https://doi.org/10.1016/j.buildenv.2017.07.003

The impact of indoor environmental quality on work productivity in university open-plan research offices

Shengxian Kang[a], Dayi Ou[a,b,*] and Cheuk Ming Mak[c]

[a]School of Architecture, Huaqiao University, Xiamen, 361021, P.R. China

[b]State Key Laboratory of Subtropical Architecture Science, South China University of Technology, Guangzhou 510640, P.R. China

[c]Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

[*]Corresponding author at: School of Architecture, Huaqiao University, Xiamen, 361021, P.R. China. E-mail address: oudayi_hqu@126.com (Dayi Ou).

Abstract:

Indoor environmental quality (IEQ) has significant impacts on office occupants' productivity and these impacts differ according to the type of office. The present study focuses on a special type of open-plan offices, university open-plan research offices (UOROs), and aims to study how the IEQ of this type of offices affects the occupants' productivity. A four-part IEQ assessment framework for the University Open-plan Research Office (UORO) is first proposed. Then the investigation is conducted based on survey responses collected from 231 people who are working in UOROs from 19 universities in China. The analysis results show a clear picture of (1) how the office productivity is affected by the five key IEQ aspects (layout, air quality, thermal comfort, lighting and acoustic environment), (2) how these five key IEQ aspects are affected by their corresponding sub-factors, such as conversation noise, and (3) how occupants' perception of sub-factors are affected by individual factors, such as occupant demographics and work activity. The results also emphasize the quality of acoustic environment has the greatest influence on the occupants' productivity in UOROs and imply occupants working in UOROs have higher requirements for acoustic environment than in other common types of open-plan offices. Based on the analysis, a decision-making strategy is also presented for the evaluation and improvement of the IEQ of UOROs.

Keywords:

University open-plan research office (UORO), open-plan office, work productivity, indoor environmental quality (IEQ), office noise

1. Introduction

The definition of "open-plan offices" in ISO 3382-3[1] is given as "offices and similar spaces in which a large number of people can work, have a conversation, or concentrate independently in well-defined work stations". According to this description, a large number of today's research rooms (or called "study rooms") in colleges and universities, which are designed and built for a group of people (especially for young researchers such as full-time postgraduate students, postdoctoral researchers and research staff) to do their daily research work, fall within this definition and can be defined as a type of open-plan offices. These young researchers, who spend most of their time working in these research rooms, are a significant and valued part of the university and contribute significantly to the research work of universities[2]. Therefore, it is of great importance to deeply explore the factors affecting the productivity of these offices and the ways of improving them. In this paper, this particular type of open-plan offices is hereinafter referred to as "University Open-plan Research Office" and abbreviated as "UORO".

There is an increasing trend of designing and building open-plan offices throughout the world. Meanwhile, a number of investigations have been carried out on this type of office buildings and demonstrated the importance effects of the indoor environmental quality (IEQ) on office occupants' comfort and work productivity. These investigations have also shown the actual influences of IEQ factors differ according to occupant demographics[3], the type of office[4-6], the type of task in which the occupants are engaged[7, 8], and so on. Therefore, although considerable studies have been conducted on open-plan offices, further careful studies specifically on UOROs are still needed. The office layout, occupant demographics and work pattern in UOROs are usually quite different from other common open-plan offices, such as open-plan offices for administrative tasks and those for financial jobs (these common open-plan offices are hereinafter referred to as "general open-plan offices"). Moreover, a more prominent difference is the type of activities and tasks in which the occupants are engaged. Unlike majority of work conducted in general open-plan offices, the work conducted in UOROs is mostly related to academic research and most of time requires higher levels of concentration, insight, creativity, inspiration and consistency[9, 10].

According to the authors' best knowledge, there is no published work on the analysis of the impacts of IEQ factors on UORO occupants' environmental satisfaction or on their work productivity. In this paper, a survey was carried out from December 2015 to March 2016 in UOROs in China, with the aim of knowing more about the current indoor environmental conditions of open-plan research offices in Chinese universities. This survey also aims to develop a guideline for the evaluation and improvement of the IEQ of UOROs by exploring the impacts of the perceived quality of indoor environmental factors on office productivity. The effects of the individual factors such as occupants' gender, age, birthplace, work position and work task are also considered and analyzed in the analysis. For better accomplishing these objectives, a relevant literature review has been done before the survey was taken, which is presented in the following section.

2. Literature review

Research on the effects of the indoor environmental quality (IEQ) on work productivity in the University Open-plan Research Office (UORO) is limited and almost non-existent. However, the IEQ and its effects on work productivity and human comfort in general open-plan offices are extensively researched. These researches can provide the foundation and reference for the analysis of the UORO.

2.1 Office layout

Office layout design is a basic IEQ factor that influences office occupants' performance and behavior[11-13]. To share an office by a couple of persons, an open-plan office accommodates more people than a private office and facilitates the communication between workmates[14]. This kind of layout design however leads to the reduction of each occupant's workspace size, the lack of visual privacy, and the increasing of uncontrollable social contacts and interruptions. Especially, it is the property of open-plan office layout that is the root cause of the poor acoustic environment[4, 5].

To ensure human comfort and efficient work performance, many pieces of research highlight the importance of open-plan office layout design. Factors such as the amount of space, comfort of furniture and adjustability of equipment are commonly considered in the design and proved to have significant effects on occupants' satisfaction and work productivity[4, 15]. Several investigations also reveal that the suitability of an open-plan office layout is affected by the work processes[13], work patterns[16] and the complexity of the work tasks[17].

2.2 Thermal environment

Thermal comfort plays important roles both in occupants' work productivity[13, 18] and occupants' satisfaction with the office environment[19]. In 2005, a survey[19] carried out in 26 open-plan offices in Europe shows occupants' satisfaction with indoor temperature is one of the most important factors to their satisfaction with the IEQ. Another investigation[20] conducted in Hong Kong in 2012 verifies again temperature comfort has the highest significantly positive correlation with work productivity. In addition, researchers find office task performance descends if room temperature increases from neutral temperatures (e.g., 21-25 ^{o}C) to higher ones (e.g., above 26 ^{o}C)[21, 22]. A very recent research by Maula et al.[23] also shows inappropriate high temperatures have adversely impact on mood, motivation, concentration and so on.

Based on the heat balance theory along with thermoregulation physiology, the well-known thermal comfort prediction model, PMV index, is determined by six parameters, including four physical parameters (air temperature, relative humidity, air velocity and mean radiant temperature) and two human variables (clothing insulation and metabolic rate)[24]. The PMV model provides a standard and efficient method for the evaluation of the indoor thermal comfort and is adopted by the international standard (ISO 7730[24]) and other well-known standards, such as BS EN ISO 7730[25] and ASHRAE 55[26]. However, it should be noted that, as a subjective state, a more accurate and comprehensive judgment of thermal comfort should include physical, physiological and psychological aspects[13, 27]. This judgment varies person individually and geographically due to a great variety of factors, including age, sex, location, time of the year and so on[13]. Further investigations[28, 29] even show the indoor thermal comfort depends on the type of task. For instance, the optimum thermal temperature for complex or creative mental work may slightly higher than that for other types of mental work[28].

2.3 Air quality

Indoor air quality (IAQ) is another significant factor affecting human comfort and office productivity. Poor IAQ can cause the reduction of work productivity[30-34] and even sick building syndrome (SBS) symptoms (such as headaches, lethargy and mental fatigue)[13, 34, 35]. As the degree of quality of the indoor air, IAQ is affected by the ventilation rate and emissions from the building, furniture, equipment and occupants[36]. Increasing the ventilation rate is an efficient way of improving the IAQ. A comprehensive review[37] of the scientific literature on the effects of ventilation rates on health reveals office symptoms can be effectively reduced when the ventilation rate is high enough (e.g., up to approximately 25 L/s per person). Moreover, experiment studies show higher ventilation rates can reduce the proportion of occupants dissatisfied with the perceived air quality[32] and increase the occupants' productivity [35].

Office occupants' feelings of air freshness have a significantly positive correlation with satisfaction with the IAQ[38]. An early investigation has concluded that odors nuisance can cause a negative effect on task performance, mood and perceived health[39]. Later studies[40, 41] further support this conclusion and demonstrate ambient unpleasant odors can influence the amplitude and time course of visual attentional capture, the speed of information processing and the performance of cognitive tasks. Some researchers even indicate the introduction of fragrances with the purpose of improving office occupants' productivity may not necessarily facilitate all aspects of work performance as anticipated[42].

2.4 Lighting environment

Lighting is the prerequisite for the use of every office and its quality inevitably influences office occupants' comfort and work productivity. The open-plan office with high quality of lighting environment is beneficial to relieve occupants' eye symptoms[43, 44] and tiredness[43, 45], to decrease motivational problems[43], and to improve productivity[45].

