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Development of outdoor air parameters for designing air-conditioning systems according to the guarantee coefficient

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Abstract: When designing the air conditioning system, it is necessary to select outdoor air calculation parameters for determining the cooling and heating loads. The pair of parameters, including enthalpy I and dry temperature t of the outdoor air, are used directly in the calculation process. The article outlines the meaning of the limit lines of the cooling/heating capacity and the airflow of an air conditioning system and presents the concept of the guarantee coefficient of the pair of parameters I and t according to the theory of probability of two events occurring simultaneously. From these, computer software was built to determine the types of guarantee coefficients Kbd and outdoor air calculation parameters for designing the air conditioning system according to the number of hours m (hours/year) that unguaranteed the indoor thermal–humidity regime. The proposed calculation method has been implemented for 30 localities in Vietnam, calculated according to twelve m values, using meteorological data over the most recent 26-30 years, which will be used to update the Vietnamese Standard for Ventilation and Air Conditioning Design (TCVN 5687:2024). The comparison of the outdoor air calculation parameters built by the guarantee coefficient method and those offered by ASHRAE for Hanoi, Vietnam, has also been carried out.

Keywords: *Air conditioning system design, Enthalpy and dry temperature, Guarantee coefficient, Indoor thermal-humidity regime, Outdoor air calculation parameters.*

1. Introduction

In the context of global climate change and the United Nations' commitment to net zero emissions by 2050, solving the technical problem of building air conditioning systems helps minimize the impact negative impact on the environment, and maintaining human comfort in the building is essential in tropical and subtropical countries with hot, humid climates [1-4].

In the United States, the design of outdoor air conditioning for air conditioning systems is determined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). According to ASHRAE, the outdoor air calculation parameters for air conditioning system design is determined based on dry-bulb temperature and wet-bulb temperature. During the Summer, the dry-bulb temperature is calculated as the hourly temperature value that is equal to or higher than a certain threshold, accounting for 0.4%, 1%, and 2% of the total hours in a year. Similarly, the wet-bulb temperature is calculated in the same manner. During the Winter, the phrase "equal to or higher" used in the Summer criteria is replaced with "equal to or lower" [5, 6]. Additionally, ASHRAE introduces the mean coincident wet-bulb temperature, which is the average value of wet-bulb temperatures occurring at thresholds of 0.4%, 1%, and 2% - referred to as "MCWB".

In Australia, the designed outdoor air conditions for ensuring comfort during Summer are the dry-bulb temperature (DBT) and wet-bulb temperature (WBT) measured at 3 PM, with the design condition based on 10 days per year (equivalent to 2.7%). For Winter, the design outdoor air conditions

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are the DBT measured at 8 AM with the same 10 days per year criteria, along with a calculated relative humidity of 80% [7, 8]. In another study Massimo Fiorentini et al. proposed an enthalpy-based index to assess the climatic potential for ventilative cooling of buildings [9]: In this study, the proposed Enthalpy Climatic Cooling Potential (CCPh) integrates humidity into the climate evaluation, using the enthalpy difference between indoors and outdoors, instead of the temperature difference.

In Hong Kong, in 1995, authors Joseph C. Lam and Sam C.M. Hui from the Department of Architecture and Building Engineering at the Hong Kong University of Science and Technology processed climate data collected over 33 years from 1960 to 1992 to assist air conditioning design [10]. Similar to ASHRAE, the above Authors processed climate data according to dry temperature (DBT) and wet temperature (WBT) with levels exceeding (greater than) the calculated values of 0.1%, 0.5%, 1%, 2.5%, 5%, and 10% for 4 months of hot season from June to September, total 2928 h and 90%, 95%, 97.5%, 99 %, 99.5% and 99.9% for 3 months of cold season from December to February, total 2160 h. The calculated data with the above limits is also calculated for the entire year, from January to December, a total of 8760 hours. However, the authors recommend that outdoor design conditions determined from design DBT may not be suitable for locations that are more sensitive to WBT and humidity. With the high humidity, region may require special attention to design WBT and enthalpy [11].

In India, the National Building Code specifies the design air temperature for air conditioning in terms of dry-bulb temperature and relative humidity or wet-bulb temperature [12].

The SS 553:2009 Code of Practice for Mechanical Ventilation and Air-Conditioning in Buildings in Singapore dictates the design of outdoor air conditions based on dry-bulb and wet-bulb temperatures. The dry-bulb temperature should not exceed more than 2% of the total hours from June to September, and the wet-bulb value is the average of the coincident wet-bulb temperature occurring at the designed dry-bulb temperature [13].

In Russia, in 1994, Academician V.N. Bogoslovski and Associate Professor P.Q. Quan also recognized the Guarantee coefficient K(I,t) and applied the theory of economic-technical optimization to progress toward determining the calculation parameters of outdoor air for air conditioning systems [14]. Following this approach, author E. Malyavina continued to advocate for incorporating temperature and enthalpy parameters in calculating the air conditioning design for hot periods throughout the year [15].

In Vietnam, authors T.N. Chan and N.Q. Huong developed the theory of flow rate and cooling capacity limit lines for air conditioning systems in 1996. Accordingly, when selecting the temperature parameter t_N and entanpy I_N as the calculation parameters for the air conditioning system, the lines t_N=const and I_N=conts on the psychrometric chart (also known as the t-d chart) represent the boundaries for airflow rate and cooling capacity of the system, respectively. A method for processing climate data to aid in selecting calculation parameters for air conditioning design in general, and specifically applying it to various regions in Vietnam was developed [16-18].

