Analysis on the grey classification to indoor air quality

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ABSTRACT: Indoor air quality is one of the main factors, which affect indoor environment. Through analyzing indoor air quality (IAQ), 9 main factors have been established in this paper, such as temperature, wind speed and relative humidity, and so on. By the adaptive degree of human's physiology and psychology to indoor environment, IAQ is partitioned into 3 grades, that is comfortable, rather comfortable and uncomfortable. By above 3 grades, the limitation scopes of every grade of all factors are given, accordingly. With the favorable assessment fucntion, the grey classification theory has been utilized to establish the assessment model of indoor air quality in this paper. This establishes the basic theory for reflecting and analyzing and comparing of indoor air quality more impersonal, exact and scientific, and this will provide references and standards for improving the indoor environment, too.

FACTOR TERMS: Indoor air quality (IAQ) Indoor environment Grey grade Grey classification analysis Assessment model

1 INTRODUCTION

Along with the development of society, the problem of indoor air quality (IAQ) has aroused more and more recognition and attention of relating research fields [1]. Favorable IAQ is one of the basic factors,which advance the ratio of production and reduce sick building syndrome (SBS) [2]. The assessment of IAQ is a scientific method in studying indoor environment, which is a new concept brought forward along with the process of studying in indoor environment filed. The factors, which have an effect to IAQ, affect and restrict each other. So, how to assess rightly IAQ is a difficult question.

The springboard of these assessment methods of [3][4][5][6][7] is based mainly on the synthetic assessment. While, the essential of synthetic assessment is based on ascertaining the subjective weights of all assessment factors. So, these methods have shortcomings of subjectivity and unilateralization to some extent. For above reasons, this paper brings forward the grey classification assessment method, which takes the impersonal data as classification and assessment standard, impersonal data as reference value.

2 RESEARCH ON THE ASSESSMENT MODEL OF GREY CLASSIFICATION

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2.1 Grey classification analysis method

Come to light, things of one grade come together. Classification analysis, which is based on the traditional classification analysis theory and takes the grey theory as tool, is a particular analysis and assessment method. The essence of this method is to classify the whitened values or fuzzy analysis' results of classification objects and get the grade (rank) of classification objects in n grey grades. In this paper, the indoor environment will be sorted by three grades: comfortable, rather comfortable and uncomfortable indoor air quality.

Taking $1^0, 2^0, ..., n^0$ as classification objects, $1', 2', ..., m'$ as classification factors, $1, 2, ..., n$ as grey grades, d_{ij} is the swatch of No j factor of the classification object 1^0. So, the swatch matrix of classification objects to $1', 2', ..., m'$ can be expressed as follows:

$$A = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1m} \\ d_{21} & d_{22} & \dots & d_{2m} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nm} \end{bmatrix} \qquad (1)$$

Here, F is the mapping function, $Opf_{jk}(d_{ij})$ is the operation of swatch d_{ij} using the grey value of No j factor, f_{jk} is k times whitened function of No j factor.

$$OPf_{jk}(d_{ij}) \rightarrow \sigma_{ik} \in [0,1] \qquad (2)$$

Here, $\sigma_{ik} = (\sigma_{i1}, \sigma_{i2}, ..., \sigma_{in})$, if σ_k^* meets the conditions: $\sigma_k^* = \max \sigma_{jk} = \max\{\sigma_{i1}, \sigma_{i2}, ..., \sigma_{in}\}$, then the classification object i belongs to grey grade k^*.

2.2 Grey classification's assessment model of IAQ

2.2.1 Ascertaining classification objects

Here, taking the indoor environment of three objects of Ⅰ、Ⅱ、Ⅲ as research objects.

2.2.2 Ascertaining the classification factor system

Classification factor system is an factor muster composed by the factors, which have an effect on assessment of the object. According to present theory and research result, this paper will adopt 9 factors muster. These factors are shown as follows: C_1=temperature; C_2=relative humidity; C_3= carbon monoxide (CO); C_4= carbon dioxide (CO_2); C_5= semivolatile organic compounds (VOC_s); C_6=dust; C_7= bacteria number; C_8=wind speed; C_9= nitrogen oxide (NO_x). Here, using j to express these factors, then:

$$j = 1^\#, 2^\#, 3^\#, ..., 9^\#$$

Here: $j = 1^\#$, $j = 2^\#$, $j = 3^\#$ … and $j = 9^\#$ shows temperature, relative humidity, carbon monoxide…. ,and nitrogen oxide (NO_x) respectively.

