Fire Risk Analysis and Prevention Measures for Old Residential Districts

Chang Li, Zini Wang*, Jianfeng Chen
School of Civil Engineering, Shenyang Jianzhu University, Shenyang, Liaoning, China
**Corresponding Author*

Abstract: The accelerated pace of urbanization has increasingly exposed older residential communities to significant fire safety risks. This study develops a fire risk assessment framework for ORCs by analyzing typical fire incidents, conducting field investigations, and administering expert questionnaires. The framework comprises three core dimensions: fire hazard factors, prevention and control capabilities, and emergency response. An indicator system for evaluating ORC fire risk was established using factor analysis, and a fuzzy comprehensive evaluation model was subsequently constructed and validated through a case study. Based on the identification of common critical factors—such as ubiquitous fire hazards, daily management proficiency, and emergency response capacity—targeted prevention and control measures are proposed. This research aims to provide a foundational basis for enhancing fire risk management in older residential neighborhoods.

Keywords: Older Residential Communities; Fire; Hazardous Factors; Fuzzy Comprehensive Evaluation; Prevention and Control Measures

1. Introduction

Statistics from the National Fire and Rescue Administration indicate that between 2012 and 2021, China witnessed 1.324 million residential fires, resulting in 11,634 fatalities, 6,738 injuries, and direct property losses of RMB 7.77 billion. Given this severe reality, the fire safety of older residential communities has become a critical societal concern. The State Council's 'Guidelines on Comprehensively Promoting the Renovation of Urban Older Residential Communities' (Guo Ban Fa [2020] No. 23) explicitly identifies fire safety as a key component of ORC upgrades during the '14th Five-Year Plan' period[1]. As integral parts of the urban fabric, ORCs contribute to cultural heritage and accommodate daily life[2]. However, unlike modern residential areas, they possess distinct characteristics—diverse building structures[3], pronounced spatial features, lack of systematic maintenance, significant physical deterioration, high resident turnover, inadequate public facilities, and a shortage of fire-fighting equipment—that collectively create significant hazards[4]. Against this backdrop, this study aims to conduct an in-depth assessment of fire risks in ORCs, identify potential hazards, and propose targeted measures to offer both theoretical and practical guidance for improving their fire safety status.

2. Development of a Fire Risk Evaluation Index System for Older Residential Communities

2.1 Selection of Evaluation Indices

This study analyzed 50 typical fire incidents in older residential communities. Through this analysis, 20 key evaluation indices were identified and categorized into three primary groups: seven fire hazard factors, seven prevention and control capability factors, and six emergency response factors.

The fire hazard factors comprise the following secondary indices: aging electrical wiring, illegal electricity use, improper use of open flames, accumulation of combustible materials, missing or malfunctioning fire protection equipment, conversion of residential units for commercial/industrial use, and damaged entry doors.

The prevention and control capability factors include: fire resistance rating of building structures, fire compartmentation, fire patrols and maintenance, resident safety awareness, automatic fire alarm systems, electric vehicle management, and the establishment of fire safety management organizations.

The emergency response factors include: timeliness of fire alarm, initial fire-fighting capability, unobstructed evacuation routes, accessibility for external rescue services, rescue arrival time, and availability of emergency exits.

2.2 Analysis and Validation of Evaluation Indices

2.2.1 Questionnaire design and survey administration

A questionnaire survey was employed to evaluate the initial set of fire risk indices for ORCs. The questionnaire utilized a five-point Likert scale, where respondents rated the importance of each index across five levels: 'Not Important,' 'Of Little Importance,' 'Moderately Important,' 'Important,' and 'Very Important,' corresponding to scores of 1 through 5, respectively.

The survey was administered systematically via email and WeChat, distributing 80 questionnaires and receiving 75 valid responses, yielding an effective response rate of 93.75%. The respondent pool demonstrated strong expertise and representation, comprising 31 fire department officials and 25 specialists, with 25 individuals possessing over 15 years of professional experience. This sample structure lends robust support to the reliability of the study's findings.

2.2.2 Factor analysis and results

Factor analysis was conducted on the questionnaire data concerning the importance of fire risk factors in ORCs. Table 1 presents the extracted factors and the variance explained. The analysis yielded four factors with eigenvalues greater than one. After rotation, the variance explained by these factors was 25.511%, 15.377%, 13.337%, and 11.900%, respectively, cumulatively accounting for 66.125% of the total variance in Table 1.