In summary, very few studies have studied outdoor design conditions for air conditioning. Almost all countries apply ASHRAE's "levels exceeding" for dry bulb temperature and wet bulb temperature separately, without considering the simultaneous factor of these parameter pairs. This is completely contrary to the natural law that air state is always defined by a pair of simultaneous parameters: either dry bulb temperature-relative humidity ($t - \varphi$), dry bulb temperature-enthalpy (t-I), or dry bulb temperature-wet bulb temperature (t-t_w), etc. Additionally, recently, ASHRAE in its calculation parameters used for HVAC system design in several countries worldwide, including Vietnam, has opted for a "levels exceeding" approach (0.4%, 1%, and 2%) only for dry bulb temperature, while the wet bulb temperature is determined using the mean coincident value (MCWB). This signifies a change in ASHRAE's methodology for selecting calculation parameters for HVAC system design, without relying on any convincing mathematical rationale.

This study represents the next step of our scientific work [19] mentioned above to refine methodologies and implement them in selected regions of Vietnam, utilizing extensive and reliable climate data (24 measurements per day, continuous data spanning 26 years or longer) to ensure the necessary reliability for supplementation into Vietnamese standards for Ventilation and Air Conditioning Design based on the pair of parameters enthalpy I and dry temperature t according to the theories of the probability of two events occurring simultaneously.

2. Research Methodology

2.1. Theory of Calculation Parameters for Vietnam

In Vietnam, air conditioning design calculations are performed using TCVN 5687:2024 [20]. It provides a formula for the guarantee coefficient of two simultaneous parameters: t_N and I_N of outdoor air based on State Capital Construction Committee [21] and probability theory and mathematical statistics of Tran Ngoc Chan [16] and Tran Ngoc Chan [16]:

$$K_{bd}(t_N, I_N) = K(t_N) \times K(I_N / t_N) \quad (1)$$

or

$$K_{bd}(I_N, t_N) = K(I_N) \times K(t_N / I_N) \quad (2)$$

In which:

$K(I_N/t_N)$ – Guarantee coefficient of outdoor air enthalpy I_N with guaranteed outdoor temperature t_N;

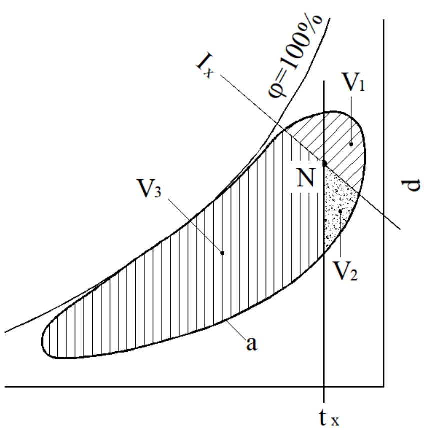
$K(I_N)$ – Guarantee coefficient of outdoor air enthalpy I_N ;

$K(t_N/I_N)$ – Guarantee coefficient of outdoor air temperature t_N with guaranteed outdoor enthalpy I_N.

$K(t_N)$ – Guarantee coefficient of outdoor air temperature, t_N ;

Formulas (1) and (2) are the key and theoretical basis leading to the deepest differences between the method we apply and the "levels exceeding" method of ASHRAE and many other countries worldwide.

In heat load calculations, the outdoor air temperature t_N and enthalpy I_N directly participate in calculations and establish the air conditioning process on the psychrometric chart [22, 23]. On the psychrometric chart – (also known as t-d chart) – we can visualize the temperature-humidity boundary zone of outdoor air appearing during the year in any given locality, limited by a closed curve "a" (see Figures 1,2). For any outside air state point N determined by the pair of parameters t_x and I_x, we can represent formula (1) or (2) with the drawing and expressions below:



$$K(I_x) = \frac{V_2 + V_3}{V_1 + V_2 + V_3} \quad (3)$$

$$K(t_x / I_x) = \frac{V_3}{V_2 + V_3} \quad (4)$$

$$K(I_x, t_x) = K(I_x) \times K(t_x / I_x) = \frac{V_3}{V_1 + V_2 + V_3} \quad (5)$$

Figure 1.
Types of the guarantee coefficients on the psychrometric chart in the Summer.
Note: V_i is the total number of hours that the outdoor air status of the calculated locality appears within the corresponding slashed area V_i on the psychrometric chart, h/year.

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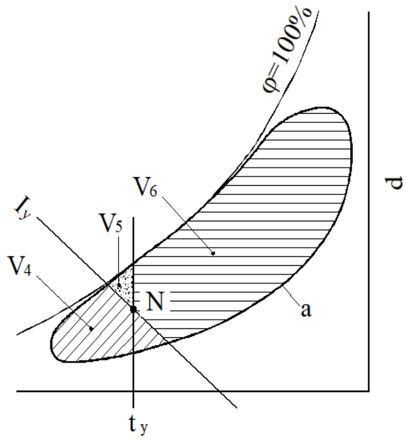
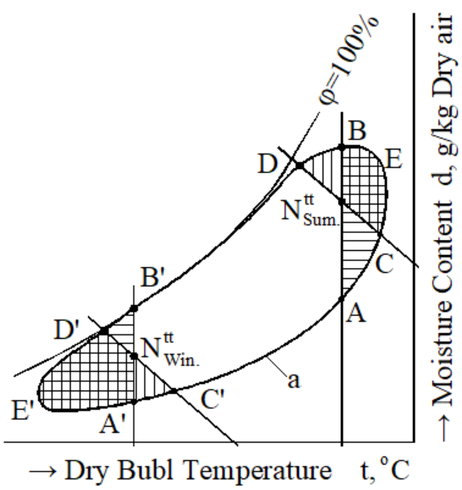


$$K(I_y) = \frac{V_5 + V_6}{V_4 + V_5 + V_6} \tag{6}$$

$$K(t_y / I_y) = \frac{V_6}{V_5 + V_6} \tag{7}$$

$$K(I_y, t_y) = K(I_y) \times K(t_y / I_y) = \frac{V_6}{V_4 + V_5 + V_6} \tag{8}$$

