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Indoor decorating and refurbishing materials and furniture volatile organic compounds emission labeling systems: A review

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The volatile organic compounds (VOC) emitted from indoor decorating and refurbishing materials and furniture is recognized as one of the main causes of bad indoor air quality, which has resulted in serious economic losses. In European countries and the U.S., labeling systems for indoor decorating and refurbishing materials and furniture were established to address this issue with good effect. This paper is a review of these existing labeling systems. The basic principle of the labeling systems is introduced. The technical, policy and operational parts of the labeling systems are then discussed. The research concentrates on target pollutants, their threshold values and the testing methods employed. Some problems were uncovered in these labeling systems: too many VOCs were targeted; the method to determine the threshold values was not very rigorous; the testing time was too long (7–28 d). Some China's special features in developing such system are stated. Therefore, as the world's largest national producer and consumer of wood based panels and furniture, China should learn from foreign experience of establishing labeling systems as much as it can. However China should not simply copy the foreign approaches but develop its own scientific labeling system for indoor decorating and refurbishing materials and furniture.

indoor air quality (IAQ), volatile organic compounds (VOCs), formaldehyde, emission, labeling, decorating and refurbishing materials, furniture

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Volatile organic compound (VOC) emissions from indoor decorating and refurbishing materials and furniture can be a significant source of indoor air pollution. Formaldehyde and a wide range of VOCs can be emitted, and concentrations can be particularly elevated in buildings following refurbishment [1–5]. It is notable that indoor VOC concentrations are higher in the Chinese mainland than overseas (Figures 1 and 2) [6,7]. Indoor air pollution can lead to sick building syndrome (SBS) [8,9], cause building related illnesses (BRI) [10] and multiple chemical sensitivities (MCS) [11] and has caused great economic loss. In the U.S. 40 billon dollars are lost per year due to poor indoor air quality [12] and 10.7 billon dollars are lost in China [13].

Three major strategies are available to solve indoor air quality (IAQ) problems: pollutant source control, ventilation and air cleaning, among which pollutant source control is generally the most cost-effective and environmentally preferable to pollutant removal [14]. In order to control pollutant sources, labeling schemes for low VOC emission products were established in many countries around the world [15–20] (Table 1). The first environment-related label for products in the world is the German Blue Angel. It was created in 1978 (http://www.blauer-engel.de/en/blauer_engel/index.php). Today about 11500 products in approximately 90 product categories carry the Blue Angel eco-label. It has had a significant number of successes in environmental and consumer policies. The experience tells us "One label says more than a thousand words".

China is currently the largest producer of wood based panels, coatings and furniture in the world [21–23]. As

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Table 1 Labeling schemes in various countries

Region	Labeling name (start year)
Europe	Germany Blue Angel(1978), GUT(1990), EMICODE(1997), AgBB(2000), Natureplus(2002) France NF Environment(1991), CESAT(2003), AFSSET(2004) Sweden Good Environmental Choice(1992), TCO(1992) Scandinavia Swan(1989), Austria Umweltzeichen(1990), EU Flower(1992), Netherlands Milieukeur(1992) Czech Republic Environmentally Friendly Products(1993), Croatia Environmental Friendly (1993) Spain Aenor(1993), Denmark ICL(1994), Hungary Environmentally Friendly(1994), Finland M1(1995) Slovakia Environmental Friendly Product(1996), Poland Eco Mark(1998), Portugal LQAI(2000)
America	U.S. Green Seal(1989), CRI Green Label Plus(1992), LEED(2000), Section 01350(2001), Greenguard(2001), CHPS(2002), SCS Indoor Advantage(2004), BIFMA(2005), Floorscore(2005), CARB(2008), Indoor air PLUS(2009) Canada Environmental Choice(1988), Brazil Environmental Quality(1993)
Australia	Australia Environmental Choice(1991), New Zealand Environmental Choice(1992)
Asia	Taiwan (China) Green Mark(1992), Hong Kong (China) Eco-label(1995), Green Label(2000) Japan Eco Mark(1989), India Ecomark(1991), South Korea Eco-label(1992) Singapore Green Label(1992), Israel Green Label(1993), Thailand Green Label(1993) Malaysia Eco-label(1996), Philippines Green Choice(2001)

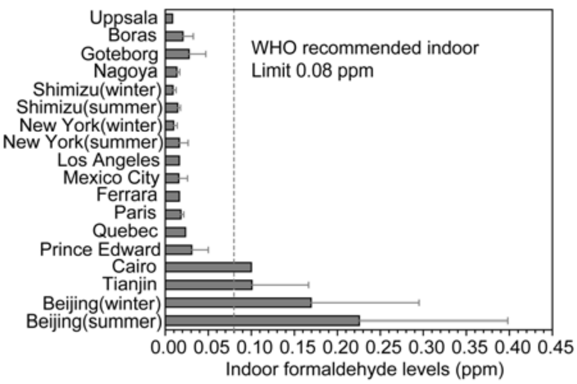

Figure 1 Indoor air formaldehyde concentrations of households in various cities [6].

