International Journal of Design & Nature and Ecodynamics
Vol 19., No. 5, October, 2024, pp. 1479-1489
Journal homepage: http://iieta.org/journals/ijdne

Green Roofs in Urban Underground Buildings: Design Impact on Perceptual Comfort

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https://doi.org/10.18280/ijdne.190502

Received: 23 September 2023
Revised: 17 May 2024
Accepted: 24 May 2024
Available online: 29 October 2024

Keywords:
comfort, green roof, underground gas insulated substation, underground space utilization, perception, urban design

ABSTRACT

The green roof is mostly affected to the urban people where they can have natural ambiance within their daily activities. It can also be applied to underground roofs, but still needed to get attention to affecting the comfort of working underground. This study will analyze the effect of the green roof on the design of the Underground Gas Insulated Substation (UGIS) as a case study of underground buildings. Using one of 3D modelling program, Sketchup, to create underground building model include green space area, the underground building can be visually presented to the next respondents. This model will be used as a refference to gain people's perceptions of the existence of green roof on their underground buildings. The results of this study indicate that the allocation for the use of the UGIS green roof area is 26%. Moreover, based on the questionnaire and after presenting the 3D green roof model, most of the respondents felt that their workspace on the surface so far had fulfilled their perception of comfort both thermally, visually and audially. Respondents' perceptions indicate that visual comfort is of more concern to determine the comfort level of work if they are moved from the surface workspace to the underground workspace. This study showed that beside the green roof can affect public benefits such as reducing the urban heat island effect, managing rainwater, and reducing air pollution, it can also enhance the perceptual comfort. One of the most significant constraints of green roofs in underground buildings is the higher initial cost compared to conventional flat roofs. Therefore, this intensive provision will reduce green roof initiation costs so that green roof investment feasibility can be achieved and make it easier for building owners to calculate the return on their green roof investment.

1. INTRODUCTION

Urbanization and the impact of climate change will cause problems for the development of urban areas such as energy supply, management of thermal conditions, rainwater handling [1, 2] and limited surface space to fulfill city functions and the needs of its citizens [3]. Many urban areas are now aware that their activities and exposure to activities will cause climate problems in the future, one of which is the phenomenon of "Urban Heat" which can become an increasing problem due to climate change [4, 5]. Therefore, reducing carbon dioxide (CO_2) emissions, measuring climate adaptation and mitigation must be regulated in urban planning to prevent climate change from becoming a serious hazard [4, 6]. Green roof has become one of the solutions to anticipate climate problems in urban areas [7, 8]. A few additional environmental benefits are derived from the use of green roofs, such as reduced urban heat [9, 10], absorption of carbon dioxide and other air pollutants [11, 12], and increase the life of buildings [13, 14]. Green roof can also provide benefits related to mitigating urban rainwater runoff [15, 16].

Regarding to the benefits of these green roof, people who live in urban areas will influence the design of their buildings to be able to feel the natural life around them [17]. Hedonic goals will also encourage the desire to make gardens above private residences or buildings, to increase the level of luxury life of urban communities [18]. The view of a green garden can be extended from the garden at ground level to the roof of the building, with the use of technology for building structures and landscaping. Therefore, various efforts have been made to further improve the quality of the thermal and energy performance of green roofs [19-21] and protect cities from the effects of "Heat Island" and the effects of climate change [22-24]. A massive increase in innovation to reduce the negative impact of the built environment has now been developed by recent researches [9, 18, 22-25] including analyzing the benefits of rainwater remediation to implement sustainable city missions [26, 27]. Current research and practice are also being utilized to gather information on the vegetation and irrigation processes selected for green roof applications [7, 28, 29].

In case of Indonesia's urban development, it is important to study perceptual comfort of the green roofs in urban underground building, due to negative perception working in the underground building. By the existence of the green roof, it can be representative of natural ambiance that can stimulate comfort perception. Dealing with the benefits of green roofs that have been described in previous studies, this study will analyze the effect of green roofs on underground buildings. The study design plan located in Indonesia also has potential for underground space development because currently underground transportation lines have been developed in the Indonesian capital, DKI Jakarta.

Using Sketchup to model the underground building, green spaces will be identified and designed in such a way that they can be represented visually. Assessments of urban communities, especially prospective users of underground buildings will then be compiled to assess the extent to which people's perceptions of the existence of a green roof over their underground buildings. Prospective occupants of the building will be shown a visual picture of the use of the roof of the electricity underground building, then their perceptions of the existence of the facilities provided by the existence of a green roof will be analyzed.