Figure 2.
Types of the guarantee coefficients on the psychrometric chart in the Winter.
Note: V_i is the total number of hours that the outdoor air status of the calculated locality appears within the corresponding slashed area V_i on the psychrometric chart, h/year.



$N^{tt}_{Sum.}$ACEBD$N^{tt}_{Sum.}$: Unguaranteed zone for indoor thermal-humidity regime in Summer;

$N^{tt}_{Win.}$C'A'E'D'B'$N^{tt}_{Win.}$: Unguaranteed zone for indoor thermal-humidity regime in Winter;

Figure-3.
Unguaranteed zone for indoor thermal-humidity regime in Summer and Winter in the calculated locality

2.2. Proposing a Method to Determine the Guarantee Coefficient for Indoor Thermal-Humidity Regime

a. Calculation for Summer (see Figure 3), index N in the following formulas can also be interpreted as $N^{tt}_{Sum.}$ in Figure 3:

If M is called the total time of the year (8760 h), the general guarantee coefficient of the air conditioning system in Summer corresponding to any selected point N will be written as follows:

$$K_{bd} = \frac{M - \sum m_{I>I_N} - \tau_{(\mathrm{ACN})}}{\mathrm{M}} \tag{9}$$

Multiply both the numerator and denominator of (9) with M - Σm(I>In), we have:

$$K_{bd} = \frac{M - \sum m_{I>I_N}}{M} \times \frac{M - \sum m_{I>I_N} - \tau_{(\mathrm{ACN})}}{\mathrm{M} - \sum \mathrm{m}_{\mathrm{I}>\mathrm{I}_N}} \tag{10}$$

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If calling:

$$K(I)=\frac{M-\sum m_{I>I_N}}{M}=\frac{\tau_{(CN^{tt}_{Sum.}DB'D'E'A'C'AC)}}{M} \tag{11}$$

As guarantee coefficient of outdoor enthalpy I_N and:

$$K(t/I)=\frac{M-\sum m_{I>I_N}-\tau_{(ACN)}}{M-\sum m_{I>I_N}}=\frac{\tau_{(AN^{tt}_{Sum.}DB'D'E'A'C'A)}}{\tau_{(CN^{tt}_{Sum.}DB'D'E'A'C'AC)}} \tag{12}$$

As guarantee coefficient of outdoor temperature t_N when outdoor enthalpy I_N guaranteed, with note that: $\tau_{(CN^{tt}_{Sum.}DB'D'E'A'C'AC)}$; $\tau_{(AN^{tt}_{Sum.}DB'D'E'C'A)}$ as well as $\tau_{(.................)}$, etc. below is the number of hours of the appearance of outdoor air parameters within the climatic boundary area denoted by letters in parentheses of the calculated locality, h/year - according to meteorological data of 24 measurements/day of many years and take the average for 1 year.

We have:

$$K_{bd}=K(I,t)=K(I)\times K(t/I) \tag{13}$$

Now multiply both the numerator and denominator of (9) with $M-\sum m_{t>t_N}$, we have:

$$\left.\begin{aligned}K_{bd}&=\frac{M-\sum m_{t>t_N}}{M}\times\frac{M-\sum m_{I>I_N}-\tau_{(ACN)}}{M-\sum m_{t>t_N}}\\&=\frac{M-\sum m_{t>t_N}}{M}\times\frac{M-\sum m_{t>t_N}-\tau_{(BDN)}}{M-\sum m_{t>t_N}}\end{aligned}\right\} \tag{14}$$

Due to: $M-\sum m_{I>I_N}-\tau_{(ACN)}=M-\sum m_{t>t_N}-\tau_{(BDN)}$ (Figure 3).

First factor $\frac{M-\sum m_{t>t_N}}{M}$ on the second side of (14) is $K(t_N)$ – guarantee coefficient of t_N:

$$K(t)=\frac{M-\sum m_{t>t_N}}{M}=\frac{\tau_{(AN^{tt}_{Sum.}BDB'D'E'A'C'A)}}{M} \tag{15}$$

The second factor on the second side of (14) is the guarantee coefficient $K(I_N/t_N)$ – the guarantee coefficient of I_N if t_N is guaranteed, meaning:

$$K(I/t)=\frac{M-\sum m_{t>t_N}-\tau_{(BDN)}}{M-\sum m_{t>t_N}}=\frac{\tau_{(AN^{tt}_{Sum.}DB'D'E'A'C'A)}}{\tau_{(AN^{tt}_{Sum.}BDB'D'E'A'C'A)}} \tag{16}$$

We still have:

$$K_{bd}=K(t,I)=K(t)\times K(I/t) \tag{17}$$

Combining 2 equations (13) and (17) we have:

$$K_{bd}=K(I,t)=K(I)\times K(t/I)=K(t,I)=K(t)\times K(I/t) \tag{18}$$

Formula (18) demonstrates the symmetric property of the probability of two events occurring simultaneously.