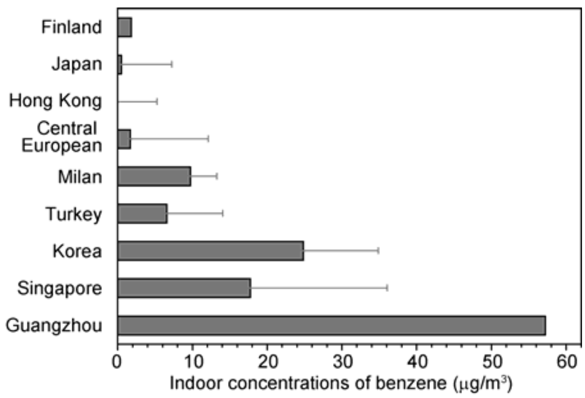

Figure 2 Indoor air benzene concentrations in various countries or regions.

important indoor pollutant sources, close attention is paid to indoor decorating and refurbishing materials and furniture. Establishing a labeling scheme following the example of Europe and the U.S. will be a good step toward improving indoor air quality in China. China should not simply copy the foreign models, but should rather consider its own special features when developing this labeling system. This paper is intended to provide a comprehensive review of the existing labeling schemes: (1) so as to learn what they do and how these schemes implement indoor materials and products labeling; (2) so that when considering the national conditions in China, we can point out which approaches are inappropriate for China. This work prepares the way for establishing a Chinese labeling scheme for indoor decorating and refurbishing materials and furniture VOC emissions.

1 Principle of labeling

Labeling of a product is a statement which means product quality has met specific criteria. The primary task of establishing indoor decorating and refurbishing materials and products VOC emission labeling schemes is to determine target pollutants, that is to say, it should be determined which pollutants must be included in the labeling. Target pollutant species included in various labeling schemes are very different. The number of target pollutants ranges from a few to more than one hundred. The second step is to determine threshold values for the target pollutants. Threshold values are those that target pollutants cannot exceed. Threshold values take different forms in the various labeling schemes. In some labeling schemes thresholds are concentration values emitted from a specific emission area. There are also threshold values that are emission rate per unit area. Comparing test results of specimens with the threshold values, we can judge whether the specimens are qualified. With target pollutants and threshold values, the next step is to determine the testing method that is the way to obtain VOC emission results. Existing labeling schemes commonly use the chamber test method (Figure 3). The testing principle is as follows: load the specimen into the chamber whose temperature and humidity are constants; supply the

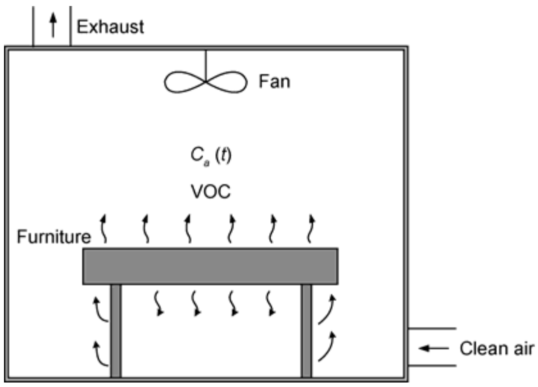

Figure 3 Schematic diagram of chamber test.

chamber with clean air at a constant flow rate and then the air mixed with VOC emission from specimen is exhausted through an air outlet port where VOC concentrations can be determined.

When it is assumed that: the air concentration in the chamber is perfectly mixed; the chamber is air tight except for the constant clean air supply; there are no chemical reactions inside the chamber; the air supplied into the chamber is clean; the adsorption of VOC on the chamber's interior surfaces is negligible, the VOC mass balance equation in the chamber is

$$V\frac{\mathrm{d}C_{\mathrm{a}}}{\mathrm{d}t} = EA - QC_{\mathrm{a}}, \tag{1}$$

where V is chamber volume (m^3), t is time (specimen loading, door closing time is zero) (h), C_{a} is VOC concentration in the chamber ($\mathrm{mg/m^3}$), E is emission factor of the specimen ($\mathrm{mg/(m^2\,h)}$), A is emission area of the specimen (m^2), and Q is clean air flow rate supplied into the chamber ($\mathrm{m^3/h}$).

At steady state or when the emission rate changes very slowly with time, the emission factor can be calculated according to equation:

$$E \approx \frac{Q}{A}C_{\mathrm{a}}. \tag{2}$$

In some labeling schemes when the emission factor E is obtained, the VOC concentration in the reference room C_s which is used for labeling is calculated according to equation:

$$C_s = \frac{A_s E}{Q_s}, \tag{3}$$

where C_s is VOC concentration in the reference room ($\mathrm{mg/m^3}$), A_s is emission area of specimen in the reference room (m^2), E is emission factor of specimen ($\mathrm{mg/(m^2\,h)}$), and Q_s is air flow rate supplied into the reference room ($\mathrm{m^3/h}$).

2 Parts of labeling

Based on these basic principles, VOC emission labeling schemes for indoor decorating and refurbishing materials and products have been established in many countries. The common feature of existing labeling systems is that they all consist of three parts: technical, operational and policy parts. Figure 4 shows details of every part and the relationships among them. The following studies will be carried out according to points described in the framework.

