without sprinklers is more realistic in the smaller building. Multiple scenarios were applied to the small model and then the worst and best case scenarios were modelled in the large building to compare the effect of building size.

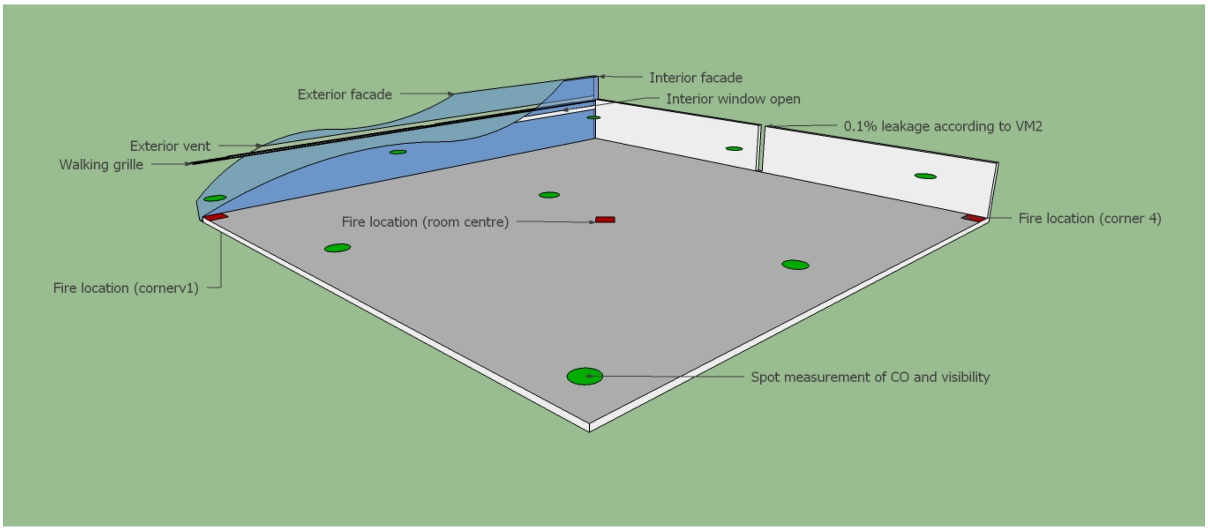

**Figure 1. Model layout (one floor only shown)**

The mesh size used was 0.5m for all simulations which is suitable for the characteristic diameter of a fire being at least 4 times the cell width (McGratten et al, 2007, p29-30). As DSF have structure to support the facade inside them, and frequently floors with grates for maintenance access and other impediments, the flow of smoke may be impeded. These obstructions are modelled in FDS as 0.5m by 0.5m horizontal barriers to fit the FDS grid every 2.0m along the DSF and offset from floor level to floor level to mimic as best as reasonably possible the hit and miss nature of these obstructions.

Fires were located in the centre of the room, in a corner next to the DSF (corner 1), and in a corner on the opposite side of the building to the DSF (corner 4), as shown in figure 1.

Spot measurements of visibility and carbon monoxide are recorded at 2.0m above each floor level, near the corners, hallway along the sides, and in the centre of the building as shown in figure 1. The CO level is reported as a fractional equivalent dose (FEDCO), which is a cumulative measure with a FED of 1.0, corresponding to incapacitation of 50% of the population.

DSFs of both 0.5m and 1m width were modelled, with 25% openings to the interior, 12.5% and fully closed. The exterior façade could have vertical openings up the building, and a horizontal opening at the top. These openings were set to be closed or open in various combinations. In some simulations the building has sprinklers installed, in which case the fire is assumed to be controlled and stop growing in size when the sprinklers activate. The various combinations of the above modelled in FDS is shown with the results in Table 3. The fire is a fast growth rate fire, defined as a fire with a growth rate proportional to time squared, reaching 1.055 MW in 150s, with combustion parameters as specified in the New Zealand Building Code document, Framework for Fire Safety Design C/VM2 (MBIE 2013) .

