

Role of Visual Environment within the Already-Designed Large Underground Development in South Korea

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ABSTRACT: Recently, an increase in the design of the utilization of underground spaces has been beginning to receive more attention in Korea. Due to continuous complaints of environmental quality, the developer must identify potentially-negative aspects that are related to the physical characteristics of underground spaces. This research aims to determine the sustainable design guidelines for underground developments in relation to the visual environment. At the first stage, this paper deals with the evaluation of already-built examples to determine the problems pervading in the underground spaces of high-rise offices recently built in Korea. The visual aspect in terms of illuminance and the human responses with regard to naturally occurring lighting in the underground environment are of the issues of major interest. A series of model simulation provides the advanced configurations of commonly-used sunken structures and skylight systems as a better solution for the need of sustainability in underground development.

Keywords: underground, underground development, sustainability, visibility, visual environment, daylighting, sunlighting

1. INTRODUCTION

By the year 2000 it is estimated that 70 percent of the world's population will inhabit urban areas. The same trend has been evident in Korea, where approximately 75 percent of the land is mountainous. Concentrated urbanization is a notable feature of land use in Korea and thus, this has caused extremely high land prices. This trend will continue and, therefore, it becomes more important to effectively utilize urban spaces. When the underground space proved to have a great value in time of defense need since the World War II and at present, we have seen that the underground space attracts a great deal of attention for its three-dimensional space use for the creation

of city cores with very high and compact density. For the major cities of our present time, thus, the use of the underground space has become a necessity and an important producer of underground amenity, energy saver and economy.

One of the problems in the use of underground environment stems from the fact that most of us still have a great longing for natural sunlight and unobstructed views to the outdoors. In this paper, we will focus on the visual qualities of the underground space as a most important key development factor. Therefore, applicable research in relevant technologies has been expanding, both in universities and in construction industries. The particular emphasis of the study is placed on the evaluation of current problems related to placing people in the

underground environment. To achieve this goal, an actual measurement of both illuminance and luminance in the underground work space of high rise office buildings recently built in Korea was performed. By using a questionnaire, a survey of occupants' satisfaction with the visual environment was carried out and a relevant statistics was used. In addition, a series of model simulations provided the basic guidelines to equip the optimal sunken structures and skylight systems for sustainable underground developments.

2. VISUAL ENVIRONMENT IN UNDERGROUND DEVELOPMENTS

2.1 Characteristics of underground spaces

Underground habitation and space utilization is almost as old as the existence of human beings on this earth. The underground structure is a hidden mass. Since the studies on people in underground and windowless spaces are not conclusive, the major issues appear fairly clear and the same set of problems emerges to varying degrees in most cases. It is interesting to identify that these potentially negative effects are all related to one of the basic physical characteristics of the underground structures; that is, lack of visibility from the exterior and lack of windows. The absence of windows, as expected, causes a sense of confinement, lack of stimulation and connection to the outdoors, and lack of sunlight. The windowless nature of the underground building also contributes to lack of spatial orientation since the reference points to the exterior are missing. The lack of spatial orientation is related to a fear of inescapability in an emergency. Although windows are often sealed in modern buildings, the lack of windows, nevertheless, contributes to a perception of poor ventilation. Simply being underground elicits associations with darkness, coldness, dampness, poor air quality, lower status, and fear of collapse or entrapment (Carmody and Sterling 1993).

Although studies on people in the subsurface building report a predominantly negative picture as the generally perceived characteristics of the underground, there are, nevertheless, some positive associations and characteristics as well. These are a sense of security and protection, a quiet environment without distractions, and sometimes a stimulative setting due to novelty and even a sense of mystery and adventure.

2.2 Lighting in underground development

Lighting affects the appearance of the space and the occupant's mood. It is thus integral to creating perceptions of spaciousness, providing definition and character in spaces, as well as simply providing light to facilitate the performance of activities and tasks. While lighting is only one of many considerations in the interior design of a building, it takes on fundamental importance in the design of underground spaces. Associations with darkness are frequent in underground imagery and lack of windows and natural light are among the most commonly cited drawbacks of below-grade facilities. If underground spaces are designed to be positive, healthy environments for people, both natural and artificial light will play a significant role (Carmody and Sterling 1993).

