Contribution of Space Factors to Decisions on Comfort of Healthy Building Design

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Abstract. Healthy buildings are closely related to human health and comfort. Based on the literature survey, this paper explores the definition of comfort in healthy buildings. Through literature analysis and expert interviews, 16 building space factors affecting building indoor environment were identified. To introduce the building space factors into the research on the comfort evaluation of healthy buildings, 152 questionnaires were sent out and the relationship between these factors and building indoor environment comfort evaluation and their rankings were discussed. Data analysis includes the reliability analysis, normal distribution test, Pearson correlation coefficient and MANOVA. The results have shown that the perceived comfort is strongly influenced by the building space factors, and the relationship is complicated. The rankings from professionals and non-professionals were different. Several factors have been identified as key influencing factors. Besides, the perceived comfort is also related to other factors such as age, gender, etc. Such discovery primarily provides an ordering of building space design factors, which will contribute to the buildings’ health, comfort and sustainable development through architectural design from an architect’s perspective.

1. Introduction
The building design aims to provide a healthier and more comfortable environment for people. People stay indoors for more than 90% of the time [1], so most countries believe that the indoor environment has a major impact on human health and well-being [2][3]. Studies have shown that healthier buildings can reduce occupants’ stress [4], increase productivity, and reduce health care costs by 1-5% [5]. Therefore, to determine the relationship between building environment and comfort is conducive to the design and operation of healthy buildings.

In the indoor environment, the literature review examining the comfort of building occupants mainly focuses on the impact of physical environmental conditions on overall IEQ satisfaction, such as noise, light, and temperature [6][7][8]. The influence of architectural design on the indoor environment is mainly reflected in the space characteristics, and the building space factors can interact with occupants [9]. Studies have shown that the architectural decoration and light color have little effect on thermal comfort [10][11], but the building space factors exert a significant influence on overall IEQ satisfaction [12]. Calculating the impact of spatial factors on human comfort and their importance index can help architects design healthier buildings.

1.1. Connotation and elements of healthy buildings
In 2000, the healthy building was explained at the Healthy Building Conference in Espoo, Finland. In addition to temperature, humidity, ventilation and light, the healthy building is also seen as a way to build an indoor environment, including layout, color and personal psychological needs [13]. In
October 2014, the International Well Building Institute (IWBI) in the United States released the world’s first healthy building assessment standard, The Well Building Standard V1 (WELL). The WELL is divided into seven health concepts, i.e. air, water, nutrition, light, fitness, comfort and spirit [14]. In March 2015, the standard was officially introduced into China by the Green Business Certification (GBCI) and IWBI. The Architectural Society of China released the Healthy Building Evaluating Standard T/ASC02-2016 (HBES) on January 6, 2017. The evaluation index system includes six categories: water, air, comfort, fitness, humanities and services [15]. The ASHB first defines a healthy building as a building that provides a healthier environment, facilities and services for building users, promotes physical and mental health, and improves health performance, based on the realization of building functions.

The concept of a healthy building is believed to be a ‘built environment that encourages positive well-being of human beings’ [16]. For decades, researchers have conducted studies to investigate the relationship between human health and the built environment. Different factors in a building affect its safety and hygiene. For example, factors such as lighting, quality of air, thermal comfort, aural comfort, colors, and textures are known to have a positive relationship with a healthy built environment [17]. Apart from these physical dimensions, some immeasurable aspects, such as aesthetics, job satisfaction, and social relationships, play important roles in the state of general well-being [18].

1.2. Comfort of healthy buildings

The comfort specified in the WELL focus on significantly reducing the most common causes of physiological disturbances, distraction and irritation, and largely enhancing acoustics, ergonomics, smell and thermal comfort to avoid stress and injury and improve individual comfort, work efficiency and health level. HBES incorporates natural light and lighting into comfort evaluation. As shown in Table 1, the concept of comfort in the standard includes three elements of indoor environmental quality (sound, heat, vision) and ergonomics. However, even if the requirements of existing standards are met, not all occupants are satisfied with the indoor environment [19].

