

UNDERGROUND PARKING GARAGES – CHANGING PERCEPTIONS ON SMOKE CONTROL CRITERIA AND COMBINING AN INTEGRATED SYSTEM FOR SMOKE CONTROL AND VENTILATION.

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ABSTRACT

Underground parking garages are either fully or partially closed. While only some of the partially closed garages are required by standard and regulations to install an electro-mechanical smoke control system, fully enclosed garages that exceed one underground level are always required to install such systems.

Smoke Control and Ventilation (SCV) system designers, along side fire protection engineers, are facing three major challenges: The first maintaining Air Quality levels according to health and environmental regulations by means of toxic gas extraction (Co, Co₂, No_x). The second by providing a Smoke Control system for emergency fire situations, which in many cases are held to building Tenability standards, among them smoke layer height, which is rarely achievable in low ceiling clearance facilities. And last by designing an integrated all-in-one solution for both demands.

While Israeli Health and Environmental Standards and Regulations define at least 8 Air changes per hour, using an extraction of 20% from lower layers (floor level) and 80% from Higher Layers (ceiling level) alongside a PPM threshold, Fire and rescue authorities and Buildings construction regulations require only 6 Air changes per hour (adopting American NFPA Standard), and must effectively extract smoke from upper ceiling level.

Under these integrated requirements, system designers tend to almost automatically design a system that is based on Vents, Jet Fans and Air ducts, resulting in a complex cost-ineffective system that is high on installation costs, energy consumption and is rarely esthetic to the eye.

This paper will present a case study portraying a change in perception regarding smoke control demand criteria for underground parking garages - "Smoke control by smoke zones" utilizing an optional criteria as proof of sufficient ventilation –

"Airflow Threshold" for the mater of CO evacuation. Both new perceptions are approved and acceptable by

local authorities in Israel while maintaining a realistic and economic viable solution.

INTRUDOCTION

Underground parking garages come in a variety of design characteristics. They can be fully or partially closed, partially or completely underground, consist of one floor or several and vary in motor capacity, usage, congestion and size.

While only some of the partially closed garages are required by standard and regulations to install an electro-mechanical Smoke Control and Ventilation (SCV) systems, fully enclosed garages that exceed one underground level are always required to install such systems.

Underground garages are unique in their low clearance ceiling height between 2.2m to 3m (including cable and duct area) and by being a large compartment area that usually lacks separation by walls and distinct fire zones. In addition, the use of fire resistant walls and doors is rarely present.

THE MAJOR CHALANGES DESIGNER ARE FACING

When designing an underground garage, SCV system designers, alongside fire protection engineers, face three major challenges: Maintaining Tenability conditions on egress routes for evacuation and rescue times in case of fire; maintaining a level of tenable Air-quality for daily use; designing an integrated, all-in-one solution, for both emergency and daily use demands.

1. Air Quality

Since underground garage facilities are not naturally ventilated, system designers and engineers are required to take in account several air quality issues,

a challenge of which the most problematic is high levels of Carbon monoxide (CO) gasses emitted by vehicles entering, existing and traveling through the domain.

Other issues to be taken under consideration are the presence of oil, gasoline fumes, nitrogen oxides (NO_x), CO₂ and smoke haze from diesel engines [10]. Furthermore, in the near future, adaptation to new energy carriers due to global warming issues must be taken under consideration in both ventilation aspects and risk assessments for emergency scenarios. Designers need to take under consideration the emission of different range of gasses that are still under study and experiment. These gasses and are not yet addressed in current regulations [12].

Regulation addressing the issue of Air-quality level and the system's requirements to maintain Tenable conditions for normal operation of underground garages vary on a international, national and local level. Part of the regulation codes address the PPM threshold for CO exposure while others only address the number of air changes (ACH) per hour, or state a sufficient extraction of air according to gross floor area.

To demonstrate this inconsistency:

NFPA 88A [2] states the fixed ventilation of 5 L/s-M² of floor area is the minimum required.

NFPA 502 [6] states CO exposure PPM threshold to be only for fire emergency.

ANSI/ASHRAE Standards [7] 62-1989 state that a fixed ventilation of 7.62 L/s-M² of floor area is the minimum required while including a PPM threshold exposure time of 8 hours for 9 PPM and 1 Hour for 35 PPM .(More examples can be found in reference 10)

2. Smoke Control system criteria

Regulation addressing the issue of smoke control and smoke management for underground parking garages is almost non-existent in terms of building usage for human occupancy. These structures are at times addressed as a storage occupancy areas or vast space areas [3].

NFPA 204 [5] is at times used as a guide for smoke and heat venting in underground parking garages. This code addresses the smoke layer boundary height and temperature for building spaces with ceiling heights that permit the fire plume and smoke layer to develop.

This design criteria is rarely met when addressing low clearance spaces.

A smoke management system shall be adopted and designed to minimize the impact of smoke upon occupants and emergency services personnel.

The main criteria for smoke management are to provide tenable conditions within the building for the time required by occupants to evacuate to a safe area.

The smoke management system should also provide suitable conditions for emergency services to enter the building, assist with the evacuation, rescue occupants and initiate fire fighting strategies. Smoke layer Criteria is usually regarded as the threshold of smoke layer height ranging between 1.8m-2.5m [4].

Furthermore, Fire and rescue authorities in Israel require at least 6 air changes per hour [8], and expect smoke to be evacuated completely rather than managed and contained.

3. Integrating an all-in-one coast effective system

When presented with such integrated requirements of both normal operation ventilation system and emergency ventilation system, designers tend almost automatically to design a system that is based on Vents, Jet Fans and Air ducts, resulting in a complex cost-ineffective system that is high on installation costs, energy consumption and rarely esthetic to the eye.

OUR GOAL

Meeting with both authorities integrated requirements while maintaining a viable, cost-effective, energy saving, low maintenance system should result in a system that is neither over nor under the required safety and egress measures.

ALTERNATE PRECEPTION ON SMOKE CONTROL

Past experience teaches us that retaining and maintaining the building and code regulating of smoke layer height as a Tenability factor on low height ceiling such as underground parking, is neither applicable nor practical. Thus the need to search for a more realistic and appropriate criteria on the challenge of smoke control for this type of building.

