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A structured approach to overall environmental satisfaction in high-rise residential buildings

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Abstract

A survey was conducted with a sample of 482 residents in high-rise residential buildings to investigate the impact of aspects of indoor environmental quality (IEQ) on occupants' overall environmental satisfaction (OES). A three-step approach was proposed to structure the OES. The structure was first tested by the non-parametric tests and the results of statistical analysis showed that the combined aspect of air quality and thermal comfort had the greatest influence on OES in apartments, followed by luminous comfort and acoustic comfort. A detailed structure was then developed and proved residents' subjective feelings about certain sub-factors, such as air freshness, had strong correlations with each IEQ aspect. The individual items, namely gender, age, physical environment, and adaptive behaviors, were further explored and tested. The results show that most of the items had significant impact on occupants' feelings regarding sub-factors. The adaptive behaviors of shading and lighting affect luminous comfort significantly and activity intensity and mental stress decides acoustic comfort most. In further studies, the OES could be quantified with the data from both real condition simulation and questionnaire survey.

Keywords: Overall environmental satisfaction; Residential buildings; Air quality; Thermal comfort; Luminous comfort; Acoustic comfort

1. Introduction

People spend nearly 87% of their time indoors (Klepeis et al., 2001) and over half of this time in their homes. Some studies have shown that indoor environmental quality (IEQ) has a significant impact on human productivity (Leaman, 1995), health (Jones, 1999), and satisfaction (Abbaszadeh, Zagreus, Lehrer, & Huizenga, 2006). Unlike human productivity and health, satisfaction is subjective, but a high level will lead to good mood and health in the long term (Faragher, Cass, & Cooper, 2005). Therefore, it is necessary to investigate the way in which residents' perception of their indoor environment affects their overall environmental satisfaction (OES). A number of studies have indicated that it is complicated to break down satisfaction into categories and determine how these categories contribute to overall satisfaction. Some results are contradictory due to the researchers' different purposes, methods, and hypotheses.

Rehdanz and Maddison (2008) showed that higher noise levels and local air pollution significantly diminish occupants' subjective satisfaction when controlling other factors. Frontczak, Andersen, and Wargocki (2012) claimed that the acceptability of overall indoor environment could be estimated by combining the acceptability of thermal, visual, and acoustic conditions and air quality. Beside these aspects, privacy has also been considered to have a great impact on OES (Amole, 2009; Hua, Göçer, & Göçer, 2014; Kim & de Dear, 2012; Newsham, Veitch, & Charles, 2008). Lai and Yik (2009) said that IEQ attributes were intended to give more consistent judgment by residents who have familiarized themselves with their living environment over time. Newsham et al. (2009) investigated occupants' satisfaction by focusing on other physical measurements, such as furniture dimensions, and an assessment of potential exterior view. Kim and de Dear (2012) estimated the individual impacts of 15 IEQ aspects on occupants' OES and distinguished between aspects that have a linear and a non-linear relationship with overall satisfaction. These studies recognized thermal, visual, and acoustic conditions and air quality as the key contributors to OES, even when other aspects were accounted for. Therefore, it is reasonable to state that OES decreases if occupants have problems with these IEQ aspects. Leaman and Bordass (2001) developed sophisticated approaches for capturing and understanding user requirements. With new approaches, the Building Use Studies (BUS) methodology could help design a questionnaire and make it possible to obtain quantitative and qualitative feedback through post-occupancy evaluation.

Frontczak et al. (2012) found that noise level and sound privacy had a significant influence on office occupants' satisfaction. Humphreys (2005) conducted a survey about office in Europe and found that air temperature and quality were more important than satisfaction with lighting. Leaman and Bordass (1999) reported that building attributes, such as the depth of the building, can affect the occupants' satisfaction. As the buildings get deeper, the satisfaction levels with buildings and self-reported productivity will decrease. Lai and Yik (2009) conducted a survey in residential buildings in Hong Kong and showed that residents who have familiarized over time with their living environment tend to give more consistent judgment of the relative importance between pairs of: thermal comfort, air cleanliness, odor and noise. A strong positive correlation was also found between perceived Indoor air quality (IAQ) and OES by Chan, Lam, and Wong (2008). However, the ranking of OES aspects differs in residential buildings. An occupant survey conducted in Danish homes (Frontczak, Andersen, & Wargocki, 2012) concluded that the relationship between air quality and overall acceptability was the most important, followed by visual, acoustic, and thermal quality. A similar conclusion, that indoor air had the highest impact, was also obtained in a study of Swedish apartment buildings (Zalejska-Jonsson & Wilhelmsson 2013). Frontczak and Wargocki (2011) drew the conclusion that thermal comfort is ranked by occupants to be of greater importance than other aspects. An investigation conducted in China also suggested that thermal comfort has the highest impact on OES (Cao et al., 2012).

From the results mentioned above, one can see that the relative importance of the four key aspects differs from country to country. Different regions, cultures, and population densities make it impossible to develop a valid general formula to evaluate OES. It is therefore reasonable to evaluate each key aspect separately rather than relying on a combined index (Humphreys, 2005).

