Analysis of Comfort Indices and Their Impact on the Environment

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In this paper, the following comfort indices and their implication on the environment are analyzed: the effective equivalent temperature index (TEE), the humidity temperature index (UTI) and the Thom discomfort index (DI Thom). These indices highlight the comfort or thermal discomfort of a region depending on the values for the air temperature, the relative humidity of the air during the period 2009-2018 recorded by the weather station AWWS/EV from the Faculty of Engineering of Biotechnical Systems, Politehnica University of Bucharest.

Keywords: the equivalent temperature index, the humidity temperature index, the Thom discomfort index

The feeling of thermal comfort must be understood as a thermal balance of the human body under the influence of the physical environment [4, 5].

The state of thermal comfort is the feeling of good physical state due to the heat exchange between the human body and the environment achieved without overloading the thermoregulatory system [13].

In order to ensure the thermal comfort to the occupants of the rooms, the quality of the indoor air must be ensured, this characterizing the content of pollutants in the room. The Romanian standards [13] classify the categories of buildings in classes 1, 2, 3, 4 according to table 1.

Indoor air pollution is caused by sources inside buildings, but can be caused outside. The pollution is caused by the cleaning operations or the fuel used for cooking and heating. For the area occupied by the civilian rooms, four categories of indoor air quality are mentioned in table 1.

Table 1
CATEGORIES OF INDOOR AIR QUALITY (IDA) [13]

Category	The description
IDA 1	High quality of indoor air
IDA 2	Average indoor air quality
IDA 3	Moderate indoor air quality
IDA 4	Low indoor air quality

For civil buildings, where the main source of pollution is the bioeffluents emitted by humans, the air quality in the non-smoking rooms is classified according to the concentration of carbon dioxide accepted indoors above the outdoor concentration (table 2) [27, 32].

Table 2
CATEGORIES OF INDOOR AIR QUALITY ACCORDING TO CO_2 CONCENTRATION

Category	CO_2 level above outdoor air level [ppm]	
	Values	Value through lack
IDA 1	≤ 400	350
IDA 2	400 – 600	500
IDA 3	600 – 1000	800
IDA 4	≥ 1000	1200

To maintain indoor air quality in one of these four categories, it is necessary to introduce fresh air through ventilation to dilute the pollutant concentration in the area under consideration.

The air conditioning aims to achieve the indoor environment that responds to the conditions of thermal comfort [15, 18, 19]. Indoor air quality and thermal comfort play a major role in the lives of the inhabitants [21, 22, 27].

Thermal comfort is determined by the following parameters: indoor air temperature, average radiation temperature of

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surfaces with which the human body radiates heat through radiation, relative humidity of indoor air, speed of indoor air movement, partial pressure of water vapor, thermal insulation of clothing, the activity of the occupants that determine the heat released (metabolism), the heat production of the human body, the heat transferred, the thermoregulation; the thermal resistance of the garment and its influence on evaporation [24, 25].

Indoor air temperature is the essential parameter on which thermal comfort depends. The thermal comfort also depends on the humidity of the indoor air, which can be controlled by air conditioning [27].

The relative humidity can vary between 30 and 70 [%] while maintaining an acceptable state of thermal comfort.

The lower limit (30%) must be observed to prevent drying of the eyes, to prevent the circulation of dust and other pollutants into the indoor air [4]. Limit superior humidity (70% or less, depending on the temperature inside) must be respected in order to avoid the appearance of condensation on the interior facade of the poorly insulated exterior building elements (walls) in winter; the sensation of suffocation, which may occur at relatively high humidity relative to the temperature inside; development of fungi in indoor air and degradation of building materials.

The speed of air in a room influences thermal comfort through heat loss through convection between a person and the environment, which can cause local thermal discomfort due to air flow [27]. The speed of the air movement is an important factor that influences the thermal comfort, because it takes place in the exchange of heat of the body with the environment through convection and the evaporation of the phenomena of perspiration on the skin.

The importance of the evaporation phenomen depends on the partial pressure difference of the vapor from the skin surface and the ambient air. At the same temperature, the sweat is released faster as the humidity relative to the environment is lower. When the evaporation phenomenon is not sufficient for the total heat evacuation (shaking) the subject is exposed to illness (headaches, circulatory disorders), common phenomena in overcrowded or unventilated rooms (figure 1).