In this paper we will examine "Smoke zones" approach as alternative criteria to smoke layer height for tenability objectives. Based on the design flexibility described in the NFPA Life Safety guide, chapter 5[4], and the NFPA Handbook of Fire Protection Engineering [1]: using a performance based design to achieve the goals of a reasonable level of life safety and achieving of objectives regarding safety level, such as the protection of occupants not intimate with the initial fire development, for the time needed to evacuate, relocate, or defend oneself in place. Integrated with tenability criteria of maintaining tenability conditions on egress routs [6] and to provide clear path access for fire fighters and rescue team.

We will portray our alternative as satisfying for these goals and objectives.

Smoke Zones

A "Smoke Zone" is a pre-defined area in which smoke layer and fire effect will be restricted and maintained throughout. The goal is to maintain this area in a steady state of smoke capacity. And to prevent smoke layer from traveling between building levels thus preventing it from obscuring egress routes and rescue routes. This approach incorporates the use of "Push-Pull" method for creation of Barriers and Exit Points and the use of Smoke Screens. By implementing this approach we comply to "smoke control" objectives rather than commonly expected "Full Smoke Clearance".

ALTERNATE PRECEPTION ON AIR QUALITY CONTROL

Over design in regulation demands on air changes of 7.6 ACH (ANSI) [7], 8 ACH (Israeli Environmental Regulations) [8], 5 ACH (NFPA calculated for a 2.5m ceiling) [2] alongside the 20%/80% division of duct location, usually leads to an over kill system and an ineffective duct usage.

As a goal air in the underground structure should be circulated for ventilation rather than being completely purified. By using an air circulation of acceptable "Airflow threshold" approach, which introduces fresh air into the vicinity we lower Toxic-concentrations and achieve the ventilation goals at hand. The Air Quality criteria of PPM concentration are monitored in this approach by CO measurement detectors.

Airflow Threshold

Definition of "Airflow threshold" – Maintenance of air flow of at least 0.5 m/s as a satisfying proof of air circulation in individual parking level has been agreed via collaboration and consultant with the local authority having jurisdiction, for this matter The Environmental authorities in Israel which agreed on the criteria for future regulation demands.

CASE STUDY

As a case study for the above goals and challenges we will examine the CFD Analysis of the Azrieli Group's Hi-Tech Center, Holon .A 4 story Underground Parking lots.

This Case is suitable for the goal at hand for it is a fully closed underground garage, with partially open characteristics, such as ceiling apertures by means of "English courts" and a central atrium opened to the atmosphere. (This criteria does not meet code definition for open garages, it is used solely for descriptive purposes)

Preliminary System Design for ventilation and smoke control was based on natural ventilation. This meets with local regulations for parking garages that have at least 2% of the ceiling area open [8]. Furthermore, the investor's architectural design criteria had allowed natural light to flow into the internal domain via the "English courts"

We were asked to check and advise on the subject of an all-in-one system to meet both ventilation and smoke control demands and standards.

CFD Analysis

The CFD Analysis was carried out using the FDS – Fire Dynamics Simulator Version 5, by NIST. FDS is a CFD fire Model that uses the Large Eddy Simulation (LES) Techniques to calculate the gas density, velocity, temperature, pressure and concentrations in each control volume. More on FDS model can be found in reference [13].

Preparation of Run Files and Models were made using Pyrosim Software version 2010, By Thunderhead Engineering.

Smoke View was used in order to visualize the output data.

The Model is in Ideal Conditions. No winds are present. Ambient Temperature 20c°

An egress simulation has been conducted for estimated evacuation times, as a part of the tenability criteria demands regarding maintaining egress routes.

Garage Characteristics and Geometry:

A 4 Level Underground Garage. Each level is approximately 20,000 Square meters (net area). The Full scale model dimension: 200m (L) x 150m (W) x 14.5m(H)

Lower Levels -4 and -3 are fully closed

Upper Levels -2 and -1 are partially opened. (*This criteria, does not meet code definition for open garages, only for descriptive purposes*)

All 4 Levels Share a Central open air atrium in the middle. And a row of "English courtyards" on the floor out lines

Ceiling Height:

Floor -4 Ceiling Height 2.5m

Floor -3 Ceiling Height 2.5m

Floor -2 Ceiling Height 2.5m

(Double height on loading/unloading Zone)

Floor -1 Ceiling Height 2.5m

Atrium Ceiling Opening dimensions:

Floor -4 Atrium open dimensions 174 m²

Floor -3 Atrium open dimensions 341 m²

Floor -2 Atrium open dimensions 535.5 m²

Floor -1 Atrium open dimensions 722.75 m²

English Courtyards Opening dimensions:

- Floor -4 Total Ceiling Opening 326m²
- Floor -3 Total Ceiling Opening 270m²
- Floor -2 Total Ceiling Opening 142m²
- Floor -1 Total Ceiling Opening 38m²

Entrance Ramp dimensions:

- To Level -4 – None
- To Level -3 – None
- To Level -2 – 96 m²
- To Level -1 – 58 m²

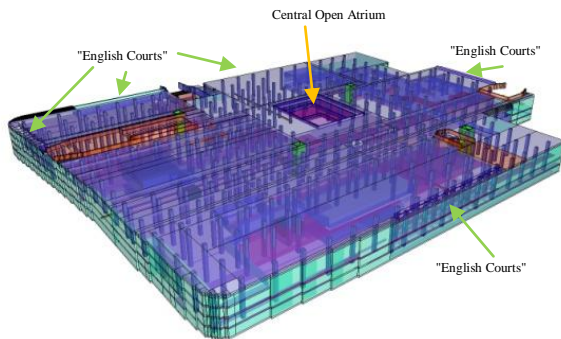


Figure 1: Azriely Group "Hi-tech center Holon" Underground Garage CFD Model (Architectural Model version 2.0)

Methodology

In order to check effectiveness and usability of the system design, an Evacuation-analysis has been carried out to determine evacuation and egress time, followed by two fire scenarios selected according to FPE Risk analysis:

- Scenario 01 - Car Fire @ Park level -4
 - Scenario 02 - HGV Fire @ Loading/Unloading Zone Park level -2. (Not presented in this article)
- CFD engineering analyses for performance design is carried out following this methodology:

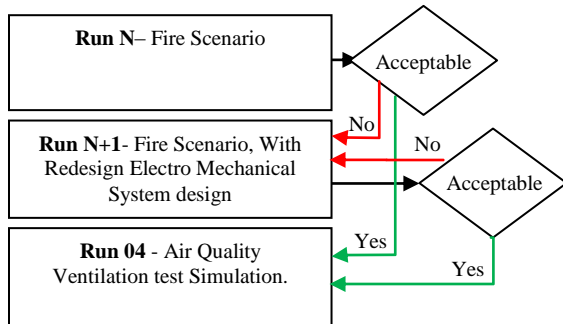


Figure 2: Design Process for simulations

Following this chart of methodology, our CFD analysis process resulted in the following runs:

1. Fire Scenario, without electro mechanic ventilation system – Natural ventilation –Run 01
2. Fire Scenario, With Original Electro Mechanical System design-Run 02
3. Fire Scenario, With Redesigned electro mechanical systems- Run 03
4. Air Quality Simulation, Based on System Design in Run 03

Fire Specifications

For the first scenario portrayed in this paper a 5mv Car fire was selected with a Medium Fire Growth Rate. Maximum HRR is reached @ 654 sec [9,11].

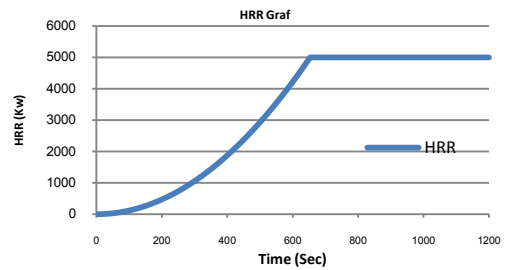


Figure 3: HRR Graf for Car Fire

- Burner area – 4.5m²
- Soot yield – 0.1
- CO yield – 0.02

Fire reaches peak HRR, without natural or forced suppression as a part of a conservative policy.

The burning car was placed near the atrium ceiling opening (Figure 3) in parking level 4 (lower level).



Figure 4: Top View- Fire Location (Architectural Model version 1.0)

Smoke Control And Ventilation (SCV) System Configuration and specifications

SCV System – Run 01

Natural ventilation, open Atrium and "English courts".

SCV System – Run 02

Smoke Extraction and ventilation via Extraction Fans Located within Ducts through "English Court" space.

Table 1: Run02 Smoke Exhaust Fans Configuration and specifications.

Level	Duct Opening m ²	Extraction Power m ³ /s	Number of Fans
-1	1m ²	7.22 m ³ /s	12
-2	1m ²	7.22 m ³ /s	13
-3	1m ²	7.22 m ³ /s	15
-4	1m ²	7.22 m ³ /s	17

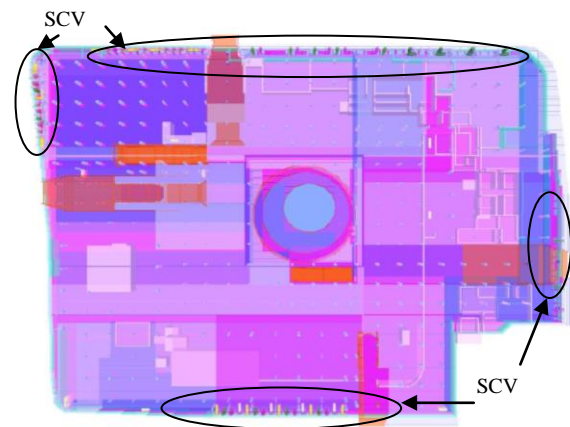


Figure 5: Top View- SCV Original System (Architectural Model version 1.0)

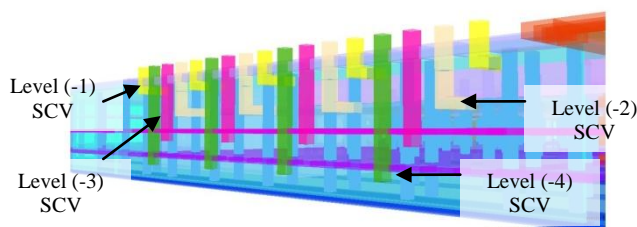


Figure 6: Side Close-up View- SCV Original System (Architectural Model version 1.0)

Table 2: Jet Fans - Configuration and specifications.

Level	Jet Diameter	Extraction Power m ³ /s	Number of Fans
-1	71	7.22 m ³ /s	4
-2	71	7.22 m ³ /s	4
-3	71	7.22 m ³ /s	5
-4	71	7.22 m ³ /s	6



Figure 7: Top View- SCV Jet Fans Original System -Level (-4) (Architectural Model version 1.0)

SCV System – Run 03

Smoke Extraction and Air Ventilation redesigned using 4 Main Extraction Shafts, on each Shaft 4 Fans per Level, Based on Push-Pull per Smoke Zone.

Table 3: Run02 Smoke Exhaust Fans Configuration and specifications.

Level	Exhaust Griller on Shaft	Extraction Power m ³ /s	Number of Fans	Level Fans Per Shaft
-1	1m ²	14.38 m ³ /s	16	4
-2	1m ²	14.38 m ³ /s	16	4
-3	1m ²	14.38 m ³ /s	16	4
-4	1m ²	14.38 m ³ /s	16	4

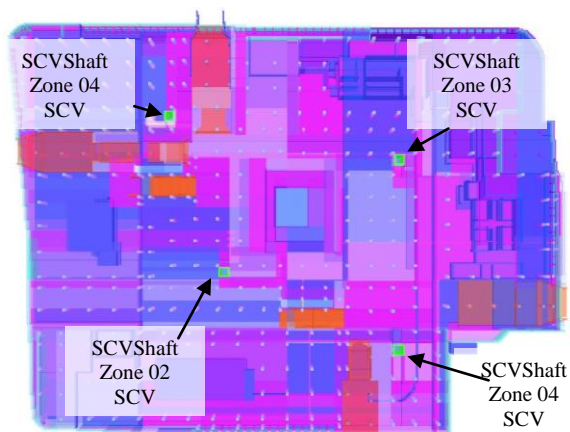


Figure 8: Top View- SCV Redesigned System
 (Architectural Model version 2.0)