A healthy building should provide a comfortable indoor environment for occupants, which makes them healthy, both physically and psychologically [20]. The importance of indoor environment has reached a consensus among many researchers. Comfort perceived by human is disrupted by many (individual, social, and architectural) factors. Jaakola believes that different determinants simultaneously affect both human health and comfort, and sometimes the effects may be synergistic [21]. They combine to form an overall comfort experience, which is the concept of comfort that is discussed in this paper, that is, the occupants’ overall satisfaction with the indoor environment.

| Standard | Comfort characteristics | Comfort characteristics | Standard |
|----------|-------------------------|-------------------------|----------|
| WELL | Accessibility design standard in ADA | Indoor artificial cold/heat source | HBES |
| Ergonomics: vision and physiology | Ergonomics | Acoustic environment |
| Outdoor noise intrusion | Indoor noise | Thermal and humid environment |
| Reverberation time | Sound masking | Light environment |
| Silencing surface | Sound barrier | |
| Thermal comfort | Independent thermal control | |
| Radiant thermal comfort | Olfactory comfort | |

1.3. Hypotheses
The purpose of this paper is to confirm the impact of building space factors on human comfort, to enrich the terms of comfort characteristics in standard of healthy buildings. Obviously, it is important for architects to make decisions to optimize building design and thus to improve space comfort. The lack of space quality standards has led architects to rely entirely on personal experience in optimizing space design, and unfortunately their preferences are not the same as those of occupants. After interviews and questionnaires, this paper discussed whether all spatial factors contribute to comfort and counted the rankings of space factors that occupants consider important. This paper also attempted to identify several factors that unrelated to space but affect the comfort experience. These factors include occupants’ age, gender, etc.

We attempted to make three hypotheses:

Hypothesis 1: There are several building space factors that are important for people to evaluate whether a room is comfortable or not.

Hypothesis 2: When physical environmental conditions meet the standards, assessing whether the indoor environment is comfortable mostly depends on the spatial conditions that are of high importance to people’s comfort.

Hypothesis 3: Factors unrelated to space such as age, gender, etc., also have an impact on people’s overall comfort evaluation.

2. Determination of building space factors

The internal space of the building is separated from the natural space for some purpose by people with the use of a certain material and technical means. It has the closest relationship with people and has the greatest impact on people. It should have a beautiful form under the premise of meeting functional requirements, and thus meet people’s mental and aesthetic needs.

| Code | Item                                      | Grade 1       | Grade 7       |
|------|-------------------------------------------|---------------|---------------|
| A1   | Floor dimension b                         | Too small     | Too large     |
| A2   | Height of ceilings b                      | Too short     | Too high      |
| A3   | Shape of rooms a                         | Unsatisfactory| Satisfactory  |
| B1   | Openness of spaces b                      | Too closed    | Too open      |
| B2   | Size of windows b                         | Too small     | Too large     |
| B3   | Orientation of windows a                  | Unsatisfactory| Satisfactory  |
| B4   | Presence of natural images a              | Unsatisfactory| Satisfactory  |
| B5   | Indoor/outdoor sunshades a                | Unsatisfactory| Satisfactory  |
| B6   | Entrance/exit location a                 | Unsatisfactory| Satisfactory  |
| C1   | Separation in the room (column, mezzanine, etc.) a | Unsatisfactory| Satisfactory  |
| C2   | Layout a                                  | Unsatisfactory| Satisfactory  |
| C3   | Function districts a                      | Unsatisfactory| Satisfactory  |
| D1   | Color of ground/wall/ceiling a            | Unsatisfactory| Satisfactory  |
| D2   | Material of ground/wall/ceiling a         | Unsatisfactory| Satisfactory  |
| D3   | Texture of ground/wall/ceiling a          | Unsatisfactory| Satisfactory  |
| D4   | Other decorations a                       | Unsatisfactory| Satisfactory  |

* These items have a 7-point scale: 1-being not satisfactory, 7-being satisfactory.

* These items are two-sided, the best score is 4, both grade 1 and 7 being most negative. For analysis, we re-encode them into a negative-positive 4-point scale (1 and 7: mark 1; 2 and 6: mark 2; 3 and 5: mark 3; 4: mark 4)

In the 21st century, study about spatial attribute perception started [22]. Most studies examined single space attribute, such as size, window-wall ratio, and color. The perception content of these space attributes includes space forms, such as spaciousness, closure, complexity, and organization, and general preferences, such as like and satisfaction [23]. Other studies have examined the relationship between certain human emotions (like pleasure, stress and anxiety) or their work efficiency and architectural design features [24]. It is believed that architectural design factors are important for
human experience [25]. We summarized the building space factors discussed in the literature and interviewed 50 professionals. According to their comprehensive results, we classified the building space factors, which are divided into four categories (dimension, enclosure, layout and separation, color and texture) and a total of 16 factors, as shown in Table 2. For the convenience of further study, these impact factors were coded.

