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EDITOR

Prof. Dr. Atila GUL

Prof. Dr. Oner DEMIREL

Assoc. Prof. Dr. Seyithan SEYDOSOGLU

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ENVIRONMENTAL IMPROVEMENT OF A BUILDING'S UNDERGROUND FLOORS IN HEBRON, PALESTINE

BADER ALATAWNEH
Assistant Professor, Department of Architecture, Palestine Polytechnic University,
Bader_k3@ppu.edu, ORCID No: 0000-0002-4564-9423

NOOR ABUREESH
Master's student, Master Program of Architecture: sustainable design, Palestine Polytechnic University,
noorabureesh96@yahoo.com

JENAN QADI
Master's student, Master Program of Architecture: sustainable design, Palestine Polytechnic University,
jenankadi1996@gmail.com

ABSTRACT

Improving the underground spaces in an environmental approach facilitates the use of theses spaces besides the energy saving. However, the issue concerned with lighting and natural ventilation has become a major challenge in order to use the underground spaces in its current process. Underground floors require good ventilation to acquire comfortable environment, in addition to the lighting systems that play a significant role in this experience, where people always need to navigate such spaces easily and safely. Nowadays, the artificial illumination and mechanical ventilation are commonly used to get good lighting and air quality in underground spaces, while these systems consume more energy. This research aims to enhance the natural lighting and ventilation in underground spaces in order to enhance the quality of these space. To achieve this goal, a research methodology has been developed to study the problems of ventilation and lighting that face the underground floors of the parking central building of hebron city in Palestine, which was randomly selected. The study focuses testing the appropriate solutions to solve the problems of daylight and ventilation in an efficient way. Dependently, the main result of the research is a highlight of the alternative passive design solutions those can be adopted in any retrofit process in order to enhance the natural lighting, ventilation and reduce energy use in these spaces.

Keywords: Underground Floor, Daylight, Ventilation, Passive Solutions.

1. INTRODUCTION

Rapid and irregular growth of technology generates changes of human life, his habits, and his surrounding environment. However, it is not recognized as the only reason for environmental disturbance. Ever increasing population and concentration on urban life have caused a considerable increase in the population of city inhabitants, followed by increased demands and requests in areas (Vaezizadeh, Kazemzade, 2013). The merits of developing underground spaces meet the needs of today's society. It can become a solution for urban problems; shortage of land, growth of land values, environmental problems, and etc. However, environmental limitations of human activities underground need consideration when planning underground buildings (Lee, Kang, 2016).
The most important environmental issue that must be considered when designing underground spaces is providing natural lighting and ventilation to these spaces, in order to achieve human comfort and reduce the overall building energy consumption (Akadiri, Chinyio, 2012). Underground spaces are a resource of great potential benefit which has been exploited in different parts of the world for thousands of years. Underground architecture means constructing properly designed spaces below ground level which are functional and have all the amenities that an above ground structure has (Jain, 2017).

1.1. Daylight Need In Underground Spaces

Daylight plays a significant role in architectural design, since it involves many aspects regarding visual comfort for the occupants of a space (Baroncini, Chella and Zazzini, 2007). Furthermore, the availability of natural light in a closed space allows us to limit the use of electric light so as to obtain an efficient energy saving effect. In underground space, daylight is not only to meet the requirements for illumination and energy saving, but more essentially, to meet people's psychological requirements for perceiving such natural information as natural sunlight, sense of direction, day and night shift, weather change, season and climate. At the same time, daylight in underground space can improve the spacious sense of space and improve the ventilation effect (Wang, Jia, 2018).

1.2. Natural Ventilationin In Underground Spaces

One of the major environmental factors in human comfort is the air quality, which occupies a specific environmental role, as it is usually renewed through natural ventilation (Lee and others, 2009). Natural ventilation can be used to provide fresh air for the occupants, necessary to maintain acceptable air quality levels, in addition to cooling the buildings in cases where the climatic conditions allow it (Heiselberg, 2006). Therefore, it is essential to incorporate a natural ventilation system in an underground building tohelp in acheiving the human comfort and reduce the overall building energy consumption.