Table 1. Fire Risk Factor Analysis Loading Matrix

Item	Factor Loadings				Communality
	Factor 1	Factor 2	Factor 3	Factor 4	
A Aging Electrical Wiring	0.063	-0.022	0.817	0.087	0.679
A Illegal Electricity Use	-0.017	0.306	0.542	0.609	0.759
A Improper Use of Open Flames	0.145	0.004	0.082	0.790	0.652
A Accumulation of Combustible Materials	0.521	0.072	0.489	0.280	0.594
A Missing or Malfunctioning Fire Protection Equipment	0.692	0.179	0.294	-0.047	0.599
A Residential-to-Commercial Conversion	0.778	0.221	0.039	0.276	0.732
A Damaged Entry Doors	0.138	0.027	0.228	0.559	0.384
B Fire Resistance Rating of Building Structure	0.713	0.167	0.163	0.378	0.706
B Fire Compartmentation	0.805	0.162	0.246	0.086	0.742
B Fire Patrols and Maintenance	0.813	0.190	0.086	-0.053	0.707
B Establishment of Fire Safety Management Organizations	0.747	0.112	0.153	0.314	0.692
B Infrastructure	0.522	0.145	0.412	0.079	0.470
B Electric Vehicle Management	0.398	0.247	0.614	0.101	0.607
B Electric Vehicle Management	0.592	0.260	0.011	0.549	0.720
C Timeliness of Fire Alarm	0.425	0.177	0.595	0.319	0.668
C Initial Fire-Fighting Capability	0.177	0.576	-0.007	0.386	0.513
C Unobstructed Evacuation Routes	0.457	0.221	0.486	0.270	0.566
C Accessibility for External Rescue	0.227	0.801	0.113	0.102	0.717
C Rescue Arrival Time	0.204	0.856	0.214	-0.043	0.822
C Emergency Exits	0.183	0.925	0.079	0.033	0.896

The varimax rotation method was applied to clarify the correspondence between factors and observed variables. The Table 1 displays the information extraction for each variable. The communality value for 'A Damaged Entry Doors' was below 0.4, indicating a weak association with the extracted factors and insufficient information extraction. Consequently, this variable was removed, and the factor analysis was re-run.

2.2.3 Data reliability and validity testing

To ensure the scientific rigor and reliability of the survey data, systematic tests for reliability and validity were performed in Table 2. Reliability was assessed based on the following criteria:

(1) A Cronbach's α coefficient > 0.8 indicates high reliability; 0.7–0.8 indicates good

reliability; 0.6–0.7 indicates acceptable reliability; < 0.6 indicates poor reliability.
(2) Items with a Corrected Item-Total Correlation < 0.3 were considered for removal.
(3) Items whose 'Cronbach's α if item deleted' value was substantially higher than the overall α coefficient were considered for removal, followed by re-analysis.

Table 2. Reliability Analysis Results for Scale Items

Cronbach's Reliability Analysis			
Item	Corrected Item-Total Correlation	Cronbach's α if Item Deleted	Cronbach's α Coefficient
A Aging Electrical Wiring	0.355	0.921	0.921
A Illegal Electricity Use	0.513	0.919	
A Improper Use of Open Flames	0.394	0.921	
A Accumulation of Combustible Materials	0.655	0.916	
A Missing or Malfunctioning Fire Protection Equipment	0.636	0.916	
A Residential-to-Commercial Conversion	0.733	0.913	
A Damaged Entry Doors	0.364	0.921	
B Fire Resistance Rating of Building Structure	0.758	0.913	
B Fire Compartmentation	0.749	0.913	
B Fire Patrols and Maintenance	0.644	0.916	
B Establishment of Fire Safety Management Organizations	0.730	0.916	
B Infrastructure	0.580	0.917	
B Electric Vehicle Management	0.619	0.916	
B Resident Safety Awareness	0.715	0.914	
C Timeliness of Fire Alarm	0.688	0.916	
C Initial Fire-Fighting Capability	0.454	0.920	
C Unobstructed Evacuation Routes	0.665	0.917	
C Accessibility for External Rescue	0.531	0.918	
C Rescue Arrival Time	0.514	0.918	
C Emergency Exits	0.501	0.919	