As a main source of indoor lighting, daylight (also called "natural lighting") is regarded as the preferred source that offers best light for human visual comfort without causing any environmental burden. Xue et al.[46] have recently investigated the effects of lighting and human behavior patterns on subjective luminous comfort in residential buildings in Hong Kong, and find the degree of luminous comfort is most affected by people's satisfaction with natural lighting. Similar findings are reported by several previous researchers[47-49], who further point out that the importance of natural lighting and windows in the office to the occupants is not only because of the occupants' physical needs for view and light but also because of their psychological needs. Artificial lighting is another indispensable lighting source in open-plan offices. Although people are much more likely to prefer natural lighting, systems of artificial lighting ensure conditions for visual activity when natural light is not adequate or not available. The type and level of artificial lighting used in the office affects not only the total building energy consumption but also human comfort. Dissatisfaction with artificial lighting conditions is a common problem in open-plan offices[6]. Occupants feel uncomfortable if artificial lighting in their office is overused and their preferred artificial lighting levels are dependent on daylight levels and weather type[50].

Office occupants' satisfaction with the lighting environment (i.e., luminous comfort) is also affected by the type of activities in offices[8, 51-53]. For instance, people who are working on computer tasks prefer lower light levels than those who are not doing their work on computer[52]. Similar findings are obtained by Jennings et al.[51], who show that graphic designers prefer lower light levels than lawyers because the former need to finish most of their work on computer.

2.5 Acoustic environment

Acoustic comfort is one of the most concerned IEQ factors of open-plan offices. A number of researches[3, 15, 20, 54-61] have already demonstrated that poor acoustic condition is harm to office occupants' job satisfaction, work productivity and even health; while noise level and sound privacy are two of the major factors related to acoustic environmental quality of open-plan offices.

Quietness (i.e., low noise level) is one basic requirement for a satisfying office environment[15]. However, the existence of various types of office noise (e.g., traffic noise, conversation noise, machine noise and human activity noise) is very common in today's open-plan offices, which has been identified as a major cause of annoyance, dissatisfaction with work environment and work productivity decrements[3, 20, 54-59]. Moreover, these negative effects caused by noise are affected by many factors[5, 7, 20, 62], such as the types of noise and demographic factors of occupants. For example, some particular noise sources (such as human activity noise) are found to have more significant negative impacts on the people with low-productivity than those with high-productivity; while other noise sources, such as conversation noise and machine noise, have similar significant negative impacts on all the people[20]. In addition, numerous studies have shown varying degrees of effects of noise on difference types of work tasks. For instance, the negative effects of conversation noise on the tasks of serial recall, proof-reading and mental arithmetic task are found to be different[5, 7, 57, 63].

Among these noise sources, conversation noise (i.e., so called "irrelevant speech noise") is one of the most uncontrollable noises in the open-plan office, which unfortunately is also likely the most annoying one[20, 55].

The speech privacy, as one property against this type of noise, is therefore considered to be important for the open-plan office and is adopted by the international standard (ISO 3382-3[1]) and other well-known standards such as BS EN ISO 3382-3[64] and ASTM E1130[65]. In these standards, the related parameters such as distraction and privacy distances are used in ISO 3382-3 and BS EN ISO 3382-3 for the evaluation of speech privacy, while Articulation Index (AI) is used in ASTM

E1130. Many laboratory experiments and field studies have also manifested that higher speech privacy indeed can reduce the negative influence of irrelevant speech noise and effectively improve occupants' productivity[7, 63, 66].

The overall message from this literature review can be summarized as follows: (1) Office layout, air quality, thermal environment, lighting environment and acoustic environment are five key IEQ aspects of open-plan offices. Occupants' perception with these five aspects directly influences their total environmental satisfaction and work productivity in offices. (2) For office layout, occupants' perception depends on the items such as personal space, equipment and comfort of furniture. For air quality, occupants' satisfaction is related to the quality of ventilation and air freshness. For thermal environment, temperature, relative humidity and air velocity are vital physical parameters. For lighting environment, natural lighting and artificial lighting are two key factors that determine the luminous comfort. For acoustic environment, the noise problem has the greatest negative impact on office environmental quality. (3) Occupants' comfort requirements may differ according to the type of work activity and their demographic characteristics.

Based on these previous findings, to achieve the objectives mentioned in Section 1, this study also focuses on these five key IEQ aspects, and especially on how the occupants' productivity in UOROs, as well as their research-related activities and individual characteristics, is affected by these five key IEQ aspects.

3. Methodology

~~From the above literature review, it is seen that layout, air quality, thermal environment, lighting environment and acoustic environment are five key IEQ aspects of open-plan offices. Occupants' perception and satisfaction with these five aspects (as well as their sub-factors) directly influence their total environmental satisfaction and work productivity in offices. In addition, most of the time occupants' comfort requirements of these aspects depend on many individual factors, such as~~

~~occupants' demographic characteristics and the types of work activities in which they are engaged.~~

As shown in Figure 1, an IEQ assessment framework for the University Open-plan Research Office (UORO) is proposed. To achieve the objectives mentioned in Section 1, the framework consists of 4 parts. The first part assesses occupants' work productivity in UOROs. The second part investigates the quality of the five key IEQ aspects, as well as their impacts on work productivity in UOROs. In the third part, how these key aspects are affected by their corresponding sub-factors is explored. The effects of individual factors, such as age, gender and work activities, on occupants' perception on these sub-factors are investigated in the last step.

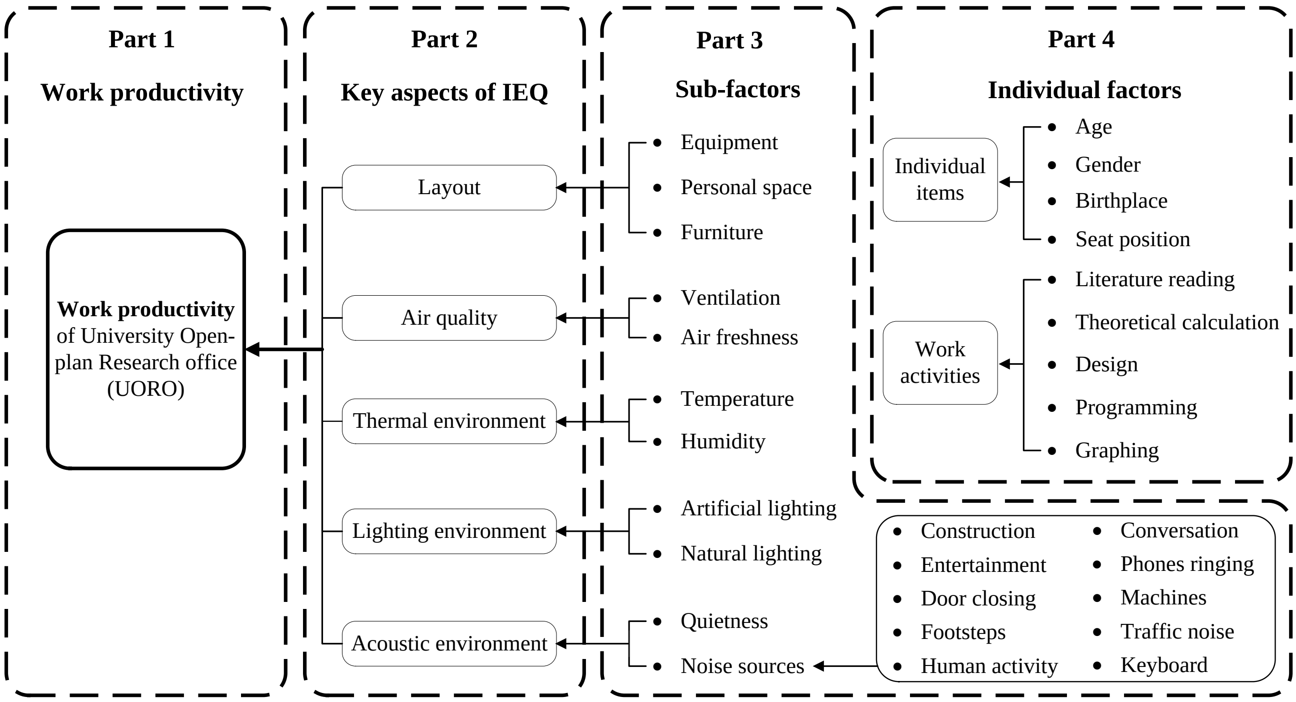

Figure 1. The IEQ assessment framework

3.1 Questionnaire survey

A pilot study with a sample size of 18 respondents was conducted prior to the main study to develop the questionnaire and check the reliability of the questionnaire. A preliminary analysis of these results indicates most questions in the questionnaire are clear. Some questions are modified according to the respondents' comments. Especially, the pilot results show acoustic condition is an extremely important IEQ aspect of UOROs in China. Therefore, a separate part is added to the final questionnaire to investigate particularly the noise sources in the UORO as well as their effects.