Hong Kong is one of the world's most densely populated cities, with the largest number of skyscrapers and high-rise buildings. Residential buildings of 40-plus stories are the most common type of housing in Hong Kong, and most citizens live in these high-rise apartment buildings. Private housing is generally occupied by high-income owners. Although the living space in these flats is larger than average (Lai & Yik, 2009), the per capita area is still smaller than in other countries. Owing to its position in the sub-tropic of Cancer and its dense buildings, most occupants tolerate higher air temperatures, dimmer daylight inside their residence, higher noise levels, and higher dust concentration in their daily life than average (Chan, Lam, & Wong, 2008).

The objective of the present study is to propose an approach assessing the impact of IEQ aspects on occupants' OES. This survey also aims to understand how sub-factors such as air freshness affect each IEQ aspect separately and to investigate the effects of physical environment and residents' adaptive behaviors on their subjective feelings about those sub-factors. The analysis is based on response data collected during the autumns of 2013 and 2014. The results offer insights into how residents perceive OES in high-rise residential buildings. This result is a fundamental work to quantify the OES. It will also be possible to find and benchmark the key parameters with these questionnaire data and future simulation results. Therefore, guiding the building-efficiency design without eroding occupants' satisfaction with overall environment could be achieved.

2. Literature review

OES, as a subjective evaluation, can be affected by various aspects. The literature provides evidence that IEQ, building physical environment, and adaptive behaviors contribute significantly to how occupants perceive their indoor OES.

2.1 Indoor environmental quality

Air turbulence transfers energy and the velocity field has a great impact on concentration and temperature fields.

Air temperature is the key sub-factor of thermal comfort and air quality (Indraganti, 2010). In the thermal comfort equation, air velocity and humidity should also be measured first (Fanger, 1970). Nicol and Roaf (2005) clarified the relationships between clothing insulation, metabolic heat, and the thermal balance of the body. Research groups under the supervision of Mak found that building features could reduce the indoor average velocity for most rooms (Ai et al., 2011). The incursion of outdoor pollutants by infiltration and ventilation has also been found to be an important sub-factor in IAQ (Ai, Mak, & Niu, 2013; Cui, Mak, & Niu, 2013). Givoni, Khedari, Wong, Feriadi, and Noguchi (2006) expected humidity to be another important sub-factor, but their result shows that humidity level had a very small impact upon the thermal comfort of their subjects. Though air quality and thermal comfort are two important aspects of IEQ, many studies have investigated them together (Huizenga, Abbaszadeh, Zagreus, & Arens, 2006; Lee, 2011; Mendes et al., 2013).

Luminous comfort is satisfaction with the luminous environment, and the level is most affected by the quality of daylight (Galasiu & Veitch, 2006; Xue, Mak, & Cheung, 2014). The window is the medium by which daylight accesses indoor areas and it is a significant predictor of satisfaction with lighting (Newsham et al. 2009; Aries, Aarts, & van Hoof, 2013). Features (such as floor plan, façade elements, type and shape of exterior shading, interior shade type, window size) (Hua, Oswald, & Yang, 2011), uncomfortable glare (Hirning, Isoardi, & Cowling, 2014; Kim & Kim, 2010; Beck, Körner, Gross, & Fricke, 1999), luminance distribution (Hwang & Jeong, 2011), and solar access hours (Xue, Mak, & Cheung, 2014) are also thought to be key sub-factors determining luminous comfort.

Satisfaction with acoustics is strongly affected by physical environmental parameters (Leder et al., 2015) and sound insulation performance when residents want a quiet environment for relaxation and sleeping (Hongisto, Mäkilä, & Suokas, 2015). Studies have shown that building features can reduce the level of noise from outside, such as traffic noise (Bleiberg, Rosenhouse, & Shaviv, 2007; Lee, Kim, Jeon, & Song, 2007; Ishizuka & Fujiwara, 2012). Indoor noise sources, such as conversation, ringing phones, and machines, can also reduce satisfaction (Sundstrom, Town, Rice, Osborn, & Brill, 1994).

2.2 Building physical environment

Physical environment has been shown to have relationships with satisfaction with lighting, ventilation, and acoustics (Newsham et al., 2009). Floor level, orientation, window area, living room area, building features, and external obstructions have been confirmed as significant sub-factors of IEQ (Li, Wong, Tsang, & Cheung, 2006; Oswald, Jopp, Rott, C& Wahl, 2011; Xue, Mak, & Cheung, 2014). Dynamic façade technology also has an important role in balancing various aspects of IEQ (Bakker, Hoes-van Oeffelen, Loonen, & Hensen, 2014).

2.3 Adaptive behaviors

OES is influenced not only by physical conditions, but also by residents' psychological adaptive behaviors (Kaplan, 2001; Keyvanfar et al., 2014). Studies have demonstrated that adjusting behaviors, such as opening windows, closing blinds, and fitting clothing, is important to enhancing indoor comfort effectively (Farley & Veitch, 2001; Schweiker et al., 2012). Experiments have revealed that these behaviors are often affected by physical environment (Shin, Kim, & Kim, 2013) and climate (Jamaludin et al., 2014; De Freitas, 2015), though there is a little difference between females and males in perception of the same environment (Karjalainen, 2012). Residents are aware that their behavior is influenced by IEQ (Frontczak et al., 2012), so qualitative behavior studies are still called for to establish a reasonable range of indoor comfort levels (Lee, Cho, & Kim, 2012).

