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Paper Title: **"Integrating Human Behaviour Into Mass Egress Design"**

Abstract: With the ever growing population, modern construction has moved towards "Mega" size project in terms of floor space and height. Public assembly buildings – for example sports stadiums, exhibition centres and multi-occupancy risks shopping complexes, some of which encompass city-in-city concept. Column less open floor spaces housing large departmental stores and hundreds of retail stores and restaurants; multi-storey hotels, office and residential apartments soaring into the sky; underground car parks that can accommodate thousands of motor vehicles all pose challenges for mass egress design for modern built environment. Not to mention the life safety concern for fire fighters due to deeper, higher and longer search and rescue operations into these buildings.

For mega size project, fire engineering performance-based design is pre-requisite due to the limitation of prescriptive codes. CFD and zone models are often used to preview the potential fire and smoke movement as well as mass egress scenario. Basing on horizontal and vertical human empirical

data for digital simulations is it sufficient to determine RSET and ASET?

This paper will focus on the impact of human behaviour and response in mass egress process; audibility of fire alarm signals under high ambient noise environment and a re-analysis of RSET (Required Safe Egress Time). This paper will also touch on best mass egress strategy for multiple risk occupancy buildings.

Paper Title: "Integrating Human Behaviour Into Mass Egress Design"

Mass egress lifesaving strategy is a necessity and is a crucial part of Fire Engineering Performance-based Design for all modern built environments to cater for possible fire incidents, bomb threat, earthquake, gas leakage, terrorist attacks as well as any other emergencies.

To cater for ever increasing patronage of mass crowd and population for modern office blocks, hotels incorporate city in city concept with mixed occupancy risks, human behaviour needs to be taken into consideration as little study has been conducted in this areas and not much data bank is available. If we look at most Building regulations, Codes and Standards, the objective is to protect public life. From fire engineering point of view, it is the application of scientific and engineering principles for the protection of people, property and the environment from fire with emphasis on life safety.

Modern built environment trend has shifted over the past decade. Due to increase in population and high land cost, highrise condominium, office blocks hotels mushroom in most major cities. Columnless mega size shopping complexes, sports stadiums, public assembly buildings all form iconic buildings expressing the creativity of architects and developers alike. While it signifies a developed society with modern living style, it does pose challenges to the designers in terms of fire safety and mass evacuation as most of these build environment go beyond prescriptive Code guidelines.

Fire Engineering Performance-based design (FEPBD) was introduced and fire engineer needs to propose possible fire scenario, formulate and accord the building with appropriate fire protection strategy. FEPBD was introduced as mega size buildings goes beyond conventional compartment limit. Hence qualified fire engineers need to conduct FEPBD by assuming possible Fire sizes, possible fire source of origins, rate of smoke propagation through CFD (computational Fluid Dynamics) or zone model simulations. Mass evacuation is also carried out through computer software simulations in order to satisfy authority for RSET (Required Safe Egress Time) as maximum travel distances are often exceeded.

This paper looks at human behaviour as one of the important factor for tabulation of RSET. At present, apart from Scandinavian countries, not much study has been conducted and incorporated into the response time of RSET.

To enable mass egress from highrise buildings and mega size projects, many factors must be fulfilled in tabulation, failing which the value of RSET may not be as realistic as projected.

Building Regulations 2000, Requirement B1 for Means of Warning and Escapes defines the function as "The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape during a fire incident, from the building to a place of safety outside the building, capable of being safely and effectively used at all times". In RSET, perception of audio alarm signal is a preclude before evacuation action can be initiated. Even though minimum sound pressure level of 65db(A) has been defined by various Prescriptive Code and Standards, often ambient noise level has not been taken into consideration as one of the design factor and part of subsequent validation process. For public assembly areas, e.g. discotheques, night clubs, sports stadiums, shopping complexes, etc, the ambient noise level may/will mask the audible audio alarm signal. So are heavy industries or hazardous processing plants where the ambient noise level exceeds permissible level for workers and ear plugs or headphones are mandatory personal protective equipment.

EN54 stipulates that minimum audible audio alarm signal shall be 65dB (A) or 5dB (A) above ambient. It is a fire safety design recommendation that manual call points and audio alarm units should be installed along egress path around exit points. But should there be high ambient noise level, the positioning as well as the distribution of the audio alarm units should be relocated to achieve the minimum requirement of 65dB (A). For occupancy risk involving sleeping occupants (temporary or permanent – BS9999 risk profile classification), the audible alarm signal shall be 75dB(A) above bedhead. This is due to lowering of sense of hearing while sleeping not to mention under the influence of alcohol or medications. This category of occupancy risks includes hotels, condominiums, hostels, service apartments, etc. The requirement of additional minimum sound pressure level of 10dB(A) is also to compensate for attenuation of sound pressure level due to closing of hotel room doors or condominium doors.

