Evaluation of the old residential area modification by applying improved fuzzy comprehensive evaluation

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Abstract. In order to make a global assessment on the modification effect of existing old residential areas in hot summer and warmer winter zone, an improved fuzzy comprehensive evaluation (FCE) model of old residential building modification is established based on the aspects of structural safety and architectural appearance, indoor comfort system, outdoor environment, public service facilities, building equipment efficiency and operation management, etc. Analytic hierarchy process is used to determine the weights of evaluation factors at all levels. And the model is used to evaluate the modification effect of the old residential buildings in Xiamen city. The evaluation result shows feasibility of this modification method on the old residential building. The evaluation grade of this area’s modification can be assessed as “Good”, which can provide a reference for the modification of the old residential areas with hot summer and warm winter. Measures, such as increasing government financial input, institutionalized ways to tracking energy consumption, popularization of energy-saving awareness, should be taken for the modification.

1. Introduction

Residential buildings share the maximum proportion as 69.3% of civil building in the China [1]. It is a major work to transform the old residential areas for a safety and comfortable living. Xiamen city locate in hot summer and warm winter area. Xiamen Municipal Government clearly defined the division scope of old residential areas [2], there were 390 old residential areas that met the requirements in the city. Most of these communities have such problems as damaged buildings, poor environment, imperfect municipal facilities and management mechanism, and imperfect community governance system. Three residential areas have been renovated as demonstration sites, and these old residential areas will be renovated in batches in the next few years. It is necessary to evaluate of the old residential area modification and to put forward some improvement measures.

Existing old residential building renovation research, scholars focused on the feasibility, technical research and evaluation ways, Kedi Chen [3] summarized the existing problems and solutions of existing old buildings. Li junfeng [4] and Songbai-zhou [5] searched for the measures to modification works for the old residential areas based on environment suitability evaluation. Luhe-Bai [6] Came up with a new evaluation method which can save energy and be economically feasible, LI Jing etc. [7-9] searched for an evaluation system for greening existing buildings, and established a model to improved fuzzy comprehensive evaluation. LIU Xiaojun [10] put forward the concept of "tracing variable", and come out with a calculation and verification method of energy conservation amount in energy conservation reconstruction of existing civil buildings. Ran Haoran [11] searched the factors that promote social forces to participate in the renovation of old residential areas. In the existing
research, the evaluation method of new building is very complete, old building renovation technology and methods are relatively mature, for the particularity of region, existed research findings can’t be used the modification effect of existing old residential areas in hot summer and warmer winter zone.

2. Evaluation index system
The complexity, regionality and singleness of building products determine the complexity characteristics of its evaluation factors and levels. According to the current national norms [12], the main impact factors of modification effect on existing old residential area are analyzed in this article, which as structural safety and architectural appearance, indoor comfort system, outdoor environment, public service facilities, building equipment efficiency and operation management, etc. The weight of the parameter is determined by its influence degree, then a comprehensive evaluation system for building modification is established. The evaluation index system is divided into three levels, six aspects and 21 evaluation indexes, which divided into two categories, qualitative and quantitative. The evaluation index system is shown in Table 1. The order of evaluation factors is determined by its importance which made by teams of experts.

| Evaluation factors                          | Second level evaluation index          |
|--------------------------------------------|----------------------------------------|
| Structural safety and architectural appearance | Evaluation factors                               |
| Structural safety                          | Fire safety                             |
| Appearance of security                     | Functional requirement                  |
|                                             | Indoor thermal and humidity environment |
| Indoor comfort system                       | Evaluation factors                               |
| Indoor acoustic and optical environment    | Indoor air quality                      |
|                                             |                                             |
| Outdoor environment                        | Evaluation factors                               |
| Road traffic system                        | Lighting system                          |
| Sound and ventilation environment          |                                             |
|                                             |                                             |
| Public service facilities                  | Evaluation factors                               |
| Entertainment and sports facilities        | Community services                       |
| Rubbish classification                     |                                             |
| Building equipment efficiency              | Evaluation factors                               |
| Equipment efficiency of HVAC               | Energy efficiency of lighting installation |
| Equipment efficiency of water supply and drainage system |                                             |
|                                             |                                             |
| Operation management                       | Evaluation factors                               |
| Qualifications of realty management enterprise | Measures to popularize energy-saving knowledge |
|                                             | Energy consumption statistics and publicity |