2. PROBLEM IDENTIFICATION

Different disadvantages include social and psychological problems of underground spaces which compel most people to reject those spaces (Vaezizadeh, Kazemzade, 2013). People in underground spaces feel suffocated because they just sit in a space without any natural ventilation and daylight. In order to increase the comfort level, natural features such as natural ventilation and daylight should be incorporated when designing the underground spaces (Jain, 2017). The lack of natural light and the view is, both psychologically and physiologically, the single greatest concern related to underground space (Lee, Kang, 2016). The lack of natural light is one of the most often mentioned negative characteristics of underground space. Access to natural light is important to users of a building even if the proportion of daylight to artificial lighting for work tasks is relatively low. The feeling produced by daylight, its variability, and the sense of contact with the outside world are important reasons for its desirability. Another important positive psychological association of natural lighting is that sunlight connotes warmth (Dronkelaar, Cóstola and Mangkuto, 2018).

The lack of fresh air reduces indoor air quality making an environmental problem in the underground spaces. The air in the underground spaces contains contaminants such as CO^2, CO, radon, dust, NO_x and asbestos to name but a few. Due to these reasons, appropriate ventilation for the provision should be considered as a viable option as an effort to minimize costs in equipment, installation and maintenance. (Lee and others, 2009)Also, the earth covering the underground buildings eliminates most of the causes of air-infiltration because of its tight construction. A well designed underground building should therefore include a ventilation system so that stale air can be exhausted and fresh air is added at a sufficient rate (Dronkelaar, Cóstola and Mangkuto, 2018).

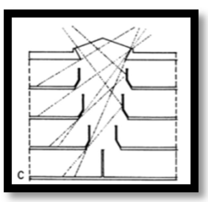
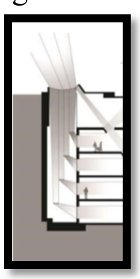
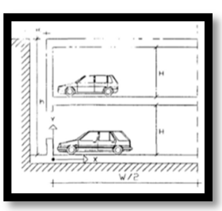
3. METHODOLOGY

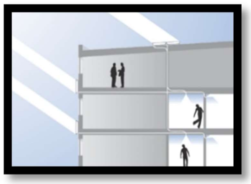
The study has been conducted based on a quantitative method started with studying and analyzing the underground buildings daylight and natural ventilation problems, by highligting the best solutions those should be applied. Due to the huge number of variables that play a role in enhancing the indoor environment of a building, a case study was randomly selected from the city of hebron, Palestine, it is the parking central station building which has underground floors and a poor daylight and ventilation. The case was analyzed based on the site observations and measurments, then it was tested using the Design Builder and Energy Plus softwares as a simulation tool. After that, sifferent enhancement passive strategies and techniques have been tested to select those can be used in a retrofit process, after the adjustments on their initial shapes. This study is a comparative study which compares the base case analysis with a re-designed case considering the indoor environmental conditions, followed by the assessment of the results of both daylight and CFD simulations.

4. ENHANCEMENT OF DAYLIGHT AND NATURAL VENTILATION

Many passive strategies have been developed in the light of contributing to an energy efficency and saving by using daylight and natural ventilation in buildings. Systems can provide deeper distribution to the interior space, by means of channeling the sunlight and works as air channels into the building, after collecting using the reflectant tubes. In underground floors, some parameters should be considered to enhance daylight and natural ventilation, where passive strategies must be selected at the same time, to ensure the efficiency of the system, some of the selected strategies are clarified in the following table.

Table 1: Passive strategies of daylight and natural ventilation enhancement

DEVICE	CONCEPT	Why it was EXCLUTED
1. Traditional light pipe 	They are able to collect natural light with a mobile or fixed collector and redirect it into the interior spaces away from the collection point. (Baroncini, Chella, and Zazzini, 2019)	Not effective in multi-story buildings
2. The Ventilated Double Light Pipe 	Its geometry is modified to optimize the air coming in and out and collect natural light. (Baroncini, Chella, and Zazzini, 2019)	Because its effectiveness decrease in buildings that are more than 3 floors, and will be hard to place in these buildings.
3. Atrium 	It's a large open air or skylight covered space surrounded by a building, to enhance the daylight and natural ventilation in the inner spaces. (Cambridge English Dictionary)	In the existing buildings, it's not possible to redesign the inner spaces and make an atrium
4. Light well 	It's an external space provided within the volume of a large building to allow light and air to reach what would otherwise be a dark or unventilated area. Light wells may be lined with diffusers and reflectors to increase the reflection of sunlight within the space. (Lee, Kang, Han and Lee, 2016)	Staircases have a gap between that are used as elevators made of glass in addition to non-used spaces besides the staircases
5. Shaft 	The shaft is working as a duct system, both for the external air and natural light. (Gugliermetti, Grignaffmi and Dell'Omo, 2000)	It's an existing element in the design
6. Sky light	A light-transmitting structure that forms all or part of the roof space of a building for daylighting purposes.	It is effective for one floor only