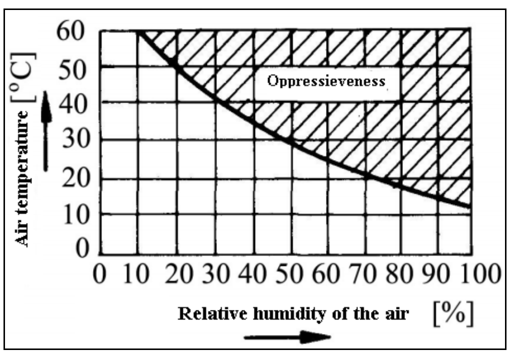

Fig. 1 Limit curve of occurrence of claws [27]

Dependence between the temperature of the air and that of the delimiting surfaces of the rooms. The way in which man feels the temperature, corresponds approximately to the average value of these two temperatures and is called subjective temperature:

$$t_s = \frac{t_i + t_{si}}{2}, [^0C] \quad (1)$$

where: t_s - is the subjective temperature; t_i - average air temperature; t_{si} - the average temperature of the surfaces surrounding the room.

The difference between the average room surface temperature and the air temperature should not exceed 2-3 ^{0}C.

Indoor air quality is given by: all the secondary factors which, besides the thermal comfort factors, ensure a pleasant microclimate in an enclosure. The components are: dust content in the air (high concentration can cause irritation of the mucous membranes and airways); gas and vapor content in the air; the smell; the noise; lighting; ionization degree.

The sources of pollution inside the rooms are: breathable particles due to: cigarettes, sprays, cooking, volatile condensation, combustion; organic vapors from: solvents, pesticides, sprays, combustion, resins; NO_2 from combustion, engines, cigarettes; SO_2 from heating; sulphates from matches, stoves; clothing fibers, carpets, wood; CO_2 from combustion, humans, animals [12, 14].

In rooms with low occupancy (homes, offices) the required fresh air flow is easily achieved through the leaks of doors and windows (natural ventilation).

The purity of the indoor air, respectively the concentration of some pollutants in the air of the rooms, is influenced by the emissions existing in the outdoor air and which are introduced into the rooms with the ventilation air [26, 28].

Thermal comfort affects people's physical and mental health [1, 2]. A major challenge worldwide is the protection of the natural environment and the improvement of the quality of housing, in the spirit of the concept of sustainable development [11, 17, 20, 23].

Occupied urban areas are characterized by higher outdoor air temperatures than in rural areas, because the vegetation has been replaced by buildings and asphalted roads [3]. Comfort stimulates rest, for practicing different activities [5]. Discomfort can mean pronounced and prolonged stress that causes a danger to human health [10].

The thermal comfort index has a critical threshold of 80. If the comfort index has a value greater than or equal to 80, the thermal discomfort appears and people must adequately protect themselves. The thermal discomfort during the summer is represented by shades of color and by the most intense of them (dark red), signals that reach and exceed the threshold. The high thermal discomfort during the winter is caused by values of the air temperature below -20^{0}C and / or cooling under the index - 32 (severe wind conditions). The high thermal discomfort during the winter is represented by five shades of color, and the intense signals (blue) reaching and exceeding the threshold, require the implementation of new measures: hot tea distribution; ensuring a pause of adjustment capacity for recovery; the provision of personal protective equipment [6, 30, 31].

Materials and methods

The study of thermal comfort and discomfort was performed using a mathematical algorithm based on the air temperature values, the relative humidity of the air in the municipality of Bucharest in the period 2009-2018 recorded by the weather station of the Polytechnic University of Bucharest, the Faculty of Biotechnical Systems Engineering.

The Missenard index

The Missenard index or the equivalent temperature (°TEE) reflects the actual temperature felt by the human body at some point, under certain conditions of temperature, humidity and degree of air movement in the atmosphere. This index highlights the comfort of the weather in summer and winter. The classes of values for this index are presented in table 3.

$$TEE = 37 - \frac{37 - T}{0.68 + 0.00014 \cdot U + \frac{1}{1.76 + 1.4 \cdot V^{0.75}}} - 0.29 \cdot T\left(1 - \frac{U}{100}\right) \qquad (2)$$

where: T - air temperature [°C]; U - relative humidity [%]; V - wind speed [m/s].