Green roof

In general, the design and arrangement of green roofs on buildings, as described in Figure 1. Green Roof Layer [30] consists of:

(1) Building roof, insulation, and watertight coating
(2) Protective coating and shading
(3) Drainage layer
(4) Root layer
(5) Plant growth media
(6) Plants and vegetation

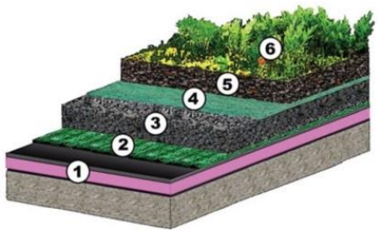


Figure 1. Green roof lining
Source: Study [30]

The green roof system has several components that have specific roles [31] which will be adapted to geographical location and climatic conditions [32, 33]. In general, the following roles for green roofs open opportunities for green roofs as open green space areas that will increase the proportion of green open spaces in urban areas [34-36] includes:

(1) Management of Storm Water
(2) Protecting habitats and ecosystems
(3) Reducing city temperature
(4) Reducing the cost of energy consumption
(5) Reduce noise interference and enhance visual appearance
(6) Improving water and air quality
(7) Presenting social functions of society and adding value to the urban environment

Management of water runoff on green roofs

Clean water supply, wastewater disposal, and flood mitigation are areas of urban water management that have evolved from a single focus to a more integrated urban watershed system [37]. This main service was established to ensure public health and urban water management in many cities [38]. Improvement of the urban microclimate, protection of fresh water, and social convenience are some of the goals that should be integrated with water management [39, 40]. Urban water management in many places has a variant of the approach method to achieve sustainability [41, 42]. Rainwater runoff has a basic source of degradation of river ecosystems [43]. Rainwater management is still focused on pollution and flood recovery, while there are some critical issues regarding ecological protection and flow function [44]. Strategies for managing water runoff in urban areas vary across countries, regions, cities, and regions [44]. differences in existing infrastructure, even in political [45-47]. Walsh et al. [44] identify 5 (five) principles of rainwater management to protect river ecosystems in urban areas by using rainwater control methods.

(1) Identify and restore urban waterway ecosystems. Thus, management targets for these ecological conditions must be determined.

(2) The post-development water balance must be the same as the pre-development water balance.

(3) The design must be capable of delivering flows in a quality and flow similar to the predominant pre-development hydrological processes.

(4) Rainwater Control Methods must be designed to prevent all untreated runoff from being discharged into the river except in heavy storm conditions.

(5) Application of Rainwater Control Methods must be suitable for all impermeable surfaces to maximize flow catchment.

As one of the functions of green roofs which can reduce the volume of runoff from roofs, green roofs can be the main object of research to analyze their role as part of rainwater runoff management [48].

Green roof can increase the proportion of green open space in urban areas, reduce noise, and beautify the visual appearance. Green roofs also enhance the natural environment which can create a more aesthetically pleasing area [49]. Peng and Jim [50] have noticed that although it is a difficult way to measure in urban areas, green roofs end up having a significant function as urban ecology [51]. Various studies from Francis and Lorimer [52] and MacIvor and Lundholm [53] show that one of the benefits of green roofs is to preserve urban habitats [52-54]. In addition to its function to promote wildlife in urban areas [55], green roofs also promote recreation areas that can add social benefits [56] and attract people to connect together in community activities such as gardening [57]. In addition, green roofs can increase urban farming opportunities by producing a wide variety of vegetables and fruits [58, 59]. Selection of vegetation types and appropriate green roof management will greatly help to increase food production from green roofs. Green roofs provide a transitional view from concrete buildings to green space views [60]. Previous studies from Cook-Patton and Bauerle [61] explained that green roofs have a pleasant effect on urban communities by controlling air and noise pollution [49].