To ensure fire alarm is audible to all occupants after the fire incident is detected, selection of alarm sounder unit is important. According to human physiology, human's perception of alternating frequencies within the audible range is more acute than audio alarm unit that generates single frequency due to the familiarization of single frequency sound. Single frequency audio alarm signal once familiarised will artificially sound less obvious once human ears get

used to it. Hence police, ambulance and fire engine sirens are easily audible and distinguishable from a distance as the sirens adopt alternating frequencies.

Installation and placement of audio alarm unit will also contribute to distribution of sound pressure level of the audible fire alarm signal. Basing on acoustic engineering principles, sound pressure waves travel in straight lines such as light source. Locating audio alarm unit at inlets leading to fire escape staircase will buffer the sound pressure level of the audio fire alarm signal generated and restrict the propagation of the alarm signal thus reducing the coverage area. Audio alarm units mounted on the walls of protected corridors will have fire alarm signal distribution over a 180° plain. While mounting of audio alarm units on the ceiling will be the most effective in achieving a 360° distribution of fire alarm signals in multi-directions achieving maximum coverage.

Sound waves travel in straight line, when it strikes a surface (depending on the hardness of the surface) part of the energy will be absorbed, part transmitted through the medium while the rest will be reflected. Fire alarm sound energy also loses energy while travelling through the air due to air resistant. If Fire alarm audio unit is installed in a protected corridor of a hotel building, much of the energy may be dissipated through the interior finishes (e.g. carpet, dry wall ceiling board, wall papers, etc) due to damping property of the finishes. If designers do not take this and the rest of the attenuation factors into consideration, it will be difficult to achieve minimum 75dB (A) at bed head as per sleeping occupancy risk requirement. All hotel room, apartment and condominium room door which are fire rated may also provide a further attenuation of 5 to 10dB (A) depending on construction.

Prescriptive Building Regulation adopts “Deem to Satisfied” rule of thumb for fire safety and fire protection design which is more suited to traditional built-environment. The changes in complex modern built-environment call for validation of design factors in order to fulfil the objective of fire safety and more importantly live safety.

Performance-based definition of RSET (Required Safety Egress Time) is the sum of five event’s duration. Time from fire ignition to detection (t_{det}); Time from detection to general alarm (t_{alm}); Time taken in responding to general alarm (t_{rec}); Time taken until evacuation commence (t_{res}) and Total travelling time to places of safety (t_{trav}).

Of the five events, should fire detection and alarm system is properly maintained; the duration from detection to sounding of general fire alarm should be quite consistent. Total travelling time to place of safety should be quite standard in accordance with the normal moving speed of human being. But further studies need to carry out to develop data for different age group for different occupancy risks group especially public assembly complexes where travelling speed will vary according to age group and sexes.

Out of the five factors, the two factors which may have wide dynamic range in duration are time taken in responding to general alarm and time taken until evacuation commence.

This is the area where human behaviour is unpredictable and irrational and fire engineers using outdated statistical data to tabulate RSET could incorporate margins of errors with unrealistic results eventually. Modern full scale investigation on human behaviour during fire incident simulation established empirical data which is interesting and alarming. It revealed the unrealistic assumption on time taken until evacuation commence. Assumption of occupants commencing evacuation within a certain period of time frame after hearing the general fire alarm is not more viable in most cases. Most people do not start evacuating for a mere reason they did not sense any danger as they do not see physical smoke or fire. Many also just ignore the fire alarm with the presumption that “It’s another false alarm”.

As for time taken in responding to general alarm there are many other factors that need to be taken into consideration within this factor itself some of which already highlighted in this paper earlier.

When RSET is being established with uncertain variables, there are other operation considerations which may disrupt the formulated and desired RSET. Aged group, variants of age group, percentage of disables, occupants who have medical conditions, obese group, possible stampede due to panic situation, injuries cause by stampede or tripping within egress route, crowd control, etc all can or may prolong RSET.

We are all aware that RSET (Required Safe Egress Time) should not exceed ASET (Available Safe Egress time) otherwise the situation will be untenable for occupants. Hence establishing RSET should not depend on Fire and Detection System alone and expect volunteering evacuation. Fire protection hardware should also be supplemented by emergency response management (software personnel) for effective evacuation. This may be termed as software of fire

safety concept. There are evacuation program that can be put in place for self-induced evacuation which can be easily implemented without incur high cost.

For RSET to be realistic, emergency response planning and management should be put in place. Control and Induce mass evacuation after confirming that fire incident is imminent on detection of fire incident will be the way forward.