Building and Environment 138 (2018) 53–62

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

# The effects of indoor plants and artificial windows in an underground environment

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ARTICLE INFO

*Keywords:*
Underground environment
Indoor plants
Artificial windows
Human–nature relations
Human well-being
Urban development

ABSTRACT

People have negative perceptions of underground environments on account of the absence of natural elements. To alleviate negative perceptions, many investigators have proposed indoor plants and artificial windows. Although a few studies have provided quantitative evidence of the benefits of indoor plants and artificial windows in an otherwise windowless environment, research has yet to systematically investigate these effects in an underground environment. To address this gap in our knowledge, the present study investigated the effects of indoor plants and artificial windows in an underground environment by means of a room-assessment questionnaire, an electrodermal activity (EDA) measure, and a response-time task. The findings indicate that indoor plants in an underground environment increase positive perceptions along the semantic-differential scales "Artificial–Natural", "Unsuitable for a task–Suitable for a task" and "Monotonous–Diverse", and that they reduce response times. By contrast, artificial windows are effective only on the "Monotonous–Diverse" scale, and are associated with increased response time. These findings should contribute to improvements in underground environments using indoor plants and artificial windows, so that people can maintain above-ground ways of living and working.

## 1. Introduction

The global population is growing and becoming increasingly urbanized as it grows. A recent report predicts that two-thirds of the world's population will live in cities by 2050 [1]. Because cities have been subject to increasing demand for living-space, underground space has been utilized to meet these needs [2,3]. In the past, the use of space below ground-level has focused mainly on storage, transport, emergency shelters, and pipelines requiring temperature-controlled, safe, and secure conditions [4]. For environmental reasons, underground space has been expanded by connecting existing buildings and/or new buildings [5,6], and nowadays there are many large-scale underground developments for commercial and office use, such as the RÉSO in Montreal and the PATH in Toronto [7]. Moreover, recent statistics have revealed that in major cities such as Paris, Beijing, Stockholm, Shanghai, and Helsinki, the demand for underground space continues to grow [8].

Despite increasing use of underground space, people generally think of it negatively because vital features of everyday life, such as daylight [9], natural ventilation [10], external connections with the natural world, and so on, are absent underground [11]. Accordingly, working in an underground environment can have multiple disadvantages, including reductions in perceived safety, lowered job satisfaction [12], negative attitudes to working spaces, and self-assessed mood-changes [13,14]. Previous studies have suggested several design strategies to mitigate those negative effects by incorporating natural elements in the building design such as light systems (e.g. glass walls, skylights, optical mirrors for introducing natural light), spacious design (e.g. wider corridors, higher ceilings), and mechanical systems (e.g. advanced HVAC for air quality, thermal and acoustic comfort) [13]. Many of these design strategies, however, may require additional cost and effort as well as needing to be taken into account early in the design phase. In this respect, previous studies have also suggested the introduction of easily adoptable natural (or apparently natural) elements to the underground environment [15].

Among these elements, indoor plants are affordable and easily accessible, and require only small areas of indoor space such as desks and shelves, so that they can be accepted as appropriate natural elements. Indeed, indoor plants are often encountered, and regarded as the most obvious and powerful additions for creating a positive underground environment [16]. In addition to indoor plants, artificial windows e.g. large display panels or screens with natural or outdoor views, known as

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https://doi.org/10.1016/j.buildenv.2018.04.029
Received 7 March 2018; Received in revised form 18 April 2018; Accepted 19 April 2018
Available online 22 April 2018
0360-1323/ 

'fake windows' or 'virtual windows', can also play an important role to mitigate the negative emotions in an underground environment. Since one of the noticeable features causing negative emotions underground is a lack of windows, the installation of artificial windows below-ground can compensate for this shortcoming. Following technological advances, artificial windows can easily be installed on walls; they can provide a realistic and customizable variety of natural panoramas, depending on user-preferences.

Indeed, several researchers have investigated the potential benefits of indoor plants and artificial windows. Indoor plants can give aesthetic pleasure [17] as well as oxygenating the air [18], thereby reducing perceived stress and increasing environmental attractiveness [19]. Artificial windows have been installed in a hospital by Friedman, Freier, Kahn Jr, Lin and Sodeman [20] to provide outside views for staff working indoors; they found that the artificial windows enhanced psychological well-being. Furthermore, Radikovic [21] showed that artificial windows were effective in enhancing the observers' mood, perception of reality, and preferences.

Nevertheless, although previous studies have demonstrated the psychological benefits of artificial windows, there has been little agreement on the degree to which artificial elements can be a substitute for natural ones [22,23]. In terms of technical development, advanced display technology (e.g. 4 K resolution display) is becoming more widely used and will allow people to experience more vivid and realistic views of the natural world. Moreover, underlying problems with artificial windows—such as motion parallax—can now be resolved by applying location-tracking systems (q.v. the Philips 'DreamScreen' [21,24]). Thus, considering the technological potential as well as the increasing use of underground space, it appears that artificial windows may be adopted more generally to encourage the use of such space.

