FIRE ENGINEERING SOLUTION FOR ECOLOGICAL SUSTAINABLE DEVELOPMENT (ESD) DESIGN – A Case Study

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ABSTRACT

This paper presents a case study of a four-storey public building that contains a large internal atrium void. The ecologically sustainable development (ESD) design for the building demands it to be internally "open" to allow free natural airflow, and to have minimum mechanical air-handling system. These are fundamentally in conflict with the Building Code of Australia (BCA) prescribed requirements, which call for compartmentation and a high-volume smoke exhaust system.

In order to resolve the conflicts, a fire engineering solution was developed. The key strategy was to utilise the atrium space as a smoke reservoir and to naturally vent smoke out of the building from the atrium roof. The roofline is raised to form a curved shape to protect the vent openings from adverse wind effects and to create wind suction to further drag smoke out of the building.

Analyses of smoke flow and occupant evacuation for the building show that a high level of fire safety is achieved with the design, and that a fire engineering solution can be developed to commensurate with the ESD design.

1. INTRODUCTION

Buildings are a significant greenhouse gas emitter. It is reported that buildings are responsible for more greenhouse gases than all the cars on Australian roads, and energy used in buildings accounts for almost 27% of all energy-related greenhouse gas emissions [1].

In order to reduce greenhouse gas emissions, there has been a concerted push to ensure energy efficiency of new buildings by integrating ecologically sustainable development (ESD) principles in their design. This includes the introduction of mandatory requirements in the Building Code of Australia (BCA) [2], and the encouragement of voluntary best-practice initiatives by industry.

ESD principles cover a range of design aspects. These include:

- improved thermal performance of the building fabric – roofs and ceiling, roof lights, walls, floors, glazing and shading to avoid or reduce the use of artificial lighting, heating and cooling
- increased natural air movement – to increase natural ventilation and reduce the need for mechanical cooling
- improved performance of building services – air conditioning and ventilating systems, artificial lighting and power systems, and hot water supply systems.

For large commercial and public buildings, incorporation of ESD principles may call for radical changes to the conventional design philosophy, which invariably yields building spaces that are compartmented, sealed and conditioned by mechanical heating, cooling and artificial lighting. In contrast, buildings that are designed using ESD principles are likely to be “open” internally and to the outside to allow natural airflow, and have a low reliance on artificial conditioning. Consequently, operable windows, floor voids, atriums and lightwells are often incorporated to allow penetration of daylight and natural airflow.

1.1 ESD and BCA

Prescribed Fire-Safety Requirements

Fundamentally, some aspects of ESD principles are in conflict with the BCA prescribed fire-safety requirements. The most prominent is the desire for internal “openness” in ESD design. In contrast, the BCA requires building spaces to be compartmentalised to prevent fire or smoke spread.

Floor voids incorporated as part of ESD design may also be subjected to the various “atrium” requirements prescribed by the BCA, including bounding construction around the atrium, which may also prevent/restrict the desired airflow of the ESD
design. The BCA also prescribes a high-volume smoke exhaust system, while the ESD design principles are aimed at minimal use of mechanical systems.

This is not to say that ESD principles cannot be applied to buildings that are designed to fully comply with the BCA prescribed fire-safety provisions. However, it does mean that their applications may be restricted and their benefits may not be fully realised.

1.2 ESD Design and Fire Engineering

Some conflicts between ESD design principles and the BCA prescribed fire-safety requirements can be deep-seated, in that they cannot be readily resolved without some fundamental changes to the ESD strategy or the architectural scheme for the building. In such situations, the best option is to seek an alternative to the BCA prescribed fire-safety requirements using a fire-engineering approach.

The challenge of the fire engineering design in such instances is to develop a cost-effective solution to allow the ESD and architectural design to be realised. Accordingly, the objectives of the fire engineering design may be summarised as follows:

- Ensure fire safety of the building (BCA objective)
- Complement the ESD design for the building
- Allow flexibility for architectural expression
- Minimise the cost of the overall building design
- Property/asset protection

It is important to note that an early involvement of fire engineering in the project is vital for its success. This will allow the fire engineer, ESD engineer, architect and other members of the design team to work closely together to resolve any fundamental issues at the earliest possible stage. As discussed earlier, some of the issues are deep-seated and can only be effectively resolved in the early stage of the project. This will be further discussed and demonstrated in the case study below.

2. CASE STUDY

The case study considered is four-storey public building (see Figure 2) with a total floor area of approximately 10,000m². The building is primarily of reinforced concrete construction with hollow core floor slabs and precast concrete panel walls.