The formal questionnaire consists of three parts. Part 1 is designed to collect the individual information of the respondents, as well as their overall evaluation of office productivity by rating on a 5-point scale from 1 (very low) to 5 (very high). The individual factors collected include the respondents' age, gender, birthplace, seat position and their main work activities in office. Part 2 involves the respondents' feeling about the five key IEQ aspects (i.e., layout, air quality, thermal environment, lighting environment and acoustic environment) and the corresponding sub-factors of each aspect (as shown in Fig.1). Apart from the questions concerning temperature and humidity, all the other questions in this part are answered on a five-point scale (from 1 = very dissatisfied to 5 = very satisfied). In order to know more detail about the respondents' actual feeling towards thermal environment, questions for temperature and humidity are answered on a 5-point scale, from 1 (very hot) to 5 (very cold) and from 1 (very wet) to 5 (very dry), respectively. Part 3 investigates the level of noise disturbance caused by 10 common noise sources (as shown in Fig. 1). Questions in this part are answered from 1 (not disturbing) to 5 (very disturbing) for each noise source.

A survey was conducted during December 2015 to March 2016 in UOROs in China. The participants were asked to answer the questionnaire according to how they feel about their office quality most of the time. Only the UORO that hold more than 5 people per room were considered in this survey. Offices that hold more than 5 people per room are also considered as typical open-plan offices by other scholars[67]. A total of 265 questionnaires were returned, out of which 231 were valid (valid response rate is 87%). These valid questionnaires were collected from 19 universities, which are distributed in 11 provinces in the south of China. The temperature is from 9℃ to 20℃ during the Investigation period. The general information of the respondents is given in Table 1. All of the respondents are research students below the age of 35.

Table 1 General information of the respondents

Age		Gender		Birthplace		Seat position		
< 24	24-35	Male	Female	South[a]	North[b]	Window seat (sitting near the window)	Door seat (sitting near the door)	Neither near a window or door (NWND) seat (sitting neither near a window or door)
95 (41.1%)	136 (58.9%)	145 (62.8%)	86 (37.2%)	163 (70.6%)	68 (29.4%)	110 (47.6%)	54 (23.4%)	67 (29.0%)

[a] The person who was born in south of the Huai River–Qin Mountains Line in China;
[b] The person who was born in north of the Huai River–Qin Mountains Line in China.

3.2 Statistical analysis

The data are analyzed by using the SPSS software. The statistical reliability is first tested by using Cronbach's alpha coefficient test to assess the overall consistency of the psychometric questions. The Spearman rank correlation coefficient[68] is a non-parametric test that assesses statistical dependence between two variables by describing the relation compared with monotonic function. This coefficient is applied to investigate the relation between office productivity and the five key IEQ aspects and the relation between these IEQ aspects and their corresponding sub-factors. Mann-Whitney U Tests and Kruskal-Wallis H Tests are non-parametric tests that can be used to determine statistical dependence between two or more variables by describing the relation compared with monotonic function. These two types of tests have greater efficiency than the t-test for non-normal distributions and are employed to identify whether the individual factors (such as demographic characteristics and the types of work activities) cause significant differences in feelings about the sub-factors.

4. Results and analysis

4.1 Reliability of the questions

Cronbach's alpha is utilized to test the reliability of data collected from the questionnaires in this survey. As shown in Table 2, the Cronbach's alpha is calculated as 0.880. Various studies have recommended that alpha values above 0.6 are acceptable[38, 46], and the scale can thus be considered to present good reliability.

Table 2 Reliability of the questionnaire

Feelings towards the psychometric questions (including feelings towards the five key IEQ aspects and their sub-factors)	Cronbach's alpha
Layout equipment, personal space, furniture	0.880
Air quality ventilation, air freshness	
Thermal environment temperature, humidity	
Lighting environment artificial lighting, natural lighting	
Acoustic environment quietness, noise sources	

4.2 Evaluation of IEQ aspects and their impacts on office productivity

The overall evaluation results of work productivity are given in Table 3. The mean score is 3.30. 41.5 percent of respondents think their work productivity is high or very high, while 58.5 percent of them do not think they have high work productivity in office. Fig. 2 shows the mean satisfaction rating for the key five IEQ aspects. The highest score is lighting environment (3.46), followed by the thermal environment (3.36); while acoustic environment and air quality are two of the most unsatisfying aspects with the scores of 3.10 and 3.12, respectively.

Table 3 Results of respondents' perception of work productivity

Work productivity				
Very low	Low	Neutral	High	Very high
2 (0.9%)	31 (13.4%)	102 (44.2%)	87 (37.6%)	9 (3.9%)

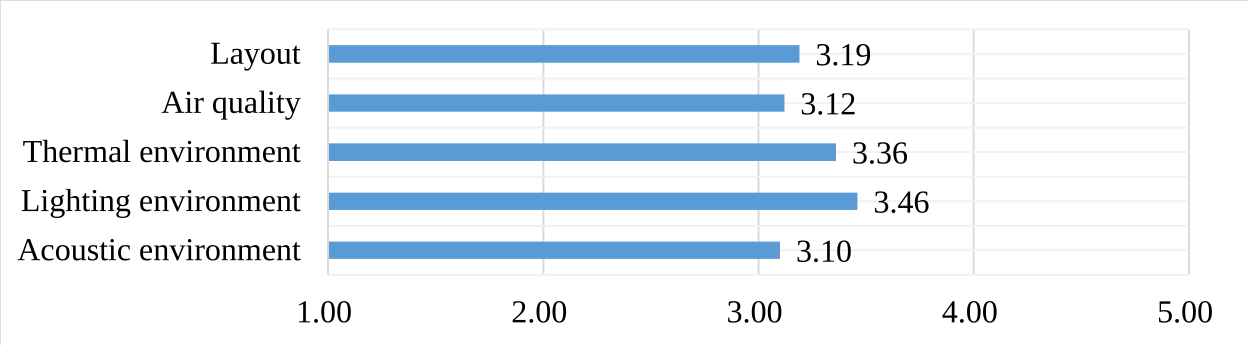

Figure 2. Mean scores of satisfaction with the five key IEQ aspects

The Spearman rank correlation coefficients are calculated to determine whether there is an association between work productivity and each of the five key IEQ aspects, as shown in Table 4. The larger the absolute value of the coefficient, the stronger the relationship between the variables. As seen in Table 4, the qualities of all these five key IEQ aspects have significantly positive correlations (P-value<0.01) with office productivity, which demonstrates again the importance of these five aspects to office productivity in UOROs. The correlation coefficients of layout, air quality, thermal environment, lighting environment and acoustic environment are 0.341, 0.231, 0.256, 0.282 and 0.432, respectively.

Table 4 Spearman rank correlation coefficients (r_s) of work productivity and IEQ aspects

	Acoustic environment	Layout	Lighting environment	Thermal environment	Air quality
Work productivity	0.432**	0. 341**	0.282**	0.256**	0. 231**

** Correlation is significant at the 0.01 level (two-tailed)

It is worth noting that the correlation coefficient of acoustic environment is much larger than those of the other aspects, which means the acoustic environmental quality of the UORO has extremely significant effects on occupants' productivity. This IEQ aspect however has the lowest evaluation score of satisfaction (see Fig. 2), suggesting that in the current situation more attention should be paid to the quality of acoustic environment in the UORO and occupants' productivity can be effectively increased by improving the quality of this aspect.

4.3 Evaluation of Sub-factors and their impacts on the IEQ aspects

The results of the respondents' feelings about the sub-factors are given in Table 5 and Fig.3, while Table 6 shows how these feelings impact on satisfaction with the key IEQ aspects by applying a Spearman rank correlation coefficient. Several points can be noted from these results.

For instance, as seen in Table 6, almost all the proposed sub-factors have significant effects on satisfaction with their corresponding IEQ aspects. More specifically: (1) equipment, personal space and furniture have significantly positive correlations (P-value$<$0.01) with satisfaction with office layout; (2) ventilation and freshness have significantly positive correlations (P-value$<$0.01) with satisfaction with air quality; (3) artificial lighting and natural lighting have significantly positive correlations (P-value$<$0.01) with satisfaction with lighting environment; and (4) quietness has a significantly positive correlation (P-value$<$0.01) with satisfaction with acoustic environment. Also, as expected, all the proposed noise sources have negative correlations with satisfaction with acoustic environment. Except for noises of construction, door closing and traffic, all the noise sources (including conversation, entertainment, phone ringing, machines, footsteps, human activity and computer keyboard) have significantly negative correlations (P-value$<$0.01) with satisfaction with office acoustic environment. Among these noises, conversation noise has the strongest negative relationship with the satisfaction with acoustic environment ($r_s = -0.448$), followed by noises of phone ringing ($r_s = -0.311$) and human activity ($r_s = -0.285$).