2.4 Improve the OES structure

The literature review indicates that occupants' OES depends mostly on three aspects of IEQ, but that the perception of these IEQ aspects depends on sets of occupants' subjective feelings about sub-factors. In addition, buildings' physical parameters and individual behaviors have impacts on feelings about these sub-factors. Therefore, we proposed a three-step approach to assess OES (Fig. 1) in order to achieve the objectives mentioned in Section 1.

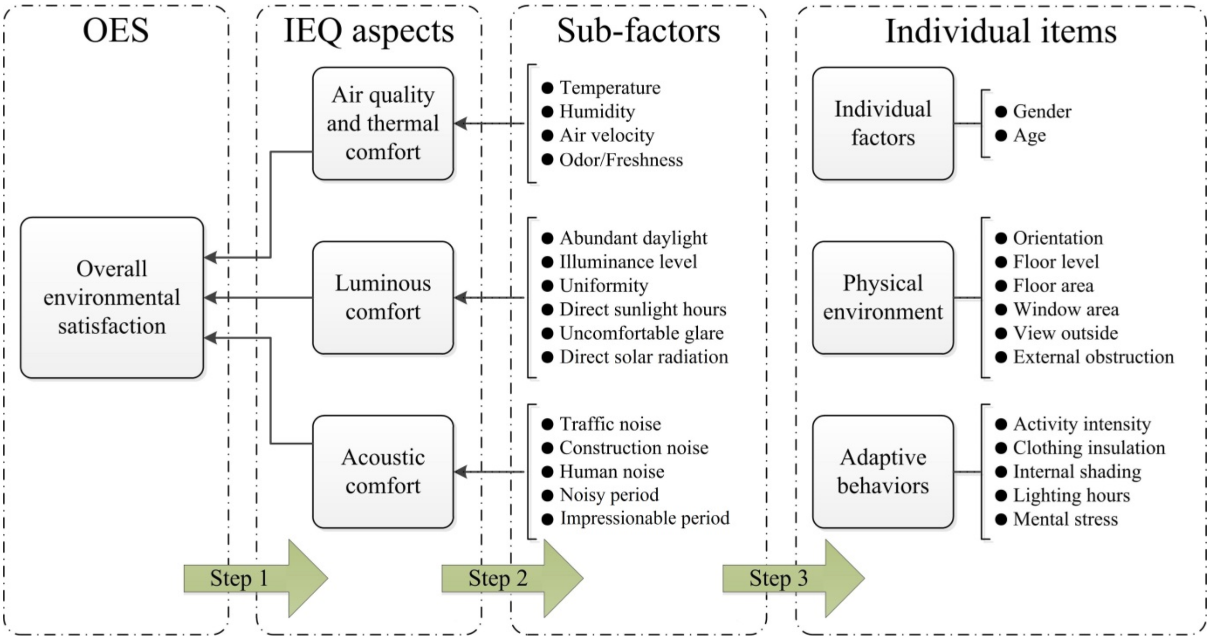

Fig. 1 Proposed structure of OES

In the first step, the impact of IEQ aspects on occupants' OES is investigated. The second step aims to understand how sub-factors such as air freshness affect each IEQ aspect separately. Then the third step investigates the effects of physical environment and residents' adaptive behaviors on their subjective feelings about those sub-factors.

3. Methodology

3.1 Questionnaire survey

The survey was conducted during the autumns of 2013 and 2014. Participants were recruited via mail from residents of five 40-story blocks and 482 valid questionnaires were returned for further analysis. All the apartments had natural ventilation without using air conditioning. The questionnaire was divided into four parts, which aimed to collect data on the residents' OES, satisfaction with IEQ aspects, and occupants' subjective feelings about sub-factors and individual items. The improved structure of OES is proposed as Fig. 1, which presents the rationale of the questionnaire. The question items are organized in four parts (https://drive.google.com/file/d/0BwM_rpEbtdprSGwxTnVpNjZnUlk/view?usp=sharing). Part 1 investigated the participants' demographic characteristics, the physical environmental parameters of their housing, and participants' general behaviors. Part 2 involved the residents' feelings about these three IEQ aspects. Part 3 comprised three questions about the residents' satisfaction with air quality and thermal condition, luminous environment, and acoustic environment. Part 4 only collected the level of occupants' overall OES. Apart from the data for the nominal variables from several questions such as a question regarding gender, all the other data were order variables because the questions were answered on a five-point scale (from 1 = very dissatisfied to 5 = very satisfied).

3.2 Sampling

Hong Kong has four types of housing: public rental housing, subsidized home ownership housing, private permanent housing, and temporary housing. In the last decade, most new residential developments have been private housing because of the temporary halt of public housing development by the Hong Kong government. The statistics of a recent survey show that private permanent housing became a major component, with 53% of all units in Hong Kong (Census and Statistics Department, 2014). A pilot study was conducted to check the reliability of the questionnaire and develop the questions. The main survey was conducted among private housing units in a newly developed district, Tseung Kwan O. All of the selected buildings had over 40 stories, and the floor area of each unit was between 45–60 m^2.