2.1 Technical part

(i) Target pollutants. In order to establish a labeling scheme, we should first determine the target pollutants. Target pollutants are the chemicals required to be analyzed in the test. Target pollutants in existing labeling schemes could be roughly divided into 2 parts: carcinogenic substances and VOC (including TVOC and aldehydes).

The carcinogens have been classified by different organizations, e.g. the European Union (EU) and the international agency for research on cancer (IARC), into various groups expressing different potential risks for people. The EU scheme which classifies the carcinogenic substances into three categories is used in many European labeling schemes [24]: category 1 includes substances known to be carcinogenic to people; category 2 includes substances which should be regarded as if they were carcinogenic to people; category 3 includes substances which cause concern for people owing to a possible carcinogenic effect. In the

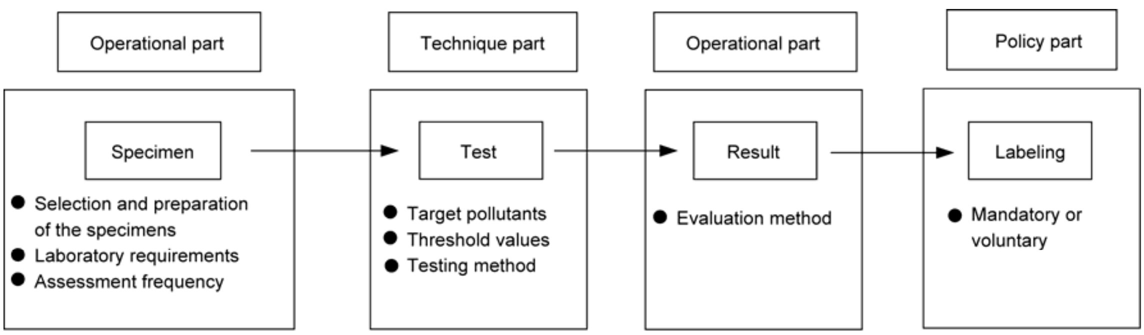

Figure 4 Framework of labeling scheme.

German AgBB labeling scheme [25], emissions of carcinogenic substances belonging to categories 1 and 2 according to EU Directive 67/548/EEC, are required to be tested. The limit values of carcinogenic substances according to this EU directive are also specified in German Blue Angel [26] and EMICODE [27] labeling schemes. American labeling scheme shave scarcely any classification and restrictions of carcinogenic substances.

In European labeling schemes the lowest concentration of interest (LCI) is the most widely used concept. It is a substance-specific value for health-related evaluation of emissions from building products [25]. VOCs that have been considered and assessed by national or international committees are used in development of the LCI. The initial LCI list was published in ECA report No.18 [24] which included 163 VOCs. This list was slightly modified and adopted in the AgBB [25] LCI that included 170 VOCs, and the French AFSSET [28] LCI that included 164 VOCs. AgBB LCI is also adopted in Blue Angel and GUT. The Danish ICL [29] does not use LCI. VOCs whose concentrations have exceeded the odor and irritation threshold values should be considered. The Finnish M1 [30] labeling scheme only has restrictions for TVOC, formaldehyde, ammonia and carcinogenic compounds and there are no other individual compound restrictions. In American labeling schemes, chronic reference exposure levels (CRELs) are most widely used. These CRELs were developed by the office of environmental health hazard assessment in the California environmental protection agency (Cal/EPA OEHHA). CRELs are inhalation concentrations to which the general population, including sensitive individuals, may be exposed for long periods (10 years or more) without the likelihood of serious adverse systemic effects other than cancer. In California Section 01350 [31] OEHHA's new CRELs are adopted which include 35 VOCs (including formaldehyde). The SCS labeling scheme [32] uses California Section 01350 as its labeling basis. Besides using CREL, the GREENGUARD labeling scheme [33] also uses a threshold limit value (TLV), an industrial workplace standard that includes 355 VOCs. The American business and institutional furniture manufacturer's association (BIFMA) labeling scheme [34] includes 4 chemical limits of indoor air concentrations due to emissions from furniture and seating: TVOC, formaldehyde, total aldehydes and 4-phenylcyclohexene which are taken from U.S. Green Building Council (USGBC)'s "Green Building Rating system For Commercial Interiors LEED" [35]. It can be concluded that most of the labeling schemes include more than one hundred target pollutants, like AgBB, AFSSET, Blue Angel, GUT and GREENGUARD. Since China's IAQ research development is still in its infancy, these labeling schemes include too many target compounds to be easily adopted. Different raw materials and production processes of indoor decorating and refurbishing materials and furniture may lead to different VOC emission performance. Therefore VOC emissions from indoor decorating and refurbishing materials and furniture in China may be different from those found in Europe and America. Target pollutants should be determined based on VOC emissions from indoor decorating and refurbishing materials and furniture that are on the market in China. This means that indoor decorating and refurbishing materials and furniture should be tested to determine what kinds of VOCs are emitted from them. The main pollutants could then be selected as the target pollutants.