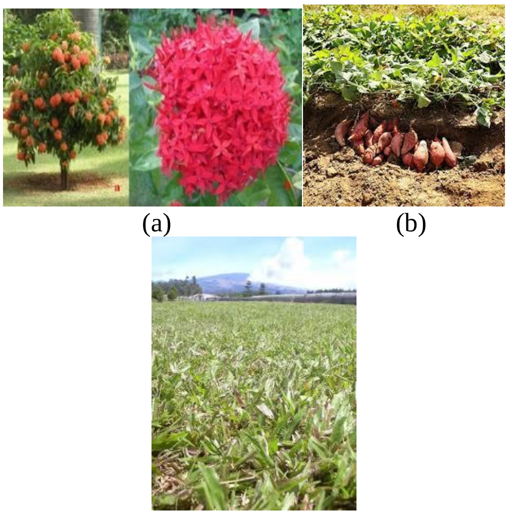
Green roof can lower city temperatures

When designing a green roof in a tropical climate, reduction in surface temperature and thermal comfort are two things every designer should pay attention to. Thermal resistance is considered in the installation of green roof coatings because of the cooling effect, especially in summer [62-64]. Selection of green roof vegetation and substrate materials not only absorbs more less solar radiation than other types of roofs but can also optimize the budget for cooling systems [62, 65]. Yan [62] has highlighted the use of green roofs in Japan which can reduce surface temperatures, Energy savings can also be made by installing green roofs in urban areas [66]. Several studies have discussed the performance of green roofs in urban areas to reduce the urban heat island phenomenon. He et al. [67] and Morakinyo et al. [68] investigated the thermal performance of green roofs by proposing two new indices called the insulation factor and a comprehensive temperature regulation factor. From the results of the analysis, it is known that the isolation factor has a slight variation, while the overall temperature control factor has a large variation in different seasons. The study by He et al. [67] showed that the function of green roofs as a cooling effect will be enhanced in summer. These results indicate that a comprehensive temperature indicator factor is influenced by many factors such as green area index, type of roof, and type of substrate layer.

Green roof can minimize energy costs

Green roofs are dynamic systems because their function is to protect buildings from extreme temperatures [69]. The main aspects that affect green roofs as temperature regulators are biomass, moisture and moisture content, and others [30]. This protection mechanism can increase the optimization of energy costs [70]. Green roofs also act as heat insulators [71]. Thermal isolators are used as protection from extreme temperatures and can also reduce energy costs for building owners [72]. The mechanism by which this occurs is complex because green roofs are dynamic systems, with varying air and moisture content, biomass, and other aspects [73]. In some conditions, a green roof can act as an insulator [74], while in other conditions the thermal mass effect will act to reduce the temperature gradient above and below the roof as the system absorbs and then releases heat slowly [30].

Vegetation



(a) (b) (c)

Figure 2. Vegetation selection for a green roof: (a) Nephrolephi bisserata, (b) Ixora coccinea, (c) Axonopus compressus

Source: Study [30]

The function of the green roof will affect the selection of vegetation. In this case, the green roof at UGIS will also consider road access for workers and equipment. The vegetation that will be planted is adjusted to the climate in the region. Because this study will be located in Indonesia, the vegetation chosen is suitable for tropical climates, namely Nephrolephis bisserata, Ixora coccine, Axonopus compressus, and succulents. From previous studies, each type of vegetation has advantages that support the Green Roof function. Figure 2 illustrates the various types of vegetation that can be grown on a Green Roof in tropical climates. The results of the study from Chow et al. [75] showed that Nephrolephi bisserata, as depicted in Figure 2(a) can be an effective vegetation to deal with water runoff. Ixora coccinea (shrub) as shown in Figure 2(b) is identified as adaptive vegetation in tropical climates [76], while Axonopus compressus according to Figure 2(c) is usually designed as a closed grass because of its ability to survive water runoff [75]. Succulents are usually used in green roof designs to add beauty.

Perceptions of work comfort in the underground space

Multidisciplinary concepts are needed to explain human interaction with the physical building of their work space [77]. Building comfort is influenced by thermal, audial and visual comfort [78, 79], then explained several parameters that influence the perception of work comfort as described in Table 1. Parameters of Perceived Work Convenience. Many environmental factors are associated with the perception of working in an underground space, such as air quality, noise, lighting, and thermal comfort [80]. These influences can be overcome by engineering a building, but there are still several aspects in the underground space that are reduced and cannot be made to resemble working spaces on the surface, namely [81]:

a. Visibility above ground level
b. Accessibility above ground level
c. Visual contact with nature
d. Space interconnection

Table 1. Parameters of perceived comfort at work

Parameter	Indicator	Criteria
Thermal Comfort	Temperature	Too cold – Too hot
	Air Circulation	Too windy – Very stuffy Very disappointing – Very satisfying
	Air Quality	Very humid – Very dry
Audial Comfort	Noise from the source outside the building	Strongly disagree – Strongly agree
	Noise from the building system (heating system, water pipe, etc.)	Strongly disagree– Strongly agree
	Noise in the building (colleagues, photocopy machine, and etc.)	Strongly disagree– Strongly agree
Visual Comfort	Privacy	Strongly disagree– Strongly agree
	Natural light	Strongly disagree– Strongly agree
	Artificial light	Strongly disagree– Strongly agree
	Reflection	Strongly disagree– Strongly agree
	Cleanliness	Strongly disagree– Strongly agree
	Layout and decoration	Strongly disagree– Strongly agree

Source: Study [79]

Labbé [82] suggests that design consideration should be given to the utilization of underground spaces to create large communal relationships and connections between workspaces that can influence the perception of working underground [1]. This is in accordance with the opinion of D'Oca et al. [83] who argue that comfort conditions are not only associated with the physical building and environmental parameters, but also social aspects that reflect the beliefs, values, hopes and motivations of building occupants [77]. Lack of windows and ventilation influences increased productivity and decision making in the context of workspace design [84]. Underground GIS development can also take advantage of online monitoring systems and system robustness analysis, which can evaluate the temperature of each GIS equipment and maintain the required temperature, thereby bringing convenience to Underground GIS workers [85].