The analysis revealed an overall Cronbach's α coefficient of 0.921, which exceeds 0.9, indicating excellent data reliability.
As shown in Table 3, the KMO value is 0.737, exceeding the threshold of 0.6 and meeting the fundamental requirements for factor analysis. Additionally, Bartlett's test of sphericity yielded a significant result ($p < 0.05$), indicating that the data are suitable for factor analysis.
Factor analysis extracted four factors with eigenvalues greater than one. As detailed in Table 4, after rotation, these factors explained 26.277%, 16.295%, 14.835%, and 10.867% of the variance, respectively, achieving a cumulative variance explanation of 68.275%. (Note: If the number of factors extracted does not align with theoretical expectations, the number of factors to retain can be specified manually in the analysis.)
Following varimax rotation, as presented in Table 5, all items demonstrated communalities exceeding 0.4, confirming a strong relationship with the extracted factors and effective information extraction. Further examination of the factor loadings (where an absolute value greater than 0.4 indicates a meaningful correspondence) clarified the assignment of each variable to a specific factor.

Table 3. KMO and Bartlett's Test

KMO value		0.737
Bartlett's test of sphericity	Approx. Chi-Square	983.842
	df	171
	p-value	0.000

2.3 Determination of Index Weights

To scientifically determine the relative importance of factors within the evaluation index system, the Analytic Hierarchy Process (AHP) was employed[5,6]. Domain experts were invited to perform pairwise comparisons of indices within the same hierarchical level. These comparisons were used to construct judgment matrices, from which weight vectors for each index were calculated. A consistency test was conducted to ensure the logical reliability of the expert judgments.

2.3.1 Determining weights for primary indices

Based on expert evaluations, the judgment matrix for the primary indices was constructed, as shown in Table 6.

Table 4. Variance Explained

Factor Number	Eigenvalue			Variance Explained Before Rotation			Variance Explained After Rotation		
	Eigenvalue	% of Variance Explained	Cumulative %	Eigenvalue	% of Variance Explained	Cumulative %	Eigenvalue	% of Variance Explained	Cumulative %
1	8.262	43.486	43.486	8.262	43.486	43.486	4.993	26.277	26.277
2	1.936	10.191	53.677	1.936	10.191	53.677	3.096	16.295	42.573
3	1.559	8.206	61.882	1.559	8.206	61.882	2.819	14.835	57.408
4	1.215	6.392	68.275	1.215	6.392	68.275	2.065	10.867	68.275
5	0.911	4.795	73.070	-	-	-	-	-	-
6	0.788	4.150	77.220	-	-	-	-	-	-
7	0.770	4.054	81.274	-	-	-	-	-	-
8	0.664	3.495	84.769	-	-	-	-	-	-
9	0.521	2.741	87.510	-	-	-	-	-	-
10	0.496	2.609	90.119	-	-	-	-	-	-
11	0.369	1.941	92.060	-	-	-	-	-	-
12	0.365	1.922	93.982	-	-	-	-	-	-
13	0.278	1.462	95.444	-	-	-	-	-	-
14	0.250	1.316	96.761	-	-	-	-	-	-
15	0.195	1.027	97.787	-	-	-	-	-	-
16	0.150	0.792	98.579	-	-	-	-	-	-
17	0.117	0.618	99.197	-	-	-	-	-	-
18	0.114	0.603	99.799	-	-	-	-	-	-
19	0.038	0.201	100.000	-	-	-	-	-	-