In this paper, three grey grades such as comfortable, rather comfortable, and uncomfortable grade will be adopted to classify IAQ. Noting grey grade as k, then k shows 1^*, 2^*, 3^* respectively. Basing upon the standards of ergonomics and references [7][9], this paper offers the following limitation value of assessment factors, which are shown in tab 1.

Table 1 Classification limitation of indoor environment

factor / limitation	C_1 ^0C	C_2 %	C_3 mg/m^3	C_4 %	C_5 mg/m^{-3}	C_6 mg/m^{-3}	C_7 CFU/9cm.5min	C_8 m/s	C_9 pph
1^*	16~22	40~60	<3	<0.1	<0.06	<0.1	<29	0.1~0.3	<0.06
2^*	10~16,22~24	>60,<40	3～5	0.1~0.15	0.06~0.5	0.1~0.2	29~40	0.3～0.5	0.06~0.5
3^*	<10,>24	>70,<30	>5	>0.15	>0.5	>0.2	>40	>0.5	>0.5

2.2.3 Researching on whitened functions of grey grade

2.2.3.1 The grey value of all grey grade

The expressions of grey grades' whitened value are shown as follows:

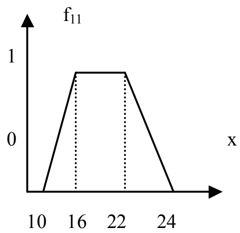
1) The grey value of comfortable grey grade: temperature(1#) $\otimes_{11} \in [14,20]$; relative humidity(2#) $\otimes_{21} \in [40,60]$; carbon monoxide(CO)(3#) $\otimes_{31} \in [0,3]$; carbon dioxide (CO_2) (4#) $\otimes_{41} \in [0,0.1]$; formaldehyde (VOC_s) (5#) $\otimes_{51} \in [0,0.06]$; dust（6#） $\otimes_{61} \in [0,0.01]$; bacteria number（7#） $\otimes_{71} \in [0,29]$; wind speed（8#） $\otimes_{81} \in [0.1,0.3]$; nitrogen oxide ($NO_x$)（9#） $\otimes_{91} \in [0,0.06]$.

2) The grey value of rather comfortable grey grade: temperature(1#) $\otimes_{12} \in [10,14]$ or $\otimes_{12} \in [20,24]$; relative humidity(2#) $\otimes_{22} \in [60,70]$ or $\otimes_{22} \in [30,40]$; carbon monoxide(CO)(3#) $\otimes_{32} \in [3,5]$; carbon dioxide (CO_2) (4#) $\otimes_{42} \in [0.1,0.15]$; formaldehyde ($VOC_s$) (5#) $\otimes_{52} \in [0.06,0.5]$; dust（6#） $\otimes_{62} \in [0.1,0.2]$; bacteria number（7#） $\otimes_{72} \in [29,40]$; wind speed（8#） $\otimes_{82} \in [0.3,0.5]$, nitrogen oxide ($NO_x$)（9#） $\otimes_{92} \in [0.06,0.5]$.

3) The grey value of rather comfortable grey grade: temperature(1#) $\otimes_{13} \in [0，10]$ or $\otimes_{13} \in [24,43]$; relative humidity(2#) $\otimes_{23} \in [70,100]$ or $\otimes_{23} \in [0,30]$; carbon monoxide(CO)(3#) $\otimes_{33} \in [0.5, +\infty]$; carbon dioxide ($CO_2$) (4#) $\otimes_{43} \in [0.15, +\infty]$; formaldehyde ($VOC_s$) (5#) $\otimes_{53} \in [0.5, +\infty]$; dust（6#） $\otimes_{63} \in [0.2, +\infty]$; bacteria number（7#） $\otimes_{73} \in [40, +\infty]$; wind speed（8#） $\otimes_{83} \in [0.5, +\infty]$;nitrogen oxide ($NO_x$)（9#） $\otimes_{93} \in [0.5, +\infty]$.

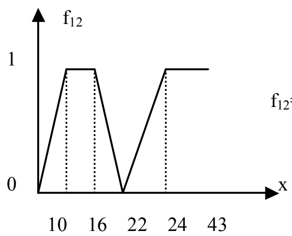
2.2.3.2 The foundation of grey grade's whitened functions

If f_{jk} is the whitened function of grey grade k of classification factor j, according to the grey system theory and grey value $\otimes_{jk}$, then it is not difficult to get fig 1(1) to fig 1(27) and their grey grade whitened functions. (Here, only the grey grade whitened functions and their figures of temperature and relative humidity are given.)



