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To cite this article: Isabelle Chan *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **703** 012043

IOP Conf. Series: Earth and Environmental Science **703** (2021) 012043 doi:10.1088/1755-1315/703/1/012043

Enhancing underground development users' health through facilities management: a study of the underground metro system in Hong Kong

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Abstract. The ever-rising global population poses a great challenge for cities to accommodate additional citizens in limited land space. As such, many high-density cities were transforming the mind from "build higher" to "dip deeper". However, most of the existing underground space were built with inadequate consideration of user's health. Thus, this study aims to enhance underground users' health using an integrated Facilities Management-Health (FM-H) model. A questionnaire survey study was conducted in 4 underground metro stations in Hong Kong, which resulted in 120 valid survey responses. Based on the extensive literature review, the survey was designed to cover eight FM factors: thermal comfort, indoor air quality, ventilation, visual comfort, noise level, greenery, wayfinding support, and immediate access, and four health indicators: physical health, emotional exhaustion, depersonalization and claustrophobia stress. Pearson's correlation and multiple regression modelling were adopted to investigate the associations between FM and users' health. The results indicate that, even though all FM factors were found to have a significant impact to at least one health indicator, thermal comfort and wayfinding support were found to have impacted on three health indicators respectively. This sheds light to the importance of needing further investigation into these two FM factors in underground studies.

1. Introduction

The growing global population and urbanization development causes many high-density cities to have a prominent conflict between urban expansion and land-scarce. It was reported that 55 % of the world population currently live in urban areas and the proportion was estimated to rise to 68% by 2050 [1]. Rapid urbanization has been acknowledged as a major global challenge [2], which requires additional policies and action to free up valuable space for additional development. The demands for space have resulted in cities to extend horizontally and upward, with ever-rising towers and skyscrapers, as evidenced in many modern cities such as New York, Hong Kong, Shanghai, etc.[3]. The so-called "vertical city", which was an entire human habitat in a high-rise building, may solve the problem of overpopulation to some extent, the prevalence also brings many negative impacts, such as blocking sunlight, the aggregation of air pollution, heating islands, etc. [4]. Many countries has legislated building height restriction to limit skyscraper development to mitigate these dis-amenities [5]. Thus, attentions has shifted from "build higher" to "dig deeper" by utilizing the downward underground space to accommodate the daily routine travels of thousands and millions of commuters[6].

Previous research has recognized the development of Urban Underground Space (UUS) as a more "compact" solution to create urban space, enhancing urban connectivity and improving the congested urban environment [7]. UUS could be served as a variety of applications, such as leisure, work, storage, and other uses[8], particularly with regard to transport. More and more often, the underground metro has become the indispensable component to help mitigate traffic congestion, noise, and air pollution in aboveground environment [9]. Today, over 50 countries have built metros, accounted for a total of 53,768 million passengers in 2017 [10]. In China, the daily passenger flow on Beijing subway was more than 10 million [11]. The MTR network in Hong Kong transports over 4.9 million passengers per day[12]. From the pressure of continuous increase of population, many of these subway systems were still expanding. Consequently, more and more citizens will have to work and/or stay underground for longer periods of time.

However, social acceptance towards staying underground has long been low, with health as the paramount concern. Previous studies have indicated various health risks facing underground users, such as sleep disorders *(physical)* due to lack of natural light exposure [13], anxiety (*psychological*) due to lack of perceived control in underground environments [14], sense of isolation (*social*) due to insufficient connectivity with aboveground [14], etc. Functioning to coordinate physical environment and assets with people in a building, facilities management (FM) has long been found to be effective in enhancing users' health and performance in various contexts [15]. However, the existing FM literature, which mainly focuses on aboveground developments, fails to address the specific needs of underground users, while the literature related to underground FM was limited, outdated and lacks empirical support [13,16]. The limited empirical studies generally focus on a particular building facility, neglecting the fact that, in reality, various facilities function and influence users integratively as a whole. Hence, this paper aims to enhance underground users' health using an integrated Facilities Management-Health (FM-H) model, developed through holistic post-occupancy evaluation covering various underground FM dimensions. Since the underground metro was one of the most popular usages of underground space worldwide, this preliminary study focuses on underground metro stations in Hong Kong, one of the most densely populated cities in the world.