Total volatile organic compound (TVOC) is an important concept that is controversial in the academic field. In ISO 16000-6 [36], TVOC is the sum of volatile organic compounds sampled on Tenax TA, which elute between and including n-hexane and n-hexadecane, are detected with a flame ionization detector or mass spectrometric detector. Some research [37] is inconclusive with respect to TVOC as a risk index for health and comfort effects in buildings since compositions of the pollutants may be very different under the same TVOC concentration, and that may cause very different health risks. Therefore there is at present an inadequate scientific basis on which to establish limit values for TVOCs. The TVOC indicator can be used for sensory irritation [38]. Others [39,40] consider that although TVOC is a crude way of describing the occurrence of VOC in indoor air, it may still be useful in testing of materials and as an indicator of insufficient or poorly designed ventilation. In European labeling schemes, TVOC is used except in the Danish ICL. In the U.S., California Section 01350 does not include TVOC but BIFMA, LEED and GREENGUARD add it to their schemes.

(ii) Threshold values. Threshold values are the maximum allowable values for VOC emissions. Comparing test results of specimens with these threshold values, we can judge whether the specimens are qualified. A few labeling schemes' threshold values are emission factors, like the Finnish M1, Portuguese LQAI and Austrian Umweltzeichen [15]. Threshold values of most labelling schemes are emission concentrations from the specimen. Figures 5 and 6 show threshold values of formaldehyde and TVOC in various labeling schemes [15,33,34]. It can be seen that the threshold values among various labeling schemes are very different.

The primary reason for this phenomenon is the various requirements of the testing time. Figure 5 shows the testing time could be 1, 3, 7 or 28 d. Secondly, the testing objects are different. GUT labeling scheme is only for textile floor coverings; AgBB, CESAT, Natureplus, LQAI and Blue Angel are for several types of construction products and indoor products; BIFMA is only for office furniture; GREENGUARD is for office furniture and school and child related indoor materials and products. Thirdly, different labeling schemes may adopt different VOC risk assessment databases and have personalized treatment. Take AgBB LCI value for example [25]. LCI values come from occupational

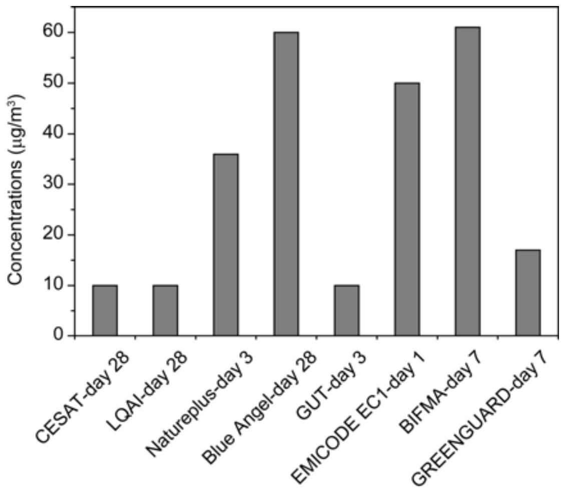

Figure 5 Formaldehyde threshold values in various labeling schemes.

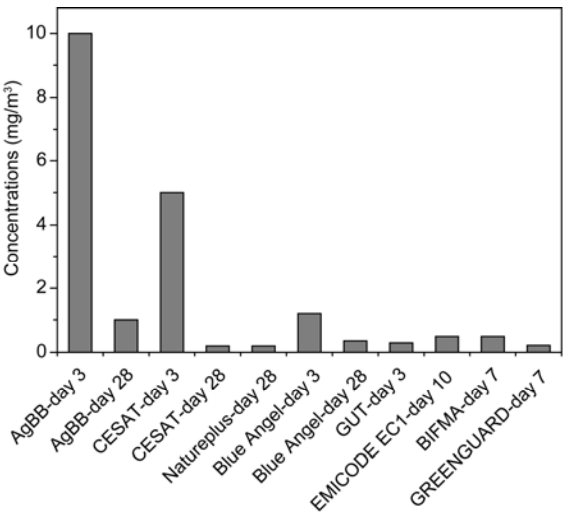

Figure 6 TVOC threshold values in various labeling schemes.

exposure limit values (OELVs) in workplace air and EU category 3 (Directive 67/548/EEC). Since various exposure times and sensitivities should be considered for the general population in comparison to workplace conditions, the relevant OELVs are generally divided by 100 applying safety factors (1000 for carcinogenic substances of EU category 3). For the evaluation of each compound *i* the ratio R_i is established (eq. (4)).

$$R_i = C_i / \mathrm{LCI}_i, \tag{4}$$

where C_i is the chamber concentration of compound *i*. The sum of R_i should be not more than 1 (eq. (5)).