**Table 3: Scenarios simulated in FDS and small building results.**

| Scenario | Smoke Detection | Sprinkler | Fire Location[1] | Interior facade open area (%) | Exterior facade open | Top vent open | Cavity width (m) | Level 1 | | Level 2 | | Level 3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Time to: | | Time to: | | Time to: | |
| | | | | | | | | $FED_{CO}$ ≥0.3 | visibility <10m | $FED_{CO}$ ≥0.3 | visibility <10m | $FED_{CO}$ ≥0.3 | visibility <10m |
| **Base** | √ | X | C | 25 | X | X | 0.5 | ≥900 | 36 | ≥900 | 314 | ≥900 | 201 |
| **1** | √ | X | 1 | 25 | X | X | 0.5 | 50 | 48 | ≥900 | 93 | ≥900 | 65 |
| **2** | √ | X | 4 | 25 | X | X | 0.5 | 517 | 30 | ≥900 | 320 | ≥900 | 166 |
| **3** | X | √ | C | 25 | X | X | 0.5 | ≥900 | 149 | ≥900 | 469 | ≥900 | 356 |
| **4** | √ | X | C | 0 | X | X | 0.5 | ≥900 | 35 | ≥900 | ≥900 | ≥900 | ≥900 |
| **5** | √ | X | C | 12.5 | X | X | 0.5 | ≥900 | 33 | ≥900 | 397 | ≥900 | 284 |
| **6** | √ | X | C | 25 | √ | X | 0.5 | ≥900 | 34 | ≥900 | 436 | ≥900 | 291 |
| **7** | √ | X | C | 25 | X | √ | 0.5 | ≥900 | 33 | ≥900 | 324 | ≥900 | 869 |
| **8** | √ | X | C | 25 | X | X | 1 | ≥900 | 36 | ≥900 | 328 | ≥900 | 230 |
| **9** | √ | X | C | 25 | X | √ | 1 | ≥900 | 34 | ≥900 | 708 | ≥900 | ≥900 |
| **10** | √ | X | C | 25(2) | X | √ | 0.5 | ≥900 | 34 | ≥900 | 900 | ≥900 | ≥900 |
| **11** | √ | X | C | 25(2) | X | √ | 1 | ≥900 | 38 | ≥900 | 900 | ≥900 | ≥900 |
| **12** | √ | X | C | 25 | √ | √ | 0.5 | ≥900 | 34 | ≥900 | 410 | ≥900 | ≥900 |
| **13** | X | √ | C | 25 | √ | √ | 0.5 | ≥900 | 145 | ≥900 | 560 | ≥900 | ≥900 |

1. C for centre, 1 for corner 1 and 4 for corner 4.
2. Openings on ground floor only

The criterion for FEDCO is 0.3 respectively. The visibility criterion is a minimum of 10m visibility at 2.0m above floor level. These are as specified in the New Zealand Building Code document, Framework for Fire Safety Design C/VM2 (MBIE 2013). As is expected in a large space, the temperature rise, away from the fire was small and did not affect tenability.

## FDS Results

The results of the scenarios for the small building are shown below in table 4 and the results for the large models are shown in table 5.

The results show that the FEDCO criterion is not reached except when the fire location is at the corner then CO is exceeded at only one point near the fire. However, visibility limits were reached in all scenarios, but differed in terms of the time taken for the visibility to drop below 10m. In scenarios 4, 10 and 11 where the internal vents were closed on the fire floor, no smoke spread to the upper levels. When all exterior vents were open (scenario 12), no smoke spread to the upper levels, despite the interior vents being fully open, so all the smoke generated has spilled to the outside, a result consistent with Deng, Hasemi and Yamada (2005). Doubling the width of the facade, slightly decreased the tenability time in upper floors with the external vents closed (scenario 8 compared with base scenario), however with the top vents open it dramatically reduced the tenability time (7 vs 9), this doesn’t seem right – need to check data. Opening the top vents or half closing the interior vents results in a moderate improvement in the tenability time (scenario 5 and 6). Installing sprinklers increased the tenability time on the top floor from about 200 to 360s, which is about the time that would be required to evacuate the floor.