Table 3

CLASSES OF TEE VALUES [6]

TEE Index, [°C]	Description of the comfort level
> 30,0	Strong thermal impact (high insolation probability)
24,1...30,0	Moderate heat impact
18,1...24,0	Comfortable warm weather
12,1...18,0	Moderate weather conditions
6,1...12,0	The weather is cool
0,1...6,0	Cold weather is comfortable
-6,0...0,0	Low risk of hypothermia
-12,0...-6,1	The risk of hypothermia, if the clothing does not correspond to the season
-18,0...-12,1	Uncovered skin can be affected in 10 to 30 minutes
-24,0...-18,1	Portions of bare skin can be affected in 5-10 minutes
< -24,0	Uncovered skin can be damaged in 2-5 minutes

Temperature index - humidity (ITU)

This index is calculated taking into account the values of air temperature and relative humidity starting from the higher discomfort threshold (80 units, respectively 40^{0}C) [8].

$$ITU = (T \cdot 1.8 + 32) - \{(0.55 - 0.0055 \cdot U)[(T \cdot 1.8 + 32) - 58]\} \qquad (3)$$

where: T atmospheric temperature [0C]; Relative humidity of air [%]

The classes of values for this index are presented in table 4.

Table 4
CLASSES VALUES ITU [8, 4]

ITU index	Type of status
≤ 65	Comfort
66 – 79	Alert
≥ 80	Thermal discomfort

THOM (DI THOM) discomfort index [°C]

The Thom Discomfort Index (DI Thom) describes the conditions of physiological discomfort due to heat and humidity [9, 33]. The Thom DI index can be calculated using the following equation [9, 33]:

THOM (° C) = Ta - (0.55 -0.0055 x U) (Ta - 14.5) (4)

where: Ta - atmospheric temperature [° C]; U - relative humidity of air [%]

The classes of values for this index are presented in table 5.

Table 5. DI Thom classes values [7]

DI Thom (° C) = T_a – (0.55 -0.0055 x U) (T_a – 14.5) (4)

where: T_a - atmospheric temperature [° C]; U - relative humidity of air [%]

The values classes for this index are presented in table 5.

Table 5
DI THOM CLASSES VALUES [7]

DI Thom [°C]	Bioclimatic discomfort
DI < 21	Comfort
21 ≤ DI < 24	Less than 50% of people felt exposed slightly uncomfortable
24 ≤ DI < 27	More than 50% of exposed individuals experiencing an increasingly more pronounced
27 ≤ DI < 29	Most of population suffers discomfort
29 ≤ DI < 32	All persons exposed to stress feels a discomfort
DI ≥ 32	Medical emergency, extreme discomfort to stress, increased risk of high-calorie shock

Results and discussions

The Missenard index

Based on the statistical analysis of the average values of the meteorological data recorded by the weather station during the period 2009 - 2018, we calculated the TEE index, it is observed that there is no thermal discomfort through heating (figure 2). The actual values of the real temperature are between minimum 15.5 °C in May 2011 and maximum 24.5 °C in August 2018, being the moderate heat according to TEE. Minimum cooling discomfort is recorded in February 2012 (-6.9^{0}C).

In January, February and December, according to figure 2 and table 3, values corresponding to the low risk of hypothermia were obtained; in March and April there are values corresponding to the cold weather; in may, june, july, august, september hot weather, in october and november the weather is cold.

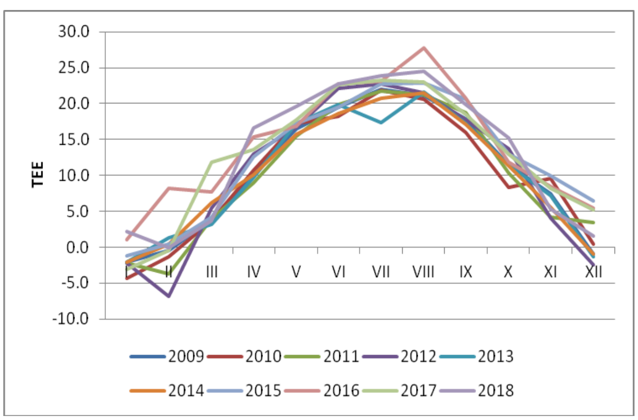

Fig. 1 Limit curve of occurrence of claws [27]

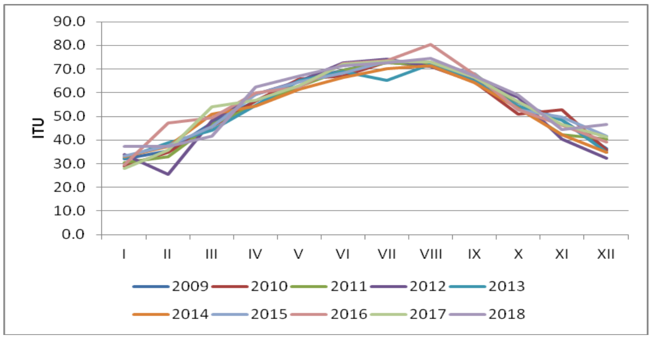

Fig. 3 Values ITU during 2009-2018

According to table 4 and figure 3, it is observed that for the ITU index calculated based on the average values of temperature and humidity with the relation (3), values corresponding to the thermal comfort in all the years in January, February were obtained during the analyzed period 2009-2018. March, April, October, November, December; values corresponding to the alert threshold in May, June, July, August and September (2009, 2011, 2015, 2016, 2017, 2018).