In addition, as shown in Table 5, the mean evaluations of satisfaction with ventilation, air freshness and quietness are lower than those for the other sub-factors. Since they all have significant positive impacts on their IEQ aspects (with r_s =0.762, 0.855 and 0.642, respectively, as shown in Table 6), the poor quality of these sub-factors can be considered as an important reason why air quality and acoustic environment have the lowest satisfaction scores among the five IEQ aspects. Specifically for the acoustic environment, as can be seen in Fig. 3, conversation noise has the highest mean perceived disturbance level (3.00). Therefore, with both the highest significant negative correlation coefficient with the quality of acoustic environment and the high perceived disturbance level among the surveyed noise sources, conversation noise is demonstrated to be a serious factor that affects IEQ satisfaction and work productivity in UOROs.

Moreover, both the conditions of natural lighting and artificial lighting have significant positive impacts on office lighting quality; however the level of satisfaction with natural lighting (3.29) is much lower than with artificial lighting (3.65), indicating that for the lighting environment more efforts should be made to improve the quality of natural lighting in UOROs. For the thermal environment, the majority of respondents (>70%) feel comfortable with the temperature and humidity, implying that the condition of thermal environment in the UORO is basically suitable for the occupants.

Table 5 Respondents' perception of the sub-factors of each IEQ aspect

Evaluation of satisfaction							
		Very dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied	Mean
Layout	Equipment	8(3.5%)	26(11.3%)	89(38.5%)	74(32.0%)	34(14.7%)	3.43
	Personal space	12(5.2%)	31(13.4%)	82(35.5%)	78(33.8%)	28(12.1%)	3.34
	Furniture	15(6.5%)	34(14.7%)	62(26.8%)	96(41.6%)	24(10.4%)	3.35
Air quality	Ventilation	16(6.9%)	59(25.6%)	65(28.1%)	69(29.9%)	22(9.5%)	3.10
	Air freshness	11(4.8%)	40(17.3%)	98(42.4%)	69(29.9%)	13(5.6%)	3.14
Lighting environment	Artificial lighting	5(2.2%)	19(8.2%)	53(22.9%)	129(55.9%)	25(10.8%)	3.65
	Natural lighting	14(6.1%)	37(16.0%)	69(29.9%)	91(39.4%)	20(8.6%)	3.29
Acoustic environment	Quietness	13(5.6%)	35(15.2%)	86(37.2%)	83(35.9%)	14(6.1%)	3.22
Evaluation of thermal feelings							
Thermal environment		Very hot	Hot	Neutral	Cold	Very cold	
	Temperature	12(5.2%)	34 (14.7%)	165(71.4%)	16 (6.9%)	4(1.8%)	
		Very wet	Wet	Neutral	Dry	Very dry	
	Humidity	11(4.8%)	22 (9.5%)	167(72.3%)	27(11.7%)	4(1.7%)	

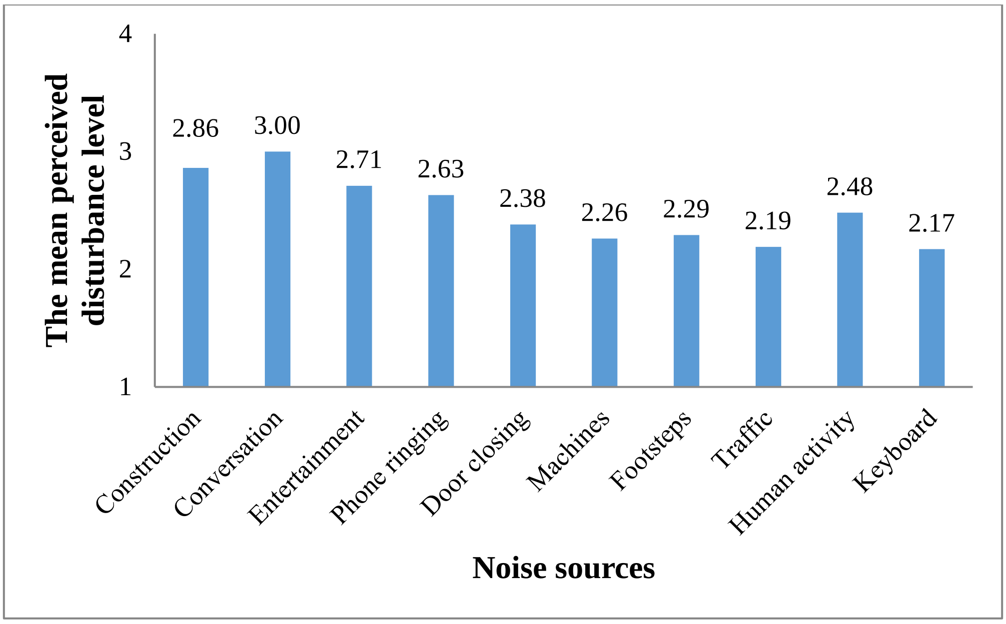

Figure 3. The mean perceived disturbance level of each noise source (through 1= not disturbing to 5= very disturbing)

Table 6 Spearman rank correlation coefficients (r_s) of IEQ aspects and sub-factors

	Layout		Acoustic environment
Equipment	0.606**	Quietness	0.642**
Personal space	0.603**	Construction	-0.108
Furniture	0.555**	Conversation	-0.448**
		Entertainment	-0.200**
	Air quality	Phone ringing	-0.311**
Ventilation	0.762**	Door closing	-0.085
Freshness	0.855**	Machines	-0.254**
		Footsteps	-0.173**
	Lighting environment	Traffic	-0.105
Artificial lighting	0.665**	Human activity	-0.285**
Natural lighting	0.763**	Keyboard	-0.231**

** Correlation significant at the 0.01 level (two-sided).

4.4 Effects of individual factors on feelings about the IEQ

Mann-Whitney U Tests and Kruskal-Wallis H Tests are utilized to further explore the effects of individual factors on respondents' assessment and perception of sub-factors. The considered individual factors can be seen in Fig.1. The calculation results are given in Tables 7 and 8, and can be summarized as follows.

For different age groups, Mann-Whitney U Tests (see Table 7) show there are statistically significant differences between younger (< 24 years old) and older (24-35 years old) groups in terms of the perception of artificial lighting, natural lighting and quietness. The mean scores of satisfaction with artificial lighting and natural lighting for the younger group are 3.87 and 3.49, respectively, which are significantly higher than for the older group, whose mean scores are 3.49 and 3.14, respectively (P-value<0.01). The mean scores of satisfaction with quietness for the younger group (3.38) is significantly higher than for the older group (3.10) (P-value<0.05). As it is known, the majority of UORO occupants are young researchers. In this survey, all the participants are below the age of 35. However, the above results suggest even in the age of below 35, older occupants (≥24 years) are more sensitive to the conditions of sub-factors (such as artificial lighting, natural lighting and office noise) and have higher requirements for office environmental quality.

For different genders, Mann-Whitney U Tests show there are statistically significant differences between males and females in several areas (see Table 7). The mean score of satisfaction with ventilation for males (3.20) is significantly higher than for females (2.92) (P-value<0.05). Also, differences are found at marginal significance levels (P-value<0.07) between males and females in terms of the perception of personal space and conversation noise. The mean score of satisfaction with personal space for males (3.41) is higher than for females (3.22), while the mean perceived disturbance level of conversation noise for females (3.15) is higher than for males (2.90). All these results suggest females have higher requirements for ventilation and personal space and are more sensitive to conversation noise. Moreover, the mean score of perception of temperature for females is 3.02, which is significantly higher than for males, whose mean score is 2.75 (P-value<0.01), which indicates that females usually feel colder than males in UOROs. In other words, females are comfortable at a temperature warmer than males.

For different birthplaces, Mann-Whitney U Tests (see Table 7) show there are statistically significant differences between participants from the south of China and the north of China, in terms of the perception of ventilation and natural lighting. The mean scores of satisfaction with ventilation and natural lighting for Southerners are 3.20 and 3.40, respectively, which are significantly higher than Northerners, whose mean scores are 2.85 and 3.01, respectively (P-value<0.05). These results imply Northerners have higher requirements for ventilation and natural lighting. However, Southerners seems to be more sensitive to some particular types of noise sources, since the mean perceived disturbance level of traffic noise for Southerners (2.28) is significantly higher than for Northerners (1.97) (P-value<0.05) and the mean perceived disturbance level of footstep noise for Southerners (2.37) is also higher than for Northerners (2.10) at a marginal significance level (P-value<0.07).