Notes:  
①Notes are referenced evaluation factors of first level evaluation factors, and the value of i is determined by the importance of the first level evaluation factors.  
②Notes are referenced evaluation factors of second level evaluation factors, and the value of j is determined by the importance of second level evaluation factors.  
③Notes are referenced quantitative factors.
3. Establishment of evaluation model

Research shows that the fuzzy comprehensive evaluation model is both feasible and scientific, which can offer the fair and objective evaluation of building energy efficiency [13]. The basic theory and method of fuzzy mathematics are introduced, the process to build the Fuzzy Evaluation model is summarized in the following paper.

3.1. Determine the evaluation set

Establish multilevel evaluation factor subset $U$, which is

$$U = \{U_1, U_2, \cdots, U_N\}$$

In the formula: $U_i = \{u_1^{(i)}, u_2^{(i)}, \cdots, u_k^{(i)}\}, i = 1, 2, \cdots, N$, which means there are $k_i$ factors in $U_i$, that is $\sum_{i=1}^{N} k_i = n$, and $U$ should satisfy the following conditions:

$$\bigcup_{i=1}^{N} U_i = U$$

The $U = \{U_1, U_2, \cdots, U_N\}$ is defined as the first level factor subset, and $U_i = \{u_1^{(i)}, u_2^{(i)}, \cdots, u_k^{(i)}\}$ is defined as the second level factor subset.

3.2. Determination of evaluation set

Evaluation set is established as $V = \{V_1, V_2, \cdots, V_m\}$, and the parameters $V_i (i=1, 2, \cdots, m)$ correspond to the actual data of the first level evaluation. In this paper, the level factor $m=4$ is taken, and each level has a corresponding fuzzy subset. The comments are in the order from senior to junior. The four evaluation grade standards are "excellent", "good", "medium", "qualified" and "unqualified". In order to facilitate the evaluation, values of 20, 40, 60, 80 and 100 can be assigned to each impact factor respectively. That is evaluation set

$$V = \{V_1, V_2, V_3, V_4, V_5\} = \{\text{excellent, good, medium, qualified, unqualified}\} = \{100, 80, 60, 40, 0\}$$

3.3. Determine the weights of evaluation factors

The weight is the key index to the Fuzzy Comprehensive Evaluation, and it can have direct effects on the accuracy of the evaluation. The evaluation factor weight set refers to the index of the importance degree of each index in the index system, which is determined by improved analytic hierarchy process (IAHP) in this paper. At the same level, the importance of each evaluation factor was compared pairwise to form the comparison matrix elements $k_{ij}$, after that the element $a_{ij}$ of the judgment matrix is obtained from the importance ranking index $r_i$, then the judgment matrix $A = (a_{ij})_{m \times m}$ is constructed, and after the optimization of formula (1), matrix $B = (b_{ij})_{m \times m}$ is obtained.

$$k_{ij} = \begin{cases} 2 & \text{if } i \text{ is more important than } j \\ 1 & \text{if } i \text{ and } j \text{ are the same important} \\ 0 & \text{if } j \text{ is more important than } i \end{cases}$$

$$r_i = \sum_{i=1}^{m} k_{ia}, r_j = \sum_{i=1}^{m} k_{ib}, a_{ij} = \begin{cases} \frac{r_i - r_j}{r_i - r_j} & r_i > r_j \\ 1 & r_i = r_j \\ \frac{1}{(r_i - r_j)} & r_i < r_j \end{cases}$$