		
7. Fiber Optics 	They can be used for transmitting light from a source to a remote location for illumination	Fiber optics needs large amount of direct sunlight, and that's not affordable because in this project sunlight is coming indirectly from the shafts, but it will be used in the inner tube of the stacks

5. THE CASE STUDY: CENTRAL PARKING STATION IN HEBRON

The building under investigation is a central parking station located in the city of Hebron, Palestine (31°32′00″N 35°05′42″E′). The station consists of seven floors of car parking, each of them has two levels. The ground floor contains a shopping center which can be reached from Al-Adel Street, and the secondary entrance is from Beersheba Street, and leads to the second floor. Two floors are underground, with a floor area of 3500 m2 and 3.6 m height. Daylight can access to part of underground floors through southeast light shaft, and mechanical systems used for ventilation.

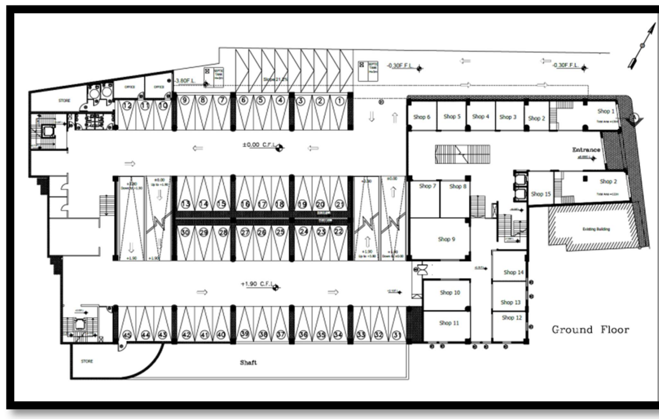


Figure 1: Central parking Station ground floor

Figure 2: Main elevation of HCS

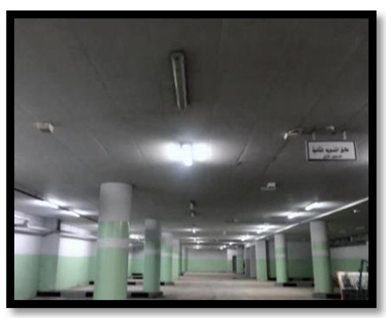


Figure 3: Basement 2

Figure 4: Basement 1

5.1. Case Study Analysis

Analysis of the case study includes analysis of daylight and natural ventilation in car parking areas of underground floors which shown in figure, in the current situation and post using suggest passive solutions for it.

A. Daylight

Based on the simulation results of the daylight inside the underground floors in the current state, as shown in the figures below, the illumination in the shaft reached 1000 Lux and more, in underground spaces, lighting is concentrated in the area near the shaft, and around the northern car entrance, the interior areas of one floor were completely darkened.

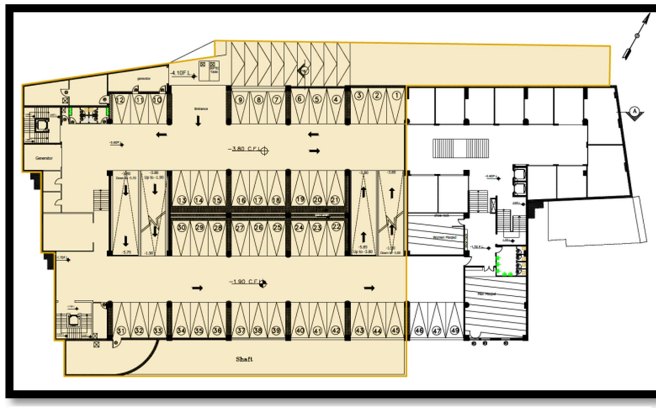


Figure 5: Parking areas of underground floors

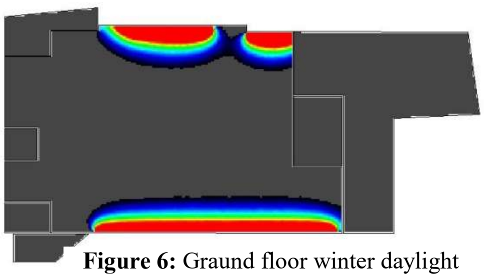


Figure 6: Graund floor winter daylight simulation.

