# AMBIENTE TÉRMICO EN PERIODO CÁLIDO PARA ESPACIOS PÚBLICOS EXTERIORES: HACIA UN ÍNDICE DE HABITABILIDAD TÉRMICA

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## Resumen

En la ciudad de El Grullo, Jalisco, México, se considera que condiciones de clima cálido semi-seco en periodo de verano, reduce niveles de habitabilidad térmica en espacios de convivencia públicos exteriores, revisión de literatura hasta 2019, indica que estudios sobre habitabilidad térmica en México, han sido desarrollados básicamente en vivienda y edificación, de ahí la importancia de llevar a cabo este estudio. El objetivo de esta investigación, es presentar el proceso del desarrollo de un Índice de Habitabilidad Térmica para espacios de convivencia públicos exteriores, a partir de la estimación del efecto de variables físicas, meteorológicas y termo fisiológicas del habitante, en periodo cálido. El caso de estudio fue la población de El Grullo, se utilizó una metodología descriptiva, no experimental y transversal. Después del análisis documental y necesidades del estudio, se adecuó la Fórmula de Confort desarrollada por Brown y Gillespie (1995). De acuerdo al diagnóstico bioclimático de horas de confort para El Grullo y el análisis de áreas de estudio, se aplicaron 534 cédulas de información de habitante y 98 de ambiente térmico y contexto urbano para periodo cálido. Para alcanzar valores del índice, se evaluó nivel de desempeño de cada indicador en complejidad, relevancia y accesibilidad de información, para análisis de datos se utilizó el coeficiente de correlación de Spearman. Los resultados muestran la importancia del desarrollo del índice, como herramienta de diseño urbano y sistema de evaluación de espacios públicos exteriores construidos, como propuesta para mejorar condiciones de uso y bienestar de sus habitantes.

**Palabras clave:** Índice de habitabilidad, sensación térmica, ambiente térmico, paisaje urbano, contexto urbano.

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# THERMAL ENVIRONMENT DURING WARM PERIOD FOR EXTERNAL PUBLIC SPACES: TOWARDS A THERMAL HABITABILITY INDEX


## Abstract

In the city of El Grullo, Jalisco, Mexico, it is considered that the semi-dry, warm climate conditions of summer period, reduce levels of thermal habitability in outdoor public spaces. Literature reviewed up to 2019, indicate that studies on thermal habitability in Mexico, have been completed basically on housing and buildings, hence the importance of carrying out this study. The objective of this research is to present the process of developing a Thermal Habitability Index for external public coexistence spaces, based on the estimation of the effect of physical, meteorological and thermo physiological variables of the inhabitant, during warm period. The case study is the population of El Grullo. A descriptive, non-experimental and transversal methodology was applied. After the documentary analysis and discovering the needs of the study, the Comfort Formula developed by Brown and Gillespie (1995) was adapted. As a result of the bioclimatic diagnosis of comfort hours and the analysis of study areas for El Grullo, 534 inhabitant information cards and 98 thermal environment and urban context cards for warm period were applied. To achieve index values, the performance level of each indicator was evaluated according to complexity, relevance and accessibility to information, for data analysis, the Spearman correlation coefficient was used. The results show the importance of the development of the index, as an urban design tool and evaluation system for exterior public spaces built, as a suggestion to improve the conditions and well-being of its inhabitants.


**Keywords:** habitability index; thermal sensation; thermal environment; urban landscape; urban context

## 1. Introduction

The inhabitants thermal environment conditions are established by the thermal habitability potential and the spatial design, due to the interaction that exists between them, the indexes can be adjusted to different types of spaces depending on the activity carried out: living areas, sport sites and pedestrian circulation areas (Gómez *et al*, 2008).

These changes are perceived both in the interior spaces and in the exterior of the city, According to Nikolopoulou and Steemers (2003), environmental comfort in outdoor spaces is one of the essential characteristics of the quality of the urban environment, since under suitable conditions (thermal, light,

as the thermal environment of people, in outdoor spaces, one of the factors that most influences the thermal habitability of public spaces in cities (Taleghani *et al*, 2014; Nikolopoulou y Lykoudis, 2006). Givoni (1989) studies show how the amount and intensity of activities that the individual performs outdoors are affected by the level of thermal discomfort experienced when exposed to weather conditions in open spaces.

acoustic, psychological comfort) it is possible to promote street activities, squares, courtyards, parks, etc. In addition to this item, Nicol *et al* (2002), indicate that the climate influences the culture and attitudes to find the thermal comfort of any group of people and the design of the building they inhabit, while the basic mechanisms of the human relationship with the thermal environment may not change with the weather.

