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A New Method for Determining Outdoor Humidity Ratio of Natatorium in Transition Season

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Abstract: The natatorium's ventilation problem receives much concern because of its large wet load. The outdoor humidity ratio in transition season is the basic design parameter of the ventilation calculation, directly affecting the rationality of architectural design. At present, the ventilation-curve (V-C) method is the most widely used method to determine the outdoor humidity ratio in the transition season in China. However, due to failing to reflect non-guaranteed hours, the rationality of this value is difficult to assess by employing this approach. This paper presents a new method, the typical transition season method (TTS), for determining the outdoor humidity ratio in the transition season of a natatorium. The TTS method selects the transition season based on the typical meteorological year (TMY) data and calculates the outdoor humidity ratio with multiple non-guaranteed hours. This can well-represent the local perennial climate characteristics and clearly reflect the non-guaranteed hours. In this study, through selecting six typical representative cities in China, the evaluation of the outdoor humidity ratio is achieved through calculating ventilation volume and air change rate, verifying the rationality of this method. The results show that the humidity ratio obtained by the V-C method is lower than that obtained by the TTS method at about 2 g/kg without guarantee of 200 h humidity ratio, and even that the maximum difference is 6.64 g/kg. Meanwhile, the validation results of the ventilation calculation show that the humidity ratio determined by the V-C method cannot meet the minimum design requirements in five cities, while the humidity ratio obtained by the TTS method cannot meet the requirements in only one city.

Keywords: ventilation rate; TMY; typical transition season method; non-guaranteed hour; moisture gain

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Citation: Lei, J.; Li, H.; Li, C.; Xu, M. A New Method for Determining Outdoor Humidity Ratio of Natatorium in Transition Season. *Energies* **2023**, *16*, 2990. https://doi.org/10.3390/en16072990

Academic Editor: Jae-Weon Jeong

Received: 28 February 2023
Revised: 20 March 2023
Accepted: 22 March 2023
Published: 24 March 2023

1. Introduction

Building ventilation rates are crucial based on their impacts on building energy use for space conditioning and on indoor air quality (IAQ) given their impacts on indoor air pollution concentrations [1]. Generally, building design standards contain requirements for minimum ventilation rates, which are measured in units of ventilation per unit area per hour or air changes per hour [2]. For example, ASHRAE Standards 62.1 include such requirements for commercial, institutional and high-rise residential buildings, while ASHRAE Standards 62.2 are for low-rise residential buildings [3]. Countries worldwide have adopted different ventilation standards to meet the demands of the ventilation designs of different architectural styles, such as the European CEN (2007) and Chinese GB50736 (2012) [4,5].

The indoor air environments of natatoriums show more complexity compared to general civil buildings [6]. This is mainly due to the swimming pool water needing to be disinfected and sterilized, resulting in the presence of residual chemical mixtures in pool water and indoor air. Long-term exposure to these substances will cause harm to human health, especially to stadium staff, swimmers and swimming enthusiasts [7]. As examples, Caro et al. [8] studied workers' and swimmers' exposure to trihalomethanes (THMs) in an indoor swimming pool, and a good correlation was found between THM concentrations in the swimming pool water and the urinary THM concentrations of the people affected after exposure. Besides, Fátima et al. [9] found seven volatile organic compounds with potential hazards except THM by studying the air quality in Olympic swimming pools. They believed that the air/water temperature ratio and relative humidity are regarded as the key parameters that are likely to trigger the transfer process of volatiles from water to air and their accumulation in the indoor environment of swimming pools, respectively. Thus, it can be seen that there are plenty of chemical pollutants in the indoor air of swimming pools. If the concentration of pollutants is not effectively reduced to an acceptable range, it will pose a threat to human health.

At the same time, due to the characteristics of high indoor humidity in natatoriums, it is not enough to only consider reducing pollutant concentrations in ventilation design. High humidity caused by a large area of water is prone to cause enclosure-structure condensation and swimming-pool corrosion. If swimmers stay in that high humidity environment long term, they may show chest tightness, dyspnea and other adverse reactions [7]. Mathieu et al. [10] used three indexes to implement numerical analysis and field measurement on the ventilation condition of a public swimming pool in Canada and concluded that the uncomfortable thermal and humid environment occupied by an indoor swimming pool is common. Methods of improving this phenomenon have been studied in the past. For instance, Gollwitzer et al. [11] proposed that reasonable ventilation control can effectively improve an indoor thermal and humid environment and air quality, with sharply reduced energy costs. Therefore, the dehumidification of swimming pools should be taken seriously.

The indoor thermal and humid environment design requirements of the swimming pool is for a temperature of 25~28 °C and a relative humidity $\leq$75%. Generally, ventilation is an effective method to dilute indoor pollutant concentrations and adjust indoor temperature and humidity. Adequate ventilation can maintain the indoor air environment at a healthy level. To be more specific, the minimum ventilation rate is the basic guarantee for IAQ [12,13].

The value of the minimum ventilation rate in ventilation design plays a key role in the energy consumption calculation and device selection as it directly affects the IAQ. Ciuman et al. [14] analyzed the influence of the ventilation system on the energy consumption of a selected indoor swimming pool located at a school in Gliwice, in the southern part of Poland. They proposed that decreasing the ventilation rate reduces energy consumption but worsens the thermal and humid conditions inside the construction. Similarly, related research conducted by Richard et al. [15,16] showed that the selection of a minimum ventilation rate has a direct impact on IAQ. So, it is of great importance to determine the minimum ventilation rate of a ventilation design accurately.

The determination of the minimum ventilation rate is related to the indoor and outdoor humidity ratio, which varies seasonally. In summer, as the outdoor humidity ratio of most cities in China is higher than the indoor humidity ratio, ventilation cannot be used for dehumidification directly. In such hot and humid conditions, other dehumidification methods should be used, such as vapor compression [17], liquid desiccant [18,19], solid desiccant [20] or solar-assisted hybrid solid desiccant [21], with more energy-saving potential. In winter, the humidity ratio of outdoor air is much lower than that of indoor air, resulting in less ventilation-volume requirement for dehumidification. Therefore, two cases mentioned above have no reference value. However, since there is little difference between indoor and outdoor humidity ratio in the transition season, the condensation of enclosure structure often occurs, leading to high requirement of ventilation volume for dehumidification. For instance, Wang et al. [22] provided the seasonal ventilation design index of typical buildings in Chongqing combined with the standards; meanwhile, the energy-saving effect of ventilation in the transition season was affirmed. Therefore, it is most appropriate to consider the calculated ventilation rate in the transition season as the minimum ventilation rate in the natatorium design process [23].