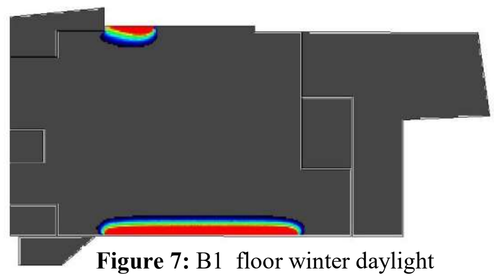
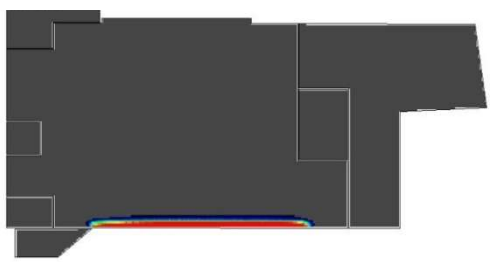


Figure 7: B1 floor winter daylight simulation.



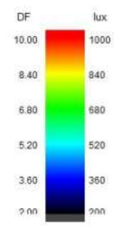


Figure 8: B2 floor winter daylight simulation.

B. Natural Ventilation

According to the simulation results, the speed of the fresh air inside the underground floors is still near zero. Where the temperature on the first and secondbasements of the building is constant and it is close to 19 ^{o}C. while the age of air ranges from 2 minutes to 25 minutes, but in the most areas it is about 12 minutes.

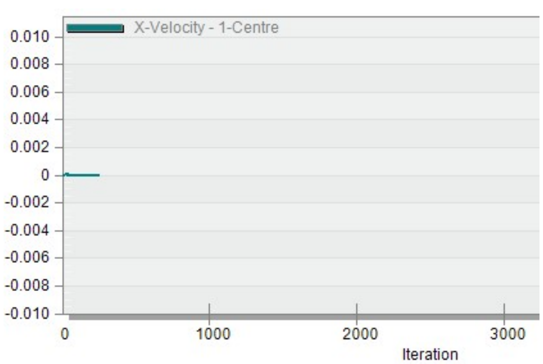


Figure 9: air velocity in summer simulation

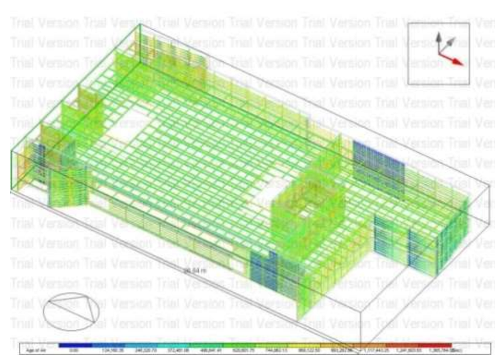


Figure 10: The age of air in summer simulation

5.2. STRATEGIES OF ENVIRONMENTAL IMPROVEMENT

The following three passive strategies were selected to develop and apply in the case study in order to enhance the daylight and natural ventilation in underground spaces of it.

- The ventilated double light pipe (Vdlp)

In a double light pipe, a reflective film is applied to both the internal and external surfaces of the inner pipe and a second larger pipe, concentric to the first one, is made of a transparent polycarbonate tube and it is internally coated by a diffusing film, as shown in Fig. 11. In this case the collector, on the rooftop of the building, is larger than the traditional, with the same diameter of the external tube, in order to partially introduce light into the inner tube and the remaining part into the outer one. The large dimensions of the technological apparatus with respect to a traditional light pipe are balanced by the advantages consisting in the possibility to have the passage room be illuminated by it (Trdine, 2012).

The Ventilated Double Light Pipe (VDLP) is a further transformation of the DLP which geometry is modified to optimize the air coming in and out. To be more precise, in the VDLP, the inner tube narrows at the top, in order to generate a convergent section at the top to improve the air extraction, while the outer tube is narrowed at the bottom, so the hole between the two tubes has a convergent section downward for the air to come in. In this way, each device can be alternatively used as an inlet or an outlet system.