3.3 Statistical analysis

The data were analyzed with SPSS 19.0. The psychometric questions were first tested using Cronbach's alpha coefficient to estimate the statistical reliability of overall consistency. Stepwise regression was used to explore the relationships between OES (dependent variables) and the three IEQ aspects (independent variables). The result shows the weights of these aspects in Hong Kong high-rise residential buildings and the aspects people most care about. The Spearman rank correlation coefficient is a non-parametric test that assesses statistical dependence between two variables by describing the relation compared with monotonic function. This coefficient was applied to investigate the relation between feelings about sub-factors and the IEQ aspects. The Chi-square test was adopted to test whether the individual items caused significant differences in feelings about sub-factors. The results of bivariate associations confirmed the impacts of gender, age, physical environment, and behaviors.

4. Results

4.1 Reliability of the questions and demographic characteristics of the participants

Cronbach's alpha should always be used first to test the reliability of psychometric questions in statistical analysis. In this study, physical environment sub-factors were excluded as objective parameters, and the rest of the questions were grouped and tested by this coefficient. The reliability of the questions concerning air quality and thermal comfort (four items), luminous comfort (six items), acoustic comfort (five items), and adaptive behaviors (five items) are shown in Table 1.

Table 1 Reliability of the psychometric questions

Scale items	Cronbach's alpha	Scale items	Cronbach's alpha
Air quality and thermal comfort	0.765	Acoustic comfort	0.711
Temperature		Traffic noise	
Humidity		Construction noise	
Air velocity		Human noise	
Odor/Freshness		Noisy period	
Luminous comfort	0.862	Impressionable period	
Abundance of daylight hours		Adaptive behaviors	0.609
Illuminance level		Activity intensity	
Uniformity		Clothing insulation	
Direct sunlight hours		Internal shading	
Uncomfortable glare		Lighting hours	
Direct solar radiation		Mental stress	

The Cronbach's alpha coefficient estimated the internal consistency of the scales, and the values of the four groups, air quality and thermal comfort, luminous comfort, acoustic comfort, and adaptive behaviors, were 0.765, 0.862, 0.711, and 0.609 respectively. Various studies have recommended that alpha values above 0.6 are acceptable, and the scales can thus be considered to present good reliability. In fact, a low alpha value could be due to too few questions or to poor interrelatedness between items. Although the relatively low alpha value of adaptive behaviors shows the narrow dimensionality of its items, the purpose of this section was to test how these behaviors affect occupants' subjective feelings about sub-factors.

4.2 Overall environmental satisfaction (OES)

Stepwise regression was used to investigate a set of predictors that would be effective in predicting residents'

OES. OES was set as the dependent variable, and three key IEQ aspects shown in Table 2 were chosen as independent variables.

Table 2 Models generated by stepwise regression

Model	R	R^2	Adjust R^2	Std. error of the estimate	F	Sig.
1	.547[a]	.299	.294	.72673	58.063	.000[a]
2	.627[b]	.393	.384	.67870	43.753	.000[b]
3	.653[c]	427	.414	.66225	33.231	.000[c]

[a]. Predictors: (Constant), air quality and thermal comfort
[b]. Predictors: (Constant), air quality and thermal comfort, luminous comfort
[c]. Predictors: (Constant), air quality and thermal comfort, luminous comfort, acoustic comfort

Table 2 shows the models generated by stepwise regression. Model 3 was then selected (R = 0.653, F = 33.231, P < 0.001) due to its superior outputs. Table 3 shows the detailed results of model 3.

Table 3 Coefficients of regression [a]

Model 3	Standardized Beta	*t*	Sig.
(Constant)		1.369	.173
Air quality and thermal comfort	.364	4.845	.000
Luminous comfort	.247	3.347	.001
Acoustic comfort	.223	2.791	.006

[a]. Dependent variable: OES

As can be seen in Table 3, these three IEQ aspects all had significant P-values and a positive relationship with OES. The standardized beta reveals the relative influence of these aspects. Essentially, air quality and thermal comfort had the greatest influence on OES, followed by luminous comfort and acoustic comfort. This result confirms the results of most of the studies conducted in residential buildings (Frontczak, Andersen, & Wargocki, 2012; Zalejska-Jonsson & Wilhelmsson, 2013; Cao et al., 2012).

4.3 Effects of occupants' feelings about indoor environmental sub-factors

4.3.1 Air quality and thermal comfort

Satisfaction with air quality and thermal environment is the major element in OES, an IEQ aspect that involves four proposed sub-factors: temperature, humidity, air velocity, and odor/freshness. Table 4 shows how the feelings about these sub-factors impact upon satisfaction with air quality and thermal environment by applying a Spearman rank correlation coefficient. This coefficient tested the monotonic function, so the larger the coefficient value, the closer the relationship between variables. In order to understand the coefficients, the box plot of the results is presented in Fig. 2.