Table 5. Factor Loadings Matrix and Communalities

Item	Factor Loadings				Communality
	Factor 1	Factor 2	Factor 3	Factor 4	
A Aging Electrical Wiring	0.074	-0.021	0.819	-0.010	0.678
A Illegal Electricity Use	-0.024	0.311	0.600	0.526	0.733
A Improper Use of Open Flames	0.110	0.001	0.165	0.826	0.722
A Accumulation of Combustible Materials	0.518	0.075	0.511	0.241	0.593
A Missing or Malfunctioning Fire Protection Equipment	0.697	0.182	0.284	-0.061	0.602
A Residential-to-Commercial Conversion	0.765	0.224	0.063	0.309	0.735
B Fire Resistance Rating of Building Structure	0.694	0.168	0.195	0.410	0.717
B Fire Compartmentation	0.800	0.164	0.247	0.097	0.738
B Fire Patrols and Maintenance	0.839	0.208	0.068	-0.129	0.768
B Resident Safety Awareness	0.576	0.267	0.062	0.556	0.716
B Infrastructure	0.533	0.153	0.414	0.014	0.479
B Electric Vehicle Management	0.390	0.242	0.623	0.087	0.606
B Establishment of Fire Safety Management Organizations	0.725	0.110	0.180	0.368	0.706
C Timeliness of Fire Alarm	0.405	0.169	0.626	0.331	0.695
C Initial Fire-Fighting Capability	0.171	0.584	0.030	0.355	0.497
C Unobstructed Evacuation Routes	0.452	0.223	0.505	0.233	0.564
C Accessibility for External Rescue	0.221	0.803	0.123	0.089	0.717
C Accessibility for External Rescue	0.197	0.852	0.212	-0.039	0.812
C Emergency Exits	0.176	0.925	0.082	0.030	0.895

Table 6. Primary Indicator Judgment Matrix

	Fire Hazard Factors	Prevention and Control Capability	Emergency Response
Fire Hazard Factors	1.000	0.200	0.333
Prevention and Control Capability	5.000	1.000	3.000
Emergency Response	3.000	0.333	1.000

Weights were calculated using the eigenvector method, and consistency was tested. The results are presented in Table 7.

Table 7. Consistency Test

Indicator	Eigenvector	Weight value	Maximum eigenvalue	CI value
Fire Hazard	0.318	10.6156%	3.039	0.019

Factors				
Prevention and Control Capability	1.900	63.3346%		
Emergency Response	0.781	26.0498%		

The random consistency index (RI) for a 3rd-order matrix is 0.520. The calculated consistency ratio (CR = CI/RI = 0.037) is less than 0.10, indicating that the judgment matrix possesses acceptable consistency and the derived weights are valid.

2.3.2 Determining weights for secondary indices

The same AHP procedure was applied to calculate weights for the secondary indices within each of the three primary index categories.

(1) Weight Calculation for Secondary Indices under Fire Hazard Factors in Table 8

Table 8. Weights of Secondary Indicators under Fire Hazard Factors and Consistency Test Results

Indicator	Eigenvector	Weight value	Maximum eigenvalue	CI value
Aging Electrical Wiring	1.834	30.5643%	6.210	0.042
Illegal Electricity Use	1.921	32.0174%		
Improper Use of Open Flames	0.974	16.2308%		
Accumulation of Combustible Materials	0.618	10.2973%		
Missing or Malfunctioning Fire Protection Equipment	0.393	6.5570%		
Residential-to-Commercial Conversion	0.260	4.3332%		

The RI for a 6th-order matrix is 1.260. The CR of 0.033 (< 0.10) confirms consistency.

(2) Weight Calculation for Secondary Indices under Prevention and Control Capability in Table 9

Table 9. Weights and Consistency Test Results of Secondary Indicators under Prevention and Control Capability

Indicator	Eigenvector	Weight value	Maximum eigenvalue	CI value
Fire Resistance Rating of Building Structure	0.263	3.7565%	7.128	0.021
Fire Compartmentation	0.606	8.6580%		
Fire Patrols and Maintenance	1.502	21.4562%		
Resident Safety Awareness	0.636	9.0883%		
Infrastructure	0.636	9.0883%		
Resident Safety Awareness	1.325	18.9352%		
Fire Patrols and Maintenance	2.031	29.0174%		
Fire Resistance Rating of Building Structure	0.263	3.7565%		

The RI for a 7th-order matrix is 1.360. The CR of 0.016 (< 0.10) confirms consistency.

(3) Weight Calculation for Secondary Indices under Emergency Response in Table 10

The RI for a 6th-order matrix is 1.260. The CR of 0.020 (< 0.10) confirms consistency.

In summary, all consistency ratios (CR) for the judgment matrices were below 0.10, indicating strong consistency in expert judgments. The calculated weights for indices at all levels are therefore scientifically valid and suitable for subsequent comprehensive evaluation analysis.

