SMOKE CONTROL DESIGN SOLUTION FOR A CURVILINEAR ATRIUM SPACE

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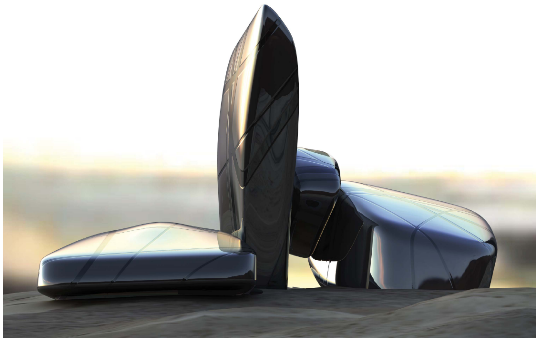
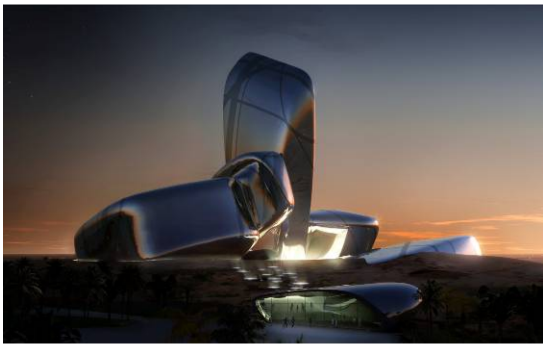
INTRODUCTION

The King Abdulaziz Centre for World Culture is a development of Cultural and Civic Buildings, currently under construction in Dhahran, KSA. Buro Happold are working with Norwegian architects Snohetta in developing the project design for this organically shaped, interlinked collection of complex structures (Figures 1(a) and 1(b)).





Figures 1(a) and 1(b). Architectural Images demonstrating the design intent (Snohetta)

The fire safety engineering design requires to meet strict client performance specifications, in particular the prescriptive requirements of International Fire Code (2003)[1]. The unusual curved shapes of the buildings present challenges to the fire engineer, as the spaces do not readily lend themselves to the types of fire engineering solutions more usually adopted with linear geometry.

The particular area of the project discussed here is a smoke control design solution developed for the Library building, which is formed as a 'pebble shaped' 4 storey atrium suspended above a Plaza circulation area. The floating atrium floors have central and perimeter voids which, in the absence of effective smoke control, would allow rapid smoke filling of the entire Library from a fire in any location (Figure 2).

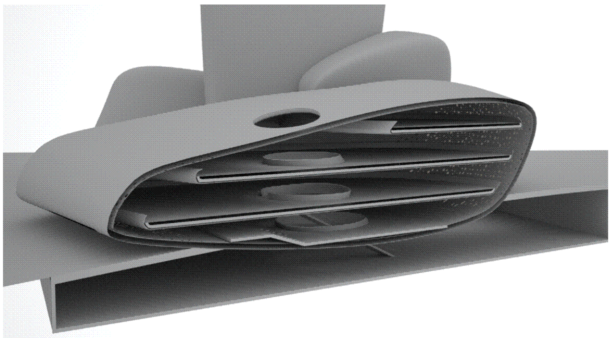


Figure 2. Library atrium suspended above the Plaza (Snohetta)

METHODOLOGY

Imposed design restrictions and design challenges

The approvals process for the development imposes prescriptive performance requirements on the fire safety design. In addition, the design solutions adopted for all building services are required to respect the architectural lines of the building, few of which are straight. The smoke control design for the Library atrium has therefore been developed respecting the following constraints:

- Compliance to IFC 2003 in calculation methodologies
- Co-ordination of smoke extraction with normal ventilation provision, to allow use of hybrid ductwork systems
- Minimal interference to the smooth ceiling surfaces
- Use of fixed smoke barriers to be avoided
- Use of linear retractable smoke curtains to be avoided as far as possible
- Lower exposed surface of Library ceilings to be a stretched plastic membrane system with largely unproven performance in fire situations
- Developing the fire safety design within a prescriptive approvals environment for a non-typical architectural space

Design process

The methodology for the design process followed a series of distinct steps:

- Use of CFD to investigate smoke flow dynamics within the atrium space
- Determining an appropriate range of design fires
- Developing an extract system for smoke that co-ordinates with the requirements for normal use air handling provision and respects the architectural vision
- Developing inlet air provision
- Determining the cause and effect matrix for system activation

Preliminary CFD investigation of smoke flow around the internal enclosure

An initial investigative exercise using a CFD model for a lower floor design fire confirmed that, in the absence of any smoke control system, untenable conditions could rapidly develop within some occupied areas of the Library before sufficient time for evacuation had elapsed. The rotating momentum of smoke flow across curved surfaces, and also the smoke flow patterns produced by the internal geometry of the floor plates, demonstrated that atrium smoke filling could not be allowed to happen (Figures 3(a), (b), (c) and (d). Applying direct extract from the atrium space at rates up to $40m^3/s$ resulted in little improvement to tenability levels, and so a storey extract smoke control solution was proven to be necessary.

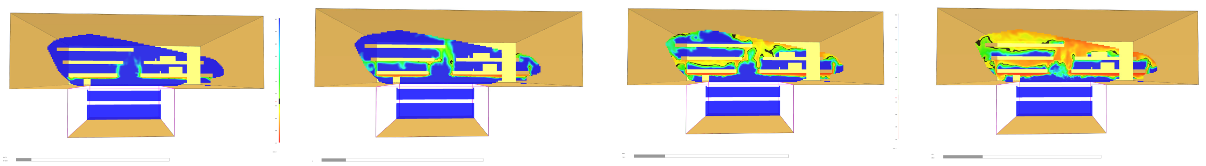


Image at 2 minutes from start of fire simulation	Image at 3 minutes from start of fire simulation	Image at 4 minutes from start of fire simulation	Image at 5 minutes from start of fire simulation

Figures 3(a), 3(b), 3(c), 3(d). CFD model images showing visibility

Slot extract into plenums

As a key architectural requirement is for smooth, uninterrupted ceilings, using a stretched plastic membrane as the visible lower surface, containment of smoke on the floor of fire origin is achieved in most areas using extract by slots into a plenum formed between the architectural ceiling and the structural slab above (Figure 4). This eliminates the need for downstands, either fixed or retractable, in the majority of areas. The slots at the ceiling edges are concealed within a shadow gap detail which is also used by the building's air handling system for the extraction of environmental air.

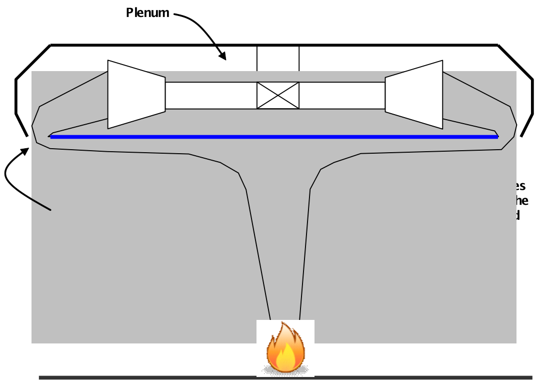


Figure 4. Slot extract concept

Extraction from the plenum is by means of a system of ductwork which also serves the building's air circulation system. Bellmouth extract points are distributed around the ceiling perimeters, in order to evenly control the rate of air/smoke extraction across all slot lengths on each level. Balancing of air extract rates is achieved by means of volume control dampers incorporated within the ductwork matrix. This exploitation of the air handling services ductwork provision provides a cost effective and efficient design.

The stretched plastic membrane ceiling utilised for the Library design raises obvious concerns, as ceiling failure above a fire would cause unacceptable loss of the plenum integrity. In order to remove this risk, a non combustible boarded ceiling structure is specified to sit above the stretched membrane, which will resist expected fire and smoke temperatures and ensure plenum integrity. The stretched membrane is therefore a cosmetic finish only.

At the topmost floor level in each area of the Library, ceiling storey slot extraction is used in combination with direct extract fans at roof level. Some sections of drop-down smoke curtain descend from the roof to form physical barriers for smoke reservoir containment, where it is necessary to prevent smoke spillage to higher levels (Figure 5).

