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Comprehensive Evaluation Model of Building Energy Efficiency Based on Rough Sets Theory

Lixing Ding, Professor, Zhongkai University of Agriculture & Technology, Guangzhou 510225, P. R. China

Xiuying Ruan, Postgraduate; Jingyuan Huang, Postgraduate; Yueming Li, Postgraduate, Central South University, Changsha 410075, P. R. China

lxding@vip.sina.com

Abstract: In order to improve the objectivity of building energy efficiency evaluation, this paper uses a new method to evaluate building energy efficiency on the basis of rough sets theory. The contribution of different subentry evaluation indicators to comprehensive evaluation is calculated with the conception of attribute-significance, and then their weights are decided by using weighted normalization. According to characteristics of subentry evaluation indicators, their scores are conformed, in the end their comprehensive evaluation is calculated depending on sums of weight normalization. The model is validated by the swatches that are given on base of the software "DeST". It is concluded that the comprehensive evaluation on base of the model coincides with the result of the software " DeST ". The contribution of shape coefficient is most important among the different factors, and building orientation is next. The method by which weight can be decided with the conception "attribute- significance from RS cuts down man-made factors" interfere., and objective results can be obtained.

Key words: building energy efficiency; rough sets comprehensive evaluation

1. INTRODUCTION

According to the existing energy standard, building energy efficiency evaluation mainly depends on the method of subentry evaluation and comprehensive evaluation. This paper adopts the method of building energy efficiency evaluation which is different subentry evaluation indicators to comprehensive evaluation. As a word, by the whole-year consumption of building the paper precedes energy evaluation. There is method of ambiguity synthesis evaluation chiefly, but ambiguity optimization model gets weight normalization indicator by adopting commonly expert evaluation or empirical evidence method, so this leads to intensive subjectivity and man-made factors' interfere in the course of evaluation, in degree the method affects its practicality and objectivity of evaluation results. Therefore, requiring a new math method catches up on this defect and makes evaluation results more objective.

Rough sets theory was brought forward by Pawlak Z from Poland in 1982. Pawlak put forward professional book which exposited fully and systematically Rough sets theory and laid strict math base. Rough sets doesn't need any transcendental information except data sets about problems required, and it is the most major difference from the theory between proof theory and ambiguity sets theory and also the most merit. Concretely speaking, Rough sets which are given locally by knowledge or data, doesn't need any transcendental knowledge and subjective appraise and doesn't need produce any transcendental knowledge which goes beyond data sets problem dealing with, only according to observation data redundancy information may be canceled, the degree of no homonymy knowledge may be compared—Rough degree, dependency and significance among the attributes, the ability of abstraction assort ordination and so on. In recent years, the theory has been applied comprehensively to medical care data analysis, airman skill appraisal, fossil oil data analysis, machine accident diagnosis and so on, and has been realized greatly. Therefore, it is correct that the theory will be completely applied to different weights analyzing of building energy efficiency comprehensive evaluation, and its merits is more objective and convenient than several views above.

2. BASIC CONCEPTIONS OF ROUGH SETS

2.1 The Upper and Llower Approximations about Rough Sets

Given knowledge base sets $K=(U,R)$, for every subset $X \subseteq U$ and an equivalent relation R, the upper approximation and the lower approximation of X as to R be defined as:

$$\underline{R}X = U\{Y \in U/R \mid Y \subseteq X\} \quad (1)$$

$$\overline{R}X = U\{Y \in U/R \mid Y \cap X \neq \Phi\} \quad (2)$$

$\underline{R}X$ is the maximal set which consists of those o bjects judged belonging certainly to the knowledg e X from given knowledge, also is the positiviv eregion of X, writing down $pos_R(X)$. The negat iveregion of X is a set which is composed by t hose objects judged not belonging certainly to the knowledge X from given knowledge, writing d own $neg_R(X)$, $\overline{R}X$ is the minimal set which is composed by those objects judged possibly bel onging to the knowledge X from given knowled ge, $bn_R(X)=\overline{R}X \quad \underline{RX}$ is the border domain o f X ,which is composed by those objects judged neither belonging certainly to the knowledge X nor belonging certainly not to the knowledge X. if $bn_R(X)$ is null set, then writing down X a s to R is crisp; by contrast，if $bn_R(X)$ is not null set, then writing down set X is rough sets about R .