After the optimization of formula (1), matrix $B = (b_{ij})_{m \times m}$ is obtained:

$$b_{ij} = \frac{\prod_{i=1}^{m} a_{ij}}{\sum_{i=1}^{m} \prod_{j=1}^{m} a_{ij}} \quad (1)$$

After further normalization, a single weight value is obtained:
1. Establishment of fuzzy relation quantitative evaluation matrix

The single factor evaluation value of the quantitative evaluation index is calculated by using the index method, then, together with qualitative evaluation indexes, the evaluation score is determined by using the Delphi method: the membership function of evaluation index \( r_j \) is established by the semi-trapezoidal method, and \( x \) is the score of evaluation index.

The membership function of the evaluation factor to \( v_k \) and \( v_{k+1} \) is respectively:

\[
\begin{align*}
    r_x = \begin{cases} 
        \frac{x-v_{k+1}}{v_k-v_{k+1}} & v_k+1 \leq x \leq v_k \\
        0 & x > v_k \text{ or } x < v_{k+1}
    \end{cases}
\end{align*}
\]

Here, membership degree of hierarchical fuzzy subset \( R \) can be expressed by single factor, and the fuzzy relation quantitative evaluation matrix \( R \) can be obtained:

\[
R = \begin{bmatrix} 
    R | u_1^{(i)} & r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{1m}^{(i)} \\
    R | u_2^{(i)} & r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{2m}^{(i)} \\
    \vdots & \vdots & \vdots & \ddots & \vdots \\
    R | u_p^{(i)} & r_{p1}^{(i)} & r_{p2}^{(i)} & \cdots & r_{pm}^{(i)} 
\end{bmatrix}
\]

3.5. Synthesis of fuzzy comprehensive evaluation results at all levels

By using the composition operation of fuzzy matrix, the fuzzy comprehensive evaluation result vector \( B \) is obtained by the product of weight vector matrix \( W \) and fuzzy relation quantitative evaluation matrix \( R \):

\[
W \circ R = \begin{bmatrix} 
    r_{11} & r_{12} & \cdots & r_{1m} \\
    r_{21} & r_{22} & \cdots & r_{2m} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{p1} & r_{p2} & \cdots & r_{pm} 
\end{bmatrix} = (b_1, b_2, \ldots, b_m) = B
\]

The effect of fuzzy comprehensive evaluation will be greatly influenced by the selection of synthetic operator [13], in the operation \( \circ \) can take \( (\wedge, \vee) \) or \( (\bullet, +) \).

3.6. Interpretation of fuzzy comprehensive evaluation results

There is a corresponding relationship between the fuzzy comprehensive evaluation set \( B \) and comment set \( V \), so the fuzzy comprehensive evaluation set is determined as the result of comprehensive evaluation. By using the maximum membership method, in the comment set \( V \) the element \( v \) which is the most "close" to \( \max_j b_j \) is taken as the evaluation result:

\[
v = \{ v_j \mid v_j \rightarrow \max_j b_j \}
\]

4. The case analysis

Through a thorough investigation, there are 334 old residential areas of non-commercial housing and non-personal collective housing completed and accepted by the end of 1989 in Siming district, with a total construction area of about 2.58 million square meters, involving 1183 buildings. Take one of the communities as a case study, which built in 1986 and with a total construction area of about 135
thousand square meters [2]. For two years, this old village transformation of content, including municipal facilities, residential environment and supporting facilities, building ontology, the public service facilities such as content, and combining the sponge city, public security prevention and control, the construction of barrier-free facilities requirements, focus on transformation of old district municipal facilities, public part for residential area environment, service facilities, etc.

4.1. Construct evaluation index system and weight
The evaluation index system is divided into 3 levels, 5 aspects and 21 evaluation indexes. Experts and scholars from the fields of architecture, structure, municipal administration and planning are invited to form a panel to evaluate the single factor of each influencing factor. The evaluation system and evaluation status are shown in Table 2.