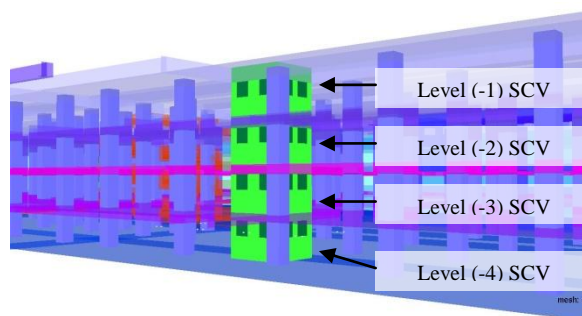


Figure 9: Side Slanted Section View- SCV Redesigned System Shaft close-up
 (Architectural Model version 2.0)

Smoke Evacuation System is triggered via Smoke zones on individual levels, only level -4 system activated in this scenario.

Air Supply – All Runs

In all runs and scenarios, air supply is passive via "English courts", entrance ramp and main central open atrium.

Note: since CFD Analysis is carried out parallel to architectural design stages, geometry tends to change between preliminary and final runs. Runs 01 and 03, share the same natural opening dimension, according to final Architectural Geometry. Run 02 differ on atrium dimensions and are shaped as a round opening, and was the preliminary Architectural design.

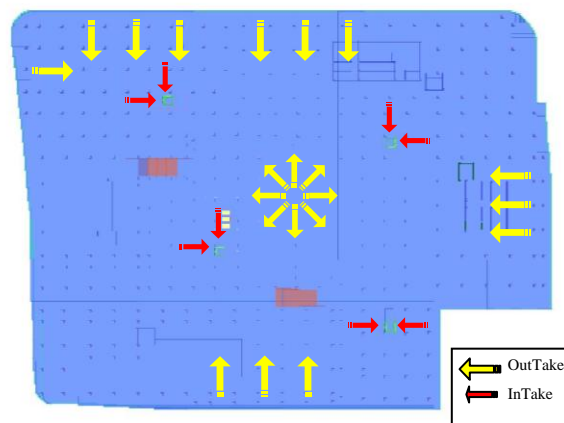


Figure 10: Top View- SCV Redesigned System
 Flow Directions for Level (-4)
 (Architectural Model version 2.0)

Smoke Screens

Smoke screens are used to divide each level into 4 "Fire/Smoke Zones". In order to segment the vast open area of the level domain into controllable areas.

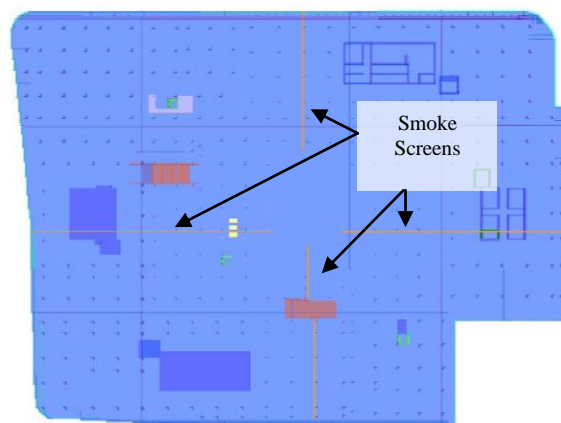


Figure 11: Top View- Smoke Screens Location – level (-4). (Architectural Model version 2.0)

Smoke Detectors Specifications and location

Smoke Detectors have been placed in the vicinity of the fire area only – covering an area of 13m x 25m. Smoke detectors are used as an indication of smoke detection time, although in reality they are not present in the domain
 Smoke detector activation trigger threshold: 3.28%/m

Heat detectors Specifications and location

Heat Detectors have been placed in the vicinity of the fire area only – covering an area of 13m x 25m. Heat detectors are used as an indication of sprinkler activation time, and are the operation trigger of the SCV System.

Heat detector Specifications:

Activation trigger threshold: 68 C°
 RTI –Fast Response 50(m-s)²

Smoke Layer Devices Specifications and location

Smoke Layer Devices measure the smoke layer height descending from top end of measure point (ceiling level) to bottom end (floor Level), and are located throughout the egress routes.

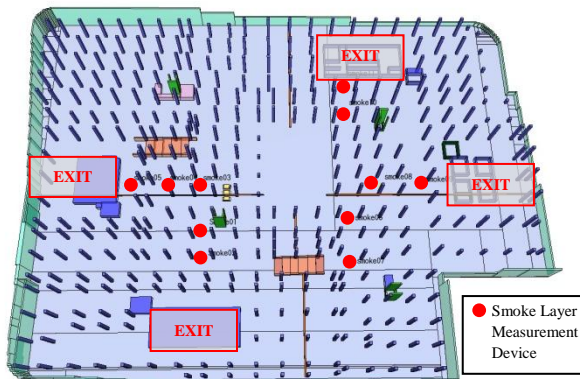


Figure 12: Top Slanted View- Smoke Layer measurement device Location – level (-4).
 (Architectural Model version 2.0)
 Pyrosim Model

System Operation regimint

SCV System operates by Fire Zones.
 For Run 02 – Level -4 System Activated
 For Run 03 – Level -4 Zones 1 and 2 Activated.
 Each fire zone has a separate Sprinkler grid.
 On Sprinkler activation, SCV of Specific zone commence its operation respectively.
 Each SCV Shaft it governing a unique fire/smoke zone

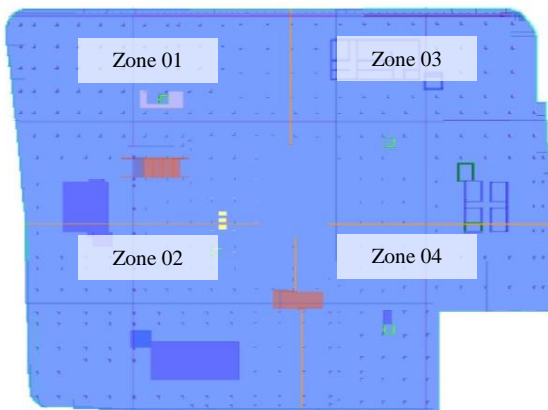


Figure 13: Top View- Smoke Zone, level (-4).
 (Architectural Model version 2.0)

CFD Analysis Results and predictions

Evacuation analysis

In order to predict the egress times form level (-4) an evacuation simulation has been carried out.