2.2 Supporting Subsets

If $W \subseteq U$, for assorting U/a ,defining the lower approximation about W is $W^{(U/a)} = \cup_{V \in U/a. V \subseteq W} V$, also using $S_a(W)$ to represent. Subset $S_a(W)$ is supporting subset of W as to the attribute a, $spt_a(W) = |S_a(W)|/|U|$ is supporting degree of W to the attribute a.

2.3 Supporting Degree of Decision Attribution

If $y \in D$ is a decision attribution in decision figure (U, A), $A = C \cap D$, $C \cap D = \varphi$ supporting subsets and support-

ing degree of decision attribution $y \in D$ about condition attribution $a \in C$ parting is:

$$S_a(y) = U_{W \in U/y} W^{(U/a)}$$

$$= U_{W \in U/y}(U_{V \in U/a, V \subseteq W} V) \quad (3)$$

$$spt_a(y) = |U_{W \in U/y} W^{(U/a)^-}|/|U| \quad (4)$$

2.4 Significance of Attribution

If $\Phi \subset X \subseteq C$, $\Phi \subset Y \subseteq D$, $U/Y \neq U/\delta = \{U\}$. Given attribution $x \in X$, we define the significance of X to decision attribution Y as

$$sig^{Y}_{X\ \{x\}}(x) = (|S_X(Y)| - |S_{X\ (x)}(Y)|)/|U|$$

3. COMPREHENSIVE EVALUATION METHODS BASED ON RS

3.1 Establishing Building Energy Efficiency Comprehensive Evaluation index System

3.2 Using RS Theory the Weight of Subentry Index is confirmed, and its processes are the following:

3.2.1 At the beginning of the lower indicators, the system of knowledge for father indicators (building energy consumption comprehensive evaluation value) is established, every sub-indicator (building energy efficiency index) composes condition set C , and father index is decision attribution D .

Assuming $C = (x_1, x_2, ..., x_n)$;

3.2.2 By the equal-distance method the paper deals with decision attributions and condition attributions of knowledge showing system and cancels the repeated range using discretization method.

3.2.3 According to each condition attribution the simple objects are sorted out, then the objects are sorted out based on condition attribution full set C and C- X_i ; the significance of each condition attribution is calculated $p_i = sig^{Y}_{X-\{x\}}(x)$;

3.2.4 Significance of each attribution is incorporated into, if there is $P_A = \sum_{i=1}^{n} P_i$, then $W_i = P_i / P_A$ is weight of subsets to father index.

3.3 According to the correlative data evaluation value S_i of every index is confirmed.

3.4 Judging whether the building confirms to building energy efficiency standard or not based on building comprehensive evaluation value $E = \sum_{i=1}^{n} W_i S_i$

4. CERTIFICATION OF THE EXAMPLE

4.1 Establishment Decision table of Building Energy Efficiency

The paper adapts to drawing materials of some buildings from Chang Sha, in order to better reflect the practicality of the model, the paper takes the example which is more common and reasonable match from realistic life, and does not consider extreme situations in which windows are not installed or thermal conductivity coefficient is too big or too small, the following is the specimen by software "DeST", each subentry energy efficiency index is condition attribution, where: X_1 -dimensionless shape coefficient, X_2 - building orientation, X_3 -roof thermal conductivity coefficient, X_4 -exterior wall thermal conductivity coefficient, X_5 -window thermal conductivity coefficient, X_6 - ratio of front window-to- wall, X_7 - ratio of back window-to-wall, X_8 - ratio of left window-to-wall, X_9 - ratio right window-to-wall, "energy efficiency ratio" decision attribution. We can obtain building energy efficiency evaluation decision table as the following:

The definition of building energy efficiency ratio is:

$$BEP_i = \frac{E_s - E_i}{E_s} \times 100\% \qquad (5)$$

Where: E_s is annual electrical consumption which is confirmed on degree-day, kWh/m^2: E_i is annual electrical consumption about building appraised from software "DeST", KWh/m^2

4.2 After Discretization of Every Attribution Value Betting Tab.2

4.3 Ascertaining Weight of Each Subentry Index in the Building Energy Efficiency Evaluation Knowledge System

For building energy efficiency evaluation knowledge system, after the values are discretizated, then counting out the attribution significance of each subentry index to the father index: $sig^{y}_{X\ \{x_1\}}(x_1)$ the others are 0. Considering actual conditions, each subentry index effects energy efficiency, therefore, in order to explain the problem, according to physics meaning of each Subentry index, the significances of these indexes are fixed man-made a relative small value: $sig^{y}_{X-\{x\}}(x) = 0.01$. According to them:

$sig^{y}_{X\text{-}\{x_1\}}(x_1)=0.4$， $sig^{y}_{X\text{-}\{x_2\}}(x_2)=0.067$， the $W_3=W_4=W_5=W_6=W_7=W_8=W_9=0.02$ 4.4

significance of $P_A=\sum_{i=1}^{n}P_i=0.537$,but

$W_1={P_1}/{P_A}=0.74$,the same argument

$W2=0.12$

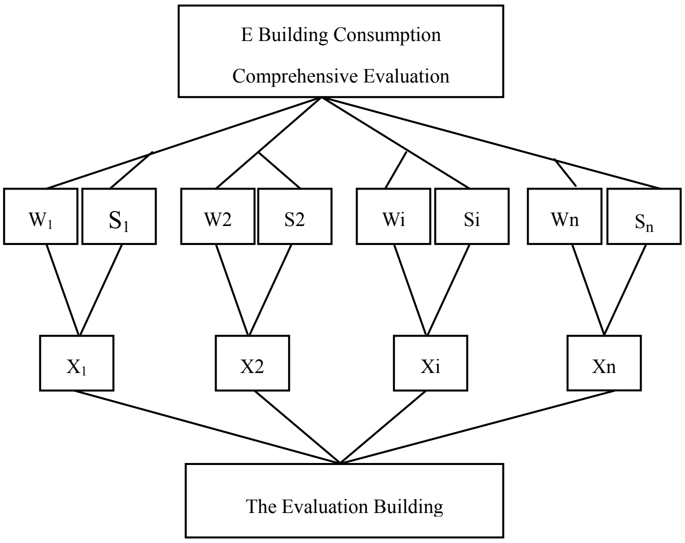

Fig.1Building Comprehensive

Tab.1 Building energy efficiency evaluation decision table

U/A	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	Y
1	0.311	-1.57	0.61	0.622	2.5	0	0	0	0	0.383
2	0.311	-1.57	0.61	3.665	5.7	0.5	0.4	0.45	0.45	-0.574
3	0.311	1.57	0.812	1.01	2.5	0.5	0.25	0	0.45	-0.440
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
28	0.255	-0.733	1.134	1.098	5.7	0.32	0.37	0.36	0.35	-0.122
29	0.280	-0.349	0.61	1.033	5.7	0.2	0.14	0.17	0.14	0.122
30	0.206	0.628	1.134	3.665	5.7	0.5	0.4	0.45	0.45	0.0475

Tab.2 Building energy efficiency evaluation decision table

U/A	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	Y
1	4	0	0	0	0	0	0	0	0	4
2	4	0	0	2	2	2	2	2	2	0
3	4	5	1	0	0	2	1	0	2	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
28	2	1	2	1	2	1	2	2	2	2
29	3	2	0	1	2	1	1	1	0	3
30	0	3	2	2	2	2	2	2	2	3

Tab.3 Shape coefficient index reference grade table

Shape Coefficient	0.206	0.208	0.210	0.211	0.219	0.225	0.228	0.234	0.235	0.244
Marking	89	89	89	89	87	86	86	85	85	83
Shape Coefficient	0.252	0.255	0.256	0.260	0.280	0.285	0.289	0.311	0.319	
Marking	82	81	81	80	77	76	76	72	70	

Tab.4 Building orientation index reference grade table

Building Orientation	-1.57	-1.04	-0.73	-0.56	-0.35	0	0.09	0.14	0.17
Marking	69	80	86	89	93	100	99	98	97
Building Orientation	0.21	0.49	0.56	0.63	0.84	0.98	1.19	1.26	1.50
Marking	96	91	89	88	84	81	77	75	70

Tab.5 Roof thermal conductivity coefficient index reference grade table

Roof Thermal Conductivity Coefficient	0.610	0.812	1.134
Marking	90	83	70

Tab.6 Outside wall thermal conductivity coefficient index reference grade table

Exterior Wall Thermal Conductivity Coefficient	0.622	0.775	0.816	1.010	1.033	1.098	1.074	1.043	1.175	3.665
Marking	90	89	89	88	88	87	88	88	87	70

Tab.7 Window thermal conductivity coefficient index reference grade table

Window Thermal Conductivity Coefficient	2.5	2.9	3.0	3.1	3.2	3.3	3.4	4.7	5.7
Marking	95	91	90	89	88	87	86	73	63

Tab.8 Ratio of window to wall reference grade table

Ratio of Window-to-Wall	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.5
Marking	90	89	88	87	86	85	84	83	82	81	80