From another perspective, the analysis of bioclimatic models are those studies that make a compilation, description and analysis of at least two thermal comfort models, without necessarily being the basis for the development of new models. Representative works are: Givoni (1969), Auliciems and Szokolay (1997), Auliciems and De Dear (1998), Noguchi *et al* (1997).

Another position in this regard, is the one developed by De Dear and Brager (2002), mention that the (optional method to determine acceptable thermal conditions in naturally ventilated spaces), can be used where the thermal conditions are regulated with the opening and closing of windows.

In the Asian continent, Ghasemi *et al* (2015), developed a study that analyzed the importance of urban areas and effective parameters in the assistance of people. The objective of this work was the presentation guidelines based on the creation of wind and thermal environment in these places.

On the other hand, Stocco *et al* (2015), developed a study that evaluated the thermal behavior and comfort conditions in different sites (downtown, plots and gardens) that usually make up the urban squares of the city of Mendoza, Argentina, with warm humid weather. The main objective of this research was to propose combinations of variables (vegetation, materials, sealed green relationship, distribution of roads and internal spaces, among others) for an efficient design of urban spaces.

In relation to literature, it is important to point out some aspects that intervene in the welfare of users of outdoor public spaces, such as green areas, pedestrian areas, roads and non-motorized surfaces, public furniture, trees and other elements that generate shade. Some studies, carried out in Mexico, which contributed with information based on scientific evidence, are analyzed. Bojórquez *et al* (2017), carried out a correlational study under subjective evaluation criteria of ISO 10551: 1995, a thermal habitability index was developed based on qualitative and quantitative perceptions.

An opportunity that was presented and valued for this research is the fact that studies on thermal habitability in Mexico, up to 2019, have been developed basically in the housing and building sector, so it was decided to work with exterior public spaces; therefore, have better knowledge of the subject. So as to analyze the proposed indicators, it was determined that the object of study was the town of El Grullo, which is located in the Sierra de Amula region of the state of Jalisco, Mexico. A critical examination of literature, not older than 10 years, was done. Texts were selected based on their relevance, mentioned by other authors, or addressed the concepts of habitability, urban planning and thermal environments.

In relation to urban habitability, Sosa (2017), analyzed the interaction between microclimate and urban morphology to determine the degree of thermal comfort of low density areas in a city with arid climate (Mendoza-Argentina). In the study seven urban road channels (URC) were selected and were monitored micro climatically.

According to literature, it is thought that the balance which exists between the section of roads, urban elements, landscaping and bearing surfaces and pavements, generates an effect of damping and dissipation of heat flow by radiation, conduction and convection that, simultaneously, causes the occupants' well-being in outdoor public spaces and participates in its perception and thermal sensation. Likewise, thermal habitability, a discipline of architecture, has evolved and assumes criteria that participate in the well-being of an individual and allows to enhance his activities

and productivity in any field. In the same way, it contributes so that people will assist and stay in public spaces and encourages socialization and interaction with other citizens. See figure 1.
A habitability index is composed of indicators and parameters of quantitative and qualitative nature, which can be measured on a scale of 0 to 1, depending on their function and what is valued at that moment.
According to D'alencon *et al* (2010), a habitability index integrates the performance levels of the different parameters in an indicator, which allows decision-making with the quality of housing, and the capacity in habitability habits that are related to the index obtained.

Consequently, public space categorizes and feeds a city, users are clearly identified in the place that surrounds them, symbolically represents their origin, customs or idiosyncrasy and are part of a story that has patterns and characteristics of relevance of that interest place.
Another perspective, habitability has two elements: the quantitative, referring to the general standards of housing, only this quantitative element was what Colavidas, Oteiza, & Salas (2006), referred to as habitability and qualitative, which is the diverse, and alludes to the assessments, the perceptions of the inhabitants, the way they live, and the relationship between man and space.

