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Development of a Healthy Assessment System For Residential Building Epidemic Prevention

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A R T I C L E   I N F O

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A B S T R A C T

During the period of COVID-19, the number of residents infected in urban communities continued to rise, implying that most of the current building layouts can’t effectively resist the spread of infectious diseases, and the outbreak of COVID-19 has led to the need of changes for the current building environment. Therefore, the epidemic prevention should be considered in the residential building design, and the health design of residential community should be carried out from the perspective of epidemic prevention. In order to improve the ability of epidemic prevention of residential buildings and deal with the sudden pandemic and influenza in the post-epidemic era, a Healthy Assessment System for Residential Building Epidemic Prevention (HASRBEP) was developed according to the epidemic impact on residential buildings, the design and measures of epidemic prevention for residential buildings and the Chinese Assessment standard for healthy building (T/ASC 02-2016). Both entropy weight method and expert scoring method were used to determine the specific weight of the index. The HASRBEP includes control item assessment, preliminary assessment and extension assessment. The newly developed HASRBEP was used to assess the residential buildings of the Yulongzhuang Building Community located in Quanzhou, Fujian Province, China. The results show that the HASRBEP can be used to guide the health and epidemic prevention design of residential buildings.

1. Introduction

Building is an important place for people to work, study, live, communicate and rest. On average, 90% of people’s life is spent in buildings [1]. Good living environment, medical facilities and fitness conditions are beneficial to people’s physical and mental health, but most of the current building layout and community environment are not so optimistic [2]. In particular, the outbreak of COVID-19 epidemic has posed new challenges to the building environment. The environment should be designed to prevent the spread of the virus and improve the protection of the residents in buildings and cities [3]. Large and high-density cities with high inter and intra-city mobility flows have more difficulties in containing the epidemic spread, but improving healthcare infrastructure adequacy and urban governance capacity can increase time efficacy of pandemic control [4]. Furthermore, improving the governance capacity and infrastructure in regards to residential community is the most effective way to control the epidemic, so as to improve the resilience of cities and communities against pandemic.

According to the survey of World Health Organization (WHO) in 2019, 432,000 cases of diarrhea died every year due to poor environmental sanitation [5]. Moreover, WHO found that there are four essential factors affecting people’s health: lifestyle factors (60%), environmental factors (17%), genetic factors (15%) and medical supporting factors (8%) [6]. The cause of chronic diseases is closely related to behavior and environment, and bad living habits [7].

The spread of epidemic diseases in buildings is an important factor affecting people’s health, and the risk of infection in buildings is very high. Therefore, it is very important to study the epidemic prevention design of buildings. Since early 2020, COVID-19 has brought unprecedented impact on people’s life, work, study and communication. Offices, restaurants, retail places, schools, factories, religious places of worship and cultural and entertainment places have been closed one after another. During the epidemic period, most of the infections occurred in buildings, with one person infected, the whole family and even many other families in the whole building and community could be infected. The dangerous infectious waste caused by the pandemic increases the...
risk of virus transmission [8]. It can effectively change the spatial distribution residents’ living space by increasing the isolation of residential areas, so as to control the spread of epidemic in the community [9].

Therefore, communities and buildings are important links in epidemic prevention and control, and improving the health performance of buildings plays a positive role in epidemic prevention and control [10]. The COVID-19 pandemic shows that most of the current building layouts cannot effectively resist the spread of infectious diseases. Now it is generally believed that residential buildings are the core of controlling the spread of infectious diseases [1]. It is urgent to study the design, measures and strategies of residential building epidemic prevention, understand the impact of residential buildings on epidemics, and carry out epidemic prevention into the design of residential buildings, so as to design a healthy and sustainable living environment.

At present, there is no comprehensive design standard or standard system for epidemic prevention in China or even in the world. After 2014, the United States issued a number of standards of WELL series [11, 12], and China worked out the Assessment standards for healthy buildings and Assessment standards for healthy housing [13,14] in 2016. After the outbreak in 2020, China urgently issued the Guidelines for office buildings to deal with new coronavirus operational management emergency measures and the Pneumonia in new coronavirus - Guidelines for public protection, to deal with the epidemic prevention. In March 2020, the International WELL Building Institute made an urgent compilation of the WELL health-safety rating for facility operations & management as a supplement to COVID-19 epidemic. However, these guidelines and standards can’t completely guide the design of epidemic prevention, and do not have a perfect technical system of epidemic prevention design. In addition, these guidelines and standards are temporary measures to control COVID-19 mostly associated with public spaces and public protection. They can’t guide the design of long-term epidemic prevention of residential buildings due to the difficulty of comprehensively carrying out the epidemic prevention design along with architectural design, water supply, drainage design, intelligent design and so on. Therefore, it is urgent and necessary to develop a healthy assessment system to guide the epidemic prevention design of residential buildings.