The value of the ventilation rate is determined by the indoor and outdoor humidity ratio and indoor wet load. Generally, one of the reasons for the inaccurate calculation of ventilation rates is that there is no appropriate design value of the indoor and outdoor humidity ratio. In terms of the indoor humidity ratio, it can be calculated from indoor design temperature and humidity and local atmospheric pressure. Regarding the outdoor humidity ratio, the ASHRAE Handbook: Fundamentals 14.1 derives the value of the outdoor humidity ratio in summer based on annual uncertainty rates of 0.4% and 1% [24]. However, considering the outdoor humidity ratio in the transition season, the national standards worldwide do not explicitly stipulate its determination method.

To solve this problem, some relevant studies have been discussed in the literature. The Hunan Architectural Design Institute proposed the ventilation-curve (V-C) method to obtain the outdoor calculated humidity ratio of the swimming pool during the transition season. This value was used for the ventilation rate calculation of the natatorium. However, the humidity ratio measured by the V-C method cannot reflect the non-guaranteed hour. In addition, Zhang [25] conducted research in which the non-guaranteed rate was taken into account. He initially proposed the climate statistics method and the typical annual meteorological data method to obtain the outdoor calculated humidity ratio. The results showed that the humidity ratio obtained by this method, which is used for calculating ventilation rates and selecting equipment, had achieved good results in practical operation. Likewise, in recent years, Jia et al. [26] determined the outdoor humidity ratio in the transition season according to the non-guaranteed hours per year for swimming pools in Hainan, showing that the humidity ratio selected according to the non-guaranteed hours per year is too high to be ventilated and dehumidified.

In summary, the reference value of the calculated minimum ventilation rate can be guaranteed only when the indoor and outdoor design humidity ratio of the natatorium is determined accurately. According to the previous literature, there have been few, if any, studies on the calculation parameters of the ventilation and dehumidification of swimming pools in the transition season worldwide, while the existing approaches have not comprehensively considered the applicability of the dehumidification capacity and guarantee rate of the outdoor humidity ratio. Thus, there is a research gap in terms of the determination of the outdoor humidity ratio.

To solve this problem, this paper proposes a new method for calculating the outdoor humidity ratio value of a natatorium in the transition season, with the comparison of the existing approaches. Through the verification of the calculated ventilation rate, the method is universal and can get multiple non-guaranteed hours of the humidity ratio, which provides a variety of choices for designers. The results show that the obtained outdoor humidity ratio meets the minimum design requirements and has significant dehumidification ability.

2. Weather Data

2.1. Basic Data

The vast territory of China, covering 9.6 million square kilometers, accounts for nearly 1/15 of the world's total land area, resulting in great variations in climate across China. For this reason, relevant standards in China divide China's land-climate zones from the perspective of building thermal designs [27]. The standard takes the average temperature of the coldest month and the hottest month as the main indexes, and the number of days meeting the daily average temperature requirements as the auxiliary indexes, as the first-level zoning index. The heating days based on 18 °C are opted for as second-level zoning indexes. The first-level zoning index divides China into five zones, namely severe cold, cold, hot summer and cold winter, hot summer and warm winter, and mild climate zones. The second-level zoning index divides each zone into A, B and C, namely severe cold (1A, 2B and 3C), cold (2A and 2B), hot summer and cold winter (3A and 3B), hot summer and warm winter (4A and 4B) and mild (5A and 5B) climate zones.

To verify the reliability of the method, according to China's code for the thermal design of civil buildings [27], typical cities with obvious climate differences were selected for analysis from five districts. The selected cities were Harbin (SCZ, 1A), Urumqi (SCZ, 1B), Beijing (CZ), Wuhan (HSCWZ), Guangzhou (HSWWZ) and Kunming (MZ). Weather data measured during a 30-year period (1988–2017) were gathered and analyzed. The specific geographical distribution is shown in the Figure 1:

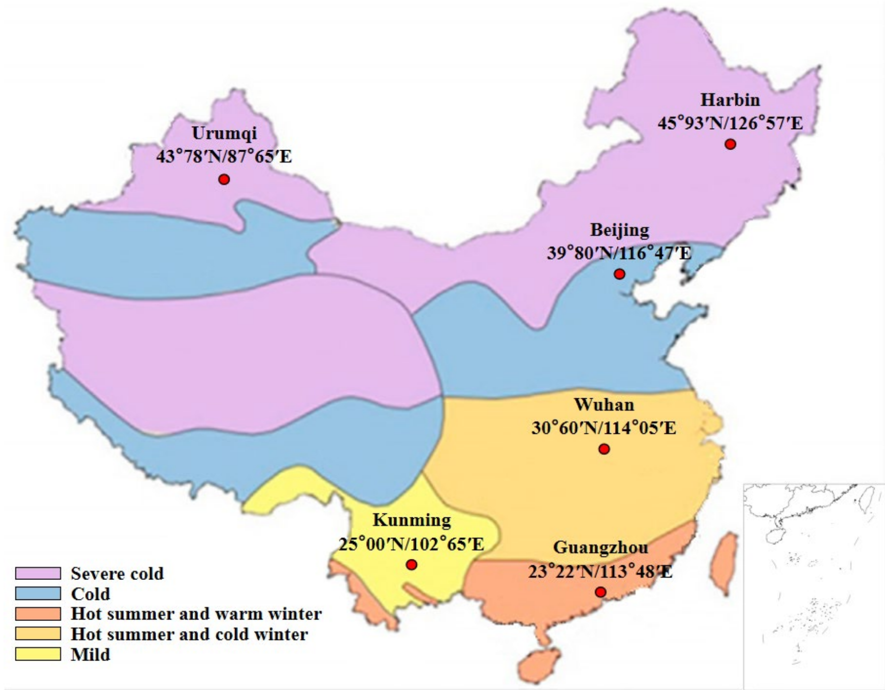


Figure 1. Geographical location information of the six typical cities.