One of the recurrent problems associated with windowless underground environments is lack of stimulation or variety. This is reinforced by overhead uniform fluorescent lighting which seems to be predominant in non-residential interiors. With this lighting, there are no differentiation of space and no patterns of light and dark.

2.3 Daylighting in underground

Over the past 12 years, a number of studies have documented the effect of light on all aspects of buildings and occupants with respect to physiology, mood, and behaviour. The results show convincingly the benefit of daylight over electric lighting. Several studies have been conducted that

show occupants' preference for daylight concomitant with their physiological, psychological satisfaction and work efficiency in offices (Sommer 1974). Even though the effect of daylight was extremely low, preconceived attitudes and desires for natural light influenced the occupants' perception for the importance of daylight. Natural light, through the slow continuous motion of the sun and the periodic influence of clouds, provides relief from monotony, information about weather and time of day, and contact with the outside world (Collins 1975). Whether it is possible to provide sunlight in the underground interior, artificial lighting can be designed to create varieties and stimulations in a number of ways. These conclude varying color, intensity, direction, and overall patterns of light and shadow. Other aspects of creating varieties are to provide changes over time, and individual control of lighting (Kim, 2003).

3. ROLE OF VISUAL ENVIRONMENT IN UNDERGROUND DEVELOPMENT

3.1 Design of actual evaluation

This study is based upon a systematic series of actual measurements and questionnaires for the occupants within the already-built underground environment, the measuring process utilized photometric sensors to read illumination and luminance levels. For this, five high-rise office buildings were selected as the target underground spaces. Quantitative measurements and qualitative surveys were performed. As a representative working time of day in those office buildings, 10 am and 2 pm were selected. On the working plane of height of which was 3 feet from the floor, nine points were selected as the locations for measurement. Only Building E equipped a huge skylight as a daylight admitting system for its underground office space, while others depended entirely on electric lighting for the underground, limiting the usage for

maintenance or garage, for example. The questionnaire for the issue of occupants' satisfaction, therefore, was performed in Building C only. Illuminance was measured and compared in terms of contrastive ratios on the brightest and darkest surface, ceiling, floor, wall, and ballast. As a main instrument to read the illumination levels both indoors and outdoors, the photocell equipment, IM-2D made by TOPCON and a Minolta Luminance Meter LS-100, were used. A 4-page questionnaire was administered to both 21 workers in daylight spaces and 34 workers under artificially lighted conditions. There were a total of 43 male and 12 female subjects in this study with the average age of 32 years old. The working time was, in average, 9 hours a day in the underground spaces.

Table 1. Target underground spaces in the selected buildings

7	Caption	Space Program	Story (Above/Under)	Construction Year	Lighting Source
A	A-a	Parking	20/6	1995	Electric.
	A-b	Control Centre			
B	B	Manager Office	24/6	1994	Electric.
	C-a	Planning Office			
C	C-b	Mech. Room	20/6	1994	Electric.
	C-c	Elec. Room			
	C-d	Union Office			
D	D	Port Office	30/6	1995	Electric.
E	E	General Office	30/7	1995	Daylit + Electric.

3.2 The measurements of the visual environment in the underground spaces

In the underground space, the amount of light might determine the hierarchy of the inner spaces in terms of psychology. The current status of lighting maintenance for the already-built underground spaces is the main interest since it reveals the need of additional consideration for the underground development. On the average, the value in the underground work spaces totally lighted by electricity was 300 Lux, which means almost the same amount of light as the

above structures. The illuminance in the daylit underground space was noticeably **higher than others**. Building E which admitted daylight from the skylight showed a value of 1110 Lux. It is an architectural means to provide more sustainable consideration for an underground development. The following figure illustrates the measured mean value for each of the underground spaces. To evaluate the evenness of light level, the standard deviation was calculated. As expected, the artificial lighting system provided a more uniform light level than natural lighting.