For different seat positions, Kruskal-Wallis H Tests (see Table 8) show there are statistically significant differences among participants in three seat-position conditions, in terms of the perception of ventilation, freshness, natural lighting and construction noise. Taking freshness as an example, the mean scores of satisfaction with freshness for the three seat-position groups (i.e., Window seat, Door seat and NWND seat) are 3.21, 3.35 and 2.87, respectively. The difference among these mean satisfaction scores is found to be statistically significant (p-value<0.05). As is known, the significant result given by Kruskal-Wallis H Tests only indicates there is an overall difference among the groups but cannot tell which specific groups are significantly different from each other[69]. A post hoc test is therefore needed to further examine the mean difference between any particular two groups. To this end, pairwise comparisons are subsequently performed using Dunn's procedure with a Bonferroni correction for multiple comparisons. This post hoc analysis reveals significant differences in mean satisfaction scores between Door seat and NWND seat (Bonferroni p-value<0.05), and Window seat and NWND seat (Bonferroni p-value<0.05), but not between Window seat and Door seat. In the same way, for both ventilation and natural lighting, the post hoc analysis reveals significant differences in their mean satisfaction scores between Window seat and NWND seat (Bonferroni p-values<0.05), but not between other group combinations. Similarly, pairwise comparisons for perceived disturbance levels of construction noise yield a significant difference between Window seat and NWND seat (Bonferroni p-value<0.05), but not between other group combinations. According to Kruskal-Wallis H Tests results in Table 8 and the above analysis of post hoc tests, it can finally be summarized as follows: (1) the mean score of satisfaction with ventilation for participants in NWND seat (2.75) is significantly lower than for participants in Window seat (3.24); (2) the mean score of satisfaction with freshness for participants in NWND seat (2.87) is significantly lower than for participants in Window seat (3.21) and in Door seat (3.35); (3) the mean score of satisfaction with natural lighting for participants in NWND seat (2.99) is significantly lower than for participants in Window seat (3.41); (4) the mean perceived disturbance level of construction noise for participants in NWND seat (3.21) is significantly lower than for participants in Window seat (2.68). These results again demonstrate that seat position is an important factor affecting occupants' satisfaction with office environment[70, 71]; and further indicate that in the surveyed UOROs the environmental quality is different in different seat positions, especially for sub-factors such as ventilation, freshness, natural lighting and even some particular types of noise (such as construction noise), and occupants in NWND seats are tend to feel more uncomfortable with all of these sub-factors.

For different work activities, Kruskal-Wallis H Tests (see Table 8) show there are statistically significant differences among participants engaging in five particular types of activities (i.e., literature reading, theoretical calculation, design, programming and graphing) in the term of the perception of machine noise (p-values <0.01). The post hoc analysis further reveals significant differences in mean perceived disturbance levels of this type of noise for design (2.40) and programming (1.97) (Bonferroni p-value<0.05), and design (2.40) and literature reading (2.02) (Bonferroni p-value<0.05) groups, but not between other group combinations, implying that occupants engaging in design work (e.g., research students of Architecture Department) are more disturbed by machine noise. Kruskal-Wallis H Tests (see Table 8) also show there are statistically significant differences among different activities in the term of the perception of human activity noise (p-values <0.05), although no significant pairwise differences could be identified by the subsequent post hoc test (Bonferroni p-value>0.05). This is not surprising since, as a strategy for controlling Type I error, the Bonferroni correction is conservative, and it is possible that a significant overall test (Kruskal-Wallis H) may yield no statistically significant pairwise comparisons[72, 73]. Nevertheless, a borderline-significant difference (Bonferroni p-value = 0.096) is shown between the mean perceived disturbance levels of this type of noise for graphing (2.62) and programming (2.23).

Table 7 Mann-Whitney U tests between different groups with respect to the perception of Sub-factors

		Age			Gender			Birthplace		
		<24	24-35	P-value	M	F	P-value	South	North	P-value
Layout	Equipment	3.56	3.35	0.104	3.43	3.44	0.946	3.45	3.40	0.989
	Personal space	3.39	3.31	0.523	3.41	3.22	**0.057**	3.38	3.25	0.380
	Furniture	3.35	3.35	0.751	3.34	3.36	0.922	3.38	3.26	0.331
Air quality	Ventilation	3.22	3.01	0.178	3.20	2.92	**0.039***	3.20	2.85	**0.027***
	Freshness	3.17	3.13	0.972	3.18	3.08	0.360	3.16	3.10	0.665
Thermal environment	Temperature	2.76	2.92	0.091	2.75	3.02	**0.003****	2.80	2.97	0.071
	Humidity	2.89	3.01	0.270	2.96	2.97	0.850	2.98	2.93	0.842
Lighting environment	Artificial lighting	3.87	3.49	**0.005****	3.69	3.58	0.171	3.74	3.44	0.138
	Natural lighting	3.49	3.14	**0.005****	3.36	3.16	0.217	3.40	3.01	**0.020***
Acoustic environment	Quietness	3.38	3.10	**0.022***	3.28	3.12	0.181	3.21	3.22	0.955
	Construction	2.79	2.90	0.498	2.86	2.86	0.957	2.93	2.69	0.206
	Conversation	2.84	3.10	**0.058**	2.90	3.15	**0.062**	2.99	3.00	0.980
	Entertainment	2.54	2.82	0.090	2.73	2.66	0.722	2.76	2.57	0.285
	Phone ringing	2.57	2.67	0.590	2.71	2.49	0.198	2.67	2.51	0.254
	Door closing	2.53	2.28	0.167	2.38	2.38	0.993	2.45	2.21	0.082
	Machines	2.07	2.40	**0.060**	2.32	2.16	0.365	2.23	2.34	0.677
	Footsteps	2.24	2.33	0.513	2.28	2.31	0.772	2.37	2.10	**0.068**
	Traffic noise	2.14	2.23	0.703	2.27	2.06	0.166	2.28	1.97	**0.011***
	Human activity	2.40	2.54	0.225	2.50	2.44	0.736	2.53	2.37	0.171
	Keyboard	2.25	2.12	0.203	2.14	2.22	0.808	2.17	2.18	0.892

Mean scores and P-values are given in the table;
P-values<0.07 are presented in bold and shading;
* Correlation significant at the 0.05 level (two-sided);
** Correlation significant at the 0.01 level (two-sided).

Table 8 Kruskal-Wallis H Tests among different groups with respect to the perception of Sub-factors

		Seat position				Work activity					
		Window seat	Door seat	NWND seat	P-value	Literature reading	Theoretical calculation	Design	Programming	Graphing	P-value
Layout	Equipment	3.49	3.56	3.24	0.219	3.53	3.54	3.36	3.63	3.30	0.224
	Personal space	3.38	3.41	3.22	0.430	3.45	3.43	3.31	3.43	3.25	0.685
	Furniture	3.42	3.24	3.31	0.511	3.28	3.33	3.34	3.35	3.30	0.994
Air quality	Ventilation	3.24	3.24	2.75	**0.011***	3.18	3.18	3.06	3.13	2.89	0.361
	Freshness	3.21	3.35	2.87	**0.018***	3.19	3.10	3.05	3.10	3.01	0.769
Thermal environment	Temperature	2.79	2.80	3.00	0.115	2.86	2.94	2.93	2.73	2.89	0.263
	Humidity	2.95	3.07	2.88	0.527	3.00	3.01	2.91	3.15	2.89	0.075
Lighting environment	Artificial lighting	3.72	3.74	3.46	0.092	3.71	3.64	3.51	3.87	3.56	0.086
	Natural lighting	3.41	3.41	2.99	**0.035***	3.36	3.31	3.24	3.40	3.17	0.548
Acoustic environment	Quietness	3.32	3.28	3.00	0.179	3.28	3. 30	3.21	3.34	3.07	0.629
	Construction	2.68	2.78	3.21	**0.042***	2.86	2.78	2.76	2.71	2.93	0.832
	Conversation	2.87	2.94	3.24	0.122	3.06	2.97	3.02	2.85	3.10	0.658
	Entertainment	2.58	2.70	2.91	0.285	2.62	2.49	2.69	2.63	2.77	0.647
	Phone ringing	2.65	2.39	2.79	0.152	2.52	2.40	2.71	2.44	2.69	0.206
	Door closing	2.42	2.37	2.33	0.908	2.51	2.66	2.32	2.71	2.36	0.160
	Machines	2.44	2.00	2.19	0.086	2.02	2.06	2.40	1.97	2.35	**0.001****
	Footsteps	2.22	2.26	2.45	0.424	2.21	2.15	2.43	2.08	2.38	**0.051**
	Traffic noise	2.16	2.13	2.28	0.678	2.07	2.01	2.12	2.23	2.17	0.786
	Human activity	2.45	2.46	2.55	0.645	2.39	2.31	2.55	2.23	2.62	**0.022***
	Keyboard	2.20	2.00	2.27	0.391	2.05	2.13	2.23	2.16	2.19	0.615

Mean scores and P-values are given in the table;
P-values<0.07 are presented in bold;
* Correlation significant at the 0.05 level (two-sided);
** Correlation significant at the 0.01 level (two-sided).

For further analysis of how noise sources affect office productivity, Mann-Whitney U Tests are utilized again to identify differences in the disturbance scores of noise sources between the low- and high productivity participants, as shown in Table 9. Participants are separated into low- and high-productivity groups according to the mean productivity score (3.30) of all participants as the cut-point. Except for noises of construction, machines and traffic, significant differences between the low- and high-productivity participants are found with respect to all noise sources, implying that the lower productivity participants are more likely influenced and distracted by these noise sources.