$$R = \sum R_i \leqslant 1. \tag{5}$$

AFSSET LCI is similar to AgBB LCI, but some chemicals in AFSSET use different standard values and apply different safety factors. So AFSSET LCI is different from AgBB LCI. In the U.S., California Section 01350 chooses to use 1/2 of CREL as limit values. Note that there is no scientific explanation for the question of why AgBB uses 100 or 1000, or why California Section 01350 uses 1/2 as safety factor. Figure 7 shows the very big differences between AgBB LCI, AFSSET LCI and 1/2 CREL for some target compounds. In addition, the guidance value for formaldehyde in California Section 01350 is 16.5 μg/m^3 now but will be 9 μg/m^3 beginning in 2012. The formaldehyde guidance value is 100 μg/m^3 in the Chinese indoor air quality standard GB/T 18883-2002 [41]. It seems that the limit value of formaldehyde in the Californian standard is too strict for China. In some labeling schemes VOC concentrations in a reference room are calculated according to eq. (3) and then are compared with threshold values. One reference room was defined in the Danish ICL (Table 2) and it was also used in ISO 16000-9 [42] and the Finnish M1. In American labeling schemes many reference rooms, including offices, classrooms and family rooms are established (Table 2) [43,44]. It is concluded that there are very big differences among threshold values of various labeling schemes in Europe and America. The common practice of determining threshold values is to select exposure assessment thresholds' specific multiplying factor. Some exposure assessment's limit values are occupational exposure limit values and there is generally no scientific basis for selecting the specific factor. When we determine threshold values of target pollutants in China, we should consider the indoor air quality standard GB/T 18883-2002. This would mean that decorating and refurbishing materials and furniture that are loaded in the room must ensure that the indoor air quality meets the standard. Indoor VOC concentrations are related to the materials and the amount of furniture used in the room, therefore the amount of decorating and refurbishing materials and furniture in homes should be known.

(iii) Testing method—Objective test. There are generally two means to test formaldehyde emissions of the products in existing labeling schemes: the content test and the chamber test. Wood based panels can emit formaldehyde

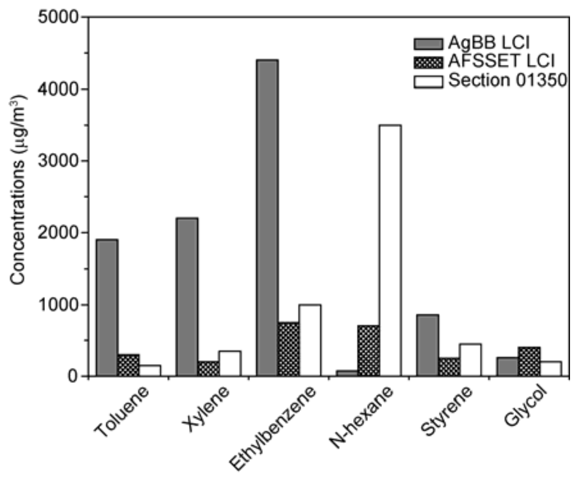

Figure 7 Comparison of AgBB LCI, AFSSET LCI and CA Section 01350.

Table 2 Characteristics of the reference rooms in European and American labeling schemes

Item		ICL[29]	CA 01350 [31]			BIFMA [43]		GREENGUARD [33,44]			
			Office	Classroom	Family	Private office	Open plan	Office	Classroom	Bedroom	Living/Dining area
Volume (m^3)		17.42	30.6	231	547	65.2	16.3	32	231	32	213
Air exchange rate (h^{-1})		0.5	0.68	0.82	0.23	0.53	0.92	0.72	0.9	0.45	0.45
Areas (m^2)	Floor/Ceiling	7	11.1	89.2	211/217	23.78	5.94	13.1	89.2	13.02	77.6
	Wall	24	33.4	94.6	562	–	–	28.1	94.6	–	–
	Door	2	1.89	1.89	7.56/37.2/44.6[a)]	–	–	1.89	1.89	–	–
	Window	0.2[b)]	1.49	4.46	38	–	–	4.1	4.46	–	–
	Wallbase	–	1.27	9.68	–	–	–	2.7	9.68	–	–
	Furniture	–	–	[c)]	–	24.92	21.76	[d)]	[e)]	–	–
	Other	0.2/4[f)]	–	11.9[g)]	779/284/343[h)]	–	–	3.0[g)]/5.5[i)]	9.9[g)]/39.1[i)]	–	–

a) Exterior doors/Interior doors/Closet doors; b) window frame; c) 27 sets of desks and seatings; d) shelving/bookcases/counter tops 20 m^2, worksurface area 3.2 m^2, 1 set of office furniture; e) 27 sets of children's desks and seatings, 1 set of teacher's desk and chair, shelving/bookcases/counter tops 7.81 m^2, worksurface area 12.3 m^2; f) sealant/Fixtures; g) markerboards; h) interior wallboard paint/thermal insulation/acoustic insulation; i) HVAC duct material.

due to the use of urea-formaldehyde resin [45]. The Nordic swan labeling scheme [46] used the perforator method in accordance with EN120 [47] to determine the content of free formaldehyde in wood panels. The perforator method is a very old and unscientific method because the value measured by the perforator method is far greater than the emittable content at room temperature, which should be our target value [48,49]. In China, we also have the perforator test method for determining formaldehyde emissions of particle and density boards [50,51] with the same problems. The chamber test method much more widely used in all the labeling schemes. It can provide people with emission data that is useful for evaluating the impact of building product emissions on the indoor air quality. There are specific standards for the chamber test method. American labeling schemes usually follow the American Society for Testing and Materials (ASTM) standards and European labeling schemes follow the International Organization for Standardization (ISO) or European (EN) standards. Table 3 shows chamber test method standards that widely used at present [42,52–57].