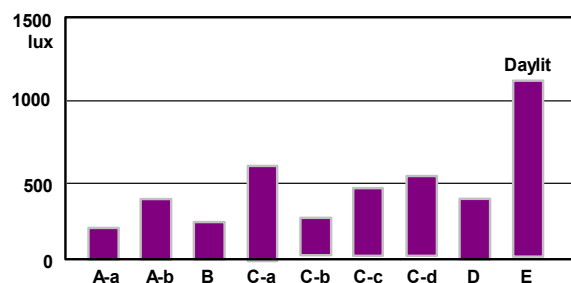


Figure 2. Measured Illuminance of the Underground Spaces (LUX)

3.3 Occupants' satisfaction in the underground space

The degree of human satisfaction in the underground development depends on various design elements and psychological factors. The visual environment plays a big role in determining the satisfaction because of the physical characteristics of underground structures. Therefore, the satisfaction with the quality of ambient lighting in the underground space should be more seriously stressed than the task lighting. The overall degree of satisfaction in the underground space is approximately affordable but the satisfaction may stem from the fact that their expectations for the environment may be lower than those in the above. In addition, the survey tells us that the occupants' visual fatigue increased since they have worked in the underground space and the occupants may have been exposed to glare when they came to the outdoors above. As the structures above, the veiling

reflection and glare play a crucial role in dissatisfaction while working on computers.

A comparison of the degrees of satisfaction between workers in daylit space and people under artificial-lit conditions reveals, not surprisingly, a high level of appreciation for daylight with the benefit from attainable views to the outdoors. Even though glare from the work surface in daylighted space has been detected, strategic architectural designs can control the harmfulness of the penetration of direct sun, while maintaining a sparkling effect and visual stimulation.

4. DESIGN OF VISUAL ENVIRONMENTS IN THE UNDERGROUND DEVELOPMENT

4.1 Sunken structure

The sunken structure can be defined as an exterior courtyard that exits beneath ground level on a flat site. This configuration affords the opportunity to set a building with at least one façade exposed. In a similar sense, an exterior sunken courtyard permits conventional windows to penetrate natural light into an underground structure. Daylight enters the spaces surrounding the sunken area horizontally through conventional windows. Providing natural light through relatively obvious conventional design approaches can be among the most powerful techniques for offsetting negative reactions to the underground building, which is a particularly important attribute of the sunken structure.



Figure 2. Conventional configurations of the sunken structure

The geometry of a sunken courtyard must be designed based on its usage and site constraints. Y. Asihara (1996) claims that the dimension of an exterior space should be 20 to 25 meters for spatial diversity. C. Alexander (1987) proposes 14 to 18 meters to be the optimal diameter for small public squares, and he further asserts that the diameter must not be larger than 21 meters. When a normal sunken depth is set to be 1 story deep; that is, 5 to 7 meters below ground, K. Lynch (1972) reports that a dimension of 12 meters appear to be intimate, and a dimension of up to 24 meters is still an easy human scale.

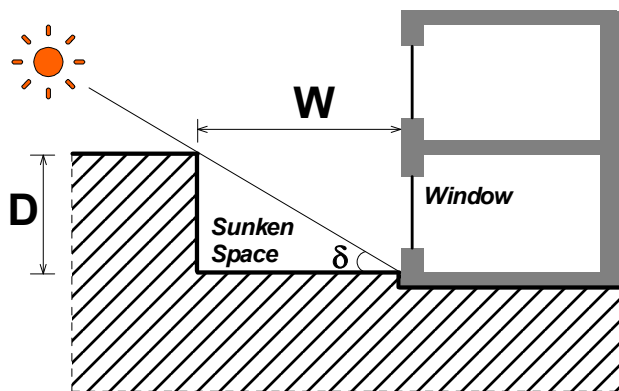


Figure 3. Sunken width for sunlighting

When daylight enters a space through the sunken area, as illustrated in Figure 3w, its configuration in daylighting performance has usually been analyzed. For this purpose, the daylighting analysis software, Lumen-micro 7, simulated an interior space of 6.4m by 8m with 2.5m in height. The wall adjacent to the sunken area has a window of 6.3 meters in width and 1.6 meters in height with 90% transparency. The interior illumination on work-plane height has been simulated under overcast sky conditions in Seoul, Korea, which means a minimal possibility of daylighting availability. The width (W) is one of the most important elements in the daylighting design with a sunken structure since the opposite wall plays a role as an outdoor obstruction. As

seen in Figure 4, illuminance increases proportionally to the width. The performance is not affected even if the width is greater than 14 meters.