Tab.9 Sample 13 reference evaluation value table

U/A	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
13	70	72	90	89	63	84	86	87	88

Tab.10 Evaluation object reference evaluation value table

U/A	1	2	3	4	5	6	7	8	9	10
Reference Evaluation Value	74.3	72.5	73.6	83.3	82.9	75.4	85.4	87.2	80.6	78.9
U/A	11	12	13	14	15	16	17	18	19	20
Reference Evaluation Value	82.3	83.7	72.2	89.8	87.0	79.2	78.9	88.5	87.9	83.2
U/A	21	22	23	24	25	26	27	28	29	30
Reference Evaluation Value	83.4	86.5	84.0	86.2	81	87.3	84.7	81.3	79.9	85.3

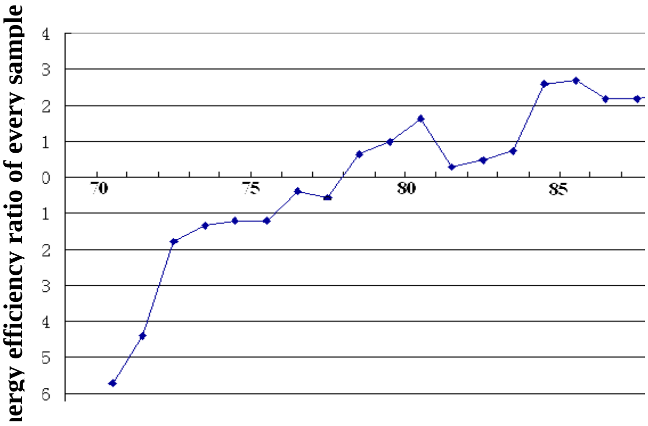

Fig.2 The contrast of the sample data reference evaluation value to software "DeST" calculation results.

The evaluation of building energy efficiency evaluation subentry index and establishment of reference grade table

The value of building energy efficiency subentry index evaluation should be graded by authoritative experts. But at present there are not concretely marking materials of building energy efficiency every subentry index, the paper extracts an approximate value which is only a reference value for conveniently recounting establishment model method from every subentry index basing on material.

4.5 Confirming Comprehensive Evaluation Value of Building Energy Eficiency Comprehensive Evaluation Eodel.

By making use of the formula $E = \sum_{i=1}^{9} W_i S_i$ the final getting scores of evaluation object energy consumption may be counted out, the following is taking the data of sample 13 for an example which is counting comprehensive energy consumption evaluation value of table 13, viding the following table:

$$E_{13} = \sum_{i=1}^{9} W_i S_i = 0.74\times70 + 0.12\times72 + 0.02\times 90+0.02\times89+0.02\times63+0.02\times84+0.02\times86+0.02\times87+0.02\times88 = 72.18$$

Comprehensive evaluation value of the other samples may be got by the same argument.

5. THE ACCEPTANCE AND ANALYZING OF BUILDING ENERGY EFFICIENCY COMPREHENSIVE EVALUATION MODEL

By the above-mentioned building energy efficiency comprehensive evaluation model we may get reference on evaluation values of all the copy. According to the evaluation values from the big to the small collating renewably, taking off minority maximum and minimum of energy efficiency ratio in the copy, the paper gets the following figure. The figure shows that the bigger is building efficiency ratio, the higher is building energy efficiency evaluation value; In contrast, the lower is building energy efficiency evaluation value. Building energy efficiency evaluation values which are basically in accordance with building energy consumption values by software "DeST" is got by building energy efficiency comprehensive evaluation model, the model appears to be correct.

6. CONCLUSIONS

6.1 Establishing building energy efficiency comprehensive evaluation model by Rough sets theory, analyzing and accounting nine subentry evaluation indicators' significance relative to decision attribution, the paper gets its weight by using weighted normalization. Therefore, it is concluded that in the middle of all factors affecting the building energy consumption, the weight of shape coefficient is biggest and most important factor, the weight of building orientation is next to it and is the second most important factor. Contrast to the ambiguity hierarchy analyses building energy efficiency comprehensive evaluation model is technique. The calculation of the weight completely depends upon data information proffered by the copy, the method diminishes man-made factors' interfere, and assures the objectivity of evaluation results.

6.2 By analyzing building energy efficiency comprehensive evaluation model the paper may get: The model may reflect basically on status of energy efficiency. Therefore, the model can be applied to selection excellence of the building items which have been designed; on the other hand, at the step of building design determination direction may be proffered to the designer in order to make design satisfied with building energy efficiency design criterions.

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