2.2. TMY Data

Based on the 30-year historical data of six representative cities, the typical meteorological year (TMY) is generated by applying the method of Sandia National Laboratory to provide data preparation for the experiment. The TMY dataset is mainly used to reflect the outdoor climate conditions of the building [28]. This dataset selects 12 typical weather months (TMM) from a period of time (usually 30 years) and combines them into one dataset of 8760 h [29]. It not only ensures the authenticity of meteorological data, but also represents climate change [30].

TMY is usually generated by using the Finkelstein–Schafer (*FS*) statistical method proposed by Sandia Labs. The method is determined by comparing the similarity between the annual cumulative distribution function (*CDF*) of the selected month and the long-term *CDF*. According to Table 1, the weight factors of each meteorological element are allocated to calculate the minimum weighted total value of the *FS* data [31]. The calculation of the weighted total value of the *FS* data is shown in Equations (1)–(3) [28].

$$FS_j(y,m) = \frac{1}{N}\sum_{i=1}^{N}\left|CDF_m\left(\left(x_j\right)_i\right) - CDF_{y,m}\left(\left(x_j\right)_i\right)\right| \quad (1)$$

$$WS(y,m) = \frac{1}{M}\sum_{j=1}^{M} WF_j \cdot FS_j(y,m) \quad (2)$$

$$\sum_{x=1}^{M} WF_j = 1 \quad (3)$$

where $FS_j(y,m)$ = the statistical value of $FS(y,m)$ in the range of x_i for the j-th meteorological parameter.

y = the research object year.

m = the month of the research object year.

N = the number of parameters, which is depended on the starting point, end point and step distance.

M = the number of daily values.

$CDF_m((x_j)_i)$ = for the m-th month, the CDF value of the j-th meteorological parameter value in the range of x_i.

$CDF_{y,m}((x_j)_i)$ = the CDF value of the long-term statistical value range of the j-th meteorological parameter in the range of x_i.

$WS(y,m)$ = the average weighted sum of m-th month in y-year.

WF_x = the weighted factor of the x-th meteorological parameter, shown in Table 1.

Table 1. The weight of each parameter in the TMY generation method.

Meteorological Parameter		Weight (TMY3) [32]
Dry temperature	Max	1/20
	Mine	1/20
	Mean	2/20
Dew-point temperature	Max	1/20
	Mine	1/20
	Mean	2/20
Wind	Max	1/20
	Mine	1/20
Solar radiation	Global	5/20
	Direction	5/20

3. Method

3.1. Ventilation-Curve Method

Currently, in the design of domestic swimming pools, the V-C method is commonly used to determine the outdoor calculated humidity ratio in the transition season. This method considers indoor natural ventilation by opening windows as boundary conditions. The principle of it is shown in Figure 2. The V-C method connects the average temperature and humidity of the local outdoors at 14:00 every month in the recent 10 years to the meteorological curve on the psychrometric chart. In addition, the humidity ratio corresponding to the intersection point of the meteorological curve and the temperature line of the indoor air dew-point temperature is the value of the outdoor humidity ratio in the transition season [33]. In the figure, d is the humidity ratio in abscissa, t is the temperature in ordinate, A is the Indoor air state point, B is the design point of outdoor air condition in transition season 1 (heating transition season) and C is the design point of the outdoor air condition in transition season 2 (cooling transition season).

3.2. TTS Method

With the increase in many factors affecting meteorological changes, such as the greenhouse effect and heat island effect, it becomes increasingly difficult to find the law of climate change in a certain region through the meteorological data over the years. If the specific temperature limit method is used to determine the transition period of each year over the years, the step length varies and requires large calculation quantity, which is difficult to unify. To solve the above problems, this paper proposes the typical transition season (TTS) method. Specific implementation steps for this method are described in this section, and the technical route is shown in Figure 3.

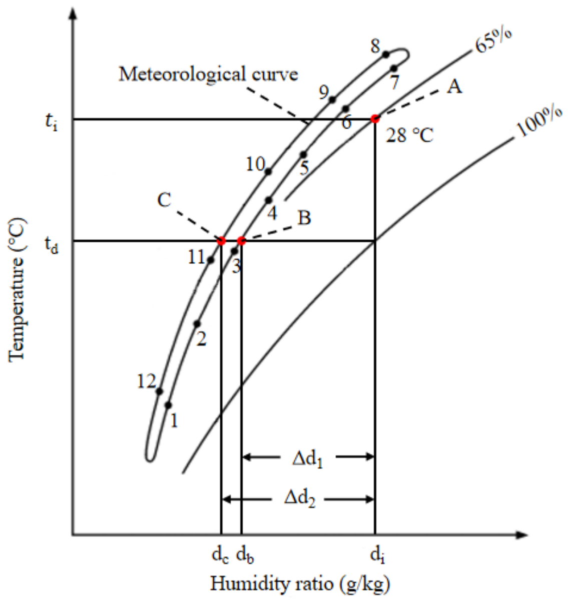


Figure 2. Principle diagram of ventilation-curve method.

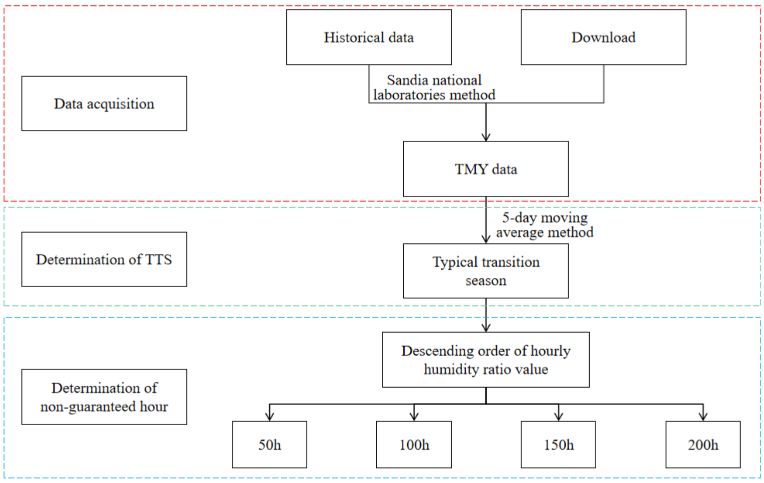


Figure 3. Technical route of TTS method.