A large atrium runs centrally along the length of the building. The atrium void connects all floor levels and contains balcony walkways and open stairways that overlook the void space (see Figure 3).
The building also contains four fire-isolated stairways, one at each corner of the building.

2.1 ESD Design

The key strategy of the ESD design for the building is to maximise the use of daylight and natural airflow. Central to this strategy is the atrium, which allows daylight to penetrate and natural air to flow through the interior of the building. From an architectural viewpoint, the atrium also forms a focal point of the building where the key circulation paths are located and where the occupants could congregate. A schematic cross-section of the building is shown in Figure 4.

As part of the ESD design, natural ventilation of the building spaces is achieved by allowing outside air to flow naturally into the building through openable external windows. The air is then allowed to flow through the occupied space, into the atrium space and out of the building through openings located around the skylights on the atrium roof (see Figure 5).

Heating/cooling of the occupied spaces is achieved by means of the natural airflow and heat transfer to/from the hollow core slabs. The floor slabs are heated/coolated by means of ducted airflow within the slabs as shown in Figure 6.

The use of mechanical means for handling airflow in the building is kept to a minimum.

2.2 Conflict between ESD Design and BCA Prescribed Provisions

The ESD design essentially requires the building to be internally "open" to allow free airflow. This is in direct conflict with the principles of the BCA prescribed fire-safety requirements, whereby the building is to be compartmentalised to prevent fire...
or smoke spread. The bounding construction around the atrium as prescribed by the BCA may prevent/restrict the desired airflow. The BCA also prescribes a high-volume smoke exhaust system for the building and the space below the atrium roof be divided into a number of smoke reservoirs (see Figure 7).

In this project, the client has considered that property or asset protection is not an objective governing the design of the building.

2.4 Fire Engineering Strategy

In order to achieve the design objectives, the following fire engineering strategy was developed to manage the smoke hazard management and occupant evacuation in the building:

- Utilising a fire safety management system to lower the fire risks.
- Utilising a sprinkler system to limit fire size and smoke production.
- Utilising the atrium space to create a large smoke reservoir. This allows smoke to be channelled into the space by natural airflow and allows the smoke to be diluted in the process.
- Utilising the natural airflow to allow smoke to escape through vent openings around the skylights. This is commensurate with the ESD design, where the same airflow paths and openings are utilised for ventilating the building.
- Utilising the exit door openings at the ground level to provide make-up air for the smoke venting.

2.3 Design Objectives

The conflict between the ESD and BCA prescribed requirements was recognised at the conceptual stage. Consequently, the input from fire engineering was sought at the very start of the project.

A set of fire engineering design objectives was developed. These have been discussed earlier.

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• Utilising the balcony walkways, internal corridors and fire-isolated stairways as the main paths for emergency evacuation of the building. The open stairways within the atrium, albeit likely be used by occupants for evacuation, are considered to be “non-required” egress paths that serve as beneficial redundancy for the fire safety systems.

In order to minimise the adverse effects of external wind on smoke venting, it was proposed as a fire engineering strategy that the vent openings around the skylights be protected by a raised curved roofline. This will also provide a beneficial effect of creating a negative pressure region outside the openings to drag the smoke out of the building.

Figure 8: Fire Engineering Smoke Hazard Management Strategy

This proposal was accepted and a curved roofline was incorporated as an integral architectural feature of the building.

The smoke hazard management strategy is summarised in Figure 8.

2.5 Evacuation Analysis

Evacuation of the building occupants was modelled using an evacuation simulation program [5]. The simulation was based on the following assumptions:
• The building is fully occupied (a total of 1,820 people)
• The occupants are randomly distributed within the floor levels
• The occupants on the ground level evacuate directly to the outside through the entries/exits located on the level
• The occupants on the upper levels use the four fire-isolated stairways only (worst-case)

Figure 9: Evacuation time

Figure 10: Positions of occupants at various time intervals
• The occupants do not use the open stairways within the atrium for evacuation (worst-case)
• Pre-movement time for all levels is three minutes.

The results of the analysis are summarised in Figure 9. Figure 10 shows the positions of occupants on Level 4 at 30-second intervals after the commencement of occupant movement. Each dot on the figure represents an occupant.

2.6 Smoke-Flow Analysis
In order to determine the conditions in the event of a fire, a 3-D computational fluid dynamic (CFD) program [4] was used to model the smoke flow in the building. Due to the continual changes and evolution of the building design, three main rounds of smoke flow analyses were carried out during the project to reflect the changes. The CFD model of the final building design is shown in Figure 12.

Figure 13 shows the analysis result, in terms of air temperatures within the building, for one of the credible worst-case fire scenarios examined.