Air sample collection and analysis systems should be specified in the chamber test method. Samples for analyses of aldehydes and VOCs are required to be collected and analyzed using instrumental methods that are capable of positively identifying and quantifying individual VOCs and aldehydes. The methods used in the various labeling schemes are basically the same. VOCs are collected using a Tenax tube and then thermally desorbed to a GC/MS system for identification and quantification. Aldehydes are collected onto DNPH (2,4-dinitrophenylhydrazine) cartridges and analyzed by high performance liquid chromatography (HPLC) with ultraviolet (UV) detection. ISO and ASTM have standards of detailed methods for VOC and aldehyde determination. ISO 16000-6 [36] and ASTM D6196 [58] are for VOCs. ISO 16000-3 [59] and ASTM D5197 [60] are for aldehydes.

Chambers for VOC emissions tests should satisfy corre-

Table 3 Chamber test method standards

No.	Target pollutants	Specimen	Volume (m^3)	Temperature (°C)	Relative humidity (%RH)	Air exchange rate(1/h)	Loading factor (m^2/m^3)
ISO 12460-1[52]	Formaldehyde	Wood based panels	1	23	50	1	1
ISO 16000-9[42]	Formaldehyde and VOC	Building products or furnishing	–	23	50	[a)]	[a)]
EN717-1[53]	Formaldehyde	Wood based panels	0.225/1/≥12	23	45	1	1
ASTM E1333[54]	Formaldehyde	Wood products	≥22	25	50	0.5	0.95/0.43/0.26
ASTM D6007[55]	Formaldehyde	Wood products	0.02-1	25	50	[b)]	[b)]
ASTM D6670[56]	Formaldehyde and VOC	Indoor materials/products	[c)]	23[d)]	50[d)]	0.5[d)]	–
ASTM D5116[57]	Formaldehyde and VOC	Indoor materials/products	≤5	[e)]	[e)]	[e)]	[e)]

a) Annex B in ISO 16000-9: floor 0.40, wall 1.38, sealant 0.011; b) air exchange rate/loading factor=0.526/1.173/1.905/3.846 m/h; c) room-size chamber; d) only an example; e) examples test matrix are given in Table 1 in ASTM D5116.

sponding performance requirements. In order to assess the overall performance of the chamber, Zhang et al. [61] developed the standard VOC emission source whose emission rate could be measured independently from the chamber testing method. In Zhang et al.'s study, an uncovered petri-dish containing liquid VOC was used as a reference emission source. The reference source was placed in the test chamber and its weight loss due to evaporation was measured by an electronic balance to determine the reference emission rate. The chamber testing result was compared with the reference value to obtain the difference. ASTM D6670 [56] adopted this method. The overall performance of the chamber was quantified by the relative difference δ (eq. (6)). For quality assurance, the time average of δ should be within ±15%.

$$\delta = \frac{R}{R_r} - 1, \tag{6}$$

where R is the emission rate calculated from the VOC concentration in the chamber, and R_r is the reference emission rate determined by electronic balance.

However, this method is imperfect. Due to the petri-dish being uncovered during testing, the ambient air flow above the petri-dish could greatly influence the evaporation rate, making the emission rate unstable [62]. Cox et al. [63,64] developed a new standard reference VOC emission source by dissolving toluene into a polymethyl pentene (PMP) polymer substrate. Chamber test concentration results were compared with emission model values. However, uncertainty of emission rate is not easy to evaluate because of the uncertainty of the emission model itself. In addition, the emission rate of the PMP film changed with time, which may be not be appropriate for testing over a long period [62].

Various labeling schemes have different testing schedules (Figure 8). For most of the European labeling schemes, the entire duration of the emission test is 28 d. During these 28 d, one or several chamber air samples may be collected at day 1, day 3, day 10 or day 28. In the American labeling schemes, test periods are always 7 or 14 d. It can be seen that existing labeling schemes need long test times (7 or 28 d). The testing methods of European labeling schemes are developed from EN 13419-1 (superseded by EN ISO 16000-9). In EN 13419-1 the test period is 28 d, so the test period of the labeling scheme is 28 d. But EN 13419-1 does not explain why the test period is 28 d. BIFMA has given an explanation for their test schedule. The minimum time between the completion of installation and occupancy is 16 d. Therefore the standard [65] recommends a 14-d testing period. However, analyses of furniture emission characteristics and past test data suggest that it is adequate to use 7-d test data to predict the VOC emission rates at the 14th day. That is why the test period is 7 d. Testing times of 7–28 d are unnecessarily long, and may lead to a higher cost that increases the economic burden on the producer and thus hinder popularization and application of the labeling scheme.