The novelty of this study lies in the design which is represented visually to help respondents determine their attitudes and perceptions. In addition, the research questions of this study are how the green roofs can affect the perceptual comfort, especially to the underground building users. By presenting the opportunity to apply green roofs to underground buildings, it can be a view to develop underground spaces, especially in urban areas.

2. RESEARCH METHOD

This study used the Underground Gas Insulated Substation (UGIS) design as a case study of underground buildings. The reason for using this electricity facility was to reduce negative perceptions of electricity buildings, especially in urban areas. The construction of a Gas Insulated Substation (GIS) in urban areas has its own challenges due to community resistance when it is built in their area. Using an area in the city center, UGIS is designed in the city center. A green garden is equipped on the rooftop to accommodate community activities. Limited land makes this green park has a minimalist design but can still provide sufficient vegetation area. The framework for designing a green garden with a green roof concept is explained in Figure 3.

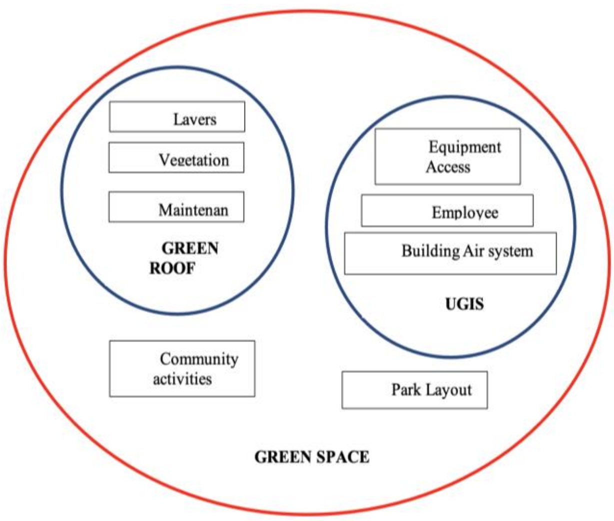


Figure 3. Utilization of green space at UGIS
Source: Study [86]

Sketchup is used to visualize designs and place designs on study locations. First, 3D design is carried out to depict the underground building. Then, surface space access design is carried out to estimate the percentage of green space that can be planned. The type of vegetation is also planned so that the plants planted do not affect the construction of the building underneath.

The layout and the outbuildings on the land will follow up on the previous study from Indira et al. [86] according to Figure 4. From the need for green space for GIS according to Figure 3 and Figure 4, there are several buildings that need to be provided on ground level space such as: entry areas for workers, air conditioning systems for transformer areas, air conditioning systems for main GIS equipment, and ventilation for 20 kV room [86, 87].

Figure 4. Green roof layout
Source: Study [86]

Therefore, it is planned that almost 25 percent of the total area above the UGIS land will be used as a built-up area, while the other 50 percent will be designed as a green space including community areas. Furthermore, the waterproofing layer design for underground buildings will use the waterproofing method that has been applied in previous studies, and apply a combination layer that protects both the inside and outside of the structure. Types of waterproofing and their applications can be explained in Figure 5. Using a combination of a pre-application layer waterproof membrane system (1) and a post-application sheet (2), must be provided with an appropriate sealant system to make construction joints. Durability membrane can be strongly affected by applying double layers of waterproofing system.

Figure 5. Watertight system
Source: Study [86]

The measurement of comfort perception was then carried out on 150 & 500 kV GIS operators in the DKI Jakarta area and its surroundings. Operators were selected as the population because they work full time within the 150 and 500 kV GIS areas. Prior to the census of GIS 150 kV and GISTET 500 kV operators, the sampling technique for the pre-test questionnaire was carried out by means of convenience sampling. Questions on the questionnaire will be aimed at finding out the extent of the perception of comfort when working in the GIS area, which will then be continued with questions about the extent of the perception of comfort if the GIS is in the underground space. The green roof design in

Underground GIS will be presented to respondents when the perception of the comfort of working in the underground space is asked. Design presentation is needed to make it easier for respondents to get a visual picture of how they can take advantage of the green roof. Furthermore, the validation of the questionnaire was carried out by experts with the criteria previously determined in this research. The “semi structured” interview technique was conducted with research informants who were GIS supervisors. Selection of GIS supervisors as observer informants because they can provide information about other people, in this case the condition of GIS operators, or an incident to researchers [88].