3. Methodology

3.1. Questionnaire development

The purpose of the questionnaire survey is to investigate different views on the importance of the above spatial factors, and to determine people’s satisfaction with different building space factors and overall environmental satisfaction. Besides, there are people’s social contact, performance and emotion, and this paper also verified their relevance. Questionnaires with a 7-point semantic differential scale were used to further analyze these identified influencing factors.

There were four main parts in the questionnaire. Section 1 was the background information of the respondents. Five questions (Table 3) were designed to gather basic information about respondents (gender, age, occupation, daily working hours and work experience) which was believed to affect the overall comfort evaluation and help ensure the authenticity and validity of the data collected at the same time. In Section 2, 16 questions corresponding to 16 spatial factors (Table 2) were designed to determine the importance of each factor affecting healthy buildings and their rankings from its response. Section 3 was about other factors, including related indoor environmental quality (IEQ) factors and personal control degree, and the respondents can add other important factors that have not been mentioned before (Table 3). Section 4 was about the space atmosphere, performance and emotion of respondents (Table 3).

| Basic information | Personal control | Space atmosphere | Performance | Emotions |
|-------------------|------------------|------------------|-------------|----------|
| Gender | Flexible selection of stations $^c$ | Privacy $^d$ | Work enthusiasm $^d$ | Fatigue $^e$ |
| Age | Sunshade $^c$ | Crowding $^e$ | Work efficiency $^d$ | Anxiety $^e$ |
| Occupation | Window opening $^c$ | | Depression $^e$ |
| Working hours | Temperature $^c$ | | | |
| Work experience | Light $^c$ | Noise $^c$ | Laziness $^e$ | |

$^c$ These items have a 7-point scale: 1-being no control at all, 7-full control.
$^d$ These items have a 7-point scale: 1-very low, 7-very high.
$^e$ These items have a 7-point scale: 1-being agree, 7-being disagree.

3.2. Data collection

The questionnaires were distributed to respondents by email or QR code. According to the purpose of the questionnaire survey, the target samples from several cities in different regions such as Tianjin, Beijing, etc. were selected, including experienced professionals such as architects and non-professionals. Therefore, to determine the key factors that affect the comfort of the building space environment from their response are more scientific and reasonable.

A total of 152 questionnaires were sent out from March to April 2019, and 151 valid responses were collected with an effective response rate of 99%. The background information about the respondents is shown in Table 4.
Table 4. Distribution of the returns from different groups.

| Male/Female ratio | Age   | Daily working hours | Work experience (year) | Professional/non-professional ratio |
|------------------|-------|---------------------|------------------------|-------------------------------------|
|                  |       |                     |                        |                                     |
| 1:1.07           | under 18 | 1.99%               | 3~5                    | Less than 1                         |
|                  | 18~25  | 23.18%              | 5~8                    | 1~3                                 |
|                  | 26~30  | 41.72%              | 8~11                   | 3~5                                 |
|                  | 31~40  | 14.57%              | Over 11                | Over 5                              |
|                  | 41~50  | 11.26%              |                         |                                     |
|                  | 51~60  | 7.28%               |                         |                                     |

3.3. analysis
Data analysis was divided into three steps. First, reliability analysis and normal distribution test were carried out. Then, Pearson correlation coefficient was used to analyze the relationship between building space factors and the overall comfort of indoor environment. Finally, the effects of other factors on indoor environmental comfort were analyzed. SPSS 22.0 was used to analyze the data and research the principal components of impact factors influencing the comfort of healthy building.

4. Results and discussion

4.1. Reliability analysis and normal distribution test

Table 5. Reliability Statistics of the factors.

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items |
|------------------|---------------------------------------------|
| 0.898            | 0.896                                       |

Table 6. Normal distribution test of the factors.