Design fires

Volume extract rates are calculated by means of the standard equations set out in IBC 2003, with the final extract rate for direct extract then increased by a factor of 5/3, as advised in BR368[2] for slot extraction.

A series of design fire scenarios are considered, with each fire being considered as an initially 'moderate' growth rate fire, becoming steady state upon sprinkler activation. The assumed fire size was determined by use of the NIST FPETool Fireform[3] model to estimate time to sprinkler activation.

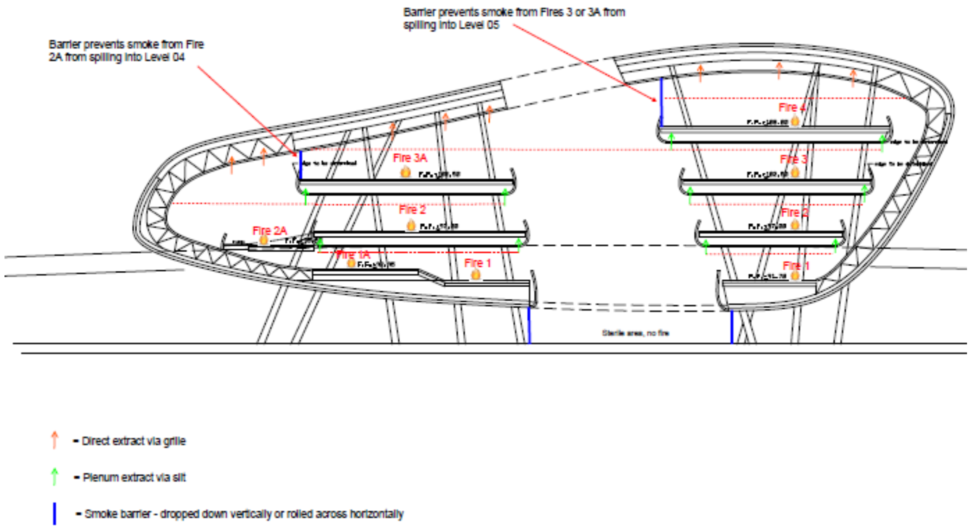


Figure 5. Finalised design concept, using a combination of direct and slot extraction of smoke.

Balancing ductwork flow rates across slot extracts

In order to ensure that the velocity of smoke flowing towards an extract slot does not exceed the capability of the slot to fully extract that smoke, a design specification is adopted that ensures that areas within 2m horizontally of a slot contain no risk of fire. By use of Alpert's correlations[4], it is calculated that this will allow a maximum smoke velocity towards a slot of 2.11m/s. The ductwork extract system is balanced to ensure that the minimum air extract velocity at any point along a slot is also 2.11m/s, in order to extract all flowing smoke. Balancing of air extract rates is achieved by means of volume control dampers incorporated within the ductwork system.

Inlet air provision

Inlet air for the smoke extract system is drawn from the central atrium void, which connects to the Plaza level beneath (the Plaza forms a main circulation area at public access level, connecting all elements of the development). Final exit doors from this Plaza open upon system activation.

The Plaza is required to have fire resisting separation from the Library, in order to prevent a Plaza area fire from spreading into the Library atrium. This is achieved by means of sideways activating fire and smoke barriers which close to separate the two sections of the complex. In the event of fire in the Library however, these barriers do not close – the connection remains open to provide air ingress to the Library.

CONCLUSIONS

The development of this project demonstrates that the basic tools for determining smoke control specifications can be effectively used to achieve a bespoke fire engineered design in a space of unusual geometry.

- Smoke control provision is provided in a complex space without adverse consequences for the architecture.
- By closely co-ordinating buildings services engineering and fire engineering inputs during the design process, significant value is achieved for a client.

REFERENCES

[1] International Code Council. 2003 International Fire Code. ISBN # 1-892395-81-9 (e-download).

[2] Building Research Establishment (1999). *BR 368. Design methodologies for smoke and heat exhaust ventilation.* Construction Research Communications. London. ISBN 1-86081-289-9.

[3] National Institute of Standards and Technology (1993). *PE Tool Fireform Sprinkler/Detector Response Model. (Version 3.20).* USA.

[4] Alpert, R.L. *Fire Tech.*, 8, p.181 (1972).