It is worth mentioning that in order to shorten testing time to 7 d, BIFMA [65] developed a power-law model for interpolation and extrapolation (eq. (7)). The power-law model can be used to predict the emission factor at 14 d based on the emission results at day 3 and day 7.

$$E = at^{-b}, \tag{7}$$

where E is the emission factor at time t, a and b are coefficients determined by

$$b = \frac{\ln E_1 - \ln E_2}{\ln t_2 - \ln t_1}, \tag{8}$$

$$a = E_1 t_1^{-b} = E_2 t_2^{-b}, \tag{9}$$

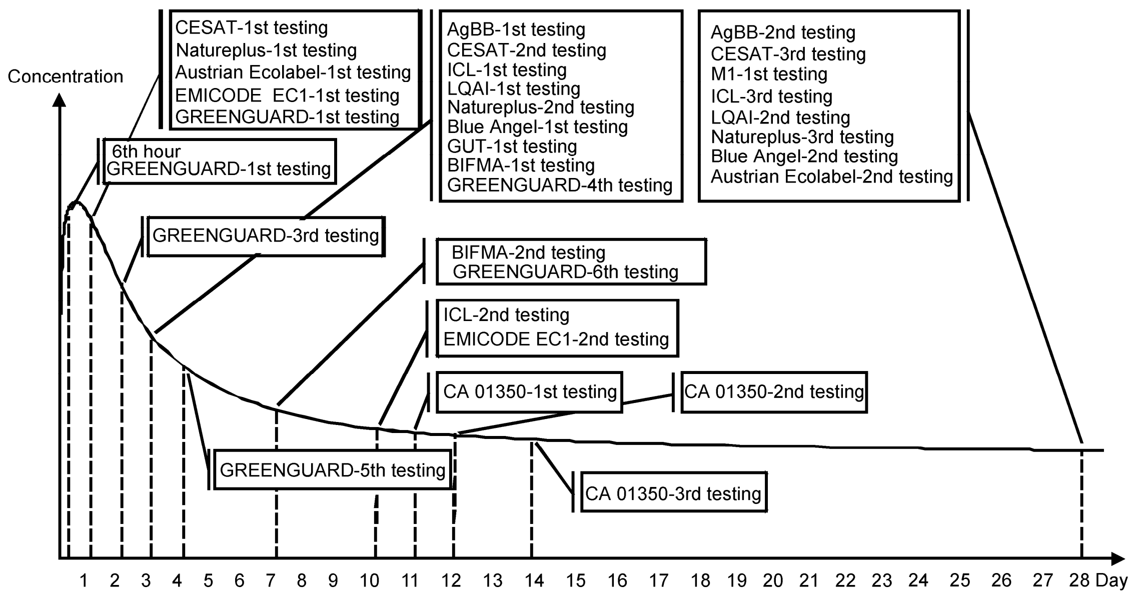

Figure 8 Testing time schedule of various labeling schemes.

where E_1 and E_2 are emission factors corresponding to time t_1 and t_2 respectively.

It is noted that this power-law model is only an empirical model. It is pointed out in the standard that the power-law model is only used to predict the emission factor at 14 d or less. It therefore seems that application of the empirical model is limited. A next step would be to develop a mass transfer theoretical model to shorten testing time.

(iv) Testing method—Subjective test. Some VOCs may produce an odor nuisance which may affect the perception of the indoor air quality by people [66–69]. Therefore a sensory test isappliedin some labeling schemes. For example, the Danish ICL [29] specified that VOC emissions of the specimen placed in CLIMPAQ [70] were sniffed and evaluated by an untrained panel. They evaluate and report their first impression of acceptablility and odor intensity in Figure 9. The indoor air quality is regarded as acceptable at an acceptability greater than 0 and an odor intensity of less than 2. The Finnish M1 also have a sensory test. There is no sensory test in American labeling schemes.

2.2 Policy part

There are some differences in the legal status of various labeling schemes. In general, most labeling systems are typically voluntary for the manufactures. Market demand for low emitting materials is their main driving force. In these labeling schemes, M1, ICL and Blue Angel are promoted by governments. Natureplus is promoted by several retailer chains. BIFMA is promoted by an industry association. Some are promoted by a third-party organization, like SCS and GREENGUARD. There are also some mandatory labeling schemes. For example, CE marking of building products is mandatory within the European economic area; the AgBB scheme has become mandatory for all floorings materials [15], California air resources board (CARB) has released a statute to reduce formaldehyde emission from wood based panels.

In China, there are two types of certification for products: mandatory and voluntary that are managed by the certification and accreditation administration (CNCA). Mandatory certification is also known as China Compulsory Certification known as 3C or CCC for short. Up until the present, 3C includes 273 kinds of products, e.g. solvent based coatings for woodenware, porcelain tile, electrical sockets, electric fan and so on (http://www.xmciq.gov.cn/wsbs/jyjy/rzjg/3crz/201003/t20100315_30933.htm). Products included in 3C should get certified, otherwise they are not allowed to be imported from abroad to be sold or used in the market. Further study is needed to determine whether other indoor decorating and refurbishing materials and furniture can be entered into the 3C catalog.