|      | A1     | A2     | A3     | B1     | B2     | B3     | B4     | B5     |
|------|--------|--------|--------|--------|--------|--------|--------|--------|
| N    | 151    | 151    | 151    | 151    | 151    | 151    | 151    | 151    |
| Mean | 3.72   | 3.98   | 4.49   | 3.87   | 3.62   | 4.50   | 4.03   | 4.21   |
| Std. Deviation | 1.167  | 1.023  | 1.356  | 1.287  | 1.258  | 1.708  | 1.645  | 1.490  |
| Skewness | -0.154 | 0.002  | -0.101 | 0.162  | -0.556 | -0.181 | -0.006 | -0.150 |
| Std. Error of Skewness | 0.097  | 0.179  | 0.197  | 0.197  | 0.197  | 0.197  | 0.197  | 0.197  |
| Kurtosis | 1.636  | 2.572  | 0.197  | 0.852  | 0.054  | -0.676 | -0.653 | -0.226 |
| Std. Error of Kurtosis | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  |

|      | B6     | C1     | C2     | C3     | D1     | D2     | D3     | D4     |
|------|--------|--------|--------|--------|--------|--------|--------|--------|
| N    | 151    | 151    | 151    | 151    | 151    | 151    | 151    | 151    |
| Mean | 4.32   | 4.05   | 4.12   | 3.88   | 4.17   | 4.20   | 4.11   | 3.99   |
| Std. Deviation | 1.378  | 1.496  | 1.469  | 1.553  | 1.375  | 1.361  | 1.329  | 1.369  |
| Skewness | -0.017 | 0.054  | -0.017 | 0.169  | 0.215  | 0.003  | 0.084  | -0.051 |
| Std. Error of Skewness | 0.097  | 0.179  | 0.197  | 0.197  | 0.197  | 0.197  | 0.197  | 0.197  |
| Kurtosis | 0.392  | -0.049 | 0.050  | -0.421 | 0.040  | 0.310  | 0.258  | 0.056  |
| Std. Error of Kurtosis | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  | 0.392  |

Cronbach’s alpha is often used to test the internal consistency of collected data. The reliability is
acceptable if the Cronbach’s alpha value is more than 0.7 [26]. Cronbach’s alpha was used in this study to test the internal consistency among the impact factors. The Cronbach’s coefficient was more than 0.7, as shown in Table 5.

The normality test of space comfort evaluation was conducted by using the kurtosis and skewness coefficients. As shown in Table 6, all the skewness and kurtosis coefficients except A1 and A2 were less than 1, so it could be considered that the results are approximately normally distributed.

### 4.2. Rankings of factors and correlation analysis

With collected data, the correlation rank of factors was calculated. As shown in the Table 7, rankings from professionals and that from non-professionals showed inconsistent performance. Layout and separation, color and texture were regarded as important to the indoor environment comfort by all the respondents. However, compared with non-professionals, professionals think that texture had little impact on comfort. Professionals believed that all three sub-factors of dimension were very important, while non-professionals believed floor dimension and height of ceilings were not so important. As far as Enclosure was concerned, the size of the window was considered important by professionals, followed by the openness of the space and interior and exterior shading measures, while non-professionals considered the openness of the space to be more important, followed by shading and window size. The reason for the difference in ranking was believed to be that professionals were more sensitive to factors such as space scale and window-wall ratio because they were engaged in architectural design. Of course, it was also influenced by personal preference. Based on the overall ranking, some factors (floor dimension / orientation of windows, etc.) were considered to have a weak relationship with the overall comfort of the room.

Pearson correlation coefficient was used to measure the relationship between the satisfaction degree of 16 factors and the overall satisfaction degree of overall comfort. As shown in the Table 8, there was a significant correlation between the evaluation of 16 factors and the overall comfort evaluation. In general, factors with obvious correlation were also considered important except four (shape of rooms, openness of spaces, size of windows and texture of ground/wall/ceiling). Dimension (A1-A3) was related to crowding degree of the room, work enthusiasm and work efficiency. Enclosure (B4-B6), layout and separation (C1-C3) and color and texture (D1-D4) were related to privacy and crowding of the room and work enthusiasm, while only B4 was related to work efficiency. Building space factors had little influence on the evaluation results of emotion.