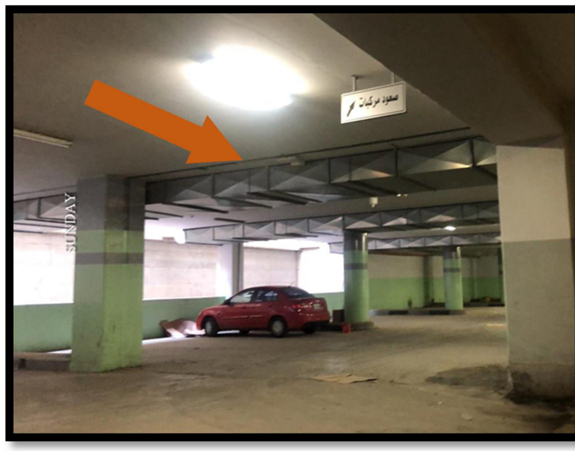


Figure 11: The horizontal metal stacks that are placed in the column axis in Hebron station

Particularly, in the inlet VDLP, the inner pipe is closed in the top and the bottom. While at the outlet, the air cavity between the two pipes is closed at the top and bottom. The technology investigated consists of concentric channels for both daylighting and natural ventilation. Horizontal and vertical stacks, where daylight enters the central stack (the light pipe) and the outer channel allows passive stack ventilation, and in Central Parking Station in Hebron, we transferred the HVAC metal stacks into part of the VDLP because it is difficult to place the vertical light pipes in a building consist of 7 floors in total, two of them underground and every floor consist of two levels, the efficiency of the VDLP will decrease, and they will be hard to place, so we took advantage of the two shafts that provides illumination 1000 lux and more, and the horizontal metal stacks that are placed in the column axis, so that every horizontal stack feeds two VDLP only (Baroncini, Chella, and Zazzini, 2019).

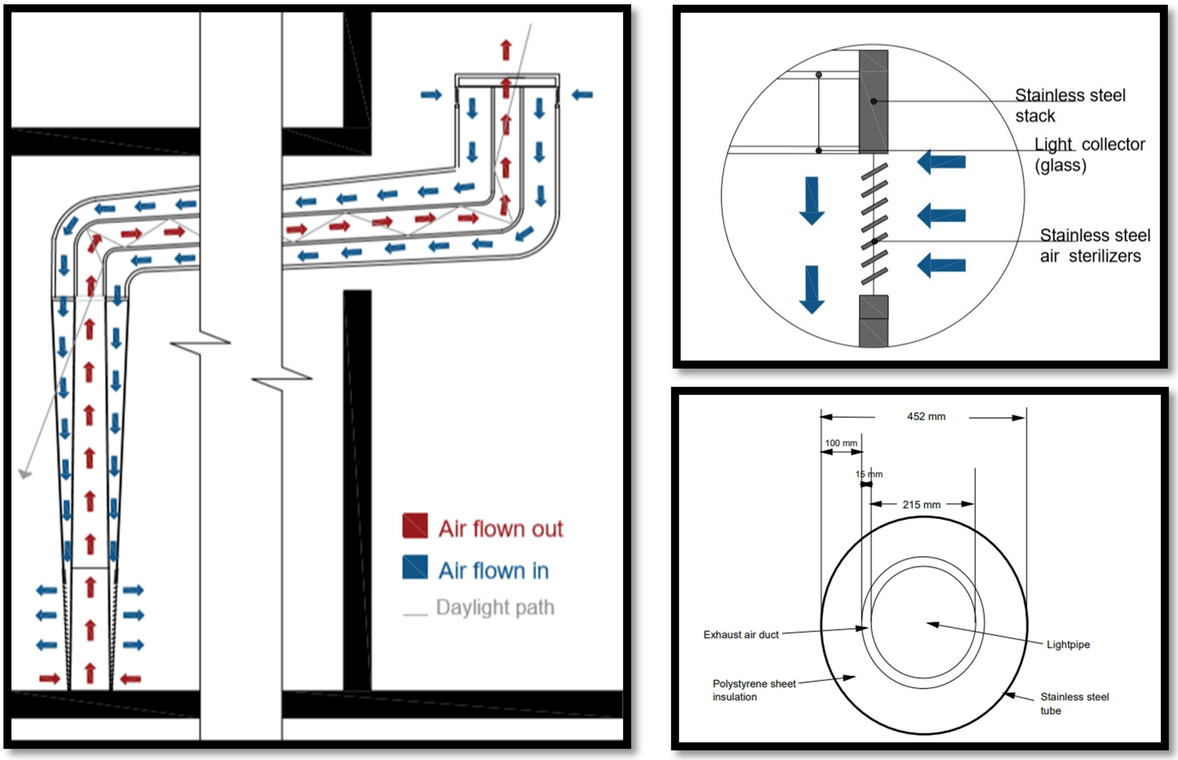


Figure 12: The air and light movement in the VDLP and the stacks

- Staircase as a lighting well

Central Parking Station in Hebron has staircases with a gap between them that are used as elevators made of glass in addition to non-used spaces beside the staircases, and this gap can be used to convey light. This possibility has developed as an idea that the space can become a "Narrow atrium" at a staircase in underground spaces. Narrow atrium between stairs uses a pairing of two primary daylighting techniques, a narrow and tall shaped skylight to bring sunlight into a duct coupled with a south-facing mirrored reflectors right behind the opening and louver shaped structure for diffusing light. The mirrored reflector and duct allow daylight into the deep under-level of a staircase, and the louver shaped structure gives effective general illumination by diffusing light.