Table 10. Weights and Consistency Test Results of Secondary Indicators under Emergency Response

Indicator	Eigenvector	Weight value	Maximum eigenvalue	CI value
Timeliness of Fire Alarm	1.374	22.9041%	6.124	0.025
Timeliness of Fire Alarm	0.562	9.3584%		
Unobstructed Evacuation Routes	2.700	45.0048%		
Accessibility for External Rescue	0.562	9.3584%		
Rescue Arrival Time	0.562	9.3584%		
Rescue Arrival Time	0.241	4.0160%		

3.Fuzzy Comprehensive Evaluation (FCE) Methodology

3.1 Construction of the Factor Set

This study establishes a multi-level factor system for comprehensive evaluation, comprising a target layer, primary indices, and secondary indices[7].

Target Layer (G): Fire Risk Level

The primary indices (U) consist of the following three dimensions with their corresponding weights:

U1 (Fire Hazard Factors), Weight A1 =

0.106156 (10.6156%)
U2 (Prevention and Control Capability), Weight A2 = 0.633346 (63.3346%)
U3 (Emergency Response), Weight A3 = 0.260498 (26.0498%)

Each primary index encompasses several secondary indices, with their names and weights detailed below.

Secondary indices under U1 (U1i) and their weights:
U11: Aging Electrical Wiring (30.5643%);
U12: Illegal Electricity Use (32.0174%);
U13: Improper Use of Open Flames (16.2308%);
U14: Accumulation of Combustible Materials (10.2973%);
U15: Missing/Malfunctioning Fire Protection Equipment (6.5570%);
U16: Residential-to-Commercial Conversion (4.3332%).

Secondary indices under U2 (U2i) and their weights:
U21: Fire Resistance Rating of Building Structure (3.7565%);
U22: Fire Compartmentation (8.6580%);
U23: Fire Patrols and Maintenance (21.4562%);
U24: Resident Safety Awareness (9.0883%);
U25: Automatic Fire Alarm Systems (9.0883%);
U26: Electric Vehicle Management (18.9352%);
U27: Establishment of Fire Safety Management Organizations (29.0174%).

Secondary indices under U3 (U3i) and their weights:
U31: Timeliness of Fire Alarm (22.9041%);
U32: Initial Fire-Fighting Capability (9.3584%);
U33: Unobstructed Evacuation Routes (45.0048%);
U34: Accessibility for External Rescue (9.3584%);
U35: Rescue Arrival Time (9.3584%);
U36: Emergency Exits (4.0160%).

3.2 Definition of the Comment Set

The evaluation results are classified into five levels, forming the comment set $V = \{V_1, V_2, V_3, V_4, V_5\}$, defined as follows: V1: High Risk (Score 0-20); V2: Moderately High Risk (21-40); V3: Medium Risk (41-60); V4: Moderately Low Risk (61-80); V5: Low Risk (81-100).

3.3 Establishment of Fuzzy Evaluation Matrices

Based on data from 55 valid questionnaires, the frequency of each index being assigned to a specific evaluation grade was calculated to determine its membership degree. These membership degrees were then used to construct fuzzy evaluation matrices R_1, R_2, and R_3, corresponding to the primary indices U_1, U_2, and U_3, respectively.

$$R_1 = \begin{pmatrix} 0.0364 & 0.0364 & 0.2545 & 0.6727 & 0.0000 \\ 0.0364 & 0.0000 & 0.5455 & 0.2727 & 0.1455 \\ 0.0364 & 0.0000 & 0.2000 & 0.7636 & 0.0000 \\ 0.0000 & 0.0364 & 0.2364 & 0.1818 & 0.5455 \\ 0.0182 & 0.0364 & 0.3636 & 0.5455 & 0.0364 \\ 0.0182 & 0.1818 & 0.5091 & 0.0000 & 0.2909 \end{pmatrix} R_2 = \begin{pmatrix} 0.0182 & 0.0182 & 0.2364 & 0.6909 & 0.0364 \\ 0.0000 & 0.0727 & 0.4909 & 0.2545 & 0.1818 \\ 0.0545 & 0.6727 & 0.2545 & 0.0182 & 0.0000 \\ 0.0182 & 0.0909 & 0.7455 & 0.1273 & 0.0182 \\ 0.0364 & 0.0545 & 0.4727 & 0.3636 & 0.0727 \\ 0.0545 & 0.4727 & 0.2909 & 0.1091 & 0.0727 \\ 0.0364 & 0.0000 & 0.5455 & 0.2727 & 0.1455 \end{pmatrix}$$