3. RESULTS AND DISCUSSION

3.1 Results

The Underground Gas Insulated Substation is designed to be built in the Kuningan area, South Jakarta. Surrounded by many high-rise buildings and office towers, this building is suitable to be built underground to avoid negative perceptions of surface GIS in congested areas. From Figure 6, it can be illustrated that UGIS is in a strategic location. As seen in Figure 6 of the UGIS Site Plan, UGIS is illustrated with a strategic location and is surrounded by office buildings. The consideration for choosing this location is related to the need for electricity distribution to areas that have a high load. The existence of a substation in this area will facilitate the distribution of electricity, as well as prevent long-term power outages. The design is planned to place all electrical equipment underground. It will be solution to overcome the scarcity of surface area on the location of study. Entrance and loading access, pump house, and exhaust are designed on the surface, but they are designed with a good impression. Entry access is the main point in the transition area between the surface and the underground area.

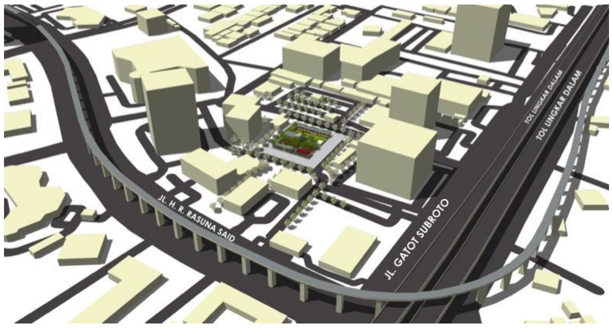


Figure 6. Site plan UGIS

Furthermore, the design of the green roof coating was reduced to 5 (five) parts, each of which has a certain thickness and specifications. Insulation and waterproofing layers are applied to structures underground due to their different exposure conditions including different levels of exposure and water pressure, static and dynamic forces such as settlements and loads, temperature variations, gases in the soil such as Methane, and aggressive biological influences such as vegetation root. External waterproofing barrier applied to external surfaces exposed to water. The structure is protected from ingress of water and from aggressive substances or influences. Figure 7 presents the design of green roofs on UGIS, include the layers of roof lining that each layer has its own use whether to make root media or to protect the building.

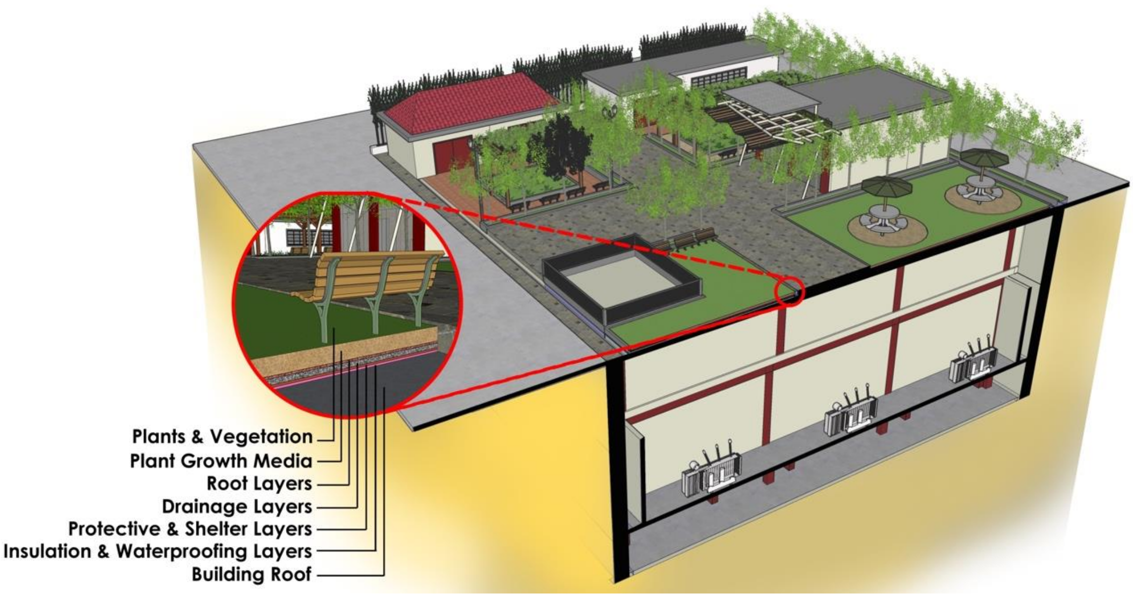


Figure 7. The green roof 3D model

The proportion of built-up area for the entire underground building area, as an allocation for the use of GIS green roof areas, is planned to be 26%. This built-up area includes the main equipment mobilization area (transformer and GIS), supporting equipment mobilization area, worker mobilization area, worker entry and exit area, and air circulation area. Vegetation space can be enlarged by optimizing the space for access in and out of workers. Planting small vegetation along the access also helps increase green space in the access area. The largest access land is reserved for the mobility of the main transport vehicles, and the land is designed for minimal vegetation conditions. To allow for absorption on the access road, natural stone and paving materials will be used as road pavement materials.