3.2.1. Determination of TTS

In the architectural design period, different types of buildings have different design requirements for the transition season. Therefore, considering the design requirements of the swimming pool, when determining the outdoor humidity ratio in the transition season, the specific temperature limit should be used to divide the transition season range suitable for the ventilation condition of the swimming pool first. This study uses the 5-day moving average method [34] to determine the transition season range.

The 5-day moving average method is a method for smoothing time-series data. The principle diagram is shown in Figure 4, where $D_i(i = 1, 2, 3...)$ is the daily ordinal number, $T_i(i = 1, 2, 3...)$ is the daily average temperature of the ith day, $F(T_i)(i = 1, 2, 3...)$ is the 5-day average temperature from day i to day $i + 4$. When the 5-day moving average method is applied to calculate the starting date of a stable temperature passing through a certain boundary, the steps are as follows:

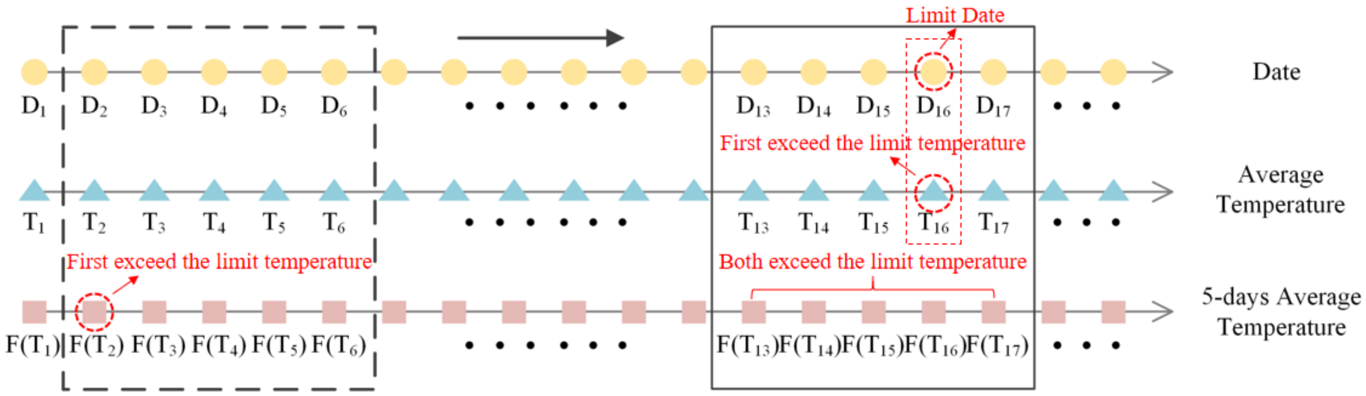


Figure 4. Principle diagram of 5-day moving average method.

Step 1. Find the date when the 5-day average temperature first exceeds the limit temperature;

Step 2. Translate backwards in chronological order from the day in five units;

Step 3. Stop when the 5-day average temperature of five consecutive units exceeds the temperature limit;

Step 4. Find the daily average temperature exceed the limit temperature for the first time in the five consecutive units and the corresponding daily ordinal number is the limit date.

In China, the critical temperature of outdoor heating design for civil buildings is defined as 5 °C, while the critical temperature of air conditioning in summer has not been clearly defined [5]. Therefore, 5 °C is taken as the lower limit of temperature when determining ventilation conditions in a transition season in this study. Studies on the upper limit temperature will be describe below.

Considering the indoor thermal and humid environment design requirements of the swimming pool building, that is, a temperature of 25~28 °C and a relative humidity $\leq$75%. Normally, temperature of 28 °C and relative humidity of 65% are chosen as the indoor air condition points in swimming pools for design calculations. The air supply temperature should not exceed 28 °C at this moment. Therefore, it is necessary to find the date when the daily maximum temperature is about 28 °C.

In this paper, three groups of meteorological samples satisfying the daily average temperature range of 22 $\pm$ 0.5 °C, 23 $\pm$ 0.5 °C and 24 $\pm$ 0.5 °C are counted, and each group has 1000 initial samples. Based on the Monte Carlo method, 100 samples are randomly selected from 1000 samples, and the hours and proportion of hourly temperature greater than 28 °C within 100 days are counted, as shown in Figure 5. The authors analyzed the results of three groups. Group 1: the figure shows that there are 276 h above 28 °C in the first group, accounting for 11.5%. In this situation, it will cause overheating in the swimming pool and affect human thermal comfort. Group 2: there are 86 h above 28 °C in the second group, accounting for 3.6%. This temperature is too conservative and will reduce the number of ventilation hours and result in energy waste. Group 3: there are 168 h above 28 °C in the third group, accounting for 7%. Taking the number of non-guaranteed hours into consideration in the architectural design period, this temperature can meet the thermal comfort requirements of an indoor human body for most of the time and can save on energy consumption to the greatest extent. Thus, 23 °C is selected as the upper limit temperature of the transition season in this study.