$$R_3 = \begin{pmatrix} 0.0182 & 0.3636 & 0.2182 & 0.3818 & 0.0182 \\ 0.1636 & 0.5455 & 0.0909 & 0.1636 & 0.0364 \\ 0.0000 & 0.0545 & 0.3818 & 0.5273 & 0.0364 \\ 0.0182 & 0.0727 & 0.4909 & 0.3455 & 0.0727 \\ 0.0000 & 0.0727 & 0.4909 & 0.2545 & 0.1818 \\ 0.0182 & 0.0364 & 0.3636 & 0.5455 & 0.0364 \end{pmatrix}$$

4.Fuzzy Composition and Comprehensive Evaluation Process

4.1 Fuzzy Evaluation of Secondary Indices

A fuzzy composition operator was applied to perform the comprehensive evaluation layer by layer. First, the comprehensive evaluation vectors for each primary index were calculated.

(1) The fuzzy comprehensive evaluation result for fire hazard factors (U1) is:

$$B1 = A1 * R1 = \begin{pmatrix} 0.0307 & 0.0251 & 0.3551 & 0.4713 & 0.1178 \end{pmatrix} \tag{1}$$

(2) The result for prevention and control capability (U2) is:

$$B2 = A2 * R2 = \begin{pmatrix} 0.0383 & 0.2541 & 0.4302 & 0.1963 & 0.0814 \end{pmatrix} \tag{2}$$

(3) The result for emergency response (U3) is:

$$B3 = A3 * R3 = \begin{pmatrix} 0.0219 & 0.1739 & 0.3368 & 0.4181 & 0.0492 \end{pmatrix} \tag{3}$$

4.2 Fuzzy Evaluation of the Primary Index

Using the vectors B1, B2, and B3 obtained above as row vectors, the overall judgment matrix R for the target layer was constructed. Combined with the weight vector for primary indices A = (A1, A2, A3), the fuzzy comprehensive evaluation for the target layer was performed:

$$B = A * R = \begin{pmatrix} 0.1062 & 0.6333 & 0.2605 \end{pmatrix} \begin{pmatrix} 0.0307 & 0.0251 & 0.3551 & 0.4713 & 0.1178 \\ 0.0383 & 0.2541 & 0.4302 & 0.1963 & 0.0814 \\ 0.0219 & 0.1739 & 0.3368 & 0.4181 & 0.0492 \end{pmatrix} = \begin{pmatrix} 0.0332 & 0.2089 & 0.3979 & 0.2833 & 0.0769 \end{pmatrix} \tag{4}$$

The final comprehensive evaluation result B represents the membership degree of the fire risk level to each comment category, providing a basis for determining the overall system risk status.

4.3 Calculation of the Comprehensive Evaluation Score

Based on the fuzzy comprehensive evaluation result B = (b_1, b_2, b_3, b_4, b_5), a weighted average method was used to calculate the comprehensive evaluation score for the fire risk level. The representative scores for each grade in the comment set were assigned as follows:

V_1 (High Risk) = 90, V_2 (Moderately High Risk) = 70, V_3 (Medium Risk) = 50, V_4 (Moderately Low Risk) = 30, V_5 (Low Risk) = 10.

The formula for the comprehensive evaluation score S is:

$$S = b_1 \times 90 + b_2 \times 70 + b_3 \times 50 + b_4 \times 30 + b_5 \times 10 \quad (5)$$

Using the previously calculated fuzzy comprehensive evaluation result, the score was calculated as: S = 46.774

4.4 Analysis of Evaluation Results

The comprehensive evaluation score S = 46.774 falls within the 41-60 range, classifying the overall fire risk level of this older residential community as 'Medium Risk' according to the defined comment set.

Applying the principle of maximum membership, the evaluated impact levels for the primary dimensions are 'Moderately Low Risk' for fire hazard factors, and 'Medium Risk' for both prevention and control capability and emergency response. The results calculated using the same method are summarized in Table 11.