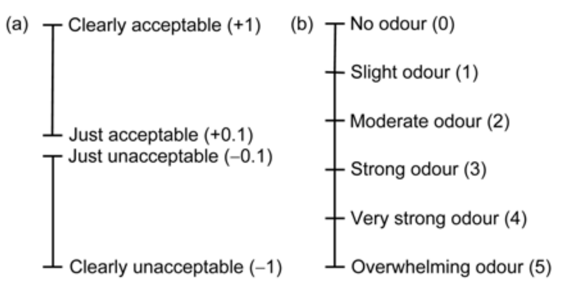

Figure 9 Sensory test [29]: (a) Acceptability; (b) odour intensity.

2.3 Operational part

(i) Selection and preparation of test specimens. Samples selected for testing should be representative of the products manufactured under typical operating conditions. If test results are to be considered representative of a group of products or materials, a representative specimen that has the potential to have the highest VOC emissions should be selected from the group. Prescreening testing or other analysis by the manufacturer in consultation with the testing facility and certification agency may be necessary to determine representative specimens [65]. A sampling, storage and preparation procedure fortest specimens is clearly statedin ISO 16000-11 [71]. Samples must be stored immediately after collection in airtight, moisture-proof containers or packaging to prevent contamination and to preserve their chemical integrity by preventing subsequent VOC emission losses.

(ii) Assessment frequency. The emission test results can be considered valid and useful for supporting claims of low emitting product as long as the materials and components, manufacturing processes and packaging methods remain the same. Significant changes to one or more of these factors should be evaluated for possible effect on emission characteristics. If it is possible that the product emissions will increase as a result of a change being implemented, a new test should be conducted [65]. The manufacturer or certification organization should establish the schedule for routine laboratory retesting of samples. Often, biennial or even annual retesting is required [31].

(iii) Laboratory requirement. Laboratories should be maintained according to a quality management system (QMS) [31]. A laboratory's QMS and applicable test procedures should be conducted in accordance with ISO/IEC 17025 [72]. The best proof of quality of the laboratory conducting testing and evaluation of VOC emissions is that the laboratory is accredited for the test methods or at least has been validated through inter-laboratory comparisons. Large-scale contrast tests have been carried out by laboratoies from Europe and the U.S. The test specimens were PVC flooring, carpet, paint and water-based liquid floor wax [73,74]. BIFMA has organized an inter-laboratory comparison study of the ANSI/BIFMA standard test method M7.1 using chairs as test specimens [75]. A reference VOC emission source has also been used in an inter-laboratory comparison study [76].

(iv) Certification method. There are three ways to certify the products. The first is a YES/NO method. If the product meets all the requirements of the labeling scheme, it will be certified and get labeling. Otherwise it can not get labeling. Most labeling schemes use this method. The second is a rating method. For example, in Finland building materials have been classified into three emission classes: M1, M2 and M3. Class M1 corresponds to the products with the lowest pollutant emission rates and class M3 indicates materials with the highest pollutantemission rates [77]. The rating method divides products into different grades that could meet the needs of various environmental conditions. Therefore it is convenient for users to buy products according to their own situations. The third method is the Danish LCI method. It would declare indoor-relevant time-value based on the results of the emission test. Indoor-relevant time-value means the time it takes to reach the acceptable indoor air quality for all emitted compounds in a standard room under standard conditions [78].

3 Conclusions

In Europe and the U.S., indoor decorating and refurbishing materials and furniturelabeling schemes were established to improve indoor air quality with goodeffect. Since China is now the primary producer of wood based panels, coatings and furniture in the world, it should learn from Europe and the U.S. so as to establish labeling schemes. China should fully consider China's national condition when establishing labeling schemes, and not simply copy the foreign models in their entirety. Some aspects of these foreign models that are inappropriate for China are as follows:

(1) Hundreds of VOCs are considered target pollutants in some labeling schemes. This is too many for China. Different raw materials and production processes of products may lead to different VOC emission performance. Therefore the large number of target pollutants in European and American labeling schemes may not be suitable for China. Instead China could determine target pollutants through indoor decorating and refurbishing materials and furniture VOC emission tests.

(2) The method to determine the threshold values is not that scientific. Some labeling schemes use occupational exposure limit values multiplying specific factors as threshold values. There is no scientific basis for selecting the specific factor. In China, determining the threshold value should simultaneously consider indoor air quality standard and the quantity of indoor decorating and refurbishing materials and furnitureused in the room.

(3) The testing time of 7–28 d is too long which leads to high testing cost which translates to a heavy economic burden on the manufacturers. This is not beneficial to popularizing and applying a labeling scheme. A theoretical model could be developed to shorten the testing time.

(4) The emission rate of a standard emission source (an uncovered petri-dish containing liquid VOC) is vulnerable to being influenced by the ambient air flow above the petri-dish. The emission rate of the standard emission source made by dissolving toluene into PMP changes over time. Both are not appropriate for testing the performance of a chamber.

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