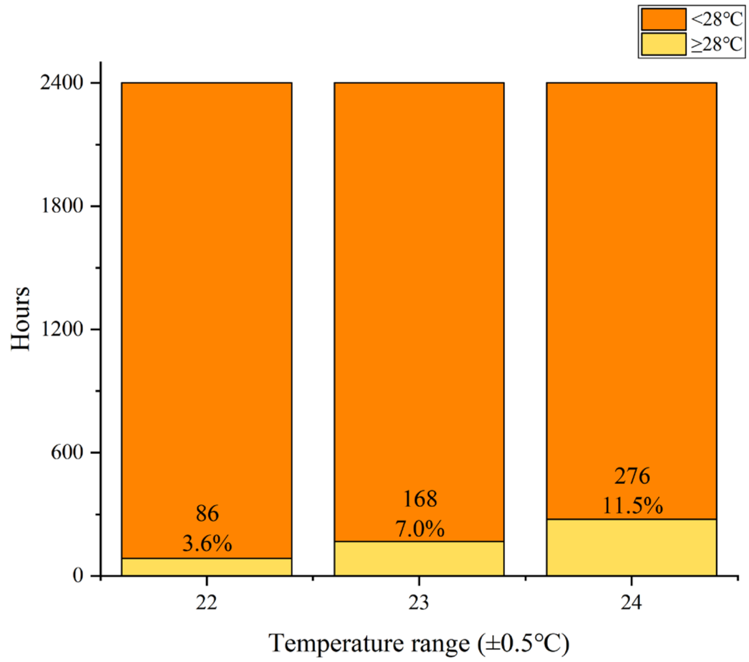


Figure 5. The hours and proportions of temperatures above 28 °C.

3.2.2. Determination of Humidity Ratio

Multiple non-guaranteed rates are often used to determine outdoor meteorological design parameters internationally, such as by the American Society of Heating, Refrigerating and Air-Conditioning Engineers [24] and the Chartered Institution of Building Services Engineers (CIBSE) (2006) [35]. The Chinese standard uses the single non-guaranteed hours to determine outdoor meteorological design parameters [5]. Therefore, in this paper, the method of parameter determination is integrated with domestic and overseas to determine the outdoor humidity ratio in the transition season with multiple non-guaranteed numbers of hours. The methods are as follows:

Assume that n is the number of the humidity ratio in the selected transition season, and there is a set $\{a_1, a_2, \ldots, a_n\}$. Arrange all subsets in a set in numerical order such that $a_{n+1} \leq a_n$ to form sequence A_n. Select a_{51}, a_{101}, a_{151} and a_{201} as the parameter selection results in sequence A_n. At this point, four different non-guaranteed hours (50 h, 100 h, 150 h and 200 h) of the outdoor humidity ratio are selected.

3.3. Theory of Ventilation Rate Calculation

After the outdoor humidity ratio in transition season is determined, it is necessary to check the ventilation volume and air change rate of the natatorium in combination with the construction project, to test whether the obtained rate of air change achieves the minimum requirements of the natatorium. If the inspection results are incapable of meeting the design requirements, the minimum ventilation volume required by the standard is taken for the design. The natatorium with different functions needs different air change rates. See Table 2 for the air change rate requirements of different types of natatoriums.

Table 2. Air change rates of different types of natatoriums.

Types of Natatoriums	Competition	Training	Recreational	Therapeutic
Air changes per hour	1–4	3–6	4–8	4–8

The calculation formula of air change rates in swimming pools is shown in Equation (4) [23]:

$$n = \frac{L}{V} \quad (4)$$

where n = air changes rate in natatorium (time per hour).

L = ventilation volume required to eliminate moisture (m^3/h).

V = volume of natatorium (m^3).

In the above formula, L needs specific calculation. The ventilation in the swimming pool should meet the following three purposes:

1. Eliminate indoor redundant moisture;
2. Meet the hygienic requirement of chlorine content being less than 1 mg/m^3 in the pool air;
3. Provide fresh air for personnel to breathe and ensure a minimum of fresh air for personnel activities.

To achieve the purposes above, it is necessary to calculate the ventilation volume and select the maximum value.

The ventilation volume calculation formula of the swimming pool is shown in Equation (5) [23]:

$$L = \frac{1000W}{\rho(d_i - d_o)} \tag{5}$$

where W = moisture gain in natatorium (kg/h).

d_i = indoor air humidity ratio (g/kg dry air).

d_o = outdoor air humidity ratio (g/kg dry air).

ρ = standard air density (kg/m^3).

From Equation (5), it can be seen that the calculation of ventilation also requires us to calculate the moisture gain in the swimming pool area. Swimming pool indoor moisture sources are pool water, poolside wetlands and personnel.

The calculation formula of moisture gain in a natatorium is shown in Equation (6) [36]:

$$W = W_1 + W_2 + W_3 \tag{6}$$

where W_1 = moisture gain of pool water (kg/h).

W_2 = moisture gain of poolside wetlands (kg/h).

W_3 = moisture gain of personnel (kg/h).

The calculation formula of W_1 is shown in Equation (7) [36]:

$$W_1 = 3.6AF_a(89 + 78.2v)(p_w - p_a)/\gamma \tag{7}$$

where A = area of pool surface (m^2).

F_a = typical activity factor [36], shown in Table 3.

v = air velocity over water surface (m/s).

p_w = saturation vapor pressure taken at surface water temperature (Pa).

p_a = saturation pressure at room air dew point (Pa).

γ = latent heat required to change water to vapor at surface water temperature (kJ/kg), calculated by $\gamma = 2500 - 2.35t_s$, where t_s = surface water temperature (°C).

Table 3. Typical activity factors of different types of pools.

Type of Pool	Residential Pool	Therapy	Hotel	Public, Schools	Wave Pools, Water Slides
Typical activity factor	0.5	0.65	0.8	1	1.5

The calculation formula of W_2 is as shown in Equation (8) [36]:

$$W_2 = 0.0171(t - t^*)F\lambda \tag{8}$$

where t = indoor design dry bulb temperature (°C).

t^* = indoor design wet bulb temperature (°C).

F = area of poolside wetlands (m^2).
λ = moisture factor, take 0.2~0.4.
The calculation formula of W_3 is as shown in Equation (9) [36]:

$$W_3 = \omega n_1 n_2 \quad (9)$$

where ω = unit personnel moisture gain (kg/(per person per hour)), take 0.123.
n_1 = number of people.
n_2 = clustering coefficient, take 0.92.