Table 9 Mann-Whitney U tests between low and high productivity groups with respect to the perception of noise sources

Noise source	Mean perceived disturbance level		P-value
	Low productivity[a]	High productivity[b]	
Construction	2.90	2.79	0.532
Conversation	3.26	2.63	0.000**
Entertainment	2.87	2.47	0.019*
Phone ringing	2.82	2.35	0.002**
Door closing	2.54	2.16	0.008**
Machines	2.35	2.15	0.159
Footsteps	2.47	2.05	0.003**
Traffic noise	2.25	2.10	0.178
Human activity	2.61	2.30	0.009**
Keyboard sound	2.37	1.90	0.002**

Mean scores and P-values are given in the table;
[a] Productivity score is lesser than the mean productivity score of all participants;
[b] Productivity score is larger than the mean productivity score of all participants;
* Correlation significant at the 0.05 level (two-sided);
** Correlation significant at the 0.01 level (two-sided).

5. Discussion

The survey of UOROs in this study demonstrates again the importance of the quality of the five key IEQ aspects (i.e., layout, air quality, thermal environment, lighting environment and acoustic environment) to work productivity in UOROs and the significant impacts of environmental sub-factors on these IEQ aspects.

In terms of UORO layout, the results largely confirm previous findings[4, 15] showing that personal space, equipment and furniture are vital sub-factors that impact occupants' workspace satisfaction.

In terms of air quality, the quality of ventilation and freshness is proved to be significant, which is in line with previous studies[35, 37, 38]. The results also reveal (1) the occupants who are female, born in the south of China, and sitting neither near a window or door tend to have lower satisfaction with ventilation, compared to those who are male, born in the north of China, and sitting near a window or door, respectively; and (2) the occupants who are sitting neither near a window or door tend to have lower satisfaction with freshness, compared to those who are sitting near a window or door.

In terms of thermal environment, the conditions of temperature and humidity in most of the surveyed UOROs are suitable for their office work. Also, the comfortable temperature for females tend to be a little higher than for males in UOROs, which is in agreement with previous studies[74, 75].

In terms of lighting environment, the perception of natural lighting has a higher correlation with the overall lighting environment than artificial lighting, which is in line with previous studies[50, 76]. The level of satisfaction with natural lighting however is found to be much lower than that with artificial lighting in the surveyed UOROs, indicating that more attention should be paid to improve the quality of natural lighting in these UOROs. The results also reveal (1) the occupants who are of older age, born in the north of China, and sitting neither near a window or door tend to have lower satisfaction with natural lighting, compared to those who are of younger age, born in the south of China, and sitting near a window, respectively; and (2) the occupants who are of older age tend to have lower satisfaction with artificial lighting, compared to those who are of younger age.

In terms of acoustic environment, the satisfaction of acoustic environment depends largely on the perception of quietness, and 7 common office noise sources (including conversation, entertainment, phone ringing, machines, footsteps, human activity and keyboard) are found to have significant negative impact on the quality of UORO's acoustic environment. The results also reveal (1) The occupants who are of older age (24 to 35 years old) tend to be more sensitive to office noise and have lower satisfaction with the quietness in UOROs, compared to those who are of younger age (below 24 years old); (2) the occupants who are born in the south of China tend to be more sensitive to traffic noise, compared to those who are born in the north of China; (3) the occupants who are engaging in design work are more disturbed by machine noise, compared to those who are engaging programming work and those who are engaging literature reading work.

Another notable observation from the surveyed results is that, among the five key IEQ aspects, the quality of the acoustic environment has the highest positive correlation with work productivity in UOROs. Previous studies on general open-plan offices also show the quality acoustic environment is important but usually not the top significant one among the key IEQ aspects[20, 71, 77-79]. The difference between the findings of this study and the previous studies seems a little surprising, since UOROs commonly have a better acoustic environment than general open-plan offices. Firstly, university's campuses are usually much quieter than other areas in the city, and offices inside the campus naturally have a better ambient acoustic environment than those outside the campus (i.e., UOROs have less noise around their buildings than general open-plan offices). In addition, it is normal that the quality of the acoustic environment in research offices is better than in general open-plan offices, because the activities in general open-plan offices, such as administrator affairs, receiving visitors and making business phone calls, make much more noise than those in UOROs (i.e., UOROs have less noise inside their rooms than general open-plan offices). Although the quality of acoustic environment in UOROs should be better than general open-plan offices, our survey shows the acoustic environment has the lowest evaluation score of satisfaction and has the highest positive correlation with work productivity in UOROs. A possible explanation for this could be that, as mentioned in the beginning of the paper, the types of activities in which occupants are engaged in UOROs are much more special, most of which are complex mental work that requires higher levels of concentration and consistency. The results in this study therefore imply that occupants working in UOROs tend to have higher requirements for acoustic environment than in general open-plan offices.

6. An IEQ evaluation approach for UOROs

Based on the results and analysis of this study, a decision-making strategy for UORO's IEQ evaluation and improvement is further proposed. Seven steps are included in this approach, with the flowchart of procedure shown in Fig. 4.

As shown in Fig. 4, the first two steps require a survey for assessing the occupants' work productivity in the office and the IEQ of the office. The office IEQ can be investigated by assessing the quality of key IEQ aspects (such as acoustic environment) and their corresponding sub-factors. Based on the survey data, the impacts of key IEQ aspects on office productivity are examined in Step 3, as well as the relationships between key IEQ aspects and their corresponding sub-factors in Step 4. Step 5 further explores how individual factors, such as age, gender and work activities, affect the perception of the IEQ, especially how individual factors affect the perception of the quality of sub-factors. Finally, the sub-factors in which UORO designers should pay more attention to as well as specific efforts that should be made by considering the effects of individual factors are identified in Step 6, and therefore gives more precise suggestions on the design and improvement of UOROs in Step 7.

Following this procedure, the findings of this study are also summarized in Fig. 4. The thin arrow lines in the figure indicate the items have significant impacts on the performance of the target items.

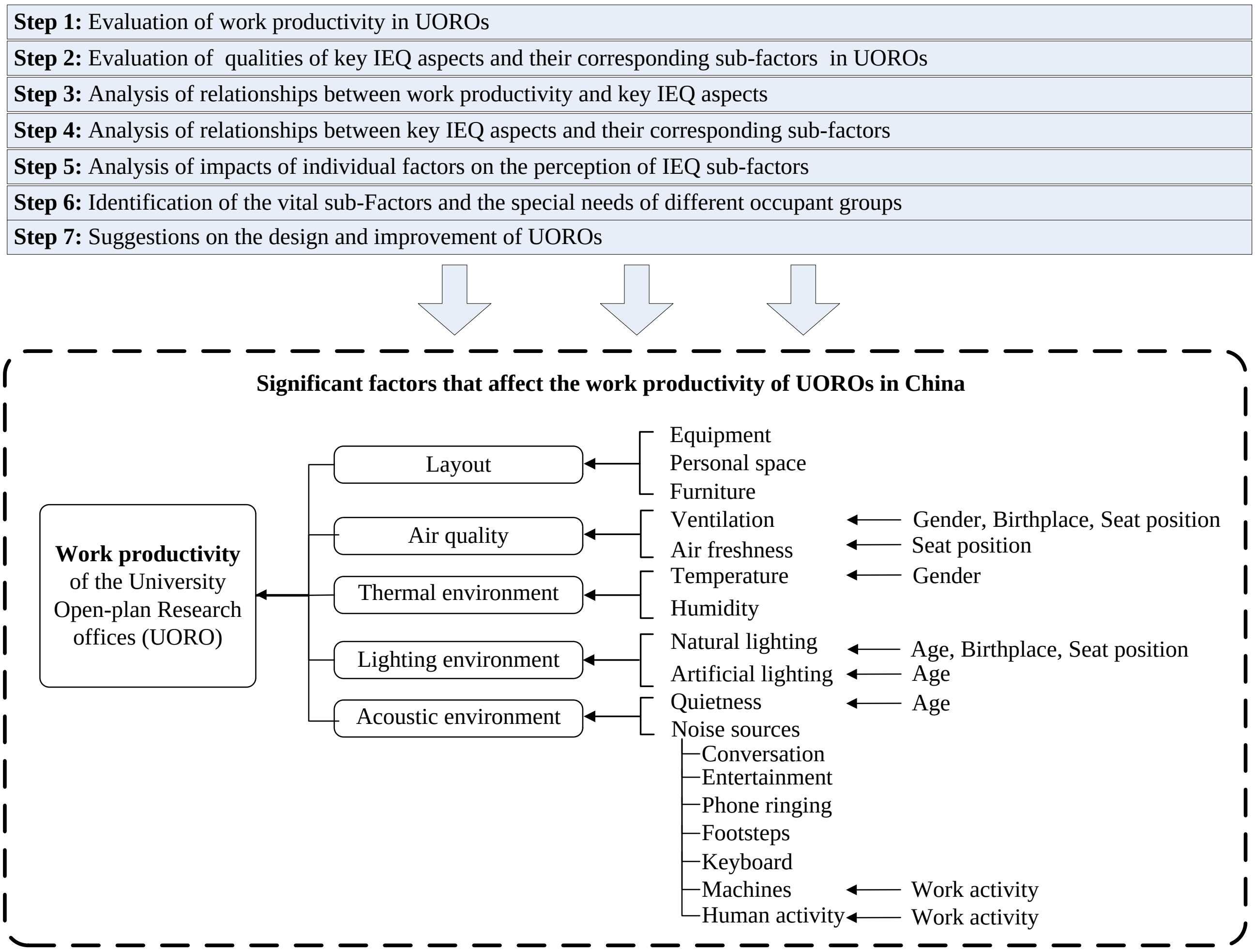

Figure 4. An IEQ evaluation approach for UOROs and its application in this study

7. Conclusions

A survey was carried out to study the relationship between work productivity and the indoor environmental quality (IEQ) in university open-plan research offices (UOROs) and the relationship between UORO occupants' perception of IEQ aspects and their corresponding sub-factors.