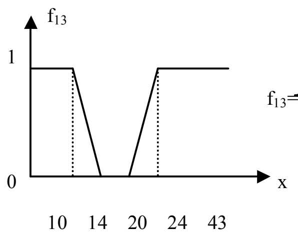
$$f_{11}=\begin{cases}(x/6)-2.667 & x\in[10,16]\\ 1 & x\in[14,22]\\ (-x/2)+12 & x\in(22,24)\end{cases}$$

Figure 1 Whitened function figure (1)



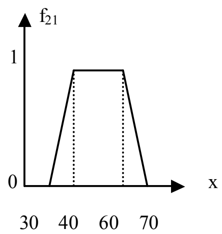
$$f_{12}=\begin{cases}(x/10) & x\in[0,10]\\ 1 & x\in[10,16] \text{ or } x\in(25,43)\\ -(x/6)+3.667 & x\in[16,22]\\ (x/2)-12 & x\in[22,24]\end{cases}$$

Figure 1 Whitened function figure (2)



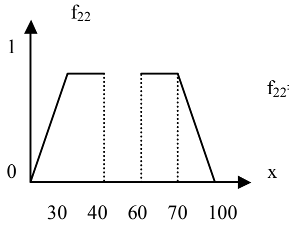
$$f_{13}=\begin{cases}1 & x\in(-\infty,10)\text{或 } x\in(43,+\infty)\\ (-x/6)+2.667 & x\in[10,16]\\ 0 & x\in[16,25]\\ (x/18)-2.389 & x\in[25,43]\end{cases}$$

Figure 1 Whitened function figure (3)



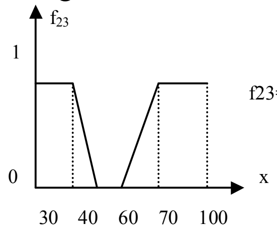
$$f_{21}=\begin{cases}(x/10)-3 & x\in[30,40]\\ 1 & x\in[40,60]\\ (-x/60)+7 & x\in(60,70)\end{cases}$$

Figure 1 Whitened function figure (4)



$$f_{22}=\begin{cases}(x/30) & x\in(0,30)\\ 1 & x\in(30,40) \text{ or } (60,70)\\ 0 & x\in[40,60]\\ (-x/30)+3.333 & x\in[70,100]\end{cases}$$

Figure 1 Whitened function figure (5)



$$f23=\begin{cases}1 & x\in[0,30] \text{ or } x\in(70,100)\\ (-x/10)+4 & x\in(30,40)\\ 0 & x\in[40,60]\\ (x/10)-6 & x\in(60,70)\end{cases}$$

Figure 1 Whitened function figure (6)

2.2.3.3 Ascertaining the classification weight

For the classification factors with different dimension, the classification factors must be changed into un-dimension when ascertaines the classification weights of classification factors. If λ_{jk} is the valve value without dimension, η_{jk}, which is the grey grade classification weight of classification factor j, can be expressed as follows:

$$\eta_{jk} = \frac{\lambda_{jk}}{\sum_{j=1^{\#}}^{9^{\#}} \lambda_{jk}} \tag{3}$$

Changing the original data into no dimension data, and by the whitened functions and whitened function figures (fig 1 to fig 27), it is not difficult to get the different valve values λ_{jk} : (λ_{11} λ_{21} λ_{31} … λ_{91}, λ_{12} λ_{22} λ_{32} … λ_{92}, λ_{13} λ_{23} λ_{33} … λ_{93}) .

Taking λ_{jk} into equation （3）, then the following equation can be gotten ：

(η_{11} η_{21} η_{31} … η_{91}, η_{12} η_{22} η_{32} … η_{92}, η_{13} η_{23} η_{33} … η_{93}) .

2.2.3.4 Counting the classification coefficient σ_{ik}

Taking the classification coefficient of grey classification object I's grey grade k as σ_{ik}, then σ_{ik} can be expressed as follows:

$$\sigma_{ik} = \sum_{j=1^{\#}}^{9^{\#}} f_{jk}(d_{ij})\eta_{jk} \tag{4}$$

Taking the known data into equation (4), the classification coefficient of grade 1^* of classification object i as σ_{11}, then σ_{11} can be expressed in following formula:

$$\sigma_{11} = f_{11}(d_{11})\eta_{11} + f_{21}(d_{12})\eta_{21} + f_{31}(d_{13})\eta_{31} + f_{41}(d_{14})\eta_{41} + f_{51}(d_{15})\eta_{51} + f_{61}(d_{16})\eta_{61}\eta_{81} + f_{71}(d_{17})\eta_{71} + f_{81}(d_{18}) + f_{91}(d_{19})\eta_{91};$$

By above method, classification coefficients σ_{12} and σ_{13} of grade 2^* and grade 3^* of classification object I can be gotten.