2. Development of a fm-health model

From an extensive literature review, holistic FM in UUS influences user's health through three main aspects, namely (1) indoor environmental quality (e.g., ventilation, temperature, humidity, noise, and lighting), (2) space management (e.g. wayfinding facilities, immediate access), and (3) greenery. Firstly, UUS has found to have common problems such as high humidity due to mould and fungal growth, poor air quality, and nature lighting scarcity [14,17]. In addition, wayfinding system has found to be essential in enhancing user's sense of perceived control in underground environment [18]. Furthermore, the introduction of greenery into UUS could enhance user's psychological well-being and increase environmental attractiveness [19]. On the other hand, four health factors were covered in the study: (1) physical health risks, such as the building-related health problems caused by the poor indoor environmental quality [20]; (2) emotional exhaustion, which can be caused by insufficient natural lighting exposure [21]; (3) depersonalization, which can be caused by the lack of perceived control to UUS environment to meet specific needs [14]; and (4) claustrophobia due to the sense of isolation between UUS and aboveground [22]. Based on the above, the study aims to investigate the impacts of the various FM indicators on health of UUS users.

3. Methodology

To achieve the research aim, a large-scale questionnaire survey study was conducted. Four underground metro stations were identified in Hong Kong. These stations were purposely selected with a variety of age (more or less than 25 years old), location (high or low density), and design (partially or fully enclosed, which may affect ventilation and natural lighting exposure of the subject stations [23]). The detailed information of the selected stations were summarized in table 1.

Table 1. Basic information of selected underground metro stations.

Stations	Age		Location		Underground Design	
	<25	>25	Kowloon	Hong Kong island	Partially enclosed	Fully enclosed
P1	-	✓	-	✓	-	✓
P2	✓	-	-	✓	-	✓
P3	✓	-	✓	-	✓	-
P4	-	✓	✓	-	-	✓

Purposive sampling was adopted, in which respondents were recruited only if they were staff working in the targeted stations. The survey was designed to have four main parts, namely, background information (e.g., gender, age, hours spent in UUS, health behaviours, medical history, etc.), UUS FM (e.g., satisfaction level towards indoor environment quality, space management, and greenery), physical health (e.g., dry eyes, itchy or watery eyes, blocked or stuffy nose, runny nose, dry throat, lethargy or tiredness, headaches, dry, itchy or irritated skin, sneezing, and breathing difficulties etc.), and psycho-social health (e.g., emotional exhaustion, depersonalization and claustrophobia). Respondents were invited to answer the questions using a 7-point Likert scale, ranging from 1 (very dissatisfied) to 7 (very satisfied). The 7-point Likert scale was also adopted to measure health symptoms, from 1 (Always) to 7 (Never). Statistical analyses were then conducted using the software SPSS, to investigate the hypothetical relationships between UUS FM components and user's health.

In sum, a total of 120 valid responses were collected, of which male and female were equally distributed (50.0% male and 50.0% female). Most of the respondents were middle-aged, with 31.7% in the 40-49 age group, followed by the 50-59 (25.0%), 18-29(19.2%), 30-39(14.2%), and 60-69(10.0%) age group. Respondents were in different job positions, of which station officer has majority of respondents (46.7%), followed by sales (35.8%), cleaner (12.5%), and security guard (5.0%). Lastly, more than 85.0% of respondents spent over 61 hours in the subject stations (including commuting and lunch).

4. Analyses and results

Correlation analysis and multiple regression modelling were conducted to examine the relationships between FM components and health of the underground metro users. A field study was further done to measure the indoor environment quality in the target stations objectively.

4.1. Correlation analysis

To discover and evaluate the strength of relationship between underground FM factors and user's health risks, Pearson's correlation analysis was firstly conducted as shown in table 2. The result showed that there was a significant relationship between underground FM and user's health: 1) thermal comfort, air quality, ventilation, noise level, greenery, and wayfinding support FM factor had a significant and negative relationship with each of the user's health indicator ($p<0.01$ or $p<0.05$); 2) visual comfort correlated positively with physical health ($p<0.05$) and emotional exhaustion ($p<0.05$); 3) The FM factor of immediate access has found to be negative correlated with physical health ($p<0.01$) and claustrophobia ($p<0.01$).

Table 2. Correlation of underground FM and occupant health.

Health / UUS FM	Physical health	Emotional exhaustion	Depersonalization	Claustrophobia
Thermal comfort	-.218*	-.500*	-.375**	-.439**
Air quality	-.376**	-.443**	-.383**	-.487**
Ventilation	-.200*	-.310**	-.272**	-.441**
Visual comfort	.218*	.230*	.039	.100
Noise level	-.230*	-.547**	-.333**	-.248**
Greenery	-.414**	-.331**	-.192*	-.461**
Wayfinding support	-.660**	-.382**	-.285**	-.598**
Immediate access	-.445**	-.099	-.166	-.572**

**. Correlation was significant at the 0.01 level (2-tailed).
*. Correlation was significant at the 0.05 level (1-tailed).