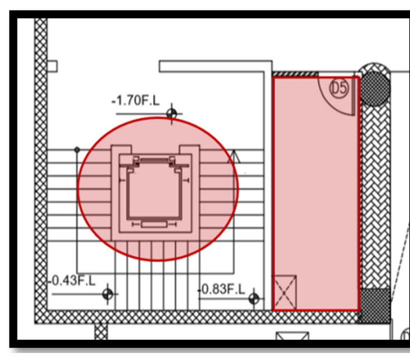


Figure 13: Light well position in staircases

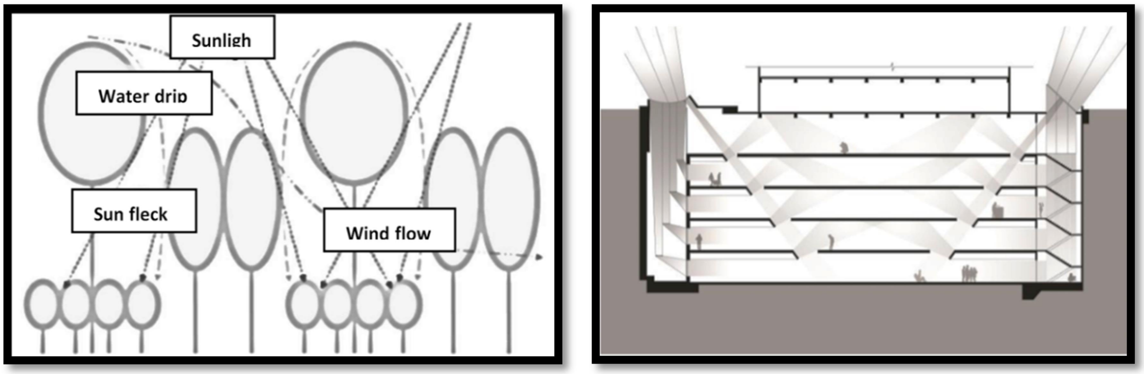


Figure 14: Lighting well design concept (Lee, J. and others, 2016)

Lighting the underground floors at the same time through the ventilation spaces has some limits in the very deep floors, as the light can not pass easily. The function of ventilation spaces can be supplemented by applying the principles founded in the forest canopy. Which is a forest consists 4 main layers. The tallest trees are the emergent layer which mostly are broad-leaved, hardwood evergreens, widely spaced which helps the vegetation in the lower layer. The canopy layer is the primary layer of the forest and forms a roof over the two layers remain. These mechanisms maintain the ecosystem in the forest and also influence biological diversity. (Lee, Kang, Han and Lee, 2016).So staircases can be used to introduce and deliver daylight to deep surfaces in underground floors. As an integrated design approach, this plan also uses light diffusers and reflectors to send daylight through minimum and diagonal open spaces. As the amount of light which enters through the ventilation space and staircases decreases in lower floors, which gives an even lightness to the deep surface. Light reflectors are installed on each floor to raise effectiveness (Lee, Kang, Han and Lee, 2016).

Figure 15: Basement 1 floor in Hebron parking, this figure shows the position of ventilation and daylight tools.

- Shafts for natural light and ventilation

Central Parking Station in Hebron has two lateral continuous shafts in the southeastern and northwestern sides, the southeastern width is 5.5 m and 7.2 m underground while the northwestern shaft width is 7.5 m and it is used as a ramp and it is 5.4 m underground, the shaft is working as a duct system both for the external air and natural light.

6. RESULTS AND DISCUSSION

The research carried out an intensive numerical analysis on three solutions for natural ventilation and daylight. Design builder and energy plus were used. The daylight simulation was analyzed in the worst case in our region with the least solar radiation and Overcast Sky, represented by winter design week from the 1st to 7th of December. Luminance distributes in underground floors as light patches from the light pipes, and lightens 55.8% of the parking zone area in B1 and 21.8%of the parking zone area in B2. Also the forest canopy concept which has been activated in the vertical space used as car ramps and staircases, this technique light 7.5% of the B1 total surface and 5.8% of the B2 total surface, and the existing shafts in the southern side and the car ramps in the northern side that works as a shaft, but only reaches B1 floor, those shafts lightens 13.5% of the B1 total surface and 5.8% of the B2 total surface.

In basement 1 floor, which is -3.8m underground, the radius of light patch's core is 1.5m, and the sum of the luminance intensity area's is 168m2, while luminance intensity in the core is (7 to 10) DF, the outer diameter of the patch is 3.5m far from the center, the whole surface lightens by the light pipes is 960m2ofthe total area of the parking zone which is 1720m2, and it's luminance intensity is(1 to 7) DF. In addition, light wells which are mainly placed in the vertical space used as car ramps lighten 129.5m2 of the B1 total surface with luminance intensity from (3.6 to 7) DF, and the southern and northern shafts still lighting 232m2 of B1 total surface with luminance intensity from (3.6 to 10) DF in both shafts.

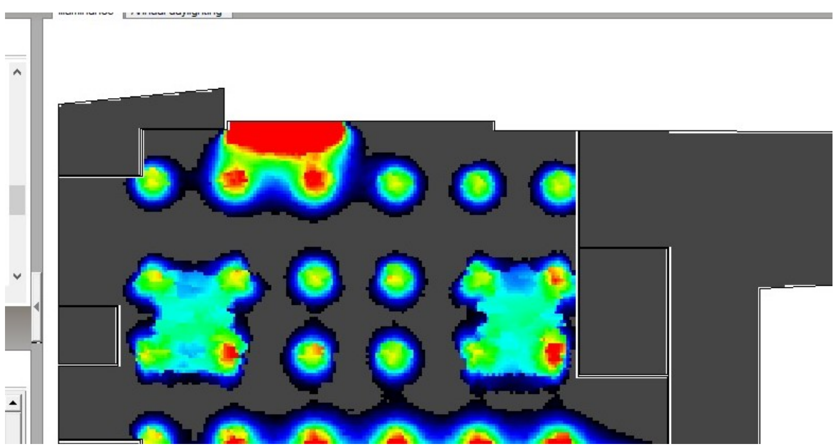


Figure 16: Basement 1 winter daylight simulation after applying the strategies

In basement 2, which level is -7.6m underground, the radius of a light patch's core is 1.1m, and the sum of the luminance intensity area's is 90m2, while luminance intensity in the core is (8.4 to 9.5) DF, the outer diameter of the patch is 2.4m far from the center, the whole surface lightens by the light pipes is 374.4m2 of the total area of the parking zone which is 1720m2, and it's luminance intensity is (3 to 8.4) DF. In addition, light wells which are mainly placed in the vertical space used as car ramps lighten 100m2 of the B1 total surface with luminance intensity from (2 to 5.2) DF, and the southern shaft still lighting 99m2 of B1 total surface with luminance intensity from (3.6 to 10) DF.

Thus, 76.8% of the parking zone area in B1 and 34.6% of the parking zone area in B2 are now naturally lighten by the passive strategies this research developed and discussed, taking into consideration that only 7.5% of the B1 and 5.8% of the B2 were naturally lighten.

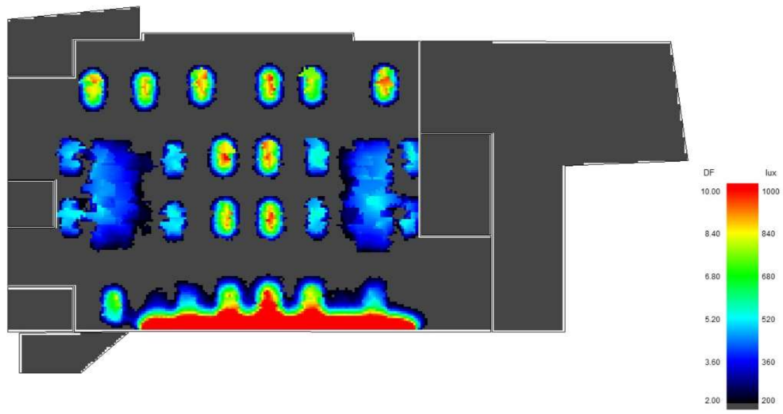


Figure 17: Basement 2 winter daylight simulation after applying the strategies

The ventilation simulation was carried out in the worst case in the region with the least speed of air, represented by summer design week from the 8th to 14th of August. The southern and northern shafts provide cross ventilation, mainly placed in the middle part of the parking zone, although underground floors have a steady indoor environment, this was clear in the primary air velocity simulation, but the problem this research aimed to fix was the air distribution, every spot in the parking zone to have the same age of air and air velocity. But due to lack of climate data or miss identification of zones in the modified model, the post-design model never gave the final simulation to be analyzed.

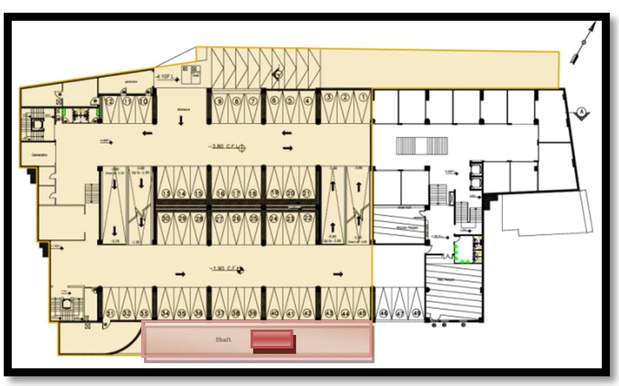


Figure 18: Cross ventilation provided from the southern and northern shafts

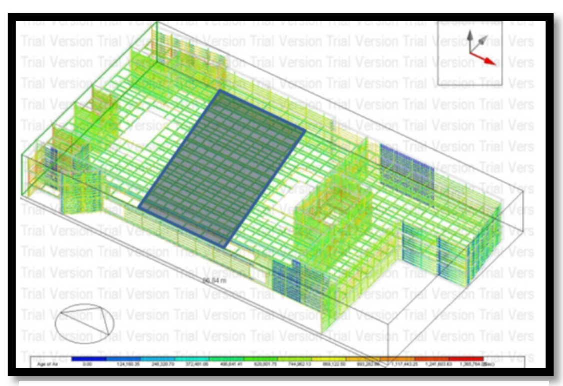


Figure 19: Zone that have the same age of air and air velocity

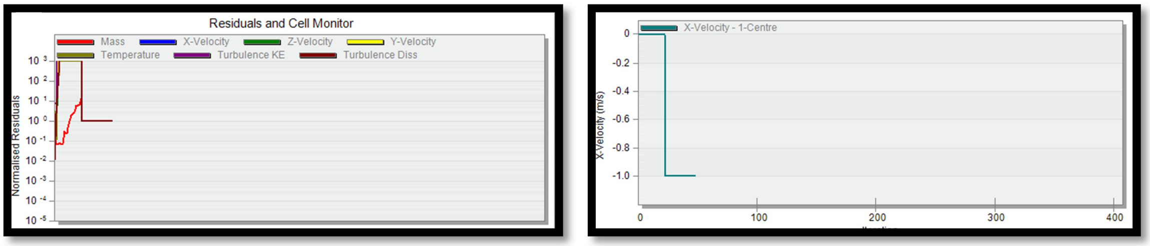


Figure 20: CFD simulation results; False result (Design builder and energy-plus simulation, 2019)

7. CONCLUSION AND RECOMMENDATIONS

People living or working in underground environments of buildings need both natural light and ventilation for well being and health as it is not a luxurious working environment. The results of this research can be used to inhance underground buildings in any environmental retrofit process considering the daylight and natural ventilation levels. Minimum open spaces, courtyards, vents, lighting well, etc. are capable to introduce and distribute daylight and fresh air into the underground spaces.

In the future researches, simulation of air flow system should be carried out to evaluate the actual effects and to concretize the details of this concept. It is also expected that the tested strategies can be developed in different ways to confirm other environmental functions. The comfort is not only subjected to the lighting and ventilation, but also related to creating a better buiding performance in terms of thermal, acoustical, and visual comfort, which can enhance the human health and productivity. Dependently, the results of this research show that other environmental aspects such as temperature and humidity, etc. should also be considered in an integrated approach of retrofit.

A set of recommendations can be highlighted here:

- During the early design phases of a building undergrounds, a courtyard or an atrium must be taken into consideration, in addition to shafts design (two shafts at least) and oriented towards the prevailing wind. Where, in this case, buildings must not exceed 3-4 floors above the ground, in order to achieve the maximum benefits of courtyards or shafts. Otherwise, some reflectors and fans should be added to these spaces in order to increase the distribution of light and the passage of fresh air.
- Vegetation can be employed in odred to improve such spaces of the building.
- The indoor environmental quality is a critical issue in underground floors, it should be a priority in the design phases of any building, and should be listed in the building licencing requirements.

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