In Bucharest there were many hot days with marked discomfort.

The high temperatures and moderate humidity in the air layer near the soil lead to the gradual increase of the temperature-humidity comfort index (ITU) reaching critical values and determining the state of discomfort. The use of this index shows the positive effects on the human body due to the state of comfort, allowing the activities throughout the year, with their differentiation according to the season and the preferences of the inhabitants. In the summer when the humidity is low, under the charge of the atmosphere with pollutant emissions, processes under the action of solar radiation can give rise, which lead to the formation of photochemical dry smog. In the cold season of the year, when the air is over-saturated by vapors, wet smog can occur in the urban atmosphere. The high heat and humidity influence the stagnation time of the pollutants in the atmosphere, they influence the neutralization of the pollutants, or their transformation through the photochemical processes that give rise [2, 29].

The THOM discomfort index (DI THOM) (°C)

The DI Thom index, calculated with the relation (4), was obtained in Bucharest values between 21-24 when less than 50% of people felt slightly exposed to the discomfort are in June 2009, 2012, 2016, 2017 and in July in all the years analyzed except in 2013, in August in all the years analyzed, the rest of January, February, March, April, May, September, October, November, December, were temperatures corresponding to the thermal comfort according to DIThom.

Air temperature influences the air pollution by its vertical distribution, responsible for the stability or instability of air masses [4, 14, 16].

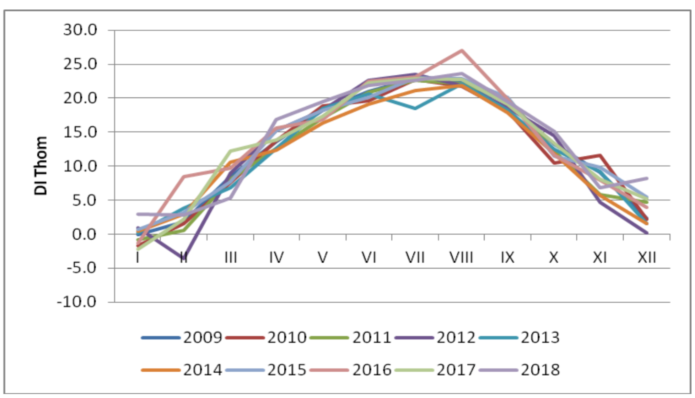

Fig. 4. DI Thom values for 2009-2018

Conclusions

In this paper, we analyzed the Missenard equivalent temperature index [° TEE] which reflects the actual temperature felt by the human body at a given time, under certain conditions of temperature, humidity and degree of air movement in the atmosphere. It was observed that during the analyzed period 2009 - 2018, there is no thermal discomfort through heating (figure 2). The actual values of the real temperature were between minimum 15.5 °C in May 2011 and maximum 24.5 °C in August 2018, being the moderate heat. Minimum cooling discomfort was recorded in February 2012 (-6.9^{0}C). In January, February and December, values corresponding to the low risk of hypothermia were obtained; in March and April there were values corresponding to the cold weather; in may, june, july, august, september hot weather, in october and november the weather was cold.

The temperature-humidity index (ITU) was calculated based on the values of the temperature and the relative humidity of the air and it was observed that between 2009-2018 the residents of Bucharest were in the thermal comfort state. During the analyzed period 2009-2018, values corresponding to the thermal comfort were obtained in all the years in January, February, March, April, October, November, December; values corresponding to the alert threshold in May, June, July, August and September (2009, 2011, 2015, 2016, 2017, 2018).

The use of this index shows that, during the period studied, the positive effects on the human body due to the state of comfort, allow the activities throughout the year, their differentiation depending on the season and preferences residents.

The Thom discomfort index calculated for Bucharest had values between 21-24 when less than 50% of people felt slightly exposed to the discomfort in June 2009, 2012, 2016, 2017 and July in all the years analyzed less in 2013, in August in all the years, the rest of January, February, March, April, May, September, October, November, December, were temperatures corresponding to the thermal comfort according to DI Thom.

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