As mentioned above, a series of guidelines and standards have been urgently formulated in China and abroad to cope with the spread of the COVID-19 epidemic. How to combine these guidelines and standards with the existing healthy building assessment standards is needed to be solved in this study. The authors have reviewed the WELL building standard V2.0, the Chinese Assessment standard for green building (GB/T 50378–2019) and Assessment standard for healthy building (T/ASC 02–2016), the main factors related to health are listed in Table 1.

The indices in Table 1 indicate that the performance of epidemic prevention is closely related to household health, however, it was not reflected in these standards in China and abroad, and how to prevent epidemic was not considered. Many other supplementary guidelines and standards had then been introduced to deal with the epidemic since the outbreak. However, these guidelines and standards are not comprehensive and systematic enough to completely and accurately guide the design of residential building epidemic prevention and judge the degree of health for residential buildings. Therefore, it is necessary to add the contents of epidemic prevention design into the assessment of residential buildings and carry out relevant research.

In the weight system, most of the existing standards adopt two ways: implicit weight and independent weight setting. Although the two ways are easy to use, it’s not easy to understand the differences of indices since they cannot be layered. If the contents of epidemic prevention are added, the weight of assessment indices will change, and the scores and weights of all levels of indices should be redistributed. Therefore, a scientific weight system of residential building health assessment indices should be established.

In terms of assessment methods, the existing assessment methods are based on linear calculation and simple weighted calculation. They are easier to be calculated, understood and accepted by nonprofessionals. However, the results can not reflect the relationship between indices and the relationship between health level and star level of each index. The assessment model should be optimized to evaluate the health of residential buildings more comprehensively.

In this study, the factors and measures affecting the health and epidemic prevention of residential buildings are analyzed, the epidemic prevention indices system for residential buildings is constructed, and the weight system and assessment model of assessment indices are studied to improve the assessment system of healthy buildings and the epidemic prevention ability of residential buildings.

2. Methods

Healthy building assessment system has the characteristics of complexity, relevance and fuzziness. After adding the contents of epidemic prevention, the original index weight system is no longer applicable and needs to be re-determined. Therefore, with comparing the advantages and disadvantages of each comprehensive assessment method, the entropy method is selected to determine the weight, and the extension assessment method is selected to comprehensively evaluate the health degree of residential buildings.

According to WHO’s research on the basic factors affecting health, the genetic factors are removed, and the first-class indices of medical treatment are set separately for assessment, and the epidemic prevention indices are added. The adjustment of air, water and comfort should be attributed to the environmental system accounting for 20%, the adjustment of medical treatment should be attributed to the medical supporting system accounting for 10%, and the adjustment of fitness, humanities, services and epidemic prevention should be attributed to the lifestyle system accounting for 70%. As a result, the weights of the first-class indices are determined, and the specific weights of the first-class and second-class indices are determined by entropy method. The third-class indices involve planning and design, fluid, heating ventilating and air conditioning, water supply and drainage and other professional details, which need to be judged by experts and scholars; and the entropy method is used to determine the weight. Finally, the

Table 1
Comparison of health-related assessment standards.

| Standard                        | Scope                                      | Stage        | First-class assessment index                                      | Weight system         | Assessment Method                          | Assessment result                   |
|--------------------------------|--------------------------------------------|--------------|----------------------------------------------------------------|-----------------------|--------------------------------------------|------------------------------------|
| WELL Building Standard V2.0    | Single building, complex building and its surrounding environment | Operation    | Air, water, sports, thermal comfort, light and sound environment, community, spirit, nutrition and materials | Implied weight        | Linear summation                          | Silver grade ≥50, Gold grade ≥60, Platinum grade ≥80 |
| Assessment Standard for Green Building | Single building, complex building         | Operation    | Healthy and comfortable, convenient life, livable environment, safe and durable, resource saving | Weight set independently | Linear summation                          | One star grade ≥85, two star grade ≥70, three-star grade ≥60 |
| Assessment Standard for Healthy Building | Fully decorated single building, building group and its surrounding environment | Design and operation | Air, water, comfort, fitness, humanity and service | Weight set independently | Simple weighting                          | One star grade ≥85, two star grade ≥70, three-star grade ≥60 |
extension assessment method is used to determine the overall health level of residential buildings.