Table 11. Evaluation Grades and Corresponding Scores for the Impact of Various Indicators on Fire Risk in Older Residential Communities

Indicator	Comprehensive evaluation result based on the maximum membership principle	Comprehensive evaluation score
Overall fire risk for older residential communities	Emergency Response Indicators	46.774
Fire Hazard Factors	Moderately Low Risk	37.592
Prevention and Control Capability	Emergency Response Indicators	49.447
Emergency Response Indicators	Emergency Response Indicators	44.019

5.Fire Risk Prevention and Control Measures for Older Residential Communities

5.1 Strengthening Hazard Source Control

Electrical Wiring Renovation: Conduct systematic inspection and replacement of aging electrical wiring[8]. Promote the use of flame-retardant wires and cables. Strictly prohibit unauthorized wiring connections[9]. Strengthen guidance on safe electricity usage among residents to eliminate hazardous practices such as using bathroom heaters (e.g., bath heaters) for drying items.

Open Flame and Combustible Material Management: Strictly regulate the use of gas and open flames. Enhance efforts to clear accumulated combustible materials[10], particularly in public areas and evacuation routes. Forbid the unauthorized conversion of residential units into high-risk commercial establishments such as auto repair shops or restaurants.

Fire Protection Equipment Enhancement: Supplement or repair missing or malfunctioning fire protection equipment. Ensure the normal water supply for indoor and outdoor fire hydrants. Guarantee that fire extinguishers are fully stocked and subjected to regular inspections.

5.2 Enhancing Building Fire Protection and Daily Management Capabilities

Improving Building Fire Performance: Reinforce building structures with inadequate fire resistance ratings. Promote the replacement of standard windows with fire-resistant windows. Strictly mandate the use of non-combustible or flame-retardant materials for external wall insulation[11]. Install or upgrade fire compartmentation facilities to contain fire spread[12].

Property Management and Patrol Mechanisms: Establish and improve fire safety management organizations with clearly defined responsibilities for property management[13]. Strengthen daily fire safety patrols, with a focus on checking whether fire lanes are obstructed by temporary structures or parked vehicles, and ensure that fire separation distances comply with regulations.

Resident Safety Awareness and Targeted Interventions: Conduct regular and differentiated fire safety education campaigns to enhance residents' awareness of fire risks and their self-rescue capabilities. Pay special attention to vulnerable groups such as the elderly, children, disabled individuals, and those with illnesses by implementing 'one-on-one' assistance programs and regular home visit reminders. Strengthen the management of electric bicycle (e-bike/scooter) charging and parking by establishing centralized charging areas and strictly prohibiting indoor charging.

5.3 Optimizing Emergency Response and Evacuation Conditions

Evacuation Routes and Escape Facilities: Ensure evacuation routes and emergency exits remain unobstructed and strictly prohibit the accumulation of combustible materials. Install additional emergency escape openings and[14], where conditions permit, add external emergency evacuation stairs to enhance the reliability of escape paths.

Alarm and Initial Fire Response Capability: Improve automatic fire alarm systems to ensure timely alerts and effective information dissemination. Enhance training for property staff and residents in initial fire suppression techniques. Equip buildings with portable fire extinguishing equipment to bolster self-rescue capabilities.

Optimizing External Rescue Support: Keep fire service access routes clear to ensure the accessibility of emergency vehicles. Establish emergency liaison mechanisms with local fire stations to reduce rescue arrival times and conduct regular joint emergency drills.

6. Conclusion

This study developed a fire risk evaluation index system for older residential communities (ORCs) encompassing three core dimensions: fire hazard factors, prevention and control capability, and emergency response. The Analytic Hierarchy Process (AHP) was employed to determine the weights of these dimensions, revealing that prevention and control capability plays a dominant role in the overall risk profile. A fuzzy comprehensive evaluation (FCE) model was subsequently constructed. Empirical results demonstrate the model's effectiveness in quantifying the overall risk level and identifying risk variations across the different dimensions. This research provides a methodological foundation for ORC fire risk assessment and offers a decision-making reference for formulating differentiated fire prevention and control strategies that prioritize strengthening daily management while addressing critical gaps in emergency response.

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