4. Results and Discussions

4.1. Use Different Method for Determining Humidity Ratio

For the TTS method, this study first used the five-day moving average method to select the TTS based on the TMY data of six representative cities. Then, the 100% ventilation hours were calculated, that is, the number of hours when the dry bulb temperature was between 24 °C and 28 °C and the outdoor humidity ratio was less than the 1 g/kg indoor humidity ratio during the transition season. The fresh air in 100% ventilation hours can directly ventilate for dehumidification without heating or cooling. Notably, the energy-saving potential of ventilation and dehumidification in this area improves with the increase in ventilation hours. As seen, the TTS and 100% ventilation hours selected from six representative cities are presented in Table 4. It shows that there are a large number of 100% ventilation hours in each city that can effectively reduce the energy consumption caused by fresh air treatment. In particular, Kunming, in mild areas, has 511 100% ventilation hours with great energy-saving potential. So, by determining the appropriate outdoor humidity ratio in the transition season, the energy-saving potential of 100% ventilation hours can be fully utilized to reduce unnecessary energy waste.

Table 4. Typical transition season of representative cities.

Climate Zone	Representative Cities	Transition Season 1	Transition Season 2	100% Ventilation Hours
SCZ, 1A	Harbin	04–12~06–13	08–19~10–23	163
SCZ, 1B	Urumqi	04–18~06–07	09–04~10–24	110
CZ	Beijing	03–11~05–18	09–17~11–13	172
HSCWZ	Wuhan	02–27~05–06	09–22~11–30	161
HSWWZ	Guangzhou	01–25~04–08	11–16~01–24	164
MZ	Kunming	12–03~07–09	07–10~11–30	511

After the typical transition season is obtained, the outdoor humidity ratio of the transition season that does not guarantee 50 h, 100 h, 150 h and 200 h in transition seasons 1 and 2 is calculated, respectively, and the indoor design humidity content of the natatorium in this region is calculated based on the local atmospheric pressure (Tem = 28 °C, Reh = 65%). The calculation results are shown in Table 5. It can be analyzed that the TTS method can directly calculate the outdoor humidity ratio suitable for a construction project according to the number of non-guarantee hours in the transition season. The calculation results have a variety of non-guaranteed hours of the outdoor humidity ratio in the transition season, providing more design references for different projects. On the basis of meeting the guarantee rate of engineering requirements, the outdoor humidity ratio calculated by the TTS method in the transition season is 1 g/kg lower than that in the swimming pool, which meets the requirements of ventilation and dehumidification (except for the outdoor humidity ratio of the non-guaranteed 50 h in transition season 2 in Guangzhou).

Table 5. Calculation results of indoor and outdoor humidity ratio in each city.

Cities	Outdoor Humidity Ratio, g/kg (Transition Season 1)				Outdoor Humidity Ratio, g/kg (Transition Season 2)				Indoor Humidity Ratio, g/kg
	Non-g 50 h	Non-g 100 h	Non-g 150 h	Non-g 200 h	Non-g 50 h	Non-g 100 h	Non-g 150 h	Non-g 200 h	
Harbin	10.72	10.05	9.55	8.98	11.89	11.13	10.82	10.47	16.95
Urumqi	7.79	7.13	6.71	6.42	7.00	6.41	5.98	5.71	18.57
Beijing	9.71	8.64	8.28	7.77	13.52	12.34	11.24	10.38	16.76
Wuhan	13.78	12.98	12.30	11.72	13.66	13.33	12.85	12.53	16.71
Guangzhou	15.24	14.68	14.23	13.93	16.14	14.13	12.70	12.16	16.78
Kunming	16.73	16.20	15.93	15.64	16.61	16.33	16.12	15.98	21.45

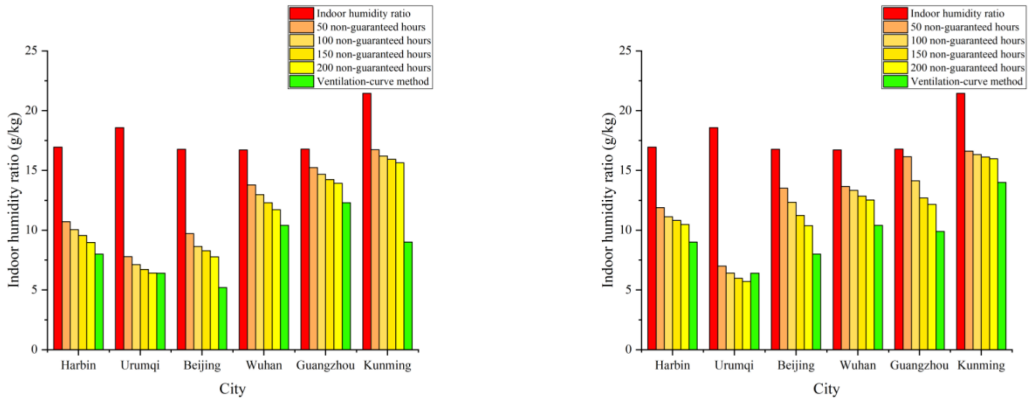
For the V-C method, first, the average temperature and humidity of each month at 14:00 in the past 10 years (2008–2017) in each city are calculated, forming connected meteorological curves on the psychrometric chart. Then, the intersection of the meteorological curve and the dew-point temperature corresponding to the indoor air-state point is determined, and the outdoor humidity ratios in transition seasons 1 and 2 are recorded. Finally, calculating the non-guaranteed hours of the humidity ratio in the TTS of cities based on TMY data, the calculation results are shown in Table 6.

Table 6. Non-guaranteed hours of the outdoor humidity ratio in a transition season obtained by the V-C method.

Cities	Transition Season 1		Transition Season 2	
	Outdoor Humidity Ratio (g/kg)	Non-g (h)	Outdoor Humidity Ratio (g/kg)	Non-g (h)
Harbin	8.0	312	9.0	431
Urumqi	6.4	202	6.4	104
Beijing	5.2	507	8.0	266
Wuhan	10.4	354	10.4	531
Guangzhou	12.3	447	9.9	278
Kunming	9.0	1821	14.0	1100

Taking cost factors into consideration, the practical projects normally use appropriate design parameters that do not guarantee the number of hours. More specifically, this means that a small amount of time that does not meet the requirements of interior design is allowed, contributing to energy saving. However, the non-guaranteed time should be appropriately limited. Generally, for the design parameters, the number of non-guaranteed hours should not exceed 200 h. The outdoor humidity ratio of the transition season obtained by the V-C method is not guaranteed to be more than 200 h. If the minimum ventilation rate is calculated based on this value, the time of the ventilation volume in the natatorium is too long to meet the operation requirement. Therefore, the V-C method is not ideal for determining the outdoor humidity ratio in a transition season in a construction project.