2.1. Entropy method

Entropy method belongs to objective weighting method, and its weight is determined by the information provided by the measured data of each index \[15\]. There are m schemes to be evaluated and n assessment indices to form the original index data matrix \(X = (X_{ij})_{m \times n}\), for a certain index \(X_j\), the greater the gap among \(X_{ij}\), the greater the role of \(X_j\) in the comprehensive assessment. If some index values are equal, it indicates that these indices cannot be used for comprehensive assessment \[16\].

The detailed steps and calculation method of entropy method are as follows \[17\].

Firstly, the basic value of the index is normalized. The specific calculation formula is as follows:

\[
S_{ij} = \frac{X_{ij}}{\sum_{p=1}^{p}X_{ij}(j = 1, 2, \ldots, p)} \quad (1)
\]

The entropy \(e_j\) and redundancy \(d_j\) of index \(j\) are calculated

\[
e_j = k \sum_{p=1}^{p} S_{ij} \times \ln S_{ij} \quad (2)
\]

\[
d_j = 1 - e_j \quad (3)
\]

where, \(k\) is adjustment coefficient, \(k = 1/\ln p\), \(k > 0\), \(e_j > 0\).

The weight \(w_j\) of index \(j\) is calculated by the following formula:

\[
w_j = \frac{d_j}{\sum_{j=1}^{p} d_j} \quad (4)
\]

According to the steps, entropy \(e_j\), redundancy \(d_j\) and final weight \(w_j\) of each assessment index can be calculated from Formulas (1) ~ (4).

2.2. Extentics

Comprehensive assessment method can integrate the information of multiple indices of an object, and then use comprehensive indices to represent the whole to describe the comprehensive characteristics of the assessed object. In 1983, Cai put forward the extentics comprehensive assessment method to study the possibility of things expanding and its internal law mechanism \[18\]. According to the principle of extentics, three-level comprehensive extentics assessment is established, and the steps are shown in Fig. 1.

2.2.1. Classical domain and nodal domain

According to the classification in the Assessment standard for healthy building (T/ASC 02-2016), the residential building assessment for epidemic prevention design is divided into four levels, i.e. non-conforming, one, two and three-star levels. According to the star rating ratio, the classic fields \(V_{ij}\) of each grade of assessment indices are: non-conforming \(V_{i0}\), one star \(V_{i1}\), two-star \(V_{i2}\), three-star \(V_{i3}\), and the section area is \(V_{ip}\). Combined with the interpretation and score of the corresponding indices in each assessment standard, definition of each index is set. The classical domain and node domain of qualitative and quantitative indices are different: the quantitative indices are determined after appropriate adjustment according to the situation; the qualitative indices are determined according to the score of multiple assessment items, the score range is \([0, C]\), and \(C\) is the maximum score of the index. For some new qualitative third-class indices in medical treatment and epidemic prevention, the total score is 10 points.

After removing the non-assessment indices, the assessment index \(C_i\) is determined and the classical domain and node domain of \(C_i\) are constructed according to the following equations.

![Fig. 1. Application of the extentics comprehensive assessment method.](image-url)
The classical domain and nodal domain of air indices.

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Table 2

The classical domain and nodal domain of air indices.

| Index | V10 | V11 | V12 | V13 | Vp |
|-------|-----|-----|-----|-----|----|
| A11   | (0.3)|     |     |     |    |
| A12   | (0.2,5)|     |     |     |    |
| A13   | (0.1)|     |     |     |    |
| A14   | (0.1,5)|     |     |     |    |
| A21   | (37.5,75)|   |     |     |    |
| A22   | (0.09%,0.18%)| |     |     |    |
| A31   | (0.7,5)|     |     |     |    |
| A32   | (0.5)|     |     |     |    |
| A41   | (0.5)|     |     |     |    |
| A42   | (0.2,5)|     |     |     |    |

2.2.3. Determination of actual weight of indices

Actual weight of indices is determined by the following equation.

$$u_i = \pi_i / \sum_{i=1}^{n} \pi_i$$

where $u_i$ is the actual weight of $C_i$, $\pi_i$ is the weight of $C_i$ in section 3.2.

2.2.4. Calculation of correlation function of third-class indices

According to the value range and the best situation of the health assessment index system of residential buildings for epidemic prevention design, the classical correlation function is selected, and the third-class index correlation function is calculated by the following equations.

$$k(v_{iyg}) = \frac{P(v_i, V_y) - P(v_i, V_p) - \alpha_i - \beta_j}{2} \quad v_i \in V_y$$

$$P(v_i, V_y) = \frac{P(v_i, V_y) - P(v_i, V_p) - \alpha_i - \beta_j}{2}$$

$$P(v_i, V_p) = \frac{P(v_i, V_y) - P(v_i, V_p) - \alpha_i - \beta_j}{2}$$

where $k(v_{iyg})$ is the third-class index correlation degree of $C_{iyg}$ to Grade j.