Model Basic Assumptions:

- Parking level capacity – 160 vehicles.
- Percentage of occupied vehicles in daily usage for active business center – 40% max = 40 Vehicles.
- Human Occupancy:
 - 20 Vehicles – 2 passengers Per Vehicles
 - 10 Vehicles – 1 passengers Per Vehicles
 - 10 Vehicles – 3 Passengers Per Vehicles
 - **Total Occupancy : 80 People**

Model Results – 70 seconds for complete egress to safe refuge area.

This model calculates the movement time excluding detection time, alarm time, pre-movement time and response time. According to FDS simulation results, sprinkler activation time for a car fire on level (-4) is 210 sec. At this point fire alarms sound and the recognition/pre-movement time starts. This is the period of time it takes for occupancies to investigate regarding the nature of the alarm. In open areas, such as a parking space, a fire would be visible in a short period of time, therefore we predict a recognition/pre-movement and response time to be not grater then 60 seconds. Preceding this stage is the actual egress time calculated in our simulation.

In order to maintain a safe margin on the actual evacuation time we use a multiplier of 1.5 as a safety factor. Thus the total time to evacuate to a safe refuge area is calculated as following [1]:

$$\left(\begin{matrix} \text{Detection} \\ \text{Time} \end{matrix} + \begin{matrix} \text{Recognition/} \\ \text{Pre-movement} \\ \text{Time} \end{matrix} + \begin{matrix} \text{Response} \\ \text{Time} \end{matrix} + \begin{matrix} \text{Movement} \\ \text{Time} \end{matrix} \right) * 1.5$$

Figure 14: Calculation of Evacuation Time

The Total Calculated Evacuation time is 495 sec = 8:15 minutes.

Run 01 – Fire only & Natural Ventilation

Smoke Detection Time: 54 sec
 Heat Detection / Sprinkler Activation Time: 210 sec

Natural ventilation does not meet the codes, regulations and tenability requirements neither for smoke control nor ventilation goals and objectives. It is used in simulation mostly to indicate a system failure scenario.

Run 01 - Smoke Behavior in Level -4

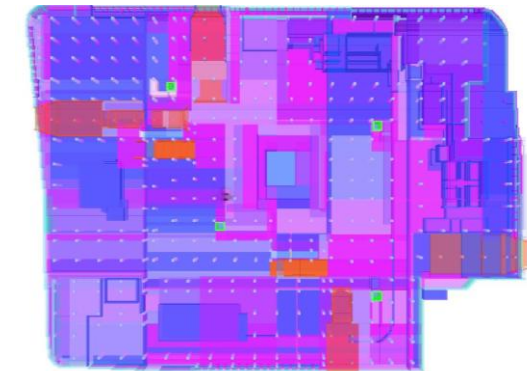


Figure 15: Run01- Smoke behavior –Top & Side view
@ t=1 min Smoke Detection Time

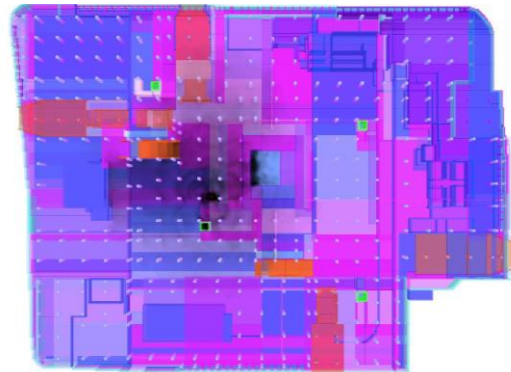


Figure 18: Run01- Smoke behavior –Top & Side view
@ t=5:40min (Egress End)

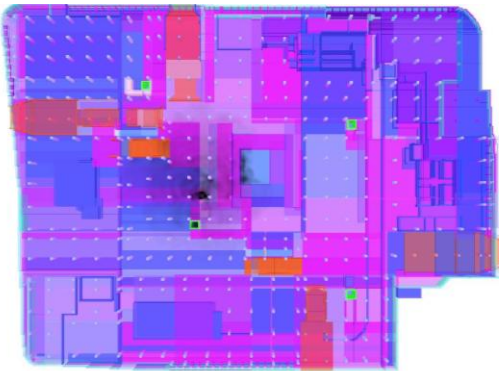


Figure 16: Run01- Smoke behavior –Top & Side
view @ t=3:30min (Heat Detection Time)

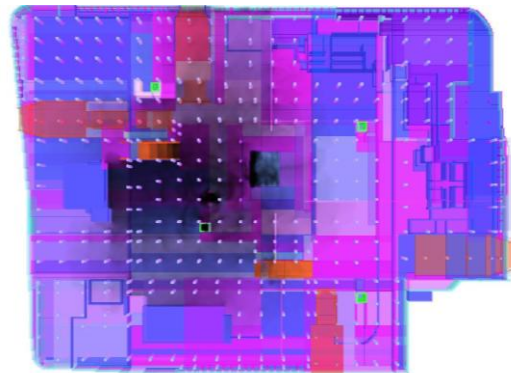


Figure 19: Run01- Smoke behavior –Top & Side view
@ t=8:15min (Safe Margin)

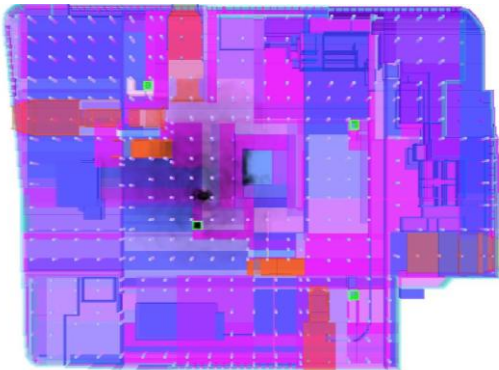


Figure 17: Run01- Smoke behavior –Top & Side view
@ t=4:30min (Egress Start)

Run 02– Fire & Original SCV Design

Smoke Detection Time: 50 sec

Heat Detection / Sprinkler Activation Time: 277sec

Original SCV System Design does not meet the tenability requirements for smoke control therefore ventilation test are not performed. Furthermore, fire location on this run, was located on the opposite side of the open atrium and differs between V1 to V2 of the architectural model.