#### Table 7. Correlation index and ranking of the factors.

| Groups       | Code | Item                      | Correlation index and ranking |
|--------------|------|---------------------------|-------------------------------|
|              |      |                           | Professional | non-professional | All  |
| Dimension    | A1   | Floor dimension           | 0.88         | 7               | 0.71  | 16        | 0.77  | 15  |
|              | A2   | Height of ceilings        | 0.92         | 3               | 0.77  | 13        | 0.82  | 10  |
|              | A3   | Shape of rooms            | 0.86         | 9               | 0.84  | 4         | 0.85  | 3   |
| Enclosure    | B1   | Openness of spaces        | 0.84         | 10              | 0.85  | 3         | 0.85  | 3   |
|              | B2   | Size of windows           | 0.90         | 5               | 0.80  | 11        | 0.83  | 9   |
|              | B3   | Orientation of windows    | 0.80         | 15              | 0.78  | 12        | 0.79  | 12  |
|              | B4   | Presence of natural images| 0.82         | 13              | 0.77  | 13        | 0.79  | 12  |
|              | B5   | Indoor/outdoor sunshades  | 0.84         | 10              | 0.81  | 10        | 0.82  | 10  |
|              | B6   | Entrance/exit location    | 0.82         | 13              | 0.72  | 15        | 0.75  | 16  |
| Layout       | C1   | Separation in the room    | 0.96         | 1               | 0.87  | 1         | 0.90  | 1   |
| and separation| C2   | Layout                    | 0.92         | 3               | 0.82  | 9         | 0.85  | 3   |
|              | C3   | Function districts         | 0.90         | 5               | 0.83  | 7         | 0.85  | 3   |
| Color and texture | D1 | Color of ground/wall/ceiling | 0.96 | 1 | 0.87 | 1 | 0.90 | 1 |
|              | D2   | Material of ground/wall/ceiling | 0.84 | 10 | 0.84 | 4 | 0.84 | 8 |
|              | D3   | Texture of ground/wall/ceiling | 0.72 | 16 | 0.83 | 7 | 0.79 | 12 |
|              | D4   | Other decorations         | 0.88         | 7               | 0.84  | 4         | 0.85  | 3   |

*Factors with high correlation.*
Table 8. Pearson correlation coefficient of the factors with the overall comfort.

| Overall comfort | Pearson Correlation | Sig. (2-tailed) |
|-----------------|---------------------|-----------------|
| A1              | .338**              | .000            |
| A2              | .231**              | .004            |
| A3              | .391**              | .000            |
| B1              | .180*               | .027            |
| B2              | .191                | .019            |
| B3              | .380**              | .000            |
| B4              | .503**              | .000            |
| B5              | .451**              | .000            |
| N               | 151                 | 151             |

Table 9. MANOVA of the factors that affect the degree of satisfaction with the overall comfort.

| Source                      | Type III Sum of Squares | Mean Square | F      | Sig. | Partial Eta Squared |
|-----------------------------|-------------------------|-------------|-------|------|---------------------|
| Gender                      | 1.538                   | 1.538       | 1.118 | .292 | .008                |
| Age                         | 13.511                  | 2.702       | 1.965 | .088 | .067                |
| Daily working hours         | 9.662                   | 3.221       | 2.343 | .076 | .049                |
| Work experience             | 4.711                   | 1.570       | 1.142 | .334 | .024                |
| Flexible selection of stations | 9.579               | 1.368       | 1.317 | .250 | .083                |
| Control of sunshade         | 6.370                   | 1.062       | 1.021 | .416 | .057                |
| Control of window opening   | 2.577                   | .368        | .354  | .926 | .024                |
| Control of temperature      | 7.744                   | 1.106       | 1.064 | .392 | .068                |
| Control of light            | 5.682                   | .812        | .781  | .605 | .051                |
| Control of noise            | 1.925                   | .275        | .265  | .966 | .018                |
| Control of air quality      | 9.074                   | 1.296       | 1.247 | .284 | .079                |

4.3. Evaluation of factors unrelated to space

Multivariate Analysis of Variance was used to analyze the effect of factors unrelated to space (age, gender, etc.) on the overall comfort evaluation. As shown in Table 9, all the eleven factors had little influence on the evaluation of overall comfort in the statistical sense. However, after statistical analysis, compared with women, men had a higher tolerance for the environment. With the increase of age, daily working hours and work experience, the evaluation of environmental comfort decreased.

5. Conclusion

In this study, questionnaire survey was used to check whether the building space factors had influence on comfort evaluation, thus contributing to the comfort decision-making in healthy building design. The results proved the three previous hypotheses. First, 11 of the 16 spatial factors selected had significant influence on the overall comfort evaluation. Secondly, in general, when the physical environmental conditions met the standards, the factors considered to be more important had a higher correlation with overall comfort. Some of the anomalies were considered to come from three reasons: professional experience, sample size, and personal preference. Finally, there were some factors (personal characteristics, personal control) that interfere with comfort assessment, although not obviously.

In this study, only questionnaires were used for investigation and analysis, the indoor environment quality of the buildings was not specifically measured, which was more convenient in the laboratory. Therefore, it is suggested that future research can quantify the impact of building space factors on comfort evaluation based on laboratory studies.
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