Table 4 Spearman rank correlation coefficients of satisfaction with air quality and thermal environment

	Temperature	Humidity	Air velocity	Odor/Freshness
Satisfaction with air quality and thermal environment	.276**	.128	.389**	.474**

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

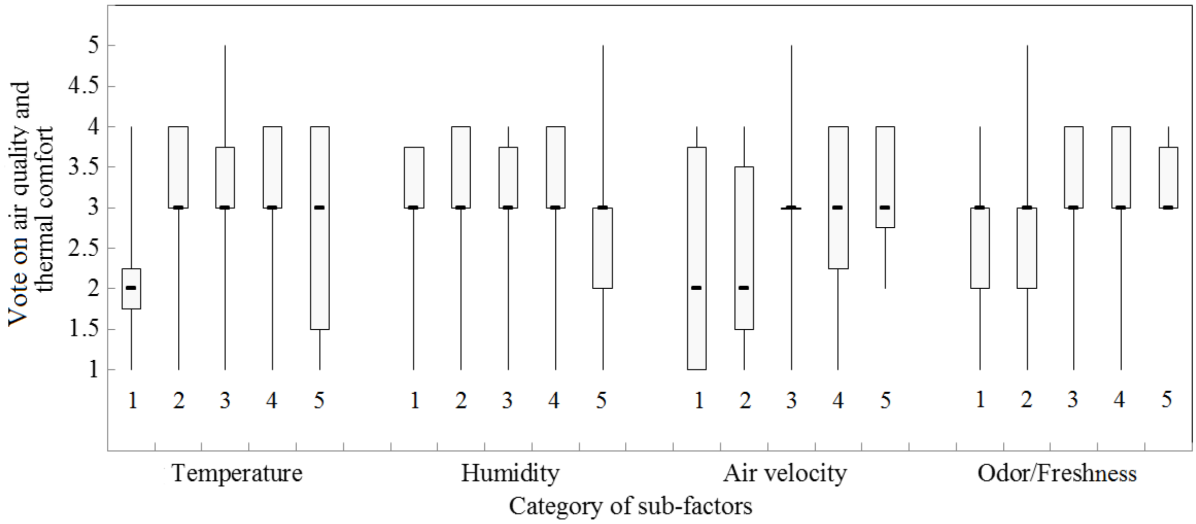

Fig. 2 Satisfaction with air quality and thermal comfort across the categories of its sub-factors (1: very dissatisfied; 2: dissatisfied; 3: neither; 4: satisfied; 5: very satisfied)

As seen in Table 4, air freshness had a significantly positive correlation (P-value < 0.01) with satisfaction with air quality and thermal environment. The correlations with air velocity and temperature were also significant, with a P-value of less than 0.05. The coefficient of humidity was 0.128, whose P-value was greater than 0.05, which meant that this sub-factor did not have a significantly positive correlation with satisfaction with air quality and thermal environment. This result echoes the finding of Givoni et al. (2006), that the effect of humidity level on thermal comfort is very small. As seen in Fig. 2, the satisfaction levels shown in X-axis group the data with different distribution of the average level of air quality and thermal comfort. The trend of comfort level has a positive relation with the satisfaction level temperature, air velocity and air freshness. It can be concluded that better agreement with air freshness, air velocity, and temperature generally leads to higher satisfaction with air quality and thermal environment.

4.3.2 Luminous comfort

Satisfaction with the luminous environment is a key element in OES. This IEQ aspect involves six proposed sub-factors: abundance of daylight hours, illuminance level, uniformity, direct sunlight hours, uncomfortable glare, and direct solar radiation. Table 5 shows the results of residents' feelings about these sub-factors' influences on satisfaction with luminous environment. Fig. 3 presents the box plot of the results to make these coefficients understandable.

Table 5 Spearman rank correlation coefficients of satisfaction with luminous environment

	Abundance of daylight hours	Illuminance level	Uniformity	Direct sunlight hours	Uncomfortable glare	Direct solar radiation
Satisfaction with luminous environment	.462**	.524**	.578**	.208*	.130	.059

[*] Correlation significant at the 0.05 level (two-tailed).

[**] Correlation significant at the 0.01 level (two-tailed).

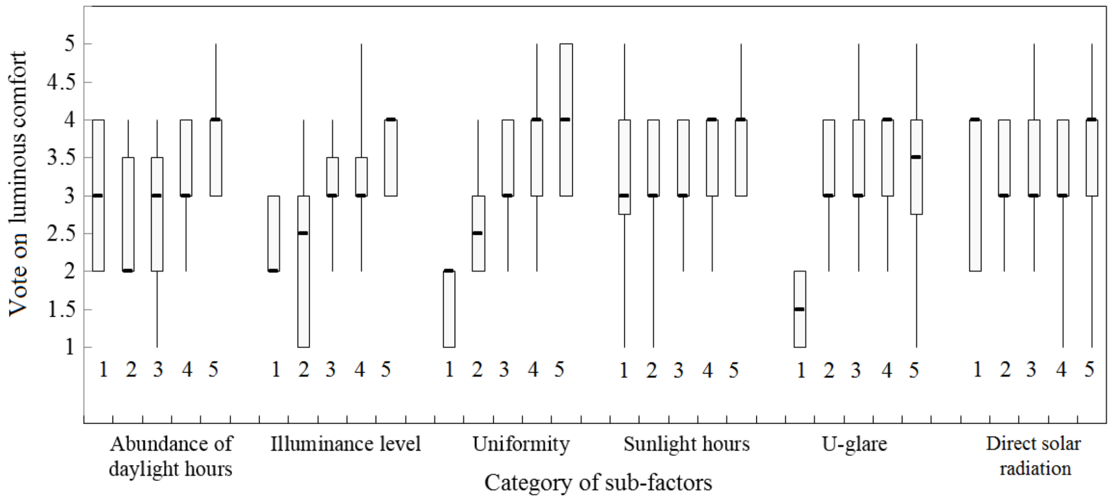

Fig. 3. Satisfaction with luminous comfort across the categories of its sub-factors (1: very dissatisfied; 2: dissatisfied; 3: neither; 4: satisfied; 5: very satisfied)