2.2.5. First class extension assessment

The assessment index system of HASRBEP is divided into three layers, thus, the extension assessment of residential building is also divided into three levels, and the correlation degree is calculated step by step.

The first class extension assessment is used to analyze the second-class indices as the matter elements to be evaluated, and the correlation degree of the third-class index is accordingly calculated.

Then the comprehensive correlation degree of the second-class indices corresponding to Grade j is

$$k(v_j) = \sum_{i=1}^{n} x_{ij} k(v_{iyg})$$

where $x_{ij}$ is the second-class index correlation degree of $C_{iyg}$ to Grade j; n is the number of the third-class indices for participating in the assessment of the g-th second-class index of the i-th first-class index.

2.2.6. Second class extension assessment

The second class extension assessment is used to analyze the first-
class indices as the matter elements to be evaluated, then the calculation of the comprehensive correlation degree \( k_j(v_i) \) of the first-class indices corresponding to Grade \( j \) is

\[
k_j(v_i) = \sum_{p=1}^{m} \mu_{ij} k_j(v_p)
\]

(12)

where \( m \) is the number of the \( y \)-th second-class index for participating in the assessment in the \( i \)-th first-class index, and \( \mu_{ij} \) is the weight of the \( y \)-th second-class index of the \( i \)-th first-class index.

2.2.7. Third class extension assessment

The correlation degree \( k_j(P) \) of the corresponding class \( j \) of the object (P) is calculated as follows:

\[
k_j(P) = \sum_{i=1}^{f} u_i k_i(v_j)
\]

(13)

where \( f \) is the number of first-class indices; \( u_i \) is the weight of the \( i \)-th first-class index.

2.2.8. Grading estimation

The grading estimation is done according to the following equations.

\[
k_j(P) = \max \{ k_j(P) \} \quad j \in \{1, 2, ..., m\}
\]

(14)

\[
\bar{k}_j(p) = \frac{k_j(p) - \text{mink}_j(p)}{\text{maxk}_j(p) - \text{mink}_j(p)}
\]

(15)

\[
j^* = \frac{\sum_{j=1}^{m} \delta j^*(p)}{\sum_{j=1}^{m} \delta j(p)}
\]

(16)

where \( k_0(P) \) is the level of \( P \); and \( j^* \) is the level variable eigenvalue of \( P \).

3. Construction of HASRBEP

3.1. Index system

In order to prevent and control the spread of epidemic diseases in residential buildings, the epidemic prevention design should be considered from the perspective of general layout planning, single building epidemic prevention design, and supporting facilities and services.

Due to the health assessment system of residential building covering many specialties, the indices are professional, sophisticated and diverse. Therefore, combined with the requirements of current epidemic prevention and control, the indices were selected according to the principles of comprehensiveness, scientificity and operability, accounting for the assessment standards of the healthy building in China and abroad. The index system of HASRBEP is established based on screening and analysis, including 9 first-class indices, 26 second-class indices and 70 third-class indices in which 19 are new indices. The newly first-class indices of epidemic prevention include 3 second-class indices and 10 second-class indices. The healthy assessment index system for residential building is shown in Table 3.

3.2. Weight system

Experts and residents from universities and research institutions, medical organizations, planning and design firms, and property companies are selected as the survey objects, and the initial data of the indices is obtained by using the questionnaire survey. Then, according to the calculation steps of entropy method in Section 2.1, the specific weights of the first-class and second-class indices are obtained by using SPSS statistical analysis software and Excel software to calculate and process.