b. Calculation for Winter (see Figure 3), index N in the following formulas can also be interpreted as $N^{tt}_{Win.}$ in Figure 3. Similarly transforming, we have:

- Guarantee coefficient $K(I,t)$

$$K(I)=\frac{M-\sum m_{I<I_N}}{\mathrm{M}}=\frac{\tau_{(C'ACEBDB'D'N^{tt}_{\mathrm{Win}}.C')}}{M} \tag{19}$$

$$K(t/I)=\frac{M-\sum m_{I<I_N}-\tau_{(N^{tt}B'D')}}{\mathrm{M}-\sum m_{I<I_N}}=\frac{\tau_{(C'ACEBDB'N^{tt}_{\mathrm{Win}}.C')}}{\tau_{(C'ACEBDB'D'N^{tt}_{\mathrm{Win}}.C')}} \tag{20}$$

- Guarantee coefficient K(t,I) :

$$K(t)=\frac{M-\sum m_{t<t_N}}{\mathrm{M}}=\frac{\tau_{(A'C'ACEBDB'N^{tt}_{\mathrm{Win}}.A')}}{M} \tag{21}$$

$$K(I/t)=\frac{M-\sum m_{t<t_N}-\tau_{(A'N^{tt}_{\mathrm{Win}}.C')}}{\mathrm{M}-\sum m_{t<t_N}}=\frac{\tau_{(C'ACEBDB'N^{tt}_{\mathrm{Win}}.C')}}{\tau_{(A'C'ACEBDB'N^{tt}_{\mathrm{Win}}.A')}} \tag{22}$$

So, we have similar equations for Winter as Summer.

Note: M in the above formulas is the number of hours in the year (8760 h)

The expressions of guarantee coefficients are composed pairwise above: (11) and (12); (15) and (16) – for Summer; (19) and (20); (21) and (22) – for Winter are the basis for building an algorithm to process climate data t, φ to serve the determination of calculation parameters for air conditioning system design.

2.3. Processing Climate Data (T, I) For Determining Outdoor Calculation Parameters Used in Designing the Air Conditioning System, Ensuring Adherence to the Guarantee Coefficient for Maintaining Indoor Thermal-Humidity Regime

2.3.1. Data Sources

Meteorological data used to process the selection of the calculation parameters of outdoor air to design the air conditioning system is provided by the Vietnam Institute of Meteorology and Hydrology of 30 meteorological stations (of a total of 64 stations) evenly distributed across the country. The data set includes temperature, humidity, and atmospheric pressure with a frequency of 24 measurements (hourly) during the day and night for temperature and humidity. As for atmospheric pressure, due to its little change, only average daily data from meteorological stations is taken. The number of years of the data set to be processed is 26-30 consecutive years until 2022.

2.3.2. Unguaranteed Time of Indoor Thermal-Humidity Regime

Each coefficient to ensure the thermal-humidity regime inside the house corresponds to a time when the thermal-humidity regime is not guaranteed, denoted m in h/year or the "unguaranteed time". The relationship between the guarantee coefficient *K(t,I)* or *K(I,t)* and the unguaranteed time m is expressed by the following expression:

$$K_{bd}=K(I,t)=K(t,I)=1-\frac{m}{M}=1-\frac{m}{8760} \tag{23}$$

In this study, it is expected to determine the calculation parameters of outdoor air for air conditioning design corresponding to m=0; m=35; m=50; m=100; m=150; m=200; m=250; m=300; m=350; m=400; m=450 and m=500 h/year. The guarantee coefficient Kbđ corresponding to those m values is taken according to Table 1.

Table 1.
Relationship between unguaranteed time (*m*) and guarantee coefficient (K_{bd})

m, h/year	**0**	**35**	**50**	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**
Kbd	1.0	0.996	0.994	0.989	0.983	0.977	0.971	0.966	0.960	0.954	0.949	0.943

2.4. Developing K(t) and K(I/t), K(I) and K(t/I) Charts – Application Methods

Software programs were developed for processing climate data and determining calculation parameters for air conditioning system design produce numerical tables of guarantee coefficients *K(t,I)* and *K(I,t)* as output results. These tables can be utilised to create corresponding charts *K(I); K(t/I)* and *K(t) ; K(I/t)* for calculations.

2.5. Calculation Steps

Below are the calculation steps applied to determine the calculation parameters for the air conditioning system according to the method proposed by the Authors.

According to formula (23), each value of m (the number of hours when the thermal-humidity regime inside the house is unguaranteed) corresponds to a value of the guarantee coefficient K_{bd} . On the other hand, according to equation (18), for a given value of K_{bd} there are multiple combinations of factor pairs *K(I).K(t/I)* or *K(t).K(I/t)* - each of which represents a calculation point N_{tt}. These calculation points form a curve with the same guarantee coefficient K_{bd} – meaning they share the same value of m. We refer to this as the contour line of m, as shown in Figure 4.

In Figure 4a below, the curved segment AN_{Sum}^{tt}B represents the contour line of m for the summer season: The endpoint A corresponds to *K(I/t)*=1 and *K(t)*= K_{bd} – which is the point $N_{Sum.}^{d}$; The endpoint *B* corresponds to *K(t/I)*=1 and *K(I)*=K_{bd} – which is the point $N_{Sum.}^{t}$. In Figure 4b, the curved segment: C$N_{Win.}^{tt}D$ represents the contour line of m for the winter season: The endpoint *C* corresponds to *K(t/I)*=1 and *K(I)*= K_{bd} – which is the point $N_{Win.}^{d}$; The endpoint D corresponds to *K(I/t)*=1 and *K(t)*=K_{bd} – which is the point $N_{Win.}^{t}$.