As seen in Table 5, uniformity, illuminance level, and abundance of daylight hours had significantly positive correlations (P-value < 0.01) with satisfaction with the luminous environment. The correlation of direct sunlight hours was also significant, with a P-value of less than 0.05. The coefficients of uncomfortable glare and direct solar radiation were 0.130 and 0.059 respectively, and their P-values were greater than 0.05, which meant that these two sub-factors did not have significantly positive correlations with satisfaction with the luminous environment. This result confirms the conclusion of Galasiu and Veitch (2006), which stated that the actual uncomfortable glare is less problematic than its predicted values. In residential environments, people have greater freedom of movement and other means to control glare than at work. As seen in Fig. 4, the satisfaction levels shown in X-axis group the data with different distribution of the average level of luminous comfort. The trend of comfort level has a positive relation with the first four sub-factors. It can be concluded that better agreement with uniformity, illuminance level, and abundance of daylight hours leads to greater satisfaction with the luminous environment.

4.3.3 Acoustic comfort

Satisfaction with acoustic environment is also a significant element of OES. This IEQ aspect involves five proposed sub-factors: traffic noise, construction noise, human noise, noisy period, and impressionable period. Table 6 shows Spearman rank correlation coefficients of residents' feelings about these sub-factors and Fig. 4 presents the box plot of satisfaction with the acoustic environment.

Table 6 Spearman rank correlation coefficients of satisfaction with acoustic environment

	Traffic noise	Construction noise	Human noise	Noisy period	Impressionable period
Satisfaction with acoustic environment	-.188*	-.286**	-.505**	-.053	-.124

* Correlation significant at the 0.05 level (two-tailed).

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

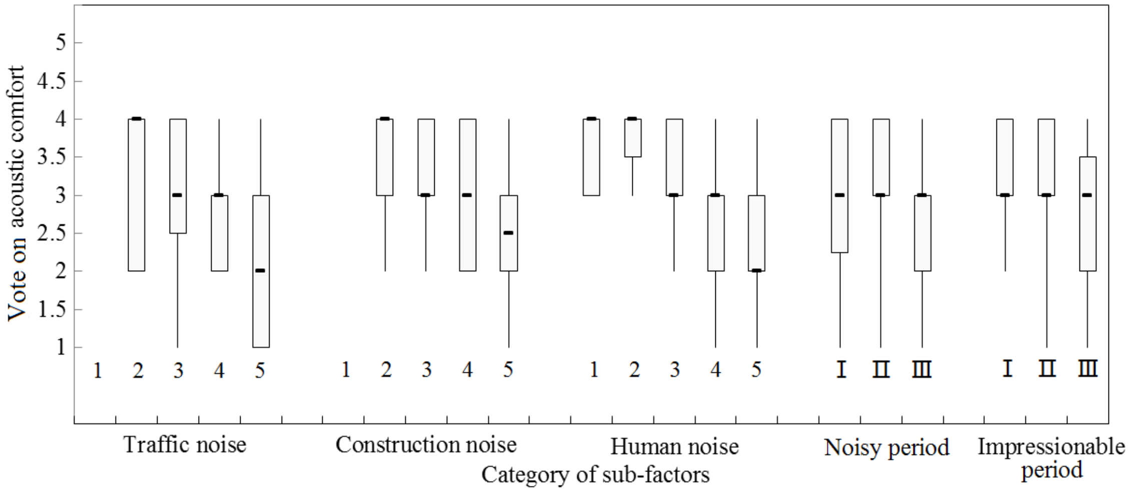

Fig. 4. Satisfaction with acoustic comfort across the categories of its sub-factors (1: very dissatisfied; 2: dissatisfied; 3: neither; 4: satisfied; 5: very satisfied; Ⅰ: 18:00~20:00 pm; Ⅱ:20:00~22:00 pm; Ⅲ: 22:00~24:00 pm)

As seen in Table 6, construction noise and human noise had significantly negative correlations (P-value < 0.01) with satisfaction with air quality and thermal environment. Since the questions about noise were asked in terms like "Are you suffering much from this kind of noise?" the correlation between this sub-factor and satisfaction was negative. The correlation of traffic noise was also significant, with a P-value of less than 0.05. Fig. 4 also shows that the noisy period and impressionable period of noise were both highest between 20:00 and 22:00. However, the coefficients of these two sub-factors were -0.053 and 0.124 respectively, and their P-values were greater than 0.05. In this case, these two sub-factors were considered insignificant. This finding is supported by Mak, Leung, and Jiang (2010), because both the predicted and measured data showed a similar trend: the higher the floor level, the lower the traffic noise level. The decibel level of traffic noise declines much with distance, and residents living on the 20th floor may have a relatively small problem with traffic noise. The Hong Kong Environmental Protection Department (2015) has intervened in the planning of new residential developments and about 90 per cent of new dwellings have been insulated from traffic noise above 70 dB L10. However, construction noise often comes from a facing building site, and has a relatively low altitude angle, so it has a larger impact than traffic noise, as shown in Fig. 4.