**Table 4: LargeBuilding Results**

| Scenario | Level 1 | | Level 2 | | Level 3 | |
|---|---|---|---|---|---|---|
| | Time to $FED_{CO}$ ≥0.3 | Time to visibility <10m | Time to $FED_{CO}$ ≥0.3 | Time to visibility <10m | Time to $FED_{CO}$ ≥0.3 | Time to visibility <10m |
| **1** | 396 | 673 | ≥900 | 709 | ≥900 | 687 |
| **11** | 601 | 285 | ≥900 | ≥900 | ≥900 | ≥900 |

The larger building is fitted with sprinklers, so the best comparison is large building scenario 1 with small building scenario 3. The larger building has about double the tenability time which simply reflects the larger size of the smoke reservoir compared to the smaller building.

The literature review raised the issue of glazing breaking under high temperatures, but temperatures found in the FDS were not high enough for this to occur. However, if a fire is close enough to the glazing for flames to impinge upon it, localised breakage will occur. If the flames then impinge upon the interior glazing on the next level, glazing on the upper level may also break. Counter-intuitively, this may be more likely to occur with a wider cavity where the smoke is more likely to impinge on the internal glazing (Chow et al, 2007).

Chow et al (2006) did not mention any mitigation measures that would reduce the impact of the DSF on the building, except for the use of tempered glazing and using small sheets of glazing to reduce the risk of glass breaking. Closing of the interior vents is an obvious mitigation measure, and one stated by the panel, but this relies on the vent closing system working and the glazing not being damaged by fire. Other options are to pressurise the DSF, but this is impractical, as the vent area is large, or to mechanically extract from the DSF. As this analysis and Deng et al (2005) have shown, with large amounts of external vents, the DSF will be at a lower pressure than the rest of the building and smoke will flow into the DSF and hence to the outside, so the addition of mechanical extract is unlikely to be warranted.

## Recommendations for DSF

The simplest way to prevent smoke spread is to prevent smoke getting into the DSF by closing the internal vents. It is prudent to design for the situation where these vents fail to close. It is also prudent to assume that the vents fail to close if the glazing fails due to flame impingement. The simulation results suggest therefore that prudent design will also provide either 1) sufficient external vents, at the top and external side of the DSF so that smoke will travel from the interior of the building and into the DSF and thence to the outside; or 2) sprinklers should be installed throughout the building, and analysis confirm that the tenability time on the upper floors exceeds the time taken to evacuate those respective floors. This type of analysis may not be accepted in jurisdictions were performance based fire safety design is discourage or prohibited.

Although buildings with both atria and DSF have not been modelled, and the behaviour of smoke will be significantly more complex, an appropriate design approach may be to use the DSF for supply air, and extracting smoke from the atrium, which is likely to have a larger smoke reservoir than the DSF.

## CONCLUSION

An analysis of common sustainable building features in 50 buildings in New Zealand found that sustainable and recyclable materials and rainwater harvesting were used in all buildings surveyed.

Systems to reduce energy usage by mechanical ventilation systems and atria were found in about two-fifths of those buildings. Distributed power generation, green roofs and dedicated storage areas for recyclables were less common. The fire safety issues from most of these can be readily addressed. Ventilation systems that reduce energy use tend to reduce airflow between spaces in a building and therefore are likely to have positive benefits in terms of reducing flow of smoke. Ventilation systems with a high degree of local control may be interfaced with the fire alarm system and programmed to further reduce smoke spread in the event of fire. Passive ventilation systems may also be designed to be used as smoke control systems.

From these common sustainable features, an expert panel ranked double skin facades (DSF) as the biggest risk in terms of fire, slightly ahead of atria and storage areas for recyclables. As potential mitigation measures for DSF are less well understood these were investigated further using a computational fluid dynamics (CFD) model, Fire Dynamics Simulator (FDS). Several strategies were found to be successful in minimising smoke spread:

- closing the internal vents,
- providing sufficient external vents, that smoke flow is to the outside, and
- installing sprinklers throughout the building.

For a robust design, it is recommended at least two of these three options is utilised along with a performance based design fire safety design to demonstrate their adequacy in each individual building design.

In the future more buildings will be built with sustainable features and some of these features have fire safety issues which need to be addressed. Most fire safety issues are obvious as are methods to mitigate the risk, and some of these features will, or can be used to, improve fire safety

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