### Table 3: Healthy assessment index system for residential building.

| First-class indices | Second-class indices | Third-class indices |
|---------------------|----------------------|---------------------|
| Air(A)              | Pollution source (A1) | Air tightness (A11), water seal (A12), building entrance dust prevention (A15), ventilation system (A14) |
|                     | Concentration limit (A2) | The concentration of particulate matter (A21), CO2 (A22) |
|                     | Purification (A3) | Air purification (A31), equipment operation (A32) |
|                     | Monitoring (A4) | Monitoring system (A41), underground garage (A42) |
| Water (B)           | Water quality (B1) | Domestic hot water (B11), transmission pipeline (B12) |
|                     | System (B2) | Dry wet separation (B21), drainage system (B22) |
|                     | Test (B3) | Water quality monitoring system (B31), water quality detection system (B32) |
| Comfort (C)         | Sound (C1) | Indoor noise environment (C11), equipment vibration isolation and noise reduction (C12) |
|                     | Optical(C2) | Natural light use (C21), lighting control (C22), comfortable illumination (C23) |
|                     | Heat and humidity (C3) | Humidity range (C31), thermal comfort monitoring and adjustable (C32), thermal environment zoning (C33) |
| Medical (D)         | Medical facilities (D1) | Basic medical (D11), emergency resources (D12) |
|                     | Medical services (D2) | Medical and health services (D21), environmental health security (D22), vaccination (D23), health science (D24) |
| Fitness (E)         | Outdoor (E1) | Fitness venue (E11), fitness trail (E12), healthy travel mode (E13), encourage sports (E14) |
|                     | Indoor (E2) | Fitness space (E21), encourage the use of stairs (E22), fitness services (E23) |
|                     | Equipment (E3) | Outdoor fitness equipment (E31), indoor fitness equipment (E32) |
| Humanities (f)      | Exchange (F1) | Social space (F11), children’s playground (F12), elderly activity venue (F13) |
|                     | Psychological (F2) | Cultural activity facilities (F21), entrance hall (F22), mental health service facilities (F23) |
|                     | For the aged (F3) | Safety design (F31), barrier free (F32) |
|                     | Ergonomics (F4) | Graphic design (F41), visual efficacy (F42), ergonomics education (F43) |
| Service (G)         | Property (G1) | System certification (G11), satisfaction survey (G12) |
|                     | Publicity (G2) | Data release (G21), food traceability (G22), intelligent service (G23) |
|                     | Activity (G3) | Public welfare activities (G31), interest groups (G32) |
|                     | Promote (G4) | Health education (G41), health publicity (G42) |
| Epidemic prevention (I) | Epidemic prevention design (I1) | Building layout (I11), indoor layout (I12), negative pressure design (I13), combination of anti-epidemic (I14) |
|                     | Epidemic prevention service (I2) | Sanitation (I21), emergency management system (I22), healthy diet (I23) |
|                     | Epidemic prevention facilities (I3) | Waste treatment (I31), epidemic prevention (I32), reduce surface contact (I33), reduce air transmission (I34) |

The third-class indices were scored by experts who worked out the epidemic prevention standards, and then the weight and score of the final third-class indices were determined by entropy method.

According to WHO’s classification of health impact, the first-class indices adjusted the weight of air, water and comfort to be 0.2, medicine to be 0.1, and fitness, humanities, service and epidemic prevention to be 0.7. The entropy method is used to determine the specific weight of air, water and comfort, as well as the specific weight of fitness, humanities, service and epidemic prevention.
SPSS software is used to analyze the questionnaire survey data of environmental indices by entropy method, and the corresponding information entropy (\(e_i\)) and redundancy (\(d_i\)) are calculated respectively. Finally, the weight coefficient \(u_i\) is obtained. The results are shown in Table 4.

The weights related to the first-class indices of environment (air, water and comfort) are respectively 0.3187, 0.2774 and 0.4038. Combined with the weight division of WHO, the weight of the first-class indices can be obtained. By repeating this method, the weights of the second-class indices can be obtained. After the third-class indices are scored by experts, the specific weight of each index can be obtained by using the entropy method, as shown in Table 5.

### 3.3. Application of HASRBEP

#### 3.3.1. Application flow chart of HASRBEP

The assessment model combines the preliminary assessment of healthy building assessment standard with multi-level extension assessment, and it divides the process of assessment into three steps: control item assessment, preliminary assessment and extension assessment, as shown in Fig. 2. The sophistication of the three steps is gradually increasing, and the assessment would be terminated once the unqualified objects are screened at one time, which saves the following extension assessment, reduces the workload of residential building health assessment, and effectively improves the assessment efficiency.

In the preliminary assessment, the method of setting the lowest score of each index in the Assessment standard for green building (GB/T 50378–2019) is used for reference, and the score of six first-class indices in the preliminary assessment of the Assessment standard for healthy building (T/ASC 02–2016) is required, which accounts for more than 30% of the total score of each index, and the total score is no less than 40 points [10]. If not, the assessment will be terminated to ensure that all aspects of the health performance of healthy buildings meet the requirements.

#### 3.3.2. Construction of extension assessment model

The extension assessment model is constructed according to the specific steps in Section 2.2, and three-level extension comprehensive assessment is used to judge the health degree of residential buildings.