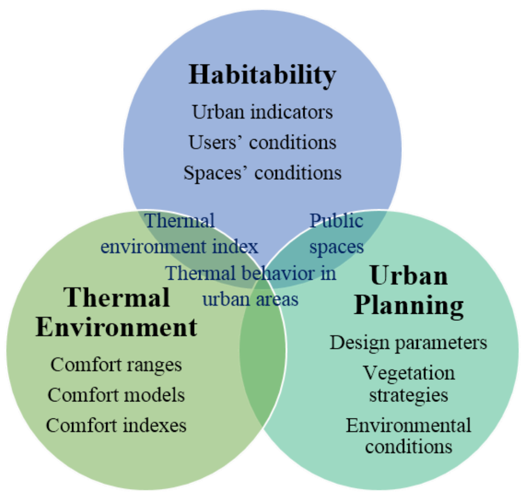


**Figure 1**. Structure and interrelation of the State of the Art.
*Source: Compiled by author*

On the other hand, Zulaica (2013), appreciates that the selection of objectives and indicators is a task where the process requires compatibility of sources of information and cover the aspects that are intended to be evaluated with an index. The index was constructed by integrating five aspects involved in the concept: educational quality, health quality, housing quality, habitat quality and environmental quality.
The indicators for the development of a thermal habitability index should gather characteristics that encompass the totality of aspects to be evaluated, that is, it should take into account the inhabitants, meteorological conditions and space conditions, in order to obtain reliable results.

The Thermal Habitability Index, unlike a thermal environment evaluation, implies an assessment of the space's conditions, where the city inhabitant operates, in addition, the index constitutes the performance levels of the various parameters of an indicator that link the strategies for progress and decision making related to the index obtained.

Based on the observed shortage in the State of the Art and after the theoretical framework was analyzed, the following research question was posed: What are the variables of greatest influence that determine the thermal performance for the development of a Thermal Habitability Index (THI) in outdoor coexistence spaces in semi-dry warm climate? The thermal environment variables have greater influence due to their effect on the inhabitant and the urban context variables for the process of construction of the THI. The general purpose was the development of a Thermal Habitability Index for outdoor public living spaces in semi-dry warm climate.

## 2. Materials and Methods

The development of a THI in external public coexistence spaces required a set of indicator parameters that evaluate thermal habitability aspects and conditions of the study areas with the variables analyzed.

Based on the bibliography analyzed, in accordance with the needs of the study, it was proposed to use and adapt the Comfort Formula (COMFA) developed by Brown and Gillespie (1995). The COMFA energy balance equation is shown below:

$S = M + R_{absorbed} - Conv - Evap - TR_{emitted}$

Where: M: metabolic energy produced by the organism; $R_{absorbed}$: solar and terrestrial radiation absorbed; Conv: sensitive heat lost or gained by convection; Evap: evaporative loss of heat; $TR_{emitted}$: terrestrial radiation emitted. This situation allows a greater differentiation between urban and vegetation characteristics, in addition to the variables of thermal environment that affect the inhabitants of an outside space. See figure 2.

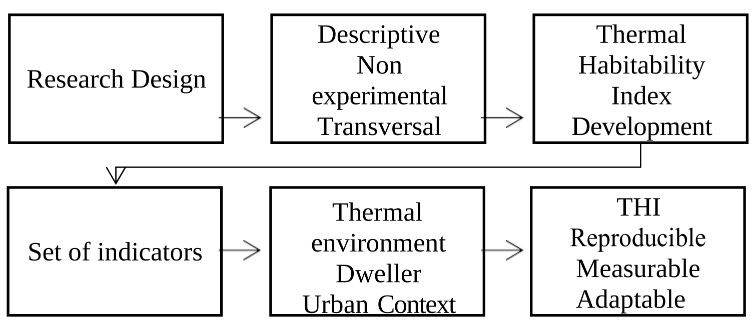


**Figure 2**. Methodological process scheme
*Source: Compiled by author*

To reach the values of the THI, it was proposed to evaluate every indicator's performance level in terms of complexity, relevance and accessibility to information that corresponds to the external public coexistence space in terms of the thermal environment, the inhabitant and the urban context; and in turn, rate the THI on a scale of one to four.