The classification coefficients $\sigma_{21}, \sigma_{22}, \sigma_{23}$ of grade1^*,2^* and $3^*$of classification object II can be gotten, too.

The classification coefficients $\sigma_{31}, \sigma_{32}, \sigma_{33}$ of grade1^*,2^* and $3^*$of classification object III can be gotten, too.

Then: $\sigma_1 = (\sigma_{11}, \sigma_{12}, \sigma_{13})$ $\sigma_2 = (\sigma_{21}, \sigma_{22}, \sigma_{23})$ $\sigma_3 = (\sigma_{31}, \sigma_{32}, \sigma_{33})$

The matrix ,which is composed with σ_1、σ_2、σ_3,can be shown as follows:

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} \tag{5}$$

if σ_{ik}^* satisfies $\sigma_{ik}^* = \max \sigma_{ik}^* = \{\sigma_{i1}, \sigma_{i2}, \sigma_{i3}, ..., \sigma_{in}\}$ and $\sigma_{ik} = (\sigma_{i1}, \sigma_{i2}, \sigma_{i3}, ..., \sigma_{in})$, then the grey grade of classification object I belongs to k.*

3 APPLICATION AND ANALYSIS IN PRACTICE

In this paper, we will use the data of 3 rooms measured by our environment-watching center to apply and research above method practically. The data are shown as follows.

Table 2 datasheet of indoor air of 3 rooms

Factor	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Room A	21.3	56.8	5.2	0.12	0.21	0.11	32.4	0.14	0.04
Room B	22.2	38.5	2.3	0.14	0.11	0.09	29.6	0.36	0.03
Room C	20.9	45.2	3.9	0.08	0.35	0.06	20.4	0.25	0.03

3.1 The ascertainment of the classification weight

Changing the data of tab 2 into un-dimension data, and by their whitened functions and whitened figures, it is easy to get the valve value λ_{jk} of different classification objects. The Valve value λ_{jk} are shown as follows:

λ_{11}=0.818; λ_{21}=1; λ_{31}=0.75; λ_{41}=0.667; λ_{51}=0.194; λ_{61}=0.667; λ_{71}=0.841; λ_{81}=0.5; λ_{91}=0.194

Taking λ_{jk} into equation (3), then the classification weight can be get:

$$\eta_{jk} = \frac{\lambda_{jk}}{\sum_{j=1^{\#}}^{9^{\#}} \lambda_{jk}} (j = 1,2,3...9; k = 1,2,3)$$

All classification weights gotten from above formula are shown as follows:
η_{11}=0.154 ;η_{21}=0.278;η_{31}=0.073;η_{41}=0.098;η_{51}=0.015;η_{61}=0.098;η_{71}=0.113;η_{81}=0.098; η_{91}=0.073;η_{12}=0.089;η_{22}=0.161;η_{32}=0.113;η_{42}=0.141;η_{52}=0.079;η_{62}=0.068;η_{72}=0.156; η_{82}=0.113;η_{92}=0.079;η_{13}=0.107;η_{23}=0.099;η_{33}=0.113;η_{43}=0.121;η_{53}=0.113;η_{63}=0.097; η_{73}=0.124;η_{83}=0.113; η_{93}=0.113.

3.2 Counting the classification coefficient σ_{ik}

According to formula (4) and the whitened functions of classification objects and their relevant data, the classification coefficients σ_{ik} can be gotten:

$\sigma_{11} = f_{11}(d_{11})\eta_{11} + f_{21}(d_{12})\eta_{21} + f_{31}(d_{13})\eta_{31} + f_{41}(d_{14})\eta_{41} + f_{51}(d_{15})\eta_{51} + f_{61}(d_{16})\eta_{61}\eta_{81} + f_{71}(d_{17})\eta_{71} + f_{81}(d_{18}) + f_{91}(d_{19})\eta_{91}$ =1 × 0.154+1 × 0.278+0 × 0.073+0.6 × 0.098+0.659×0.016+0.9×0.098+0.691×0.113+1×0.098+0.818×0.073=0.825