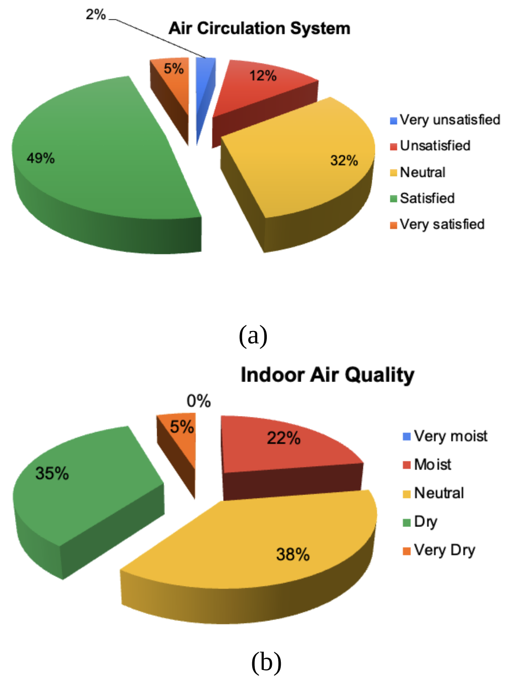


Figure 8. Distribution of respondents' answers for parameters of thermal comfort indicators. (a) Air circulation system; (b) Indoor air quality

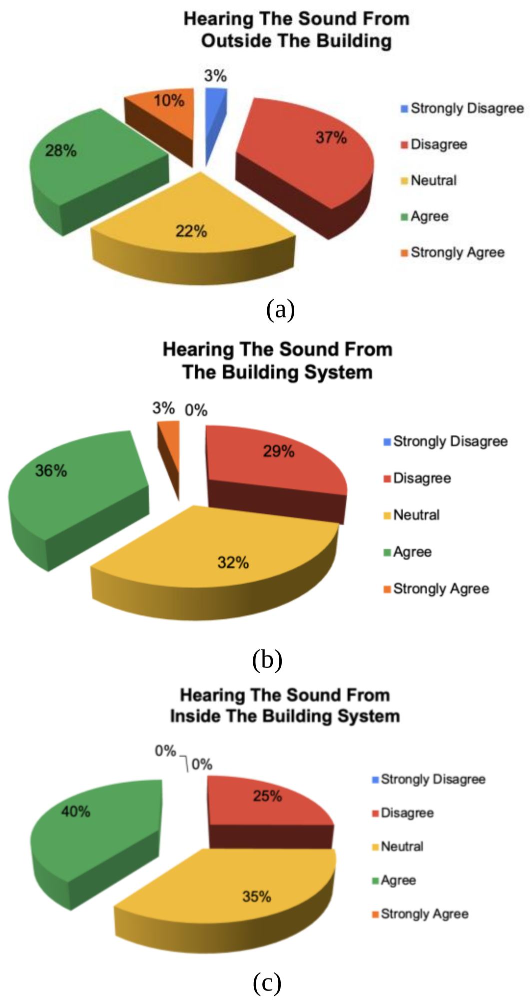
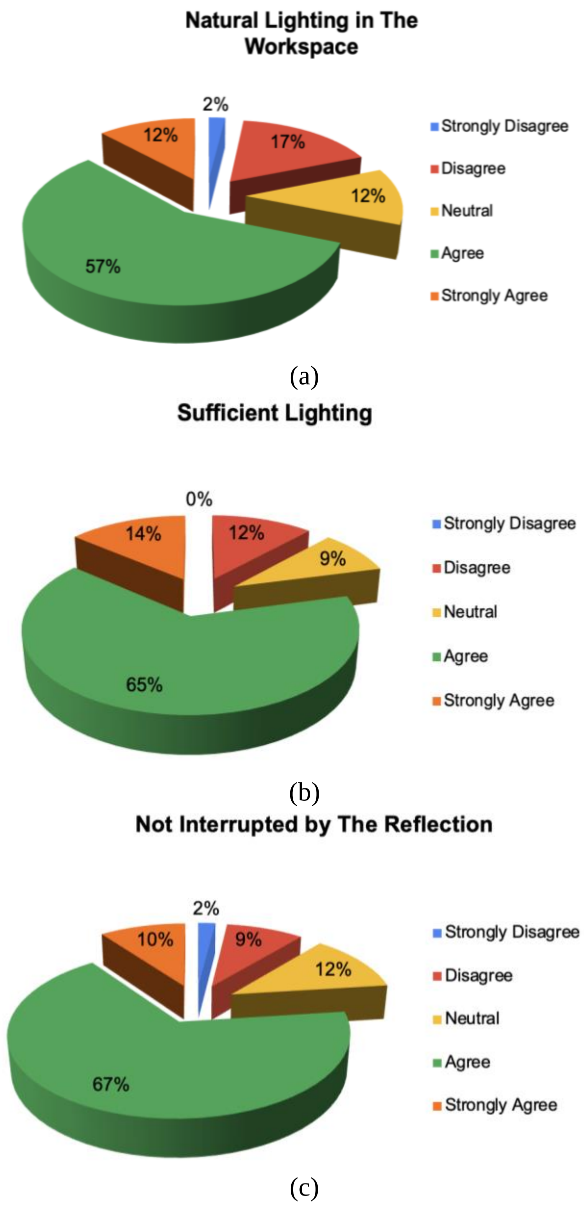
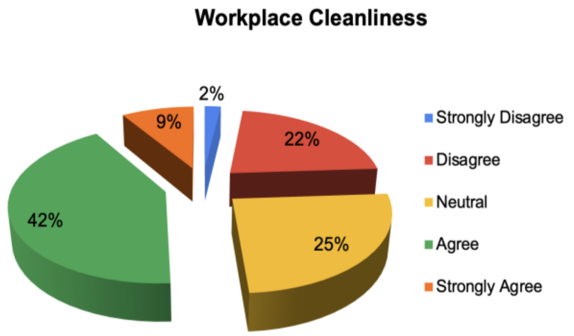