To the best of our knowledge, however, no-one has studied how indoor plants and artificial windows affect people in the underground environment. Most studies of the effect of natural elements in indoor space have been limited to investigating the influence of windowlessness [25–28]. Yet underground environments have distinctive characteristics that differentiate them from those that are merely windowless, in terms of perceptions, behavior, and environmental conditions [7,11]. For instance, people working below ground-level often report a sense of isolation, claustrophobia [29], and a lack of perceived control (i.e. the extent to which one's mind or actions can be controlled) [30]. It is clear that people are likely to be influenced by a variety of mostly negative factors inherent in underground environments, and that these lead to diverse and complex responses. Thus, it may not be appropriate to apply findings from studies of windowless environments above ground to those below ground-level, without in-depth understanding and consideration of the underground environment itself. This study seeks, therefore, to address the gap in our knowledge by employing a below-ground experimental setting to investigate the effects of indoor plants and artificial windows on human occupants. In addition, comparing our findings with those from above-ground studies will help us to understand the effects of underground environments.

## 2. Literature review

### 2.1. Characteristics of the underground environment and the effects of natural elements

In today's densely-populated cities, underground development is almost indispensable. Hitherto, the strategies have focused on transport, evacuation shelters, and storage. Now, however, the underground environment is becoming part of the residential as well as of the commercial domain [31,32]. Accordingly, more and more city-dwellers will spend time underground during their working and domestic lives. Despite the increased utilization of underground space, the core problem is that people generally perceive the underground environment unfavorably as a place to work and live, which discourages them from using it. Previous research has established that a sense of isolation, together with impressions of dark and damp, renders the underground environment unfavorable and uninviting [33]. In order to explore those impressions, Hane, Muro and Sawada [33] conducted a follow-up survey in search of a link between negative impressions and actual perceptions of the underground environment. When participants were asked to choose words to describe the underground, their most frequent choices were 'fear', 'uneasiness', and 'timidity'. Indeed, employees who spend most of their time below ground have reported negative outcomes, specifically feelings of isolation [12] and fear of confined spaces [34]. Also, researchers found underground environments to be associated with lower levels of job satisfaction and productivity, growing intentions to quit, and longer stress-recovery time [26,35].

To alleviate these negative effects, several strategies have been suggested for improving the underground environment. One is to pay greater attention to physical conditions such as temperature/humidity [36], acoustic and light settings [37]. In addition, there are strategies for inducing changes in behavior, such as requesting occupants of underground environments to seek regular exposure to direct sunlight for the prevention of vitamin D deficiency [38]. More to the point, many researchers have emphasized the importance of natural interventions to improve the underground environment itself [19,27,28]. According to Carmody and Sterling [16], natural interventions can be applied to most building features, such as exterior and entrance design, as well as layout and spatial configuration (e.g. open structure of entrances, hillside exposure, etc.). Carmody and Sterling [26] highlighted the importance of arranging natural elements as part of the décor to create diversity in natural stimuli and feelings of warmth and good quality. Among those elements, 'artificial windows' and indoor plants are frequently encountered and easily accessible; they are thus the most obvious and powerful means of creating positive underground environments [15]. Thus, it is clear that indoor plants and artificial windows could be effective natural elements, prompting a positive psycho-physiological response to the underground environment.

### 2.2. The necessity and potential of artificial windows

The window is an important element of most buildings; it allows people to enjoy clean air, natural scenery, and daylight. Indeed, the importance of windows has been confirmed by studies and systematic reviews [25,39,40]. For example, in the workplace a natural view through windows was associated with greater job satisfaction, higher productivity, with less frequent intention to quit and reduced stress-recovery time, so that people prefer to sit near windows [35]. In a windowless environment, by contrast, employees experience adverse outcomes including negative attitudes towards their environment, including heightened stress [23,25,41], leading to an increased desire for natural elements to compensate for the absence of windows [42]. In brief, findings from earlier studies demonstrate a strong, consistent, and positive association between windows and health and well-being in the workplace.

However, a marked disadvantage of the underground environment is that it is hard to locate windows. Therefore, the 'artificial window' has been used as a substitute for the actual window, and the installation of artificial windows below-ground is by no means uncommon. Nowadays, these devices are generally large display panels with the view of the natural outdoor world projected onto either a window-framed screen or the wall itself. In recent years, investigators have shown growing interest in the development of artificial windows for windowless environments. Imaging Solutions [43], for example, proposed an artificial window system, to be installed beneath the ceiling of an MRI machine to help reduce patient stress during imaging.

Several quantitative studies have been conducted to compare the effects of artificial windows and real windows, and to investigate whether artificial windows also confer psychological benefits. For example, Kjellgren and Buhrkall [44] compared a natural environment