4.4 Effects of building characteristics and adaptive behaviors

Bivariate associations between individual items and feelings about sub-factors were tested by a Chi-square test, whose results are presented in Table 7. The Chi-square test grouped the participants by their answers to individual items, and the distribution of each sub-factor’s result decided its Pearson value, which indicated either a strong difference ($P < 0.05$) between this item and sub-factor or a not significant difference ($P > 0.05$).

Table 7 Pearson Chi-square values of sub-factors with individual items

		Air quality and thermal comfort			Luminous comfort				Acoustic comfort		
		Temperature	Air velocity	Odor/ Freshness	Abundant daylight	Illuminance level	Uniformity	Sunlight hours	Traffic noise	Construction noise	Human noise
Individual factors	Gender	.048*	.044*	.067	.073	.242	.847	.745	.548	.534	.279
	Age	.211	.457	.375	.473	.585	.749	.638	.363	.260	.206
Physical environment	Orientation	.037*	.104	.439	.526	.032*	.507	.001*	.137	.340	.353
	Floor level	.652	.384	.045*	.442	.042*	.033*	.046*	.015*	.035*	.491
	Floor area	.410	.047	.079	.685	.742	.319	.813	.058	.144	.180
	Window area	.333	.874	.351	.013*	.024*	.677	.682	.720	.624	.812
	External view	.428	.299	.681	.029*	.054	.008*	.008*	.503	.191	.506
	External obstruction	.751	.855	.152	.114	.025*	.035*	.039*	.928	.625	.293
Adaptive behaviors	Activity intensity	.141	.857	.691	.876	.754	.592	.903	.605	.086	.000*
	Clothing insulation	.771	.803	.573	.337	.623	.414	.291	.439	.068	.018
	Internal shading	.528	.125	.272	.042*	.029*	.454	.009*	.567	.193	.170
	Lighting hours	.150	.531	.066	.000*	.056	.000*	.317	.611	.168	.120
	Mental stress	.141	.297	.072	.548	.556	.016*	.890	.058	.044*	.047*

* Correlation significant at the 0.05 level (two-sided).

This crosstab can be read in rows. It shows that one item can influence feelings about several sub-factors. When read in columns, the items with an impact on feelings about a certain sub-factor can be investigated easily. In this section, the results are explained by row according to the independent items. As shown in Table 7, age made no statistical difference to feelings about the sub-factors. The other individual sub-factor, gender, had a great impact on air quality and thermal comfort. The results generally suggest that males tend to be more satisfied with air velocity and temperature. Previous studies have also shown a similar trend, that females are more sensitive to deviations from an optimal thermal environment (Karjalainen, 2012).

Among the physical environment items, orientation had a significant effect on temperature, illuminance level, and direct sunlight hours. Different orientations obviously offer different sunlight hours due to the sun’s path. Floor level contributed to all three IEQ aspects. A higher floor means a greater distance from ground sources of pollution and a shorter distance from the sky, a condition that offers better air freshness, higher illuminance level, better uniformity, longer sunlight hours, and lower traffic and construction noise. However, floor area had an insignificant impact on feelings about sub-factors in these three IEQ aspects. The other three items, window area, external view, and external obstruction, mainly contributed to luminous comfort. Abundant daylight was mostly affected by window area and external view, and illuminance level was mostly affected by window area and external obstruction. Uniformity and sunlight hours were most affected by external view and external obstruction.

Among the items of adaptive behavior, the condition of clothing insulation had no influence on any occupant's feelings. It was expected to have an obvious effect on feelings of temperature and air velocity, but the results showed the contrary. De Carli et al. (2007) stated that indoor air temperature seems to influence changes of clothing during the day. Therefore, it is probable that people always try to stay in their thermal comfort zone by changing their clothes at home. The results show that activity intensity and human mental stress had strong impacts on acoustic comfort. Low activity intensity and high mental stress make people more sensitive to the surrounding acoustic environment, especially the noise generated by human activity. Higher stress could also lead to poor satisfaction with illuminance distribution and construction noise. Utilization of internal shading reduced abundant daylight hours, illuminance level, and sunlight hours. More artificial lighting hours provided less abundant daylight hours and lower satisfaction with uniformity. This result echoes previous research which found that the use of artificial lighting (measured by number of hours) was a key relevant behavior influencing levels of luminous comfort (Xue, Mak, & Cheung, 2014). It is reasonable to suppose that using artificial lighting for many hours a day indicates poor daylight.

5. Discussion

This research provides a set of rational results concerning residents' OES in high-rise residential buildings. Based on the 482 sets of valid collected data, the impacts of the proposed IEQ aspects and sub-factors were tested with statistical analysis. Residents' satisfaction with air quality, thermal, luminous, and acoustic environments all have important relationships with OES. Investigating OES sub-factors through the questionnaire surveys was confirmed to be helpful for residents in deciding their comfort levels and most of the individual items were proved to be effective in affecting residents' feelings. Feelings about air quality and thermal comfort are mostly affected by room orientation and gender; feelings about luminous comfort are mostly affected by physical environmental items and adaptive behaviors of shading and lighting; feelings about acoustic comfort are mostly affected by floor level, activity intensity, and mental stress.