4.2. Regression modelling

As shown in Model 1 in table 3,physical health was negatively predicted by wayfinding support, greenery, and noise level, and 50.7% of the variance was explained by this model. As shown in Model 2, emotional exhaustion was found to be significantly and negatively predicted by noise level, greenery, thermal comfort, and wayfinding support. The model explained 50.4% of the variance in underground user's emotional exhaustion. With 19.4% of the variance explained, Model 3 reflects that underground user's depersonalization could be mitigated by the increased satisfaction on air quality and thermal comfort. Lastly, as shown in Model 4, claustrophobia had negative interaction with wayfinding support, ventilation, immediate access and thermal comfort. The model explained 64.4% of the variance. The above-mentioned associations were summarized in table 3 and illustrated in figure 1.

Table 3. Regression modelling for underground FM and user's health.

Model	**Dependent variables**	**Independent variables**	**Beta**		**T**	**Sig.**	**R**	**R^2**	**Sig. (ANOVA)**
			UnSTD	S.E.					
1	Physical health	(Constant)	6.914	.317	21.778	.000	.712	.507	.000
		Wayfinding support	-.284	.035	-8.011	.000			
		Greenery	-.138	.039	-3.541	.001			
		Noise level	-.101	.042	-2.399	.018			
2	Emotional exhaustion	(Constant)	7.638	.282	27.047	.000	.710	.504	.000
		Noise level	-.252	.040	-6.260	.000			
		Greenery	-.112	.036	-3.087	.003			
		Thermal comfort	-.098	.033	-2.998	.003			
		Wayfinding support	-.084	.032	-2.646	.009			

Continue Table 3

3	Depersonalization	(Constant)	6.449	.187	34.424	.000	.440	.194	.000
		Air quality	-.100	.036	-2.779	.006			
		Thermal comfort	-.096	.037	-2.609	.010			
4	Claustrophobia	(Constant)	9.546	.420	22.735	.000	.802	.644	.000
		Wayfinding support	-.343	.070	-4.881	.000			
		Ventilation	-.259	.075	-3.476	.001			
		Immediate access	-.367	.056	-6.507	.000			
		Thermal comfort	-.292	.068	-4.309	.000			

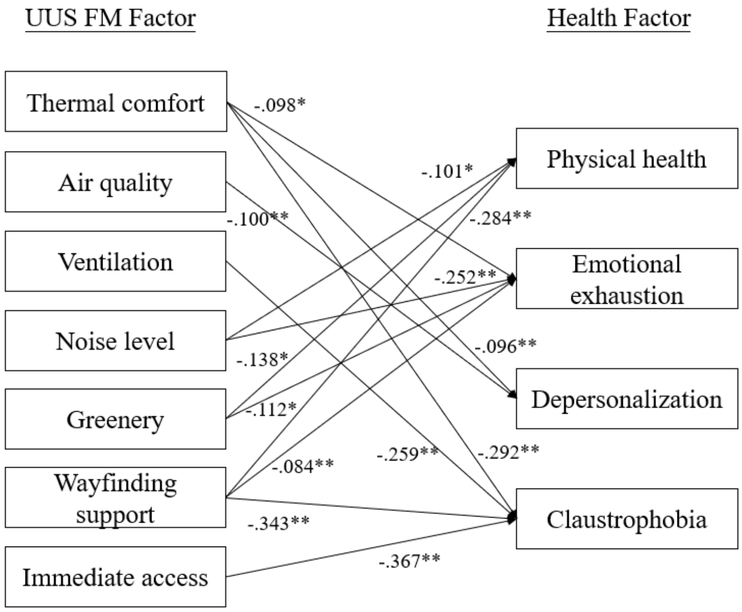


Figure 1. The resulted FM-H model (refer to table 3 for the coefficients of each relationship).

4.3. Field study - objective measurements

The figure 1 illustrated that the underground user's health was negatively affected by thermal comfort, air quality, ventilation, noise level, greenery, wayfinding support, and immediate access. However, previous studies indicate that human satisfaction level in a built environment can be affected by various psychological parameters, such as individuals' desired condition [24] and environmental beliefs [25] . To further investigate the associations between indoor environment quality and user's satisfaction level, a field measurement study was conducted. More specifically, the authors measured temperature, indoor air quality, ventilation, and noise level, within the selected case stations. To evaluate the indoor environmental quality, the author adopted the indoor air quality certification scheme developed by the Hong Kong Government [26].The guidance setup two-levels objectives, namely: "Excellent class" which represents a high-class and comfortable environment and "Good class' represents basic requirement for indoor environment.