### Table 2. Residential building reconstruction evaluation index and single factor evaluation result.

| First level evaluation index | Second level evaluation index | Single factor evaluation $r_{ij}$ |
|-----------------------------|-------------------------------|---------------------------------|
| Evaluation factors $U_i$   | Weight $w_i$                  | Evaluation factors $u_{ij}$     | Weight $w_{ij}$ | excellent $v_1$ | good $v_2$ | medium $v_3$ | qualified $v_4$ | unqualified $v_5$ |
| $U_1$                       | 0.21                          | $u_{11}$                        | 0.380          | 0.370           | 0.350       | 0.220         | 0.060           | 0.000          |
|                            |                               | $u_{12}$                        | 0.284          | 0.380           | 0.340       | 0.210         | 0.070           | 0.000          |
|                            |                               | $u_{13}$                        | 0.206          | 0.400           | 0.330       | 0.180         | 0.080           | 0.010          |
|                            |                               | $u_{14}$                        | 0.130          | 0.340           | 0.340       | 0.180         | 0.130           | 0.010          |
|                            |                               | $u_{21}$                        | 0.425          | 0.540           | 0.220       | 0.140         | 0.080           | 0.020          |
| $U_2$                       | 0.17                          |                                |                |                |             |                |                |                |
|                            |                               | $u_{22}$                        | 0.135          | 0.580           | 0.240       | 0.100         | 0.050           | 0.030          |
|                            |                               | $u_{23}$                        | 0.44           | 0.420           | 0.350       | 0.150         | 0.070           | 0.010          |
|                            |                               |                                |                |                |             |                |                |                |
| $U_3$                       | 0.17                          |                                |                |                |             |                |                |                |
|                            |                               | $u_{31}$                        | 0.550          | 0.370           | 0.450       | 0.140         | 0.030           | 0.010          |
|                            |                               | $u_{32}$                        | 0.160          | 0.460           | 0.330       | 0.120         | 0.080           | 0.010          |
|                            |                               | $u_{33}$                        | 0.290          | 0.290           | 0.320       | 0.290         | 0.060           | 0.040          |
|                            |                               | $u_{34}$                        | 0.290          | 0.599           | 0.300       | 0.101         | 0.000           | 0.000          |
| $U_4$                       | 0.15                          |                                |                |                |             |                |                |                |
|                            |                               | $u_{41}$                        | 0.340          | 0.641           | 0.104       | 0.153         | 0.102           | 0.000          |
|                            |                               | $u_{42}$                        | 0.130          | 0.640           | 0.124       | 0.144         | 0.166           | 0.101          |
|                            |                               | $u_{43}$                        | 0.420          | 0.589           | 0.144       | 0.166         | 0.101           | 0.000          |
|                            |                               | $u_{44}$                        | 0.683          | 0.390           | 0.300       | 0.210         | 0.090           | 0.010          |
| $U_5$                       | 0.16                          |                                |                |                |             |                |                |                |
|                            |                               | $u_{51}$                        | 0.203          | 0.450           | 0.240       | 0.190         | 0.100           | 0.020          |
|                            |                               | $u_{52}$                        | 0.114          | 0.530           | 0.210       | 0.170         | 0.080           | 0.010          |
|                            |                               | $u_{53}$                        | 0.369          | 0.360           | 0.310       | 0.170         | 0.150           | 0.010          |
|                            |                               | $u_{61}$                        | 0.210          | 0.320           | 0.330       | 0.250         | 0.090           | 0.010          |
| $U_6$                       | 0.14                          |                                |                |                |             |                |                |                |
|                            |                               | $u_{62}$                        | 0.157          | 0.350           | 0.390       | 0.220         | 0.020           | 0.020          |