σ_{21}=0.8274; σ_{31}=0.9489。

$\sigma_{12} = f_{12}(d_{11})\eta_{12} + f_{22}(d_{12})\eta_{21} + f_{32}(d_{13})\eta_{32} + f_{42}(d_{14})\eta_{42} + f_{52}(d_{15})\eta_{52} + f_{62}(d_{16})\eta_{62} + f_{72}(d_{17})\eta_{72} + f_{82}(d_{18})\eta_{82} + f_{92}(d_{19})\eta_{92}$ =0.883 × 0.089+0 × 0.161+0.933 × 0.113+1 × 0.141+1×0.079+1×0.068+1×0.156+0×0.113+0×0.079=0.6280

σ_{22}=0.6201; σ_{32}=0.4284。

$\sigma_{13} = f_{13}(d_{11})\eta_{13} + f_{23}(d_{12})\eta_{23} + f_{33}(d_{13})\eta_{33} + f_{43}(d_{14})\eta_{43} + f_{53}(d_{15})\eta_{53} + f_{63}(d_{16})\eta_{63} + f_{73}(d_{17})\eta_{73} + f_{83}(d_{18})\eta_{83} + f_{93}(d_{19})\eta_{93}$ =0 × 0.107+0 × 0.099+1 × 0.113+0.4 × 0.121+0.341×0.113+0.1×0.097+0.309×0.124+0×0.113+0×0.113=0.3352

σ_{22}=0.3291; σ_{32}=0.2059。

From above, the synthetic result matrix of classification is:

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix} = \begin{bmatrix} 0.8250 & 0.6280 & 0.3352 \\ 0.8274 & 0.6201 & 0.2059 \\ 0.9489 & 0.4284 & 0.1391 \end{bmatrix}$$

4 ANALYSIS OF THE CALSSIFICATION RESULT

4.1 Analysis on the horizontal row of result matrix

1) In the first horizontal row, $\sigma_{1k}^* = \max \sigma_{1k}$ = { $\sigma_{11}, \sigma_{12}, \sigma_{13}$ } =σ_{11}=0.8250, $k = 1^*$. This shows the grade of classification object Ⅰ belongs to 1^*, that is to say the IAQ of Room A belongs to comfortable.

2) In the second horizontal row, $\sigma_{2k}^* = \max \sigma_{2k}$ = { $\sigma_{21}, \sigma_{22}, \sigma_{23}$ } =σ_{21}=0.8274, $k = 1^*$. This shows the grade of classification object Ⅱ belongs to 1^*, that is to say the IAQ of Room B belongs to comfortable.

3) In the third horizontal row, $\sigma_{3k}^* = \max \sigma_{3k}$ = { $\sigma_{31}, \sigma_{32}, \sigma_{33}$ } =σ_{31}=0.9489, $k = 1^*$. This shows the grade of classification object Ⅲ belongs to 1^*, that is to say the IAQ of Room C belongs to comfortable.

4.2 Analysis on the vertical row of result matrix

1) In the first vertical row, 0.9489>0.8274>0.8250, $\sigma_{31} > \sigma_{21} > \sigma_{11}$. This shows, from approaching to the grey grade of grade 1^* in these three classification objects, the sequence of

IAQ of Room A, B, C is Room C, Room B and Room A.

2) In the second vertical row, 0.6280>0.6201>0.4284, $\sigma_{12} > \sigma_{22} > \sigma_{32}$. This shows, from approaching to the grey grade of grade 1^* in these three classification objects, the sequence of IAQ of Room A, B, C is Room A, Room B and Room C.

3) In the third vertical row, 0.3352>0.2059>0.1391, $\sigma_{13} > \sigma_{23} > \sigma_{33}$. This shows, from approaching to the grey grade of grade 1^* in these three classification objects, the sequence of IAQ of Room A, B, C is Room A, Room B and Room C.

From above, it shows that IAQ of Room C is the best, next is Room B and Room A, and IAQ of these rooms belong to first-rank.

5 CONCLUSION

1) The result of grey classification analysis, can be used to compare IAQ with that of other rooms, and can show directly IAQ of one room belonging to comfortable, or rather comfortable grade or uncomfortable, and how much is the subjection degree.

2) There is no necessity to ascertain subjective assessment weight of different factors, so this method can avoid the contrived factors influencing the analyzing result, and make the classification result more scientific, and more reasonable.

3) The grey whitened functions and theirs whitened function figures of IAQ established in this paper will set up the theory basement for studying this problem in the future.

4) This method attempted in this paper will provide a new thought way and method for researching on IAQ or indoor environment in the future.

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