In this paper, the indoor humidity ratio of each city's swimming pool is calculated, while the outdoor humidity ratios in transition season 1 and transition season 2 are calculated by both the TTS method and V-C method, as shown in Figure 6. Our findings indicate that there was a difference of over 1 g/kg between the outdoor humidity ratios obtained by these two methods and the indoor humidity ratio, which suggests that the dehumidification ability was good. However, the humidity ratio obtained by the V-C method is lower than that obtained by the TTS method by about 2 g/kg without guarantee of a 200 h humidity ratio, and the maximum difference is 6.64 g/kg. This implies that using the humidity ratio obtained by the V-C method to calculate the minimum ventilation rate could result in a severe long-term shortage of fresh air, which would ultimately fail to effectively reduce indoor humidity. Therefore, these findings have significant implications for the design and maintenance of indoor swimming pools, as they highlight the importance of choosing the appropriate method for calculating humidity ratios and minimum ventilation rates to ensure optimal indoor air quality.



(**a**) Transition season 1 (**b**) Transition season 2

Figure 6. Calculation of indoor and outdoor humidity ratios.

In addition, comparisons are made with the experimental results in the recent literature [26]. The experimental city selected in the literature is Zhanzhou City, Hainan Province, located in a hot summer and warm winter region. The indoor humidity ratio of the natatorium in this region is 16.9 g/kg, which is similar to the climate in Guangzhou in this article. The literature [26] uses the statistical method of annual average non-guaranteed hours to give the non-guaranteed outdoor humidity ratio of 50 h and 200 h for transition season 1 and transition season 2 in Zhanzhou City. The results are shown in Figure 7. It can be clearly seen from the results that the outdoor humidity ratio obtained in the literature [26] during the transition season is higher than the indoor humidity ratio of the local swimming pool, resulting in the inability to use ventilation for dehumidification. Meanwhile, the outdoor humidity ratio obtained by the TTS method in Guangzhou during the transition season shows significant dehumidification potential, as shown in Figure 6.

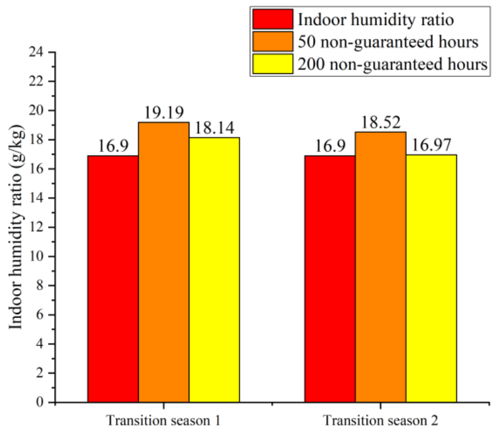


Figure 7. Comparison of indoor and outdoor humidity ratio.

4.2. Calculation of Ventilation Rate

Referring to the architectural information and design parameters of a competitive swimming pool in Xi'an, China, this paper establishes a mathematical model for ventilation calculations. The building information and indoor basic design parameters of the swimming pool model are shown in Table 7.

Table 7. Basic design parameters of natatorium.

	Parameter	Value	Unit
Building information	Area of pool surface	1250	m^2
	Area of poolside	1150	m^2
	Area of poolside wetlands [a]	316	m^2
	Hall height	15	m
Indoor design parameters	Indoor design dry bulb temperature	28	°C
	Indoor design wet bulb temperature	22.74	°C
	Relative humidity	65%	-
	Surface water Temperature	26	°C
	Air velocity over Water surface	0.2	m/s
	Moisture factor	0.2	-
	Personnel density	10	m^2/per person

[a] Take two meters out of the pool area as poolside wetland area.

In terms of the calculation of the minimum ventilation rate, three factors need to be calculated simultaneously: ventilation rate of dehumidification, the fresh air volume required by the chlorine concentration to meet the standard and the minimum fresh air required for personnel. Then, the maximum value of the three values above should be taken. With reference to ASHRAE 62.1—2016 Ventilation Standard [3], the ventilation volume to reduce chlorine concentration is calculated according to 8.78 m^3/h per square meter pool and coastal wetland area. In addition, the ventilation for providing fresh air for personnel to breathe is 30 m^3/(per hour per person). Thus, the required ventilation rate can be calculated at 13,749.48 m^3/h based on the area of pool and poolside wetlands in Table 7. Meanwhile, the minimum ventilation rate of personnel can be calculated at 7200 m^3/h on the basis of personnel density and natatorium area.

Regarding the ventilation rate for dehumidification, it is crucial to determine the outdoor calculated humidity ratio during transition seasons. To strike a balance between dehumidification effectiveness and non-guaranteed hours, we have selected the most appropriate humidity ratio obtained from the TTS method and the larger humidity ratio obtained from the V-C method in the two transition seasons, as outlined in Table 8. Using the swimming pool model, we have calculated the ventilation volumes and air change rates in six representative cities, as demonstrated in Figure 8. Given that the model is for a competitive swimming pool, the number of air changes per hour should be between 1 and 4. Hence, taking into account design requirements, if the ventilation rate corresponding to the minimum ventilation rate fails to meet the standard, then the design should be implemented at a rate of 1 air change per hour.

Table 8. Outdoor humidity ratio recommended by representative cities in transition season, (g/kg dry air).