4.2. Single factor fuzzy evaluation
According to the single factor evaluation set, after the normalization of the evaluation of statistical experts, the single factor evaluation matrix of evaluation factor $U_i$ is:

$$
R_1 = \begin{bmatrix}
0.370 & 0.350 & 0.220 & 0.060 & 0.000 \\
0.380 & 0.340 & 0.210 & 0.070 & 0.000 \\
0.400 & 0.340 & 0.180 & 0.130 & 0.010 \\
0.340 & 0.340 & 0.180 & 0.130 & 0.010 \\
\end{bmatrix}
$$
4.3. Secondary -stage fuzzy evaluation

Second level evaluation index weight coefficient of evaluation factor \( U_1 \) is \( A_1 = (0.455 \ 0.455 \ 0.090 \ 0.000) \), so its fuzzy comprehensive evaluation is \( B_1 = A_1 \circ R_1 = (0.377 \ 0.344 \ 0.212 \ 0.066 \ 0.001) \), in the operation \( ' \circ ' \) can take \((\wedge,\vee)\) or\((\bullet,+)\), which not only consider the influence of all factors, but also retain all the information of single factor evaluation.

Similarly, the comprehensive evaluation of the other five factors \( U_2 \), \( U_3 \), \( U_4 \), \( U_5 \) and \( U_6 \) as follows:

\[
B_2 = (0.527 \ 0.235 \ 0.141 \ 0.078 \ 0.019), \\
B_3 = (0.371 \ 0.425 \ 0.153 \ 0.038 \ 0.013), \\
B_4 = (0.597 \ 0.216 \ 0.135 \ 0.053 \ 0.000), \\
B_5 = (0.406 \ 0.289 \ 0.205 \ 0.089 \ 0.010), \\
B_6 = (0.357 \ 0.312 \ 0.175 \ 0.146 \ 0.010),
\]

Matrix \( R \) consists of all the factors comprehensive evaluation for the modification effect of existing old residential building:

\[
R = (B_1, B_2, B_3, B_4, B_5, B_6)^T = \begin{bmatrix}
0.377 & 0.344 & 0.212 & 0.066 & 0.001 \\
0.527 & 0.235 & 0.141 & 0.078 & 0.019 \\
0.371 & 0.425 & 0.153 & 0.038 & 0.013 \\
0.597 & 0.216 & 0.135 & 0.053 & 0.000 \\
0.406 & 0.289 & 0.205 & 0.089 & 0.010 \\
0.357 & 0.312 & 0.175 & 0.146 & 0.010
\end{bmatrix}
\]

4.4. First -stage fuzzy evaluation

First level evaluation index weight coefficient of evaluation factor \( U_1 \) is \( A = (0.21,0.17,0.17,0.15,0.16,0.14) \), then its fuzzy comprehensive evaluation is:

\[
C_1 = A \circ R = (0.436 \ 0.307 \ 0.172 \ 0.076 \ 0.009)
\]

synthesis value is:

\[
z = CV^T = 81.545, \text{ then, the grade of modification effect on existing old residential building is } v_1 = "Good".
\]

An analysis of these renovation projects reveals that there are many reasons why the grade of modification effect has not been achieved the “excellent”. As the old community is dominated by low-income groups, the limitation of funds will result in low renovation standards. Furthermore, as some residents are not fully aware of the benefits of energy-saving measures, many technical methods that contribute to low-carbon were not selected in the modification of the old residential areas, and many cost-effective measures were finally abandoned because residents could not accept them.

5. Conclusions

As the existing building reconstruction evaluation system is not perfect, this paper establishes the modification effect system of existing old residential areas which is based on the analytic hierarchy process. Meanwhile, combined with the fuzzy comprehensive evaluation method, the principles of weight determination and classification are improved respectively, which achieve quantitative and qualitative combination. The evaluation grade of this area’s modification can be assessed as “Good”, which can provide a reference for the modification of the old residential areas with hot summer and warm winter. Actions should be taken to better the effect of modification.