Three findings can be drawn from the analysis results:

1) The qualities of the five key IEQ aspects, including layout, air quality, thermal comfort, lighting and acoustic environment, have significantly positive correlations with office productivity.
2) Among the five key IEQ aspects, the quality of acoustic environment has the greatest influence on productivity in UOROs. Quietness is the most important criterion for the

acoustic environment; and among the common noises in UOROs, conversation noise has the highest significant negative impact on the acoustic environment.

3) UORO occupants’ perception of sub-factors depends on individual factors, such as age, gender, birthplace, seat position and work activity. Different age groups can have different sensitivities to artificial lighting, natural lighting and office noise. Different genders can have different sensitivities to ventilation and temperature. Occupants born in different place can have different sensitivities to ventilation, natural lighting and some certain type of noise (traffic noise). Occupants sitting in different seat positions can have different sensitivities to ventilation, freshness, natural lighting and some certain type of noise (construction noise). Occupants engaged in different activities can have different sensitivities to some certain types of noise (machine noise and human activity noise).

Based on the results and analysis of this study, a seven-step decision-making strategy for UORO’s IEQ evaluation and improvement is also proposed. This approach can help to identify the vital environmental sub-factors that affect the occupants’ productivity in UOROs and the effects of individual factors on occupants’ perception of these sub-factors in UOROs. The study of the effects of IEQ factors on work productivity in UOROs is still lacking in the literature; therefore the idea proposed in this study as well as the findings could be valuable for both academic and design practitioners.

Acknowledgments

The work was supported by National Natural Science Foundation of China (51578252), State Key Lab of Subtropical Building Science, South China University of Technology (2016ZB06), Cultivation Program for Distinguished Young Scientific Research Talents in Fujian Province University of China (2016), and Subsidized Project for Cultivating Postgraduates’ Innovative Ability in Scientific Research of Huaqiao University.

Moreover, the authors would like to acknowledge Mr Zhou Xinxin and Miss Zhang Tingting, who have helped in the early-stage preparation and questionnaire collection.

References

[1] ISO 3382-3, Acoustics - Measurement of room acoustic parameters. Part 3: Open plan offices, International Organization for Standardization, Switzerland, 2012.

[2] Walford G., Postgraduate education and the student's contribution to research, ***British Journal of Sociology of Education***, 4:241-254 (1983).

[3] Smith-Jackson T.L. and Klein K.W., Open-plan offices: Task performance and mental workload, ***Journal of Environmental Psychology***, 29:279-289 (2009).

[4] Kim J. and de Dear R., Workspace satisfaction: The privacy-communication trade-off in open-plan offices, ***Journal of Environmental Psychology***, 36:18-26 (2013).

[5] Kaarlela-Tuomaala A., Helenius R., Keskinen E. and Hongisto V., Effects of acoustic environment on work in private office rooms and open-plan offices - longitudinal study during relocation, ***Ergonomics***, 52:1423-1444 (2009).

[6] Danielsson C.B. and Bodin L., Difference in satisfaction with office environment among employees in different office types, ***Journal of Architectural & Planning Research***, 26:3-242 (2010).

[7] Venetjoki N., Kaarlela-Tuomaala A., Keskinen E. and Hongisto V., The effect of speech and speech intelligibility on task performance, ***Ergonomics***, 49:1068-1091 (2006).

[8] Villa C. and Labayrade R., A suitable and energy-efficient luminous environment for a shared office, ***Lighting Research & Technology***, 48:755-770 (2015).

[9] Lamanauskas V. and Augien D., Development of scientific research activity in university: A position of the experts, ***Procedia - Social and Behavioral Sciences***, 167:131-140 (2015).

[10] Lamanauskas V., Development of scientific research activity as the basic component of science education, ***Journal of Baltic Science Education***, 11:200-202 (2012).

[11] Haynes B.P., Office productivity: A theoretical framework, ***Journal of Corporate Real Estate***, 9:97-110 (2007).

[12] Smith A.D., Online social networking and office environmental factors that affect worker productivity, ***International Journal of Procurement Management***, 6:578-608 (2013).

[13] Horr Y.A., Arif M., Kaushik A., Mazroei A., Katafygiotou M. and Elsarrag E., Occupant productivity and office indoor environment quality: A review of the literature, ***Building & Environment***, 105:369-389 (2016).

[14] Kupritz V., Accommodating privacy to facilitate new ways of working, ***Journal of Architectural & Planning Research***, 20:122-135 (2003).

[15] Kim J. and Dear R.D., Nonlinear relationships between individual IEQ factors and overall workspace satisfaction, ***Building & Environment***, 49:33-40 (2012).

[16] Haynes B.P., The impact of office layout on productivity, ***Journal of Facilities Management***, 6:189-201 (2008).

[17] Maher A. and Hippel C.V., Individual differences in employee reactions to open-plan offices, ***Journal of Environmental Psychology***, 25:219-229 (2005).

[18] Li L., Wargocki P. and Lian Z., Quantitative measurement of productivity loss due to thermal discomfort, ***Energy & Buildings***, 43:1057-1062 (2011).

[19] Humphreys M.A., Quantifying occupant comfort: Are combined indices of the indoor environment practicable? ***Batiment International, Building Research and Practice***, 33:317-325 (2005).

[20] Mak C. and Lui Y., The effect of sound on office productivity, ***Building Services Engineering Research and Technology***, 33:339-345 (2012).

[21] Hygge S. and Knez I., Effects of noise, heat and indoor lighting on cognitive performance and self-reported affect, ***Journal of Environmental Psychology***, 21:291-299 (2001).

[22] Lan L., Wargocki P., Wyon D.P. and Lian Z., Effects of thermal discomfort in an office on perceived air quality, SBS symptoms, physiological responses, and human performance, ***Indoor Air***, 21:376-390 (2011).

[23] Maula H., Hongisto V., östman L., Haapakangas A., Koskela H. and Hyönä J., The effect of slightly warm temperature on work performance and comfort in open-plan offices – a laboratory study, ***Indoor Air***, 26:674-684 (2016).

[24] ISO 7730, ergonomics of the thermal environment analytical determination and interpretation of thermal

comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, international organization for standardization, geneva, 2005..

[25] BS EN ISO 7730, Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, British Standards Institution, London, 2005..

[26] ASHRAE Standard 55. Thermal Environmental Conditions for Human Occupancy, Standing Standard Project Committee, Atlanta, 2013 .

[27] Lin Z. and Deng S., A study on the thermal comfort in sleeping environments in the subtropics—Developing a thermal comfort model for sleeping environments, ***Building & Environment***, 43:70-81 (2008).

[28] Fisk W.J., Health and productivity gains from better indoor environments and their relationship with building energy efficiency, ***Environment and Resources***, 25:537-566 (2000).

[29] Tanabe S., Nishihara N. and Haneda M., Indoor temperature, productivity, and fatigue in office tasks, ***Hvac & R Research***, 13:623-633 (2007).

[30] Kosonen R. and Tan F., The effect of perceived indoor air quality on productivity loss, ***Energy & Buildings***, 36:981-986 (2004).

[31] Wargocki P., Wyon D.P., Sundell J., Clausen G. and Fanger P.O., The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity, ***Indoor Air***, 10:222-236 (2000).

[32] Park J.S. and Yoon C.H., The effects of outdoor air supply rate on work performance during 8-h work period., ***Indoor Air***, 21:284-290 (2011).

[33] Saari A., Tissari T., Valkama E. and Seppänen O., The effect of a redesigned floor plan, occupant density and the quality of indoor climate on the cost of space, productivity and sick leave in an office building – a case study, ***Building & Environment***, 41:1961-1972 (2006).