	Harbin	Urumqi	Beijing	Wuhan	Guangzhou	Kunming
TTS method	11.89	7.79	10.44	12.30	12.16	16.33
V-C method	9.0	6.4	8.0	10.4	12.3	14.0

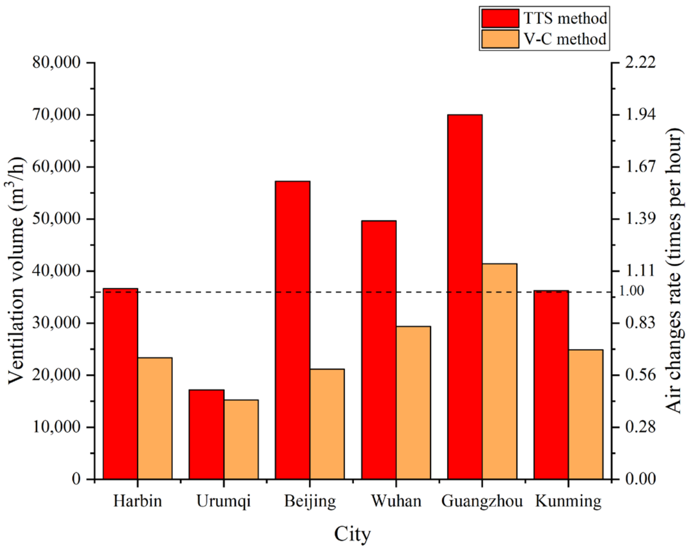


Figure 8. Ventilation volumes and air change rates.

The results of the calculations show that the ventilation rate required for dehumidification is significantly higher than the other two ventilation rates, which are the minimum fresh air required for reducing chlorine concentration and providing fresh air for personnel to breathe. Therefore, this index is the most important of the three. When the V-C method is used to calculate the ventilation rate using the outdoor humidity ratio in the transition season, despite its high dehumidification capacity, the results do not meet the minimum air change rate required by the standard. As a result, this method has no reference value for the design of the minimum ventilation rate. In contrast, the humidity ratio used to calculate the dehumidification ventilation based on the TTS method has good dehumidification capacity, and the results generally meet the demand of the minimum air change rate in the design of the swimming pool. Therefore, the outdoor humidity ratio in the transition season determined by the TTS method is a better reference value for the design of the minimum ventilation rate.

These findings are significant for those involved in the design and maintenance of indoor swimming pools as they provide valuable information on selecting appropriate humidity ratios and ventilation rates to ensure optimal indoor air quality. It is essential to strike a balance between dehumidification effectiveness and ventilation rates to prevent any long-term shortage of fresh air and to maintain a healthy and comfortable environment for swimmers.

5. Conclusions

The current V-C method in China determines the outdoor humidity ratio according to the indoor dew-point temperature and is used to calculate the minimum ventilation rate. The humidity ratio can ensure that the transportation of the outdoor air into the swimming pool without atomization and condensation and has high dehumidification capacity. However, the humidity ratio selected by this method cannot reflect the corresponding non-guaranteed hours, leaving a lack of reference value for design. To solve the problem, this paper proposes a new method to determine the outdoor humidity ratio in the transition season. The concept of a typical transition season is proposed, and the outdoor calculated humidity ratio of the transition season is generated by considering the non-guaranteed hours.

In verifying the value of the new approach, six representative cities in China are selected for research. By comparing the TTS method with the V-C method, the results show that:

1. The outdoor humidity ratio of the transition season obtained by the V-C method is not guaranteed to be more than 200 h, which cannot meet the requirements of a minimum ventilation rate. It has little reference value for design.
2. The outdoor humidity ratio of the transition season obtained by the TTS method can clearly reflect the non-guaranteed hours, and the inspection results of air change rates in 83.3% of cities have met the minimum design requirement of once per hour. It is more accurate and reasonable to use this value for minimum ventilation rate calculations.
3. The TTS method uses the TMY data to greatly reduce the demand for data size and the difficulty of data acquisition. Besides, this method well-represents the local multi-year climate characteristics without a complicated calculation process.

In consequence, the TTS method obtains the outdoor humidity ratio of transition season 1 and transition season 2 by considering 10 different non-guaranteed hours, providing multiple references for designers. For the swimming pool model in this study, the author applies one of the most suitable values for the model to inspect. Therefore, designers can comprehensively consider various factors, such as project economy and design requirements, and finally select the appropriate humidity ratio.

Further research in the field of natatorium ventilation during the transition season should focus on the impact of outdoor design parameters on the total energy consumption of natatoriums. For this reason, We will consider the impact of different outdoor moisture content values on the energy consumption of the natatoriums during the transition season. In this case, it is necessary to find outdoor design parameter values that have the highest energy efficiency and meet the minimum design requirements.

Author Contributions: Conceptualization, H.L.; Methodology, J.L.; Software, C.L.; Investigation, J.L. and C.L.; Resources, H.L.; Writing—original draft, J.L.; Writing—review & editing, H.L., C.L. and M.X.; Project administration, H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by "The 13th Five Year" National Key R&D Program of China (Contract No. 2018YFC0704500) and the National Natural Science Foundation of China (52278124).

Data Availability Statement: Not applicable.

Acknowledgments: We appreciate the data support from "The 13th Five Year" National Key R&D Program of China.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

n	Air change rate in natatorium (times per hour)	v	Air velocity over water surface (m/s)
L	Ventilation volume required to eliminate moisture (m^3/h)	p_w	Saturation vapor pressure taken at surface water temperature (Pa)
V	Volume of natatorium (m^3)	p_a	Saturation pressure at room air dew point (Pa)
W	Moisture gain in natatorium (kg/h)	γ	latent heat required to change water to vapor at surface water temperature (kJ/kg)
W_1	Moisture gain of pool water (kg/h)	t	Indoor design dry bulb temperature (°C)
W_2	Moisture gain of poolside wetlands (kg/h)	t^*	Indoor design wet bulb temperature (°C)
W_3	Moisture gain of personnel (kg/h)	t_s	Surface water temperature (°C)
ρ	Standard air density (kg/m^3)	F	Area of poolside wetlands (m^2)
d_i	Indoor air humidity ratio (g/kg dry air)	λ	Moisture factor
d_o	Outdoor air humidity ratio (g/kg dry air)	ω	Unit personnel moisture gain (kg/(per person per hour))
A	Area of pool surface (m^2)	n_1	Number of people
F_a	Typical activity factor	n_2	Clustering coefficient

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