Before the application of the extension assessment model, the first step is to preliminarily evaluate according to the Assessment standard for healthy building (T/ASC 02–2016), and judge whether the first-class indices account for more than 30% of the total score, which is no less than 40 points. With this prerequisite, according to the design and measured data of the healthy building, calculate the correlation function of the third-class indices and proceed with extension assessment according to section 4.3.5, and determine the star level of the project. The application process of HASRBEP is as shown in Fig. 3.

#### 3.3.3. Grade assessment

The result of final assessment of HASRBEP can be obtained on the basis of calculation of the three-level extension assessment index. The maximum value of the correlation degree of each level class is used to determine the level of the index, and the health degree of residential building is determined according to the eigenvalue of the level variable. The larger the eigenvalue of the level variable is, the higher the level is, and the better the health and epidemic prevention level of residential building is. In the calculation process, the correlation degree and the level of each level index are obtained. Variable eigenvalue is to judge the assessment level and health degree of the index, and the larger the eigenvalue of the level variable is, the higher the level is, and the greater the contribution rate to the overall health of residential building will be.

### Table 4

Weight results of first-class environmental assessment indices.

| Index | \(e_i\)  | \(d_i\)  | \(u_i\)  |
|-------|---------|---------|---------|
| A     | 0.9978  | 0.0022  | 0.3187  |
| B     | 0.9981  | 0.0019  | 0.2774  |
| C     | 0.9972  | 0.0028  | 0.4038  |

### Table 5

Assessment index weights of HASRBEP.

| First-class | \(u_i\) | Second-class | \(u_{iy}\) | Third-class | \(u_{iyg}\) |
|-------------|--------|-------------|-----------|-------------|-----------|
| E           | 0.1696 | E1          | 0.2755    | E11         | 0.2843    |
|             |        | E12         | 0.2954    |             |           |
|             |        | E13         | 0.2150    |             |           |
|             |        | E14         | 0.2053    |             |           |
|             |        | E2          | 0.3519    | E21         | 0.3481    |
|             |        | E22         | 0.3060    |             |           |
|             |        | E23         | 0.3459    |             |           |
|             |        | E3          | 0.3726    | E31         | 0.4880    |
|             |        | E32         | 0.5120    |             |           |
|             |        | E33         | 0.5250    |             |           |
| F           | 0.1718 | F1          | 0.2323    | F11         | 0.3258    |
|             |        | F12         | 0.3405    |             |           |
|             |        | F13         | 0.3337    |             |           |
|             |        | F2          | 0.2142    | F21         | 0.3573    |
|             |        | F22         | 0.3138    |             |           |
|             |        | F23         | 0.2989    |             |           |
|             |        | F3          | 0.2184    | F31         | 0.5287    |
|             |        | F32         | 0.4713    |             |           |
|             |        | F4          | 0.3351    | F41         | 0.3562    |
|             |        | F42         | 0.3480    |             |           |
|             |        | F43         | 0.2958    |             |           |
|             |        | F5          | 0.2322    | F51         | 0.2841    |
|             |        | F52         | 0.5287    |             |           |
|             |        | F53         | 0.2978    | F531        | 0.4637    |
|             |        | F532        | 0.5363    |             |           |
|             |        | F54         | 0.2841    | F541        | 0.4713    |
|             |        | F542        | 0.5287    |             |           |
|             |        | H1          | 0.3222    | H11         | 0.2932    |
|             |        | H12         | 0.2377    |             |           |
|             |        | H13         | 0.2393    |             |           |
|             |        | H14         | 0.2297    |             |           |
|             |        | H2          | 0.3202    | H21         | 0.3455    |
|             |        | H22         | 0.3512    |             |           |
|             |        | H23         | 0.3033    |             |           |
|             |        | H3          | 0.3575    | H31         | 0.2485    |
|             |        | H32         | 0.2434    |             |           |
|             |        | H33         | 0.2560    |             |           |
|             |        | H34         | 0.2520    |             |           |

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Fig. 2. Application flow chart of HASRBEP.
According to the general regulations, if the residential building fails to meet the HASRBEP, it is considered that the residential building does not have the ability of epidemic prevention, and the health level is very poor. One-star is considered to have the average health level and epidemic prevention ability, while two-star is considered to be good, and three-star is considered to have the highest health level and epidemic prevention ability. If max \( k_j(p) \) of a certain index is at three-star and \( j^* = 2.3 \), then the index belongs to three-star, but tends to two-star, and the actual star level is 2.3.