The calculation point $N_{Sum.}^{tt}$ *or* $N_{win.}^{tt}$ is the intersection of the line:

$t_{TB}=1/2(t_{sum}^{d}+t_{sum}^{t})$ in Figure 4a for summer, or

$t_{TB}=1/2(t_{win}^{d}+t_{win}^{t})$ in Figure 4b for winter, with the corresponding contour line of *m* - At this intersection, we can determine the calculated temperature and enthalpy values for summer $(t_{N.Sum.}^{tt}, I_{N.Sum.}^{tt})$ and for winter $(t_{N.Win.}^{tt}, I_{N.Win.}^{tt})$.

a) b)

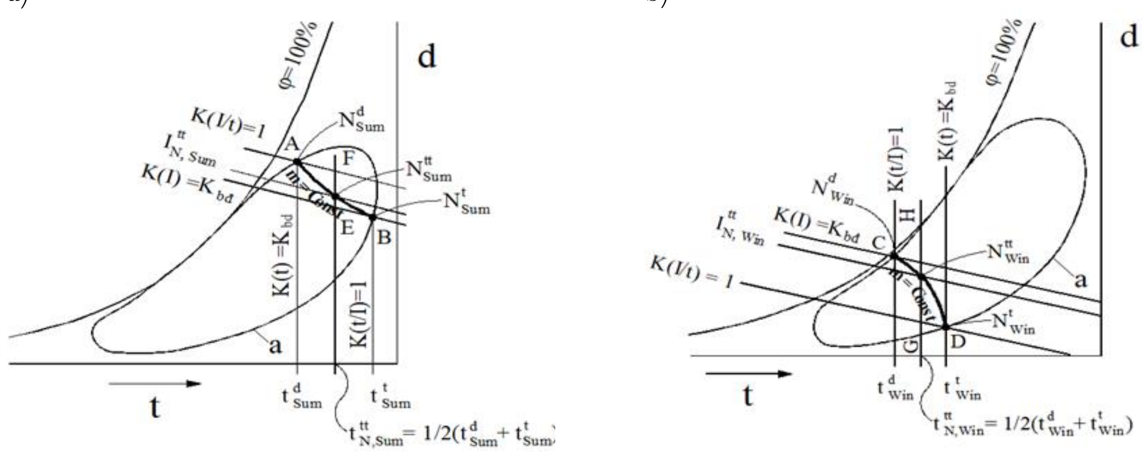

Figure 4.
Selection of outdoor calculation parameters based on contour lines m = const in Summer (4a) and Winter (4b)

The contour line m is shown on the psychrometric chart as shown in Figure 4 - curve segment A$N_{Sum.}^{tt}$B in Summer (Figure 4a) and C$N_{Win.}^{tt}D$ in Winter (Figure 4b).

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3. Results

Based on the aforementioned content and calculation steps, specific software programs have been developed and applied to determine the calculated temperature and enthalpy values for air conditioning design in both summer and winter. These calculations correspond to different m values for 30 different localities across Vietnam. The calculation results for Hà Nội are provided as examples and are presented in graphical form (see Figures 5 and 6) or in tabular form (see Tables 2 and 3).