However, there is still one issue that needs to be addressed. It is known that a higher floor means a greater distance from ground sources of pollution, but why does this influence residents' feelings about air freshness in housing? We used the Pearson coefficient to further test the relationship between floor level and air quality. The coefficient value was calculated as 0.404 with the significance at the 0.01 level, which means that the correlation is positive and linear. This result indicates that residents on a higher floor level feel more satisfied with air quality. Airborne particles in the residential environment may come from both inside and outside, and indoor particle concentration has been shown to have a clear positive relationship with outdoor particle concentration in many houses (Morawska et al., 2001). An earlier survey (Jung et al., 2011) provided a reasonable explanation for our result. Researchers have characterized the vertical gradient of polycyclic aromatic hydrocarbons (PAH; dichotomized into $\Sigma_8PAH_{semivolatile}$ (MW 178–206), and $\Sigma_8PAH_{nonvolatile}$ (MW 228–278), black carbon (BC), $PM_{2.5}$ (particulate matter)), and the results show that the concentration of airborne pollutants in an apartment depends greatly on the floor level.

After examining the results and excluding insignificant sub-factors, the tested structure of OES can be presented in a new logical figure (Fig. 5).

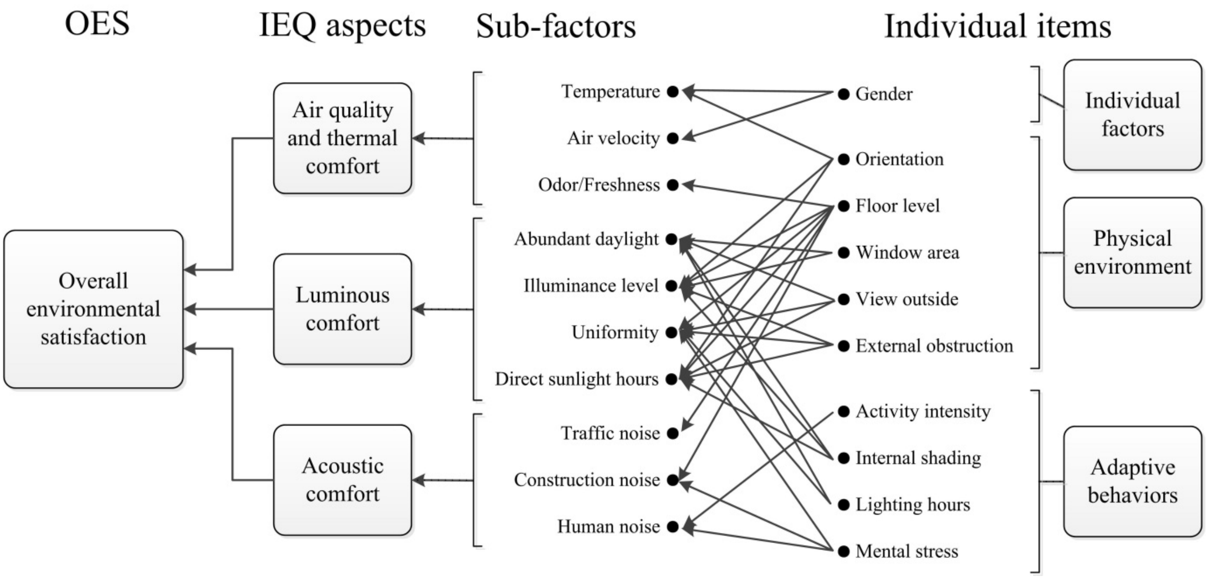

Fig. 5. The framework of OES based on analysis of the survey data

The results of this study explain and generate awareness of the sub-factors involved in OES. The sub-factors shown in Fig. 5 are tested to be the key factors of OES in high-rise residential buildings. The study also shows the importance of physical environment to people's OES, which may help the government understand OES more clearly. The adaptive behaviors shown in Fig. 5 also show great influence on the sub-factors. The arrows means the items has a significant positive correlation with the target feelings (sub-factors of comfort). Further work is required to investigate the effects of building features on OES.

6. Conclusions

Based on the analysis of the data, the following conclusions can be drawn:

1) The combined aspect of air quality and thermal comfort has the greatest influence on OES in high-rise residential buildings, followed by luminous comfort and acoustic comfort.

2) Air quality and thermal comfort are affected most significantly by the feelings of air freshness, followed by air velocity and temperature. Uniformity, illuminance level, and abundance of daylight hours have significantly positive correlations with luminous comfort. The noise from construction and human activity has the greatest impact on residents' satisfaction with their acoustic environment.

3) The occupants' subjective feelings about sub-factors of air quality and thermal comfort depend on room orientation and gender. Their feelings about sub-factors of luminous comfort are mostly affected by physical environment items and adaptive behaviors of shading and lighting. Their feelings about acoustic comfort are mostly affected by floor level, activity intensity, and mental stress.

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