Run 02 - Smoke Behavior in Level -4

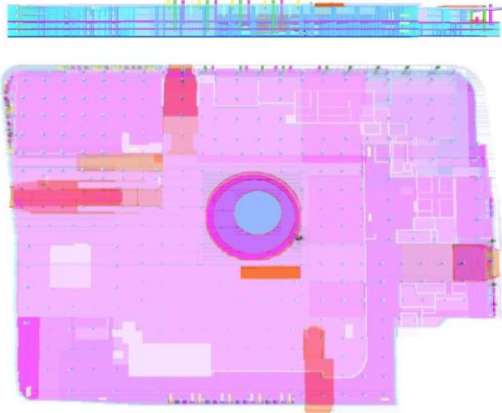


Figure 20: Run02-Smoke behavior –Top & Side view
@ t=1 min Smoke Detection Time



Figure 23: Run02-Smoke behavior –Top & Side view
@ t=5:40min (Egress End)

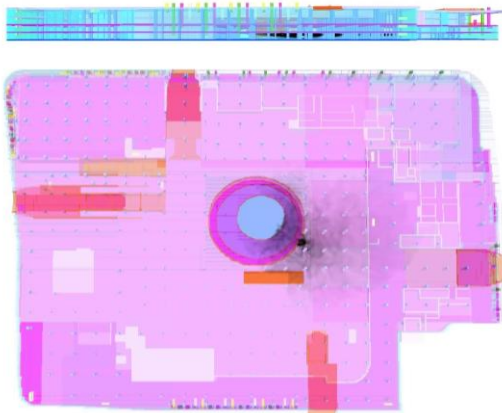


Figure 21: Run02-Smoke behavior –Top & Side View
@ t=3:30min (Heat Detection Time)

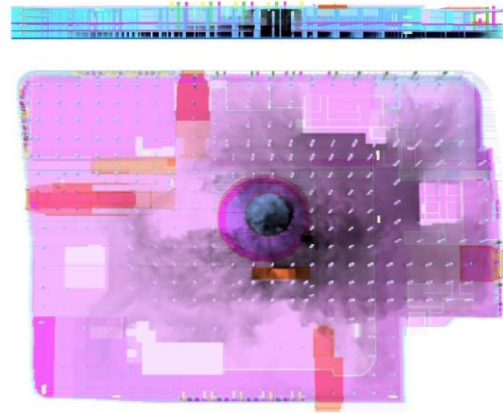


Figure 24: Run02-Smoke behavior –Top & Side view
@ t=8:15min (Safe Margin)

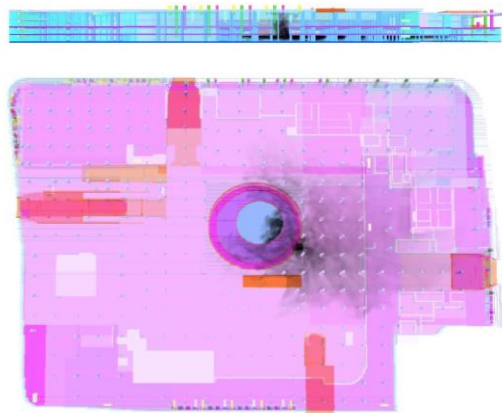


Figure 22: Run02-Smoke behavior –Top & Side view
@ t=4:30min (Egress Start)

Run 03– Fire & Redesigned SCV System, Incorporating Smoke Zone for smoke control criteria

Smoke Detection Time: 54 sec
Heat Detection / Sprinkler Activation Time: 210 sec

Redesigned SCV System meets the tenability requirements for smoke control as defined in the criteria for controlling smoke in one "Smoke Zone", while keeping egress routes and accessibility for fire rescue team.

Run 03 - Smoke Behavior in Level -4

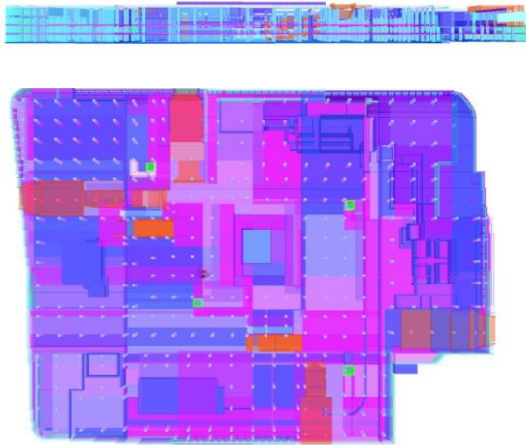


Figure 25: Run03- Smoke behavior -Top & Side view @ t=1 min Smoke Detection Time

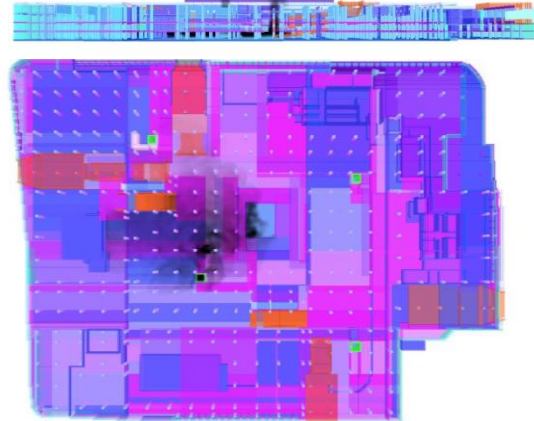


Figure 28: Run03- Smoke behavior -Top & Side view @ t=5:40min (Egress End)