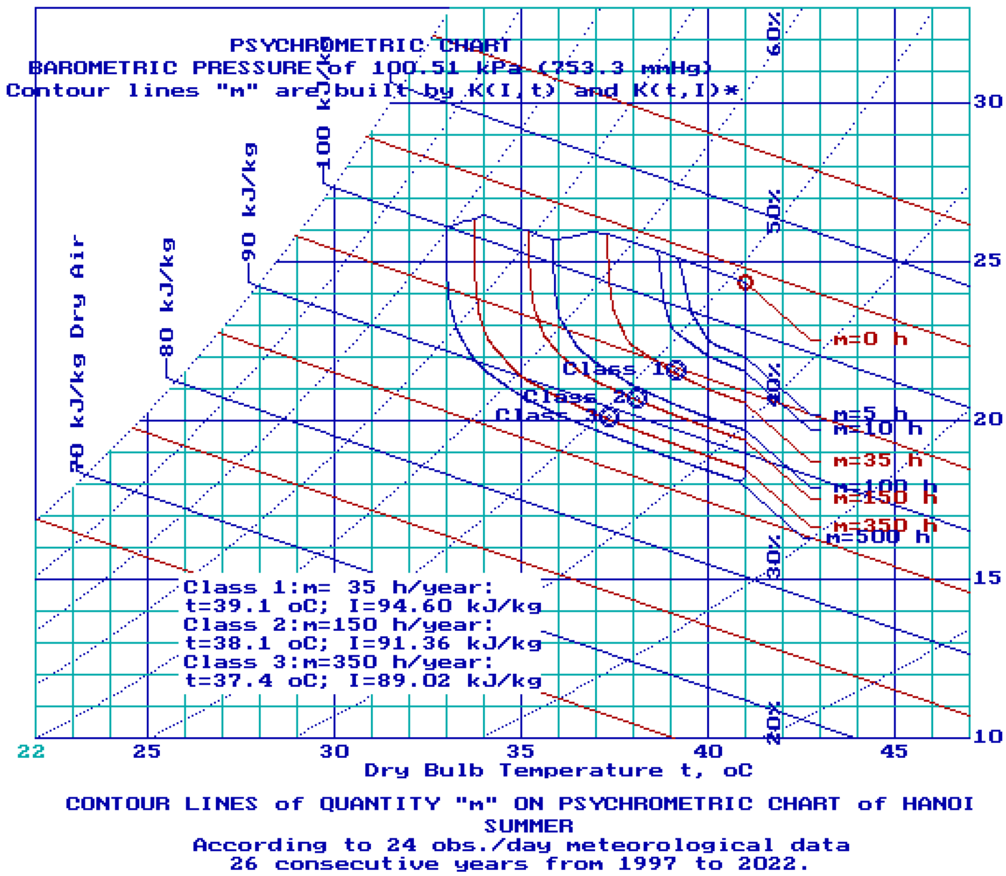

Figure 5.
Contour lines corresponding to 3 classes of calculation parameters for air conditioning in Hanoi in Summer.

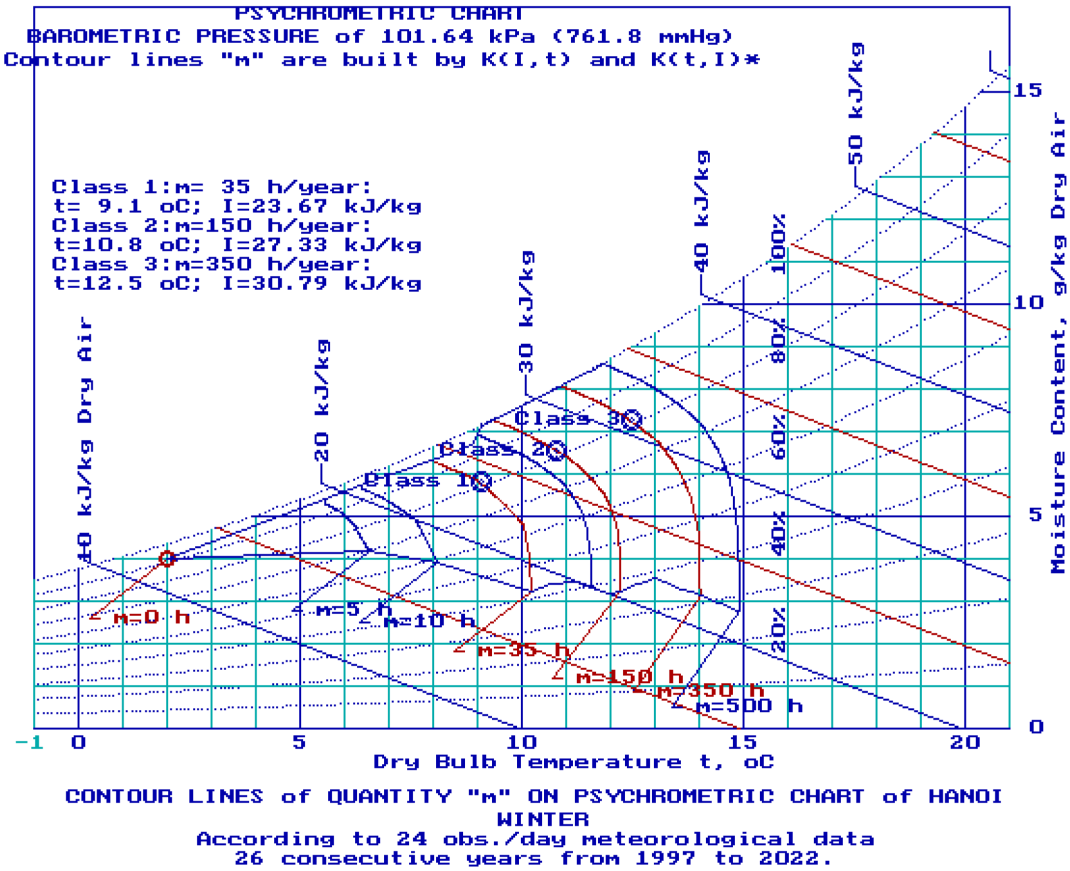

Figure 6.
Contour lines corresponding to three classes of calculation parameters for air conditioning in Hanoi in Winter.

Notes for Figures 5 and 6:

a) Class 1: m = 35 h/year – corresponding to guarantee coefficient K_{bd} = 99.6% time of the year;

b) Class 2: m = 150 h/year – corresponding to guarantee coefficient K_{bd} = 98.3 % time of the year;

c) Class 3: m = 350 h/year – corresponding to guarantee coefficient K_{bd} = 96.0 % time of the year.

Below are the tables of calculation parameters of outside air used for air conditioning design in Hanoi. For brevity, we only present the calculation parameters corresponding to the three selected m values, which represent the three classes of reliability mentioned above.