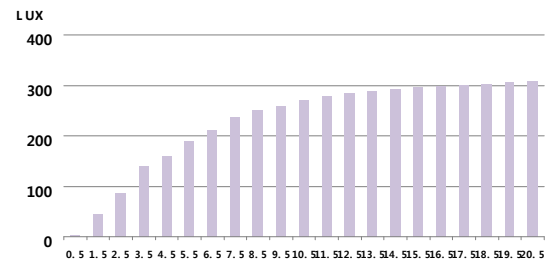


Figure 4. Impact of sunken width on illumination (Increase of illuminance in proportion to the sunken width)

It is a matter of course that a deeper sunken space means lower daylighting availability since the sunken wall plays a negative role and is an exterior obstacle for daylighting. The lumen-Micro program simulates two different sunken depths under the overcast sky. When a sunken width becomes deeper from 5 to 20m, illuminance at the center of the adjacent room decreases by 5% (Figure 8).

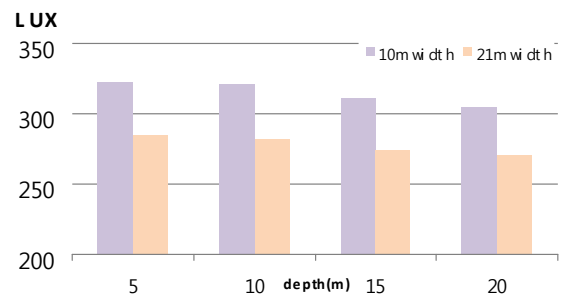


Figure 5. Changes of illuminance by sunken depth under the overcast sky

The reflectance of a sunken surface is another optical factor for the interior illumination by mean of natural light. We have dealt with a whole range of reflectance values adaptable to the sunken wall from 10 to 90%. A difference of 80% in the reflectance value from 10 to 90 produces an increase of 100% in light level. When the surface reflectance increases by 10%, the

light level does also so by 10%. In addition, the reflectance of a sunken floor might be an appropriate light guide system for the adjacent spaces. When the surface reflectance increases by 10%, the light level also increases by 10 to 20% according to the width of a sunken area.

4.2 Skylight system

Due to physical characteristics of the underground, a practical way to provide natural light into the inner space is to equip a skylight. The skylight, a glazed roof aperture parallel to the roof, is an excellent device for picking up a large quantity of light with a minimum opening and for eliminating the need for electric light, in part. It is because that the amount of luminous flux falling on the horizontal plane of the roof under an overcast sky may be much greater than what strikes the vertical plane of the window wall even.

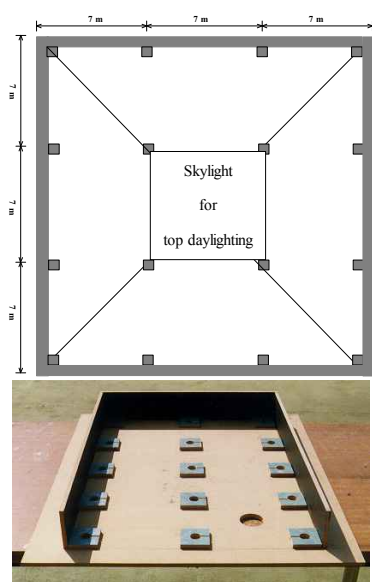


Figure 6. Prototype geometry of the underground and the scale model

It is a matter of course that the skylight is an effective tool for delivering daylight into deep interior areas in one-story buildings or the top floor of multi-story buildings. It must be emphasized, in the development of underground mega-structures, which daylight may be brought

into the lower floors of the multistory underground spaces through plenums, a light well or ecological shafts. Daylight by the skylight can also be controlled through the use of deep wells, splayed wells, and louvers to eliminate a direct view to the sun and to minimize the veiling reflection problem.

To figure out the practical usefulness of skylights under the meteorological conditions in Korea, a physical model measurement has been performed. For a comparative measurement as shown in Figure 9, a scale model (1:10) of the geometry of a unit underground space is constructed so that the glazing area of the opening can be readily changed to determine the way in which the variable sizes of skylights modify the intensity and distribution of the daylight within the interior underground.

Table 2. Reflectance of the interior finishes of the model underground space

Surface	material	reflectance
Wall	plywood with paint	68 (%)
Floor	asphalt tile 300×300mm	51 (%)
Ceiling	textile 300×300mm with paint	87 (%)

This scale model represents an actual dimension of 21m (W) x 24m (D) x 3.6m (H) in SI unit. The photocells are mounted on the block of wood so that the height of the photocell can be congruent with the desired plane height at the scale. The height from the perimeter floor level to the top of the photometric sensor, which is 75cm including the thickness of the base mount for the photocell, represents the general work-plane height. To eliminate a possibility of overestimation of daylight availability by the skylight, a measurement has been carried out only under real overcast conditions and the window of the skylight was unobstructed. The inside surfaces of the model were finished in the same materials in

the real underground space as possible so that the surface gave the same effect as a real wall for the light behaviour. The measures of reflectance are listed in Table 2.

The measurement of the scale model indicates that the interior light levels have been proportionally changed dependent upon the size of the glass area of the skylight. As the main result, under the overcast sky conditions, a 5% of open ratio in the skylight design can provide a minimal amount of light for circulation and a 10% of skylight in the floor area of the underground meets the criteria of illumination for the general visual activity. If a diffuse glazing material is applied to the skylight, the daylighting performance decreases by 20 % in light level.

5. CONCLUSION

This paper dealt with key design elements and guidance in relation to the visual environment of the underground development for office activities under the meteorological conditions in the Korean Peninsula. The results are summarized as follows:

- At first, a series of field measurements of already-built underground structures tells us that the light level in the daylit space is noticeably greater than the electric lighted space. In addition, natural light contributes to the occupants' satisfaction in the underground space with the benefit of daylighting. As long as a psychological and glare control standpoint is concerned, light should be derived from as many directions as possible. If this is not established from natural lighting sources, the need for balancing light is usually provided by additional electric sources. It can help to make occupants' satisfaction higher in a quantitative and qualitative way, particularly in large underground spaces.

- The survey also shows that the light level of the underground spaces is normally higher than needed; that is, 500 Lux for general office activities. It is noted that glare at the very time when occupants come out outdoors from underground is more serious for those who stay in the underground space without natural light. The survey also indicates that the ability to grasp an understanding of the whole structure of spaces in a straightforward and simple way is more important, particularly in the large underground building. By taking daylight with a view to outdoors, this ability to grasp the spatial legibility and visual adaptation can be simultaneously enhanced.
- As an additional natural lighting source for the undergrounds, a sunken structure can be included in a development project. The daylight availability of the sunken in Korea depends on the configuration of the sunken and solar geometry as well. A simulation generalizes that the width of the sunken area must be 2.1 times the sunken height so that the façade located in underground can be fully sunlit during the 4 hours from 10 to 2 pm. Simply, a sunken area with a width of 14m of luminous surface is recommended in respect to daylighting performance only. A brighter surface of the sunken area promises more directional rays of natural light from a vertical window, producing side lighting that renders objects more dramatically and clearly with sparkling effects.
- As The skylight, a glazed roof is one of the most effective ways to project a lot of daylight into the underground space due to its maximized potential of natural lighting. A model measurement provides the standard configuration of a commonly used skylight system in an underground development. Only a 5% of open ratio in the skylight can provide an adequate amount of light for circulation and 10% skylighting in the floor area of the

underground meets the criteria of illumination for general visual activities.

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REFERENCES

- [1] Alexander C. 1987. Korean Translation of a Pattern Language: Towns, Building, Construction, Taelim Publishing: Seoul: 287.
- [2] Asihara Y. 1996. Korean Translation of Exterior in Architecture. Kimoon-dang: Seoul: 78-95.
- [3] Boyer LL. Kim G. 1995. Design of Lightcourts and Interior Atria for People and Energy Savings in Large Underground Urban Structures. Underground Space and Urban Planning 6th International Conference: Paris.
- [4] Carmody J, Sterling R. 1993. Underground Space Design. Van Nostrand Reinhold: New York.
- [5] Collins B. 1975. Windows and People: A Literature Survey. NBS Building Science Series: Washington D. C.
- [6] Evans, BH. 1981. Daylight in Architecture McGraw-Hill: New York.
- [7] Lynch, K. 1972. Site Planning. Cambridge: MIT Press: 194.
- [8] Sommer R. 1974. Tight Spaces: Hard Architecture and How to Humanize It. Englewood Cliffs. Prentice-Hall: New Jersey.