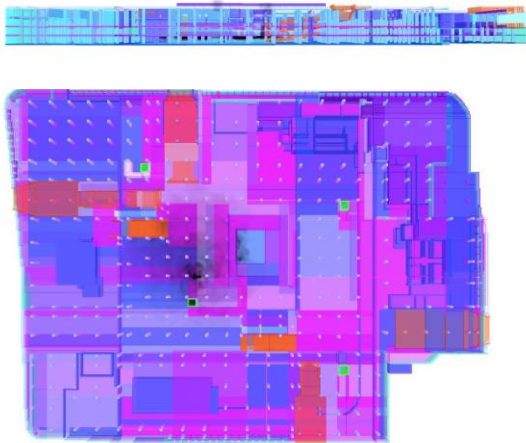


Figure 26: Run03- Smoke behavior -Top & Side view @ t=3:30min (Heat Detection Time)

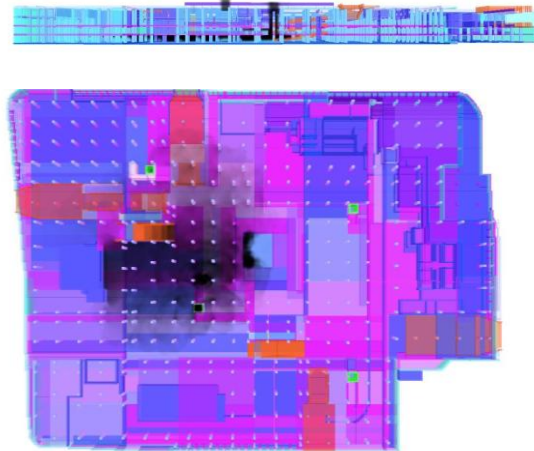


Figure 29: Run03- Smoke behavior -Top & Side view @ t=8:15min (Safe Margin)

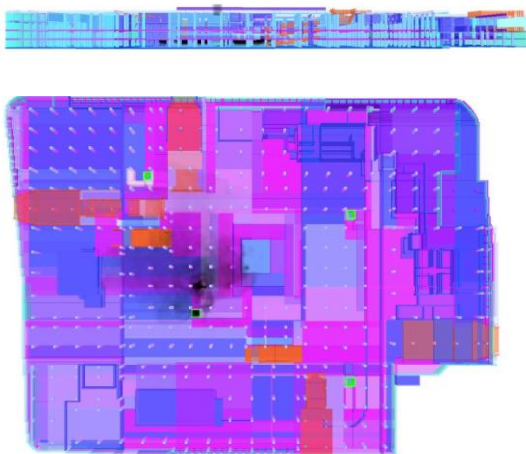


Figure 27: Run03- Smoke behavior -Top & Side view @ t=4:30min (Egress Start)

Run 03 - Visibility Slices in Level -4
 (For illuminated Exit signs, scale: Red-30m-Blue 0m)

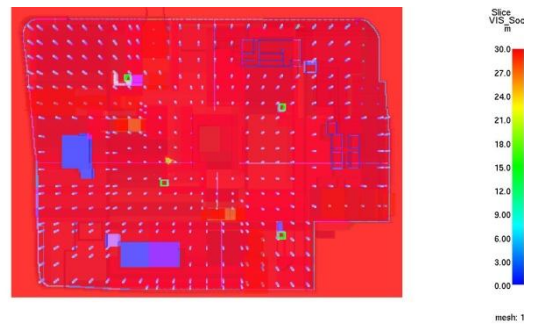


Figure 30: Run03- visibility slice, 2 m from floor level - Top view @ t=1 min Smoke Detection Time

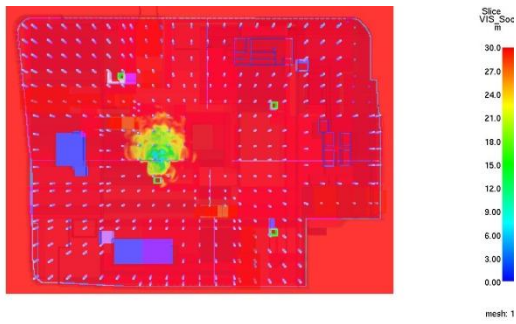


Figure 31: Run03- visibility slice, 2 m from floor level - Top view @ t=3:30min (Heat Detection Time)

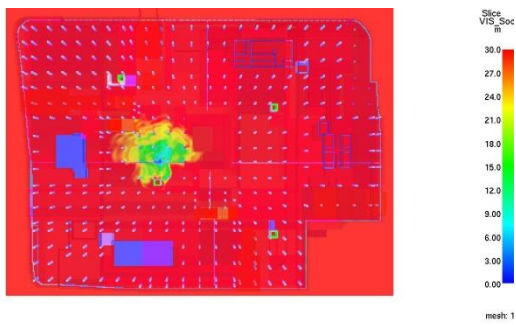


Figure 32: Run03- visibility slice, 2 m from floor level - Top view @ t=4:30min (Egress Start)

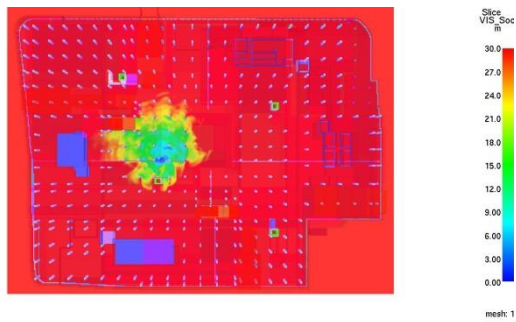


Figure 33: Run03- visibility slice, 2 m from floor level - Top view @ t=5:40min (Egress End)

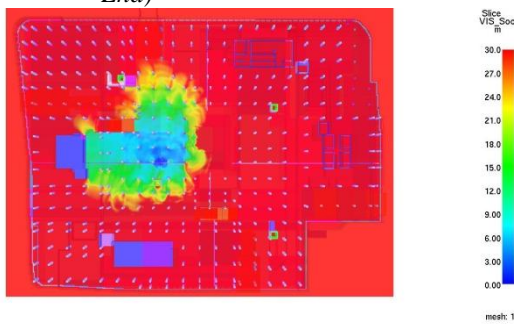


Figure 34: Run03- visibility slice, 2 m from floor level - Top view @ t=8:15min (Safe Margin)