Elevation view – section through atrium

Plan view – section through uppermost level

Figure 13: Air temperatures within building with smoke venting (time = 1800 s)

The result above corresponds to a fire occurring in the middle of the atrium, assuming that the fire:
• Is not extinguished by the occupants or the fire brigade at the early stage
• Is not effectively controlled by sprinklers
• Burns at a constant rate of 5MW (this is consistent with the design fire assumed by the BCA for the design of smoke exhaust system).

For comparison purposes, the analysis was also conducted for the case where there is no smoke venting available. The results for this case are shown in Figure 14.

Elevation view – section through atrium

fire location

Plan view – section through uppermost level

Figure 14: Air Temperatures within Building without Smoke Venting (time = 500 s)
A further comparison of the two cases is made in Figure 15 that shows the average air temperatures along the evacuation paths on the uppermost level. The temperatures were taken at locations along the paths, at a height 2m above the floor level.

The results of the analysis show that, without any smoke venting, the air temperatures at the upper level exceed 100°C after approximately 500 seconds; whereas with the proposed smoke venting, the walkway remains relatively cool even after 1800 seconds (30 minutes) of fire duration.

If a maximum air temperature at 2m above the pathways of 100°C is taken as the tenability limit, it could be argued that, without smoke venting, the upper level become untenable at approximately 500 seconds. In contrast, with the proposed smoke venting, the building remains tenable even after 30 minutes of fire duration.

Other fire scenarios were examined and tenability criteria of CO level and visibility were also checked. The results of these analyses similarly show that, with the proposed smoke venting, the building remains tenable even after 30 minutes of fire duration, and the occupants have more than sufficient time to evacuate the building.

3. OUTCOME OF THE FIRE ENGINEERING DESIGN

Fire safety
• More than sufficient time is provided for the occupants to evacuate the building in the event of a fire
• The conditions in the building are also favourable for brigade fire fighting, and search and rescue operations.

ESD Design
• The fire engineering solution is fully commensurate with the ESD principles of utilising natural airflow and minimising the use of mechanical air-handling systems
• The vent openings around the skylight provided for ESD design were found to be sufficient and are fully utilised for venting smoke out of the building. No high-volume smoke exhaust system is necessary.

Architectural Design
• No restrictions were placed on the architectural design of the building
• The curved rooftine proposed as part of fire engineering solution was adopted and integrated as part of the architectural features.

Cost-effectiveness
• Major saving was made from not having to install additional systems to manage smoke hazards in the building
• The openings/louvres are designed to fail open. This minimises their dependence on power supply for their operation and eliminates the need for emergency power supply (as prescribed by the BCA).

Overall, a high level of safety is achieved, and the fire engineering strategy has provided a cost-effective solution that is commensurate with the ESD principles for the building.

4. LESSONS LEARNED FROM THE CASE STUDY

The key lessons learned from the case study are summarised below.
• Early involvement of fire engineering is vital for the successful integration of fire engineering principles into the building design
• The architects, ESD designers, fire engineer and other design team members, to fully understand the issues and to formulate a cost-effective solution, must work as one team
• The best fire engineering solution for a building designed based on ESD principles is “going with the flow” by complementing the principles
• Natural venting can be effectively utilised for smoke hazard management
• The use of CFD program to model the smoke flow during various design stages can be very resource intensive. However, it is a very useful and powerful tool that enables the design team to better understand the fire engineering basis and to develop a cost-effective solution.

5. CONCLUSIONS

Application of ESD principles in design of buildings may result in design aspects that are in conflict with the prescriptive fire safety requirements. This conflict may be resolved using a fire engineering approach.

The case study has demonstrated that a fire engineering solution that is commensurate with ESD principles has been developed to complement the demand for the building to be internally “open” to allow free natural airflow, and to have minimum mechanical air-handling system. The key strategy was to utilise the atrium space as a smoke reservoir and to naturally vent smoke out of the building from the atrium roof. The roofline is raised to form a curved shape to protect
the vent openings from adverse wind effects and to create wind suction to further drag smoke out of the building.

The effective integration of the fire engineering strategy into the building design and architectural features is possible only through early involvement of fire engineering in the project. The fire engineer must also working closely together with the architects, ESD engineers and the project team early in the project to develop a cost-effective solution.

6. REFERENCES


About the author

Dr Weng Poh is an associate director and the head of the fire engineering group at Umow Lai. Throughout his career, Weng has completed numerous fire engineering projects. He has been closely involved in the development of methodology for fire safety designs of buildings in Australia and has published extensively in international journals, conferences and technical reports. Weng also gives lectures in postgraduate courses, aimed at training building practitioners in fire engineering design.