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Table 2.
Calculation parameters of outdoor air for air conditioning design in Summer in Hanoi according to 24 observations per day meteorological data, 26 consecutive years from 1997 to 2022.

m, h/year	K_{bd}	By $K(I,t)$; $K(I)=K_{bd}$ $K(t/I)=1$		By $K(t,I)$; $K(t)=K_{bd}$ $K(I/t)=1$		Calculation Parameters				Barometric Pressure kPa (mmHg)
		I, kJ/kg	t, °C	I, kJ/kg	t, °C	I, kJ/kg	t, °C	φ, %	$t_{Wetb.}$, °C	
35	0.996	94.15	41.0	104.00	37.3	94.60	39.1	47.6	28.9	100.51 (753.3)
150	0.983	91.12	41.0	102.00	35.2	91.36	38.1	48.5	28.2	
350	0.960	88.80	41.0	101.48	33.7	89.02	37.4	49.0	27.8	

Table 3.
Calculation parameters of outdoor air for air conditioning design in Winter in Hanoi according to 24 observations per day meteorological data, 26 consecutive years from 1997 to 2022.

m, h/year	K_{bd}	By $K(I,t)$; $K(I)=K_{bd}$ $K(t/I)=1$		By $K(t,I)$; $K(t)=K_{bd}$ $K(I/t)=1$		Calculation Parameters				Barometric Pressure kPa (mmHg)
		I, kJ/kg	t, °C	I, kJ/kg	t, °C	I, kJ/kg	t, °C	φ, %	$t_{Wetb.}$, °C	
35	0.996	23.90	8.0	18.42	10.2	23.67	9.1	81.1	7.5	101.64 (761.8)
150	0.983	27.72	9.4	20.47	12.2	27.33	10.8	81.7	9.2	
350	0.960	31.30	10.9	22.00	14.0	30.79	12.5	80.9	10.7	

Note: The calculation parameters of outside air used to design air conditioning for 30 different localities in Vietnam will be included in TCVN 5687:2024 "Ventilation and Air Conditioning - Design Standards", where all values of m are fully listed, as shown Table 1.

To compare the results of determining the calculation parameters for air conditioning design according to the *K(t,I)* and *K(I,t)* guarantee coefficient method with ASHRAE's "Excess Level" method, the software has been built to determine parameters according to the ASHRAE method with many different "Exceed Levels". Below is a comparison table – see Table 4.

Table 4.
Outdoor air calculation parameters determined with different methods for air conditioning design in Hanoi.

Season	m, h/year	This study's method *K(I,t)* and *K(t,I)*			ASHRAE method Separated Dry and Wet Temperatures (using the authors' software)		
		I, kJ/kg	t_{DB}, °C	t_{WB}, °C	t_{DB}, °C	t_{WB}, °C	t_{MCWB}, °C
SUMMER	35	94.60	39.1	28.9	37.3	28.9	27.1
	150	91.36	38.1	28.2	35.2	28.2	27.1
	350	89.02	37.4	27.8	33.7	27.8	26.9
WINTER	35	23.67	9.1	7.5	10.2	7.6	8.3
	150	27.33	10.8	9.2	12.2	9.4	9.7
	350	30.79	12.5	10.7	14.0	10.9	11.6

4. Discussion

From Table 4, we see that in Summer, the dry temperatures t_{DB} calculated by the Guarantee coefficient method are significantly higher than those calculated by the ASHRAE method, while the wet temperatures t_{WB} are almost the same in both methods. In Winter, the dry temperatures t_{DB} according to the Guarantee coefficient method are lower than those according to the ASHRAE method; while the wet temperatures t_{WB} are likely the same trend in Summer.

ASHRAE itself has issued Design Conditions for many countries around the world, including design conditions for 29 Vietnamese Localities at Levels exceeding 0.4%; 1%, and 2%. To be able to compare with this data, we have adjusted the computer software according to the Guarantee coefficient method so that the *m* values coincide with the above excess levels. Detail :

Excess level 0.4 % corresponding to $m = 35.04$ h/year;

Excess level 1 % corresponding to m = 87.6 h/year;

Excess level 2 % corresponding to m = 175.2 h/year.

In addition, another thing worth noting is that ASHRAE provides calculation parameters for 29 localities in Vietnam, but Hanoi is not included, only Noi Bai is closest to Hanoi, while our climate data is right in the center of Hanoi.

With the input adjustment as above, the results are shown in Table 5 below.

Table 5.
Outdoor air calculation parameters determined with different methods for air conditioning design in Hanoi (cont.).

Season	This study's method					ASHRAE method				
	m, h/year	I, kJ/kg	t_{DB}, °C	t_{WB}, °C	Notes	Exceed level, %	t_{DB}, °C	t_{WB}, °C	t_{MCWB}, °C	Notes
SUMMER	35.04	94.60	39.1	28.9	HANOI Period 1997-2022	0.4	36.0	-	27.4	NOIBAI Period 1990-2014
	87.6	92.68	38.5	28.5		1	34.9	-	27.5	
	175.2	90.97	38.0	28.2		2	34.0	-	27.4	
WINTER	35.04	23.67	9.1	7.5	HANOI Period 1997-2022	0.4	9.9	-	-	NOIBAI Period 1990-2014
	87.6	25.75	10.2	8.5		1	11.0	-	-	
	175.2	27.93	11.1	9.4		2	-	-	-	

From Tables 4 and 5, we see that the calculation parameters of outside air determined by the ASHRAE method give quite low results, not ensuring safety in terms of energy supply for the air conditioning system. The method proposed by the Authors in this document gives significantly higher results in terms of temperature and enthalpy. That can be explained that in the ASHRAE method, the dry temperature and wet temperature are considered separately, while the method proposed by this study is for the pair of simultaneous parameters t and I, according to the theories of the probability of two events occurring simultaneously[24].