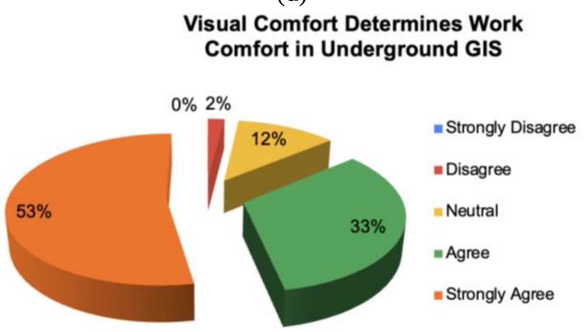
Figure 9. Distribution of respondents' answers for audial comfort parameters for noise indicators from (a) Sources outside the building; (b) Building system; (c) inside the building

In measuring perception, the questionnaire that had been tested for validity and reliability was then distributed to 120 (one hundred and twenty) respondents to collect primary data on perceived comfort. Most of the respondents have worked in GIS for more than 5 years, while a few others have worked for less than 2 years. The distribution of respondents' answers to the questions asked is illustrated in a pie diagram for each variable parameter. Figure 8 shows that most respondents rated (a) the air circulation system in their current workplace (GIS) as satisfactory (49%), and (b) even though there are some respondents feel dry (35%) and very dry (5%) for the indoor air quality, there are respondents still feel no problem with the air quality in their respective workspaces (38%). Audial comfort is felt by the majority of workers at work today through Figure 9(a) (59%) although (b) some of them still hear the sound from the building system (36%) and (c) the sound from inside the building (40%). Visual comfort is felt by the majority of workers at work today through Figure 10(a) sufficient natural lighting in their workspace (57%), (b) the lighting system in the workplace is adequate (65%), (c) not bothered by reflected light (67%), and (d) cleanliness of the workplace is well maintained (42%). Therefore, Figure 10(e) depicts that the majority of workers think that visual comfort determines their comfort working in the underground space.





(d)



(e)

Figure 10. Distribution of respondents' answers for parameters of visual comfort indicators (a) Natural lighting in the workspace; (b) Sufficient information; (c) Not interfered with monitoring; (d) Workspace cleanliness; (e) Visual convenience determines pleasure to work in underground GIS

3.2 Discussion

Underground GIS also requires land in a natural environment but tries to maintain some of that environment by implementing open green space on the roof. Green space is applied to the Underground GIS roof by applying Intensive Green Roof. Based on Figure 6, the UGIS Site Plan, this study found that the aspects considered in green roofs and UGIS, by adding public activity spaces and layout arrangements, are aspects that must be considered for designing green roofs on underground buildings. The composition of the vegetation consists of scrub areas (± 8.12%), cultivation areas (± 5.34%), and grassy areas (± 20.98%). The succulent and cactus vegetation will be designed to attach to the Underground GIS main entrance building with a vertical garden system. The layout and types of vegetation in the Green Roof design also accommodate the opinion of Amani-Beni [89], which states that grassy areas can reduce urban temperatures and increase humidity, but still provide a limited amount of grass vegetation. area as a catchment area. water according to research by Chowet al. [75]. On the other hand, one of the most significant constraints of green roofs in underground buildings is the higher initial cost for green roofs compared to conventional flat roofs. While the initial "first cost" of green roofs is usually higher [90], proper public appraisal as well as private benefits of green roofs, especially in urban areas, means choosing a green roof makes sense and even saves money in the long term. In case of specific purposes of the underground building, strategic reason can be potential issue to promote the green roof. Based on this study, green roof existence on the UGIS can be added value to increase the proportion of green space in Jakarta.