[34] Wargocki P., Wyon D.P., Yong K.B., Clausen G. and Fanger P.O., Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads, ***Indoor Air***, 9:165-179 (1999).

[35] Wargocki P., Wyon D.P., Sundell J., Clausen G. and Fanger P.O., The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity, ***Indoor Air***, 10:222-236 (2000).

[36] Varjo J., Hongisto V., Haapakangas A., Maula H., Koskela H. and Hyönä J., Simultaneous effects of irrelevant speech, temperature and ventilation rate on performance and satisfaction in open-plan offices, ***Journal of Environmental Psychology***, 44:16-33 (2015).

[37] Sundell J., Levin H., Nazaroff W.W., Cain W.S., Fisk W.J., Grimsrud D.T., Gyntelberg F., Li Y., Persily A.K. and Pickering A.C., Ventilation rates and health: Multidisciplinary review of the scientific literature, ***Indoor Air***, 21:191-204 (2011).

[38] Xue P., Mak C.M. and Ai Z.T., A structured approach to overall environmental satisfaction in high-rise residential buildings, ***Energy and Buildings***, 116:181-189 (2016).

[39] Knasko S.C., Performance, mood, and health during exposure to intermittent odors, ***Archives of Environmental Health: An International Journal***, 48:305-308 (1993).

[40] Michael G.A., Jacquot L., Millot J.L. and Brand G., Ambient odors influence the amplitude and time course of visual distraction, ***Behavioral Neuroscience***, 119:708-715 (2005).

[41] Danuser B., Moser D., Vitale-Sethre T., Hirsig R. and Krueger H., Performance in a complex task and breathing under odor exposure, ***Human Factors the Journal of the Human Factors & Ergonomics Society***, 45:549-562 (2003).

[42] Gaygen D.E. and Hedge A., Effect of acute exposure to a complex fragrance on lexical decision performance, ***Chemical Senses***, 34:85-91 (2009).

[43] Haapakangas A., Keränen J., Nyman M. and Hongisto V., Lighting improvement and subjective working conditions in an industrial workplace, ***Light & Engineering***, 20:86-96 (2012).

[44] Kowalska M., Zejda J.E., Bugajska J., Braczkowska B., Brozek G. and Malińska M., Eye symptoms in office employees working at computer stations, ***Medycyna Pracy***, 62:1-8 (2011).

[45] Baron R.A., Rea M.S. and Daniels S.G., Effects of indoor lighting (illuminance and spectral distribution) on the performance of cognitive tasks and interpersonal behaviors: The potential mediating role of positive affect, ***Motivation and Emotion***, 16:1-33 (1992).

[46] Xue P., Mak C.M. and Cheung H.D., The effects of daylighting and human behavior on luminous comfort in residential buildings: A questionnaire survey, ***Building & Environment***, 81:51-59 (2014).

[47] Nagy E., Yasunaga S. and Kose S., Japanese office employees' psychological reactions to their underground and above-ground offices, ***Journal of Environmental Psychology***, 15:123-134 (1995).
[48] Kaida K., Takahashi M. and Otsuka Y., A short nap and natural bright light exposure improve positive mood status, ***Industrial Health***, 45:301-308 (2007).
[49] Bommel W.V. and Beld G.V.D., Lighting for work: A review of visual and biological effects, ***Lighting Research & Technology***, 36:255-269 (2004).
[50] Galasiu A.D. and Veitch J.A., Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: A literature review, ***Energy & Buildings***, 38:728-742 (2006).
[51] Rubinstein F.M., Comparison of control options in private offices in an advanced lighting controls testbed, ***Journal of the Illuminating Engineering Society***, 29:39-60 (2013).
[52] Escuyer S. and Fontoynont M., Lighting controls: A field study of office workers' reactions, ***Lighting Research & Technology***, 33:77-94 (2001).
[53] Yamakawa K., Watabe K., Inanuma M., Sakata K. and Takeda H., A study on the practical use of a task and ambient lighting system in an office, ***Journal of Light & Visual Environment***, 24:15-18 (2000).
[54] Lee P.J., Lee B.K., Jeon J.Y., Zhang M. and Kang J., Impact of noise on self-rated job satisfaction and health in open-plan offices: A structural equation modelling approach, ***Ergonomics***, 59:222-234 (2015).
[55] Roelofsen P., Performance loss in open-plan offices due to noise by speech, ***Journal of Facilities Management***, 3:202-211 (2008).
[56] Jahncke H., Hygge S., Halin N., Green A.M. and Dimberg K., Open-plan office noise: Cognitive performance and restoration, ***Journal of Environmental Psychology***, 31:373-382 (2011).
[57] Haapakangas A., Hongisto V., Hy N J., Kokko J. and Ker Nen J., Effects of unattended speech on performance and subjective distraction: The role of acoustic design in open-plan offices, ***Applied Acoustics***, 86:1-16 (2014).
[58] Jones D.M. and Tremblay S., Interference in memory by process or content? A reply to Neath (2000), ***Psychonomic Bulletin & Review***, 7:550-558 (2000).
[59] Banbury S.P., Macken W.J., Tremblay S. and Jones D.M., Auditory distraction and short-term memory: Phenomena and practical implications, ***Human Factors the Journal of the Human Factors & Ergonomics Society***, 43:12-29 (2001).
[60] Banbury S.P. and Berry D.C., Office noise and employee concentration_ Identifying causes of disruption and potential improvements, ***Ergonomics***, 48:25-37 (2005).
[61] Mak C.M. and Wang Z., Recent advances in building acoustics: An overview of prediction methods and their applications, ***Building and Environment***, 91:118-126 (2015).
[62] Ou D.Y., Low frequency sound insulation analysis and evaluation of stiffened building structures, ***Building and Environment***, 94:802-809 (2015).
[63] Haka M., Haapakangas A., Keränen J., Hakala J., Keskinen E. and Hongisto V., Performance effects and subjective disturbance of speech in acoustically different office types - a laboratory experiment, ***Indoor Air***, 19:454-467 (2009).
[64] BS EN ISO 3382-3, Acoustics — Measurement of room acoustic parameters Part 3: Open plan offices, British Standards Institution, London, 2012..
[65] ASTM e1130, measurement of speech privacy in open plan spaces using articulation index, the world trade organiziation technical barriers to trade (TBT) committee,2016.
[66] Hongisto V., A model predicting the effect of speech of varying intelligibility on work performance, ***Indoor Air***, 15:458-468 (2005).
[67] Hongisto V., Varjo J., Leppamaki H., Oliva D. and Hyona J., Work performance in private office rooms: The effects of sound insulation and sound masking, ***Building and Environment***, 104:263-274 (2016).
[68] Wong H.M., Mak C.M. and Xu Y.F., A four-part setting on examining the anxiety-provoking capacity of the sound of dental equipment, ***Noise & Health***, 13:385-391 (2011).
[69] Morgan G.A., Leech N.L., Gloeckner G.W. and Barrett K.C. *IBM SPSS for introductory statistics: Use and interpretation*, Taylor & Francis Group, New York and London, 2013.
[70] Yildirim K., Akalin-Baskaya A. and Celebi M., The effects of window proximity, partition height, and gender on perceptions of open-plan offices, ***Journal of Environmental Psychology***, 27:154-165 (2007).
[71] Frontczak M., Schiavon S., Goins J., Arens E., Zhang H. and Wargocki P., Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design, ***Indoor Air***, 22:119-131 (2012).
[72] Hannah M.A. and Lam C., Patterns of dissemination: Examining and documenting practitioner knowledge sharing practices on blogs, ***Technical Communication***, 63:328-345 (2016).
[73] Sedgwick P., STATISTICAL QUESTION Multiple hypothesis testing and Bonferroni's correction, ***BMJ-***

British Medical Journal, 349:g6284 (2014).
[74] Kim J., de Dear R., Candido C., Zhang H. and Arens E., Gender differences in office occupant perception of indoor environmental quality (IEQ), ***Building and Environment***, 70:245-256 (2013).
[75] Kingma B. and Lichtenbelt W.V.M., Energy consumption in buildings and female thermal demand, ***Nature Climate Change***, 5:1054 (2015).
[76] Reinhart C.F., Effects of interior design on the daylight availability in open plan offices, ***Proceedings of the Aceee Summer Study on Energy Efficiency in Buildings***,3-309 (2002).
[77] Newsham G., Brand J., Donnelly C., Veitch J., Aries M. and Charles K., Linking indoor environment conditions to job satisfaction: A field study, ***Building Research and Information***, 37:129-147 (2009).
[78] Kim J. and de Dear R., Workspace satisfaction: The privacy-communication trade-off in open-plan offices, ***Journal of Environmental Psychology***, 36:18-26 (2013).
[79] Veitch J.A., Charles K.E., Newsham G.R., Marquardt C.J.G. and Geerts J. Environmental satisfaction in Open-Plan environments: 5. Workstation and physical condition effects. [R]. National Research Council of Canada, Institute for Research in Construction, 2003.