5. Conclusions

1- The calculation parameters for outdoor air used in designing air conditioning, and refrigeration stations for air conditioning systems need to be selected based on the guarantee coefficient of the indoor thermal-humidity regime during both Summer and Winter seasons;

2- The guarantee coefficient of the thermal-humidity regime inside a structure with a defined air conditioning system corresponds to the guarantee coefficient of two outdoor air temperature t and enthalpy I parameters when other climatic factors (such as solar radiation, wind, etc.) are assured:

$$K_{bd} = K(I,t) = K(I).K(t/I)$$

and

$$K_{bd} = K(t,I) = K(t).K(I/t)$$

3- Pairing the parameters enthalpy I and dry temperature t of the outside air has a special meaning important in calculating the cooling load and heat load of the air conditioning system, and the lines I = const and t = const are the limits of the cooling capacity and flow rate of the air conditioning system, respectively;

4- The most profound difference between the Authors' method and the ASHRAE method, as well as methods used in many other countries worldwide, lies in the fact that in our method, the two parameters of dry bulb temperature *(t)* and enthalpy *(I)* are considered as simultaneous parameters. The occurrence of these two parameters throughout the year follows the statistical probability laws of two simultaneous events, as expressed by the formulas presented in Conclusion 2. Meanwhile, according to the ASHRAE method, the exceedance levels (%) of dry bulb temperature *(t)* and wet bulb temperature (t_{wet}) — are treated separately. They are not considered simultaneous parameters and do not follow the statistical probability laws of simultaneous events, as outlined in theory by [19]. ASHRAE recently introduced a method that handles exceedance levels exclusively for dry bulb temperature while the wet bulb temperature is derived from the MCWB values of the dry bulb temperatures within the selected exceedance level;

5- To determine the calculation parameters of outside air for designing an air conditioning system according to the guarantee coefficient to ensure the thermal-humidity regime inside the house requires processing climate data according to the frequency of simultaneous occurrence of 24 measurements/day-night of 2 parameters temperature *t* and enthalpy *I*. Climate data, including temperature, humidity, and barometric pressure for 30 different locations in Vietnam have been processed according to the guarantee coefficients: *K(I)*, *K(t/I)*; *K(t)*, *K(I/t)*. The data series is 24 measurements/day-night for 26-30 years continuously or with short interruptions;

6- Several computer software has been developed for processing meteorological data according to the guarantee coefficient of the pair of parameters enthalpy *I* and dry temperature t at the same time to determine the calculation parameters of outside air used for air conditioning system design. Thanks to that, the determination of calculation parameters is carried out quickly and accurately;

7- Based on the calculated data determined by the number of unguaranteed time in hours m, we recommend using *m*=35 h/year; *m*=150 h/year, and *m*=350 h/year to make three classes of air conditioning for Vietnam. However, to have a wide choice for different investors, we provide a calculation parameters table with all twelve Kbd levels corresponding to twelve m values (according to table 1) for 30 Vietnamese Localities.

8- Comparing the results of determining the calculation parameters for air conditioning according to the guarantee coefficient method of the pair of parameters enthalpy *I* and dry temperature t simultaneously proposed by this study with the data obtained by the method by ASHRAE was conducted. The comparison results show that the calculation parameters according to the Guarantee coefficient method are significantly greater in temperature and enthalpy than the ASHRAE method. That can be explained that in the ASHRAE method, the factors dry temperature and wet temperature are considered separately, while the method proposed by the authors is for the pair of parameters *t*, *I* simultaneously follow the probability theory of two simultaneous events.

5.1. Data Availability Statement

Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (intermediate results such as a table of data on the guarantee factor *K(I,t)* or *K(t,I)*; data about pair Parameters *(t,I)* ; *(t,tw)* at the same time; data about *BIN t* , *BIN I*.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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Authorship contribution statement:

Tran Ngoc Chan, Prof.: Methodology, Funding acquisition, Visualization, Writing & editing. Nguyen Thi Khanh Phuong, PhD: Conceptualization, Formal analysis, Writing – original draft. Tran Ngoc Quang, Assoc. Prof.: Data curation, Writing – review.

Notation list:

The following symbols are used in this paper:

φ – Air relative humidity, %;

I – Air-specific enthalpy, kJ/kg Dry Air;

t – Air dry bult temperature, ℃;

d – Moisture Content , g/kg Dry Air

I_N^{tt} , t_N^{tt} , d_N^{tt} – Outdoor air calculated enthalpy, temperature and moisture, respectively, kJ/kg; oC and g/kg;

K_{bd}– Guarantee coefficient, $K_{bd} = 0 \div 1$;

M – Annual hours: $M = 8760$ h/year;

m – Total annual time when the indoor thermal-humidity regime of the air conditioning system is unguaranteed, h (hereinafter briefly referred to as the number of unguaranteed hours);

$\Sigma_{mI} > I_n$ – Total time occurring enthalpy values higher than those at outdoor point N (I_N);

$\Sigma_{mt} > t_n$ – Total time occurring temperature values higher than those at outdoor point N (t_N);

$t_{(xyz)}$ – Number of hours occurring outdoor air status in the zone xyz in Psychrometic chart, h ;

P_{kq} – Atmospheric pressure, kPa or mmHg ;

$N_{Sum.}^{t}$ $N_{Sum.}^{d}$ – Endpoints on the conture line m=const in the Summer – on the psychrometric chart;

$N_{Win.}^{t}$, $N_{Win.}^{d}$ – Endpoints on the conture line m=const in the Winter – on the psychrometric chart;

$N_{Sum.}^{tt}$, $N_{Win.}^{tt}$ – Calculated outdoor air status points in the Summer and the Winter.

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