Likewise, the Delphi method was used as a basis, considering the complexity, relevance and accessibility to the information, as it was recommended by expert researchers in the Urban Planning and the Environment area. Once the information was obtained, the indicators proposed for the development of the THI remained as follows:

**Table 1.** Indicators for the development of a Thermal Habitability Index (THI).

| Indicator No. | Category | Indicator Name | | Unit of measurement of the indicator |
|---|---|---|---|---|
| 1 | Thermal Environment | Dry bulb temperature (DBT) average maximum during warm period | | °C |
| 2 | | Dry bulb temperature (DBT) average minimum during warm period | | °C |
| 3 | | Average dry bulb temperature (TBS) maximums of vertical surface (SV) during warm period | | °C |
| 4 | | Average dry bulb temperature ( DBT ) maximums of horizontal surfaces (HS) during warm period | | °C |
| 5 | | Average dry bulb temperature (DBT) maximums of vertical surfaces on public furniture (VSPF) during warm period | | °C |
| 6 | | Average maximums of relative humidity (RH) during warm period | | % |
| 7 | | Wind speed (WS) average during warm period | | m/s |
| 8 | | Average solar radiation on the horizontal plane (SPHP) during warm period | | $W/m^2$ |
| 9 | Inhabitant | Level of metabolic activity | | Met |
| 10 | | Neutral temperature (NT) during warm period | | °C |
| 11 | | Percentage of Thermal Preference (TP) during warm period | | % |
| 12 | | Percentage of Thermal Tolerance (TT) during warm period | | % |
| 13 | | Percentage of Thermal Acceptance (TA) during warm period | | % |
| 14 | Urban Context | Urban footprint | Road areas | $m^2$ |
| 15 | | | Walkways, pedestrian and non-motorized circulation area | $m^2$ |
| 16 | | | Average anthropogenic heat (AH) generated by vehicles parked during warm period | $W/m^2$ |
| 17 | | | Urban albedo (UA) average of horizontal areas during warm period | $W/m^2$ |
| 18 | | Profile | Average building area | $m^2$ |
| 19 | | | Average building height | m |
| 20 | | | Average urban albedo (UA) of vertical areas during warm period | $W/m^2$ |
| 21 | | Vegetation | Average tree canopy area | $m^2$ |
| 22 | | | Average tree shaded area during warm period | $m^2$ |
| 23 | | | Average solar permeability (SP) during warm period | % |
| 24 | | Public furniture | Average urban albedo (UA) on public furniture during warm period | $W/m^2$ |
| 25 | | | Average vertical areas on public furniture | $m^2$ |

*Source: Compiled by author*

It should be noted that when evaluating the THI indicators, a value was assigned to each variable studied and in this way the scale of Thermal Habitability of the public space analyzed was obtained, which determines the validation of the index, which when comparing the data theoretical with those obtained in the field, confirms that the THI is reproducible, measurable and adaptable to any place regardless of the weather conditions. The THI does not seek to establish regulatory minimum requirement levels, but pursues to act as a homogeneous instrument for the evaluation of indicators in external public coexistence spaces.

A four-point scale was proposed to evaluate the indicators that participate in the index indicated and to know the degree of thermal habitability that has a space of external public coexistence.

Formula to obtain the degree of thermal habitability

$$\text{THI} \quad \left(\frac{\sum_{i=1}^{n} AT^{i}}{n}\right)*0.40 + \left(\frac{\sum_{i=1}^{n} H^{i}}{n}\right)*0.25 + \left(\frac{\sum_{i=1}^{n} CU^{i}}{n}\right)*0.35$$

Where:

THI= Thermal Habitability Index

∑= Summation

n= number of cases

i= where you have to start the sum

ATi= Thermal environment variables

Hi= Inhabitant variables

CUi= Urban context variables

0.40= coeficiente de habitabilidad térmica categoría de ambiente térmico

0.25= coeficiente de habitabilidad térmica categoría de habitante

0.35= coeficiente de habitabilidad térmica categoría de contexto urbano

**Table 