The index weight system of HASRBEP is determined on the basis of WHO’s investigation on the influential factors of human health, and the weight system is more scientific. According to the principle of extenics, the health assessment model of residential buildings divides the scope of each index into four grades: basic level, one, two, and three stars. The corresponding grade and health correlation strength of each index can be seen intuitively and clearly. The greater the correlation degree is, the higher the contribution of the index to the health degree of buildings is.

The Yulongzhuang Building Community (YBC) is located in Zhangban District, Quanzhou City, Fujian Province, China. The total land area of the building community is 99369 m\(^2\) and the total floor area is 225246.64 m\(^2\). The building community includes a multi-storey residential building group and a class of high-rise residential buildings. In December 2020, the preliminary assessment of the healthy building design for the building community obtained the credential of three-star residential design according to the Assessment standard for healthy building (T/ASC 02–2016). The assessment scores are shown in Table 6.

The YBC is selected as a case study for four reasons: 1) the building community is designed and constructed during the epidemic period, and it is the first healthy building integrated with epidemic prevention design; 2) the building community is a full decoration delivery complex building estate; 3) the preliminary assessment of the healthy building design for the building community acquired the three-star healthy building certification; 4) the building community is designed according to the REDCO Group enterprise epidemic prevention standard, and the overall health and epidemic prevention performance of the building community is good.

4. Case study

4.1. Outline of the Yulongzhuang building community

The Yulongzhuang Building Community (YBC) is located in Zhangban District, Quanzhou City, Fujian Province, China. The total land area of the building community is 99369 m\(^2\) and the total floor area is 225246.64 m\(^2\). The building community includes a multi-storey residential building group and a class of high-rise residential buildings.

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4.2. Health assessment by HASRBEP

4.2.1. Assessment of control items

The preliminary assessment of the YBC shows the credential of three-star healthy building design, which indicates that the basic health performance of the building community meets the control items of the Assessment standard for healthy building (T/ASC 02–2016) and requirements of HASRBEP.
4.2.2. Preliminary assessment
According to the preliminary assessment of the building community during operation stage by the Assessment standard for healthy building (T/ASC 02–2016), the preliminary assessment scores of the building community can be obtained from the automatic calculation table of healthy building, as shown in Table 7. It can be found that the preliminary assessment of the building community during operation stage meets the requirements of control items, scoring items of more than 30%, and total score equals to or has more than 40 points. Therefore, the YBC can be evaluated and analyzed according to HASRBEP.

4.2.3. Extension assessment
There is no special requirements of climate and lifestyle in the area where the YBC is located, so all the three-class assessment indices are involved in the assessment. According to Section 3.2, the extension assessment of the YBC is carried out. Limited to space, the extension comprehensive assessment of healthy building of the YBC is only addressed by HASRBEP.

1. First class extension assessment

According to the measured value and the index weight in Section 3.2, the $k_i(v_3)$ of the third-class indices is calculated according to Formula (8), then the $k_i(p)$ of the second-class indices is calculated combined with Formula (11), and the characteristic value $j^*$ of the level variable is calculated with Formulas (15) and (16). The computed results are shown in Table 8.

2. Second class extension assessment

According to the extension assessment results of the second-class indices in Table 8, the comprehensive correlation degree $k_i(p)$ of first-class indices is calculated by combining Formula (12) and the characteristic value $j^*$, which is calculated by combining Formulas (15) and (16). The calculation results are shown in Table 9.

3. Extension assessment results of the YBC

According to the extension assessment results of the first-class indices in Table 9, the comprehensive correlation degree $k(p)$ of first-class indices of the YBC is calculated by combining Formula (13), and the eigenvalue $j^*$ of the level variable is calculated by combining Formulas (15) and (16). The calculation results are shown in Table 10.

5. Results and discussion

It can be found from Table 10 that the YBC has the highest correlation with three-star, and seems to reach the three-star standard of HASRBEP. It is consistent with the preliminary assessment results of the Assessment standard for healthy building (T/ASC 02–2016). The characteristic value of the level variable of the YBC is 2.56, which is in line with the three-star standard. However, it also has a bias to the second-star. Therefore, the YBC is not fully in line with the three-star level. The actual healthy building level should be 2.53 between two and three stars, which is more in line with the actual health and epidemic prevention level of the YBC.