According to the guidelines adopted in Hong Kong[26], an excellent temperature should have a range of 20ºC to 25.5ºC, temperature below the minimum requirement was considered as good class. As illustrated in figure 2, all four subway stations were within the excellent level. Due to the lack of direct exposure to sunlight, the underground temperature has found to be stable and within the human comfort zone.

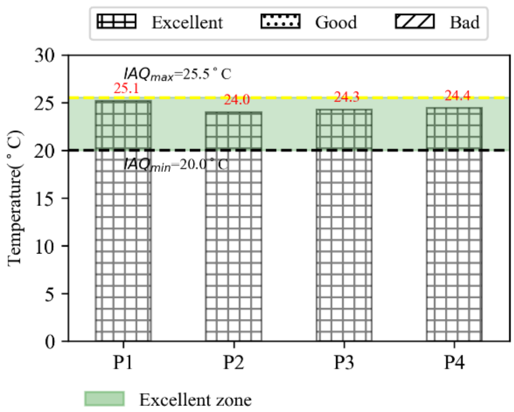
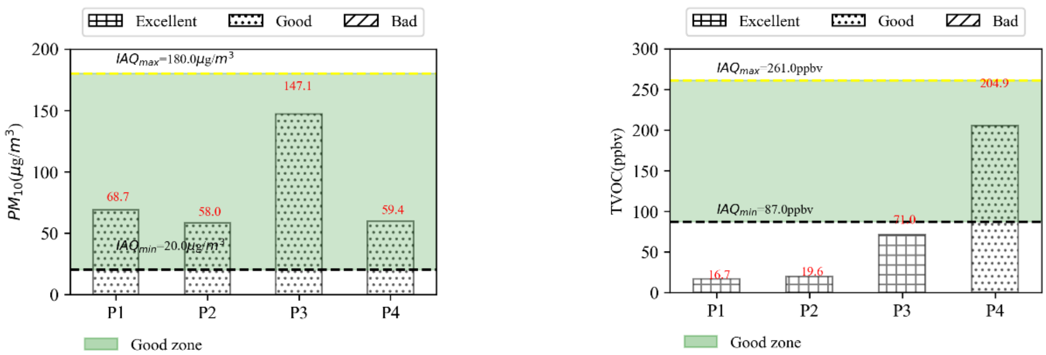


Figure 2. Temperature distribution of the four underground metro stations.

To evaluate the indoor air quality, the respirable suspended particulates (PM10) and total volatile organic compounds (TVOC) were measured and analysed to assess the underground metro air quality [27]. In general, PM10 under 20 ug/m^3 and TVOC under 87 ppbv are classified as excellent. As can be seen from figure 3, metro station P3 had reached the highest PM10 with 147.1 ug/m^3, while P4 contained 204.9 ppbv of TVOC.



(a) (b)

Figure 3. Indoor air quality distribution of the four underground metro stations: (a) PM10; (2) Total Volatile Organic Compounds (TVOC).

With regard to the ventilation performance in the underground metro stations, figure 4 demonstrated the CO2 level , which was also often considered as a surrogate of ventilation rate [28]. Metro station P1 reached the highest level of CO2 concentration with the lower rate of ventilation, while P2-P4 obtained relatively excellent performance.

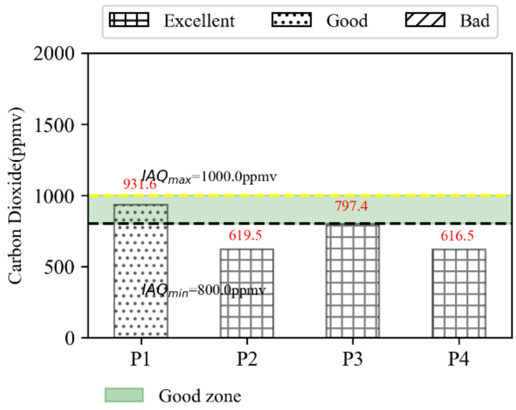


Figure 4. CO2 distribution of the four underground metro stations.

To assess the performance of noise level in figure 5, noise under 60 dB was adopted as a standard in evaluating the excellent noise performance. However, the noise performance over four stations were generally similar, with a higher volume of noise, due to the existence of transportation infrastructure and crowed populations.