Identification of perceptions and work behavior is implemented in underground built environment planning as a way to understand how humans are able to interact with the underground environment. In accordance with a study by Parriaux et al. [91], in addition to paying attention to technical and scientific aspects, the development of underground spaces which are the object of research also pays attention to social science issues, including social acceptance of the movement of activities underground, including aspects sociology and politics [91]. Based on the results of the questionnaire, most of the respondents felt that their work space so far had fulfilled their perceived comfort both thermally, visually and audially. This reinforces the opinion of Zhao and Künzli [81] regarding aspects that still distinguish underground buildings from buildings on the ground, namely:

a. Visibility above ground level
b. Accessibility above ground level
c. Visual contact with nature

In the term of comfort aspect, research by Kaplan and Berman [84] cannot be fully implemented in this study because the authors argue that experience working in an underground space also determines how strong the relationship is between comfort and work behavior. The results of this correlation test can also add to previous research from Soh et al. [80], Ajzen [92], and Lee et al. [93], who explain external factors as one of the aspects that influence work behavior.

This study presented the need of gaining perceptual comfort prior to design special building, include underground building in Indonesia. It will affect the productivity when the operational phase begins. Work experience, especially when entering a different environment, is one of the external factors that must be considered to determine work behavior in the underground space or underground. This study also showed that beside the green roof can affect public benefits such as reducing the urban heat island effect, managing rainwater, and reducing air pollution, it can also enhance the perceptual comfort.

4. CONCLUSION

The sustainable Underground GIS building model presents an opportunity to address the problem of limited land in large cities. With a land area of approximately 1700 m^2, the proportion of green open space and open space is predicted to reach 74%. Public benefits such as reducing the urban heat island effect, managing rainwater, and reducing air pollution need to be integrated into policies by increasing the development of green roof construction.

One of the most significant constraints of green roofs in underground buildings is the higher initial cost for green roofs compared to conventional flat roofs. Therefore, this intensive provision will reduce green roof initiation costs so that green roof investment feasibility can be achieved and make it easier for building owners to calculate the return on their green roof investment. The incentives provided can be in the form of floor area ratios, grants of green roofing materials, and ease of building permits. This policy support is a key component for effective sustainable urban development.

On the other hand, society's acceptance of underground work has not gone smoothly, especially for workers who have the potential to occupy underground workspaces. This study shows that workers are accustomed to working in electrical facilities but lack experience working underground, so that different perceptions have not been formed when placed in the underground space. Respondents who have no experience working underground and can still be influenced by negative perceptions about working underground, as well as the nature of work around electrical equipment also make respondents feel uncomfortable to be the concern of further research to determine perceptions of working in underground spaces. To overcome this condition, the design should consider:

a. Visibility above ground level
b. Accessibility above ground level
c. Visual contact with nature

Another design consideration of a building should be given to the utilization of the underground space to create large communal relationships and connections between workspaces that can influence the perception of working underground. The need for work safety must also be considered to increase work comfort.

Overall, green open space planning in underground space buildings must be able to increase the perception of comfort for workers who will work in the underground space. Access to the mobility of workers to surface space needs to be considered in planning green roofs so as to increase the comfort level of workers in terms of work safety. Due to the limited scope of the research, simulations of rainwater infiltration and temperature drop for the Green Roof design were not carried out in this study. Therefore, the following research can simulate rainwater catchment and temperature drop in green roof areas for design accuracy and demonstrate the benefits of green roofs on underground roofs. The proper method of rainwater catchment can be an optimal mitigation to prevent the disaster risk due to heavy rain in Jakarta. Moreover, the weather can influence vegetation and material selection, while temperature drop can reduce the durability of green roof material. Potentially, the above cases can be significant background of future research that can support to the comprehensive study.

In addition, this research can also open up further research opportunities that focus on the collaboration of Smart Building concepts and Value Engineering which applied to underground buildings.

ACKNOWLEDGMENT

This study is supported by Hibah Publikasi Terindeks Internasional (PUTI) Pascasarjana Tahun Anggaran 2022-2023/ the Grant of Indexed International Publication for Master Student - Universitas Indonesia 2022, with contract No.: NKB-355/UN2.RST/HKP.05.00/2022, dated March 22, 2022.

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