First, increase government financial input, multi-channel funds-raising should be taken for the modification.

Second, institutionalized ways tracking energy consumption that are easily accepted by residents should be explored.

Finally, residents' awareness of low-carbon life needs to be further guided and encouraged, especially for the popularization the use of low-energy buildings.

Meanwhile, the weight and membership of indicators are determined by experts review, so it is very important for the modification effect system to make sure all the experts should be fair, justice and knowledgeable. From the experience of renovation of the old residential areas in Xiamen, the
establishment of long-term co-management mechanism and implementation of the public pension system will contribute to the management and maintenance of the old residential areas in the future.

Acknowledgement
This research was supported by the National Natural Science Foundation of China (NSFC) (Grant No.71503224), Fujian Natural Science Foundation (Grant No.2019J01865) and Education and Teaching Reform Project (Grant No. JG2019020). The work described in this paper was also funded by Fujian Social Natural Science Foundation (Grant No. FJ2015C110) and University Outstanding Young Scientific Research Talent Cultivation Program Project in Fujian Province.

References
[1] National Bureau of Statistics. 2019. Web. 10 July 2019.
http://www.stats.gov.cn/tjsj/zxfb/201902/t20190222_1651265.html.
[2] Xiamen Municipal Government, P.R.China. 2016. Web.10 July 2019.
http://www.xm.gov.cn/zwgk/flfg/sfbwj/201605/t20160512_1328063.htm.
[3] Kedi-Chen 2012 Research on the Energy-saving Renovation Technology of Existing Residential Building in Hefei[D] Hefei University of Technology
[4] Li Junfeng, Wan Yan 2016 Reconstruction Design of Old Residential Areas Based on Environment Suitability Evaluation: a Case Study of Yaohai Distict in Heifei City Journal of Hefei University of Technology (Social Science Edition) 30(04) 111-116
[5] Songbai-Zhou 2018 Exploration of the Renewal of Old Residential Areas in Xiamen from the Perspective of Multiple Governance [D] Xiamen University
[6] Luhe-Bai 2011 Strategy of Energy-saving Renovation of Existing Buildings in Shanghai China[D] East China University of Science and Technology
[7] LI Jing, LI Deying, WANG Yani 2015 Potential Assessment on Greening Existing Buildings Based on Improved Fuzzy Comprehensive Evaluation[J] BUILDING SCIENCE 31(12) 41-46
[8] Zhang, Chaoqiong 2011 Study on Fuzzy Comprehensive Evaluation of Rural House Energy-saving Renovation Demonstration Effects. BMEI 2011 - Proceedings 2011 International Conference on Business Management and Electronic Information 3 406-409
[9] Jin, Hong; Zhao, Wei; Ye, Xiao-Shen December 2011 Application of the grey fuzzy comprehensive evaluation method in energy saving evaluation of existent rural dwelling house Journal of Harbin Institute of Technology (New Series) 18(SUPPL.2) 17-21
[10] LIU Xiaojun, WANG Bojun 2016 Optimization Research on Calculation and Verification Method of Energy Conservation Amount in Energy Conservation Reconstruction of Existing Civil Buildings [J] J. Xi'an Univ. of Arch. & Tech. (Natural Science Edition) 48(06) 776-782
[11] Ran Haoran 2017 Study on the Driving factors and Excitation Mechanism of Green Retrofitting Existing Buildings--Based on the View of Energy Management Company [D] Xi'an University of Architecture and Technology
[12] National Standards of the People's Republic of China. Assessment Standard for Green Retrofitting of Existing Building (GB/T 51141-2015). 2015.
[13] GUO Yan-hong, QIN Xuan, LIN Ge 2009 Multi-level Fuzzy Comprehensive Evaluation on Building Energy Efficiency Based on Whole Life Cycle BUILDING SCIENCE 25(8) 9-12