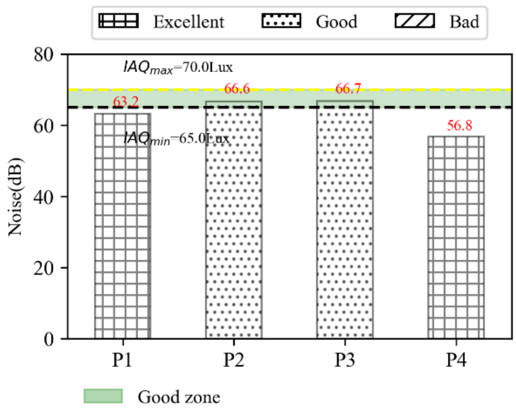


Figure 5. Noise distribution.

On the other hand, underground greenery was also found to have significant impacts on users' physical and emotional health. In fact, previous studies have indicated that introducing greenery in underground environments can fulfil users' needs for connecting with nature [29], enhancing their satisfaction and physical and psychosocial health [30–32]. However, in our field study, the underground stations were found to have no greenery at all. There was only one station which contains images of natural landscape, and the survey study indicates that users in these stations suffer from the lowest level of emotional exhaustion and depersonalization amongst the four sites. In fact, purposively designed underground greenery was still uncommon in Hong Kong. In advanced high-density cities like Shanghai, virtual windows were getting more common. Through fostering connections between underground users and the above ground environment, virtual windows have found to help reduce users' cortisol reactivity to stress induction [33].

Unlike users of aboveground buildings, it was more difficult for underground users to orientate themselves, because they cannot rely on buildings and/or natural environment outside a building. This isolation can cause emotional problems to users due to low sense of perceived control [18]. Since all of the four sites in this study were managed by the same subway organization, all of them adopt a similar signage system for wayfinding support. While amongst the four sites with similar size, the two which have the highest number of escalators have their users scoring the best in emotional exhaustion and depersonalization (P2), and physical health and claustrophobia stress (P3) respectively. This, to certain extent, support the importance of enabling adequate connection with aboveground environment in UUS.

5. Discussion

Using questionnaire study in four underground metro stations, the authors investigated critical underground FM factors that have significant effects on user's health. It was found that thermal comfort, air quality, ventilation, noise level, greenery, wayfinding support, and immediate access were all significantly associate with users' health. The increasing satisfaction towards the abovementioned factors could help mitigate the user's health risks. Furthermore, *thermal comfort* and *wayfinding support* were found to have significant impacts on *three health indicators* respectively. This sheds light to the importance of further investigating these two FM factors in future underground studies. Even though the results of the objective field measurement indicated that the temperature of all sites were within the excellent class [25]; it was found that users of P1, which was the hottest site, suffer from the highest level of risks in all four health indicators, including physical health, emotional exhaustion, depersonalization and claustrophobia stress. Furthermore, in terms of wayfinding, even though all sites adopt a similar signage system, it was found that users from the two sites with the highest number of escalators tend to suffer from lowest risks in all four health indicators. On the other hand, the objective field measurement further indicated the lack of human-focused in existing underground subway systems. For instance, amongst the four sites, none of them have purposive landscape design. Only one site contains images of natural landscape, and users in that site were found to have the least chance of suffering from emotional exhaustion and depersonalization.

6. Conclusion

The survey study adopts a self-report measurement approach, which could have resulted in common method variance. However, it should be noted that the data collection was purposively designed to include respondents with various background (i.e., age, gender, health behaviors, and health history) and in subway stations with different age, types, location and design. Meanwhile, the measurement scales in this study were adopted from the extensive literature on built environment and post-occupancy evaluation. In sum, this study provides empirical evidences that: i) underground greenery, wayfinding support, and noise level are significantly associated with users' physical health; ii) user's emotional exhaustion is predicted significantly by thermal comfort, noise level, greenery, and wayfinding support; iii) thermal comfort and air quality have a significant association with underground occupants depersonalization; iv) UUS users' claustrophobia was significantly affected by thermal comfort, ventilation, wayfinding support, and immediate access; v) among the eight FM factors, thermal comfort and wayfinding support were the keys, in which they significantly impact 3 health indicators respectively. Further studies were suggested to focus on these two FM factors in UUS. Furthermore, the study results push forward the development of built environment research from the well-studied aboveground field to the often-overlooked underground field.

Acknowledgement

This research is supported by the Early Career Scheme (No: 27203319), the Research Grant Council, HKSAR; and the Seed Funding for Basic Research, the University of Hong Kong.

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