As for the first-class indices, it can be seen from Table 9 that the YBC is relatively weak in terms of medical treatment and service since the eigenvalue of medical treatment is only 1.24. In fact, it is more inclined to one-star level, and the eigenvalue of the service is 2.17, which belongs to the two-star level. The reason may be that the YBC has just been completed, some of the operation business is not fully launched, and medical and service are the weak points. If the YBC needs to be optimized, the medical and service aspects could be significantly improved, especially the medical aspect. In addition, the eigenvalues of air, water, comfort and humanity are 2.29, 2.07, 2.01 and 2.23 respectively, which are more inclined to two-star level. It means that an effort should be made to optimize these indices toward the three-star level. The eigenvalues of the fitness and epidemic prevention are 2.59 and 2.38, which were the most inclined indices of three-star level. When COVID-19 broke out, the YBC was in the design stage, so it was then designed according to the epidemic prevention standard, therefore the level of epidemic prevention of the YBC is higher.

Exception for the fitness eigenvalue of 2.59, the eigenvalues of other first-class indices exceed two-star, which makes the overall star level of the YBC as three-star. It is because the grade score is classified according to the grade of the Assessment standard for healthy building (T/ASC 02–2016). The deviation between one-star and two-star is small, while the deviation between two-star and three-star grade scores is large, which makes the actual star level deviate from the actual building health level. Therefore, the reclassification of assessment index needs to be studied.

It can be seen from Tables 7 and 9 that the scores of fitness, water and service are lower than the ones of other indices, which are slightly different from the extension results of the first-class indices because HASRBEP improves the weights of fitness and epidemic prevention. Moreover, due to the requirements of epidemic prevention, a large
number of advanced anti-epidemic treatment facilities and equipment adopted in the YBC will be added in award items of improvement and innovation. If there were no additional items, the actual score of the YBC is only 81 points, which just meets three-star level. After the reconstruction of the system weight of the index system of residential building health assessment, the actual health star level of the YBC is 2.53. Therefore, HASRBEP is more in line with the actual situation of health and epidemic prevention level.

From the analysis mentioned above, HASRBEP has been successfully applied to the YBC. Compared with the preliminary assessment by the Assessment standard for healthy building (T/ASC 02–2016), the original design and assessment method of healthy building is not comprehensive enough to truly reflect the health level of all aspects of the epidemic prevention, and to enhance the epidemic prevention ability of the YBC. The epidemic prevention design by using HASRBEP with adding some epidemic prevention facilities can improve the health and epidemic prevention level of the YBC, and correctly evaluate the health and epidemic prevention level.

6. Conclusions

After reviewing the problems in the fields of the current healthy building and epidemic prevention design, HASRBEP was developed and demonstrated by means of the WELL Building Standard V2.0 of the International WELL Building Institute, the Assessment standard for green building (GB/T 50378–2019) and the Assessment standard for healthy building (T/ASC 02–2016). The assessment indices related to the health and epidemic prevention, weight system and extension comprehensive assessment model of HASRBEP was studied in detail. Compared with the WELL Building Standard V2.0 and the Assessment standard for healthy building (T/ASC 02–2016), HASRBEP is more detailed for the assessment level of indices, each index corresponds to four levels, and the epidemic prevention level of the YBC, and correctly evaluate the health and epidemic prevention level.
In summary, the main conclusions are as follows:

1. The index system of HASRBEP is constructed and the first-class indices of medical treatment and epidemic prevention are added, totally including 8 types of first-class indices, 26 second-class indices and 70 third-class scoring indices.

2. The weight system of HASRBEP is built and the weights were calculated by questionnaire survey, expert scoring and entropy method. The weights of eight first-class indices include air, water, comfort, medical treatment, fitness, humanity, service and epidemic prevention, which were determined to be 0.0637, 0.0555, 0.0808, 0.1000, 0.1696, 0.1718, 0.1683 and 0.1903 respectively. The specific weights of other indices were computed as shown in Table 5.

3. The multi-level extension health assessment model of HASRBEP is constructed, including control item assessment, preliminary assessment and extension assessment.

4. The comprehensive assessment of the YBC demonstrated that HASRBEP can effectively reflect the actual health degree of the assessment object and the degree of each index, which shows the feasibility of the model to some extent.

In conclusion, it is practical and effective to add epidemic prevention to the design of residential buildings. Application of HASRBEP can not only improves the health and epidemic prevention level of residential buildings, but also reflects the comprehensive health and epidemic prevention level of buildings in the aspects of building environment, architectural design and supporting facilities. However, the present study did not take the cost of additional epidemic prevention facilities and equipment into account. The design and construction of the YBC by HASRBEP show that the construction cost has increased slightly due to the addition of a large number of new epidemic prevention facilities. Furthermore, although the assessment method of HASRBEP can more clearly express the health level of all aspects of the buildings, it may be much more complex than the existing standards for application. Therefore, associated software may be developed for promoting the operability and usability of the application of HASRBEP.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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