Run 03 - Temperature Slices in Level -4

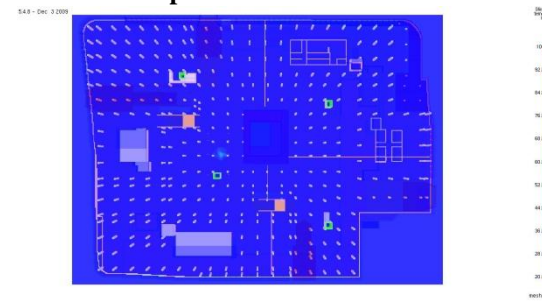


Figure 35: Run03- temperature slice -Top view @ t=1 min Smoke Detection Time

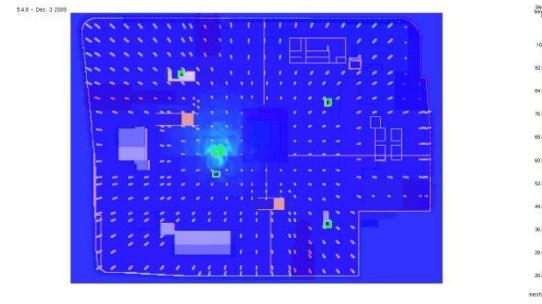


Figure 36: Run03 - temperature slice -Top view @ t=3:30min (Heat Detection Time)

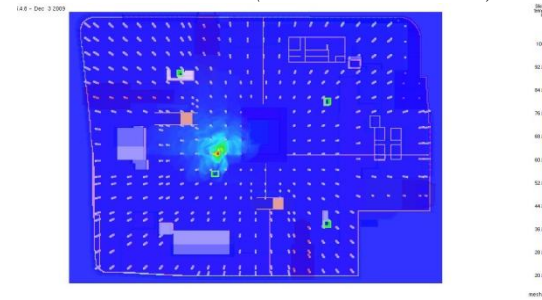


Figure 37: Run03 - temperature slice -Top view @ t=4:30min (Egress Start)

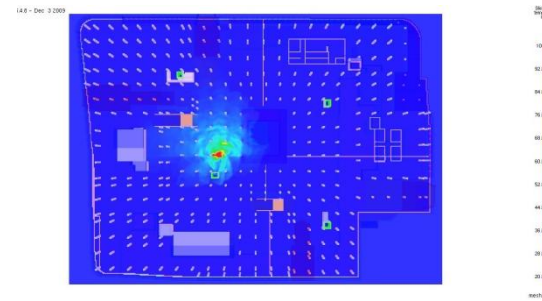


Figure 38: Run03 - temperature slice -Top view @ t=5:40min (Egress End)

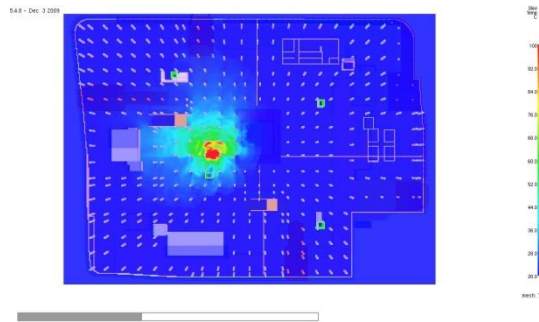


Figure 39: Run03 - temperature slice –Top view @
 t=8:15min (Safe Margin)

Ventilation CFD analysis

Based on redesigned SCV System for Run 03, a ventilation simulation was carried out to check if it meets the "Airflow Threshold" suggested and authorized by national authorities as new criteria for ventilation.

SCV system configured to supply half of its thrust for ventilation usage; only 2 out of 4 fans are operational in this case. A total of $115 \text{ m}^3/\text{s} = 4.14 \text{ ACH}$. Results show that an "Airflow Threshold" of at least 0.5 m/s is achieved throughout the domain. A problematic air congested area exists at the boundaries of zone 2, this issue was addressed in redesign suggestion by installation of low power Jet fans.

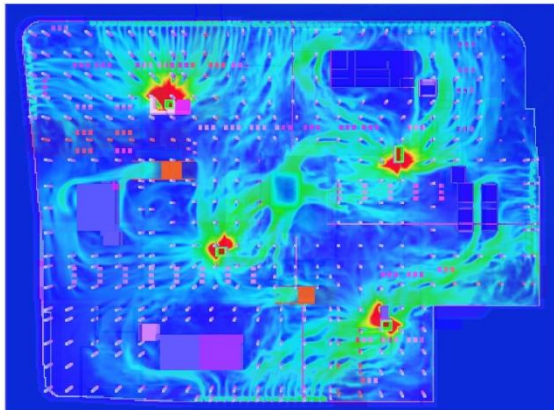


Figure 40: Ventilation Run -Velocity slice @ 1.5m
 from floor level –Top view @ t=10:00
 min (scale red 1m/s – blue 0m/s)

CONCLUSION

In this paper we have suggested a change in perception on smoke control criteria – "Smoke Zones"; a new perception on ventilation criteria for underground parking garages – "Airflow Threshold"; and an optional all-in-one design to meet all safety goals and objectives according to codes and

regulations. These perceptions were portrayed by a case study of a 4 story underground garage and have been approved for usage under Israeli regulations by the Fire and Rescue and Environmental Regulation authorities.

Additional achievements in this area:

- The utilization of an All-In-One system design that meets all integrated requirements.
- Implementation of "Mode of Action" for firefighting and rescue services, so they a priori know the best approach for a fire scenario.
- Change in Fire and rescue authorities misconception that smoke control and smoke clearance are interchangeable terminology. Where fire lies, smoke will be present.
- New criteria to be used for future system design.

We would like to suggest our perception as a tool to be used by other system designers when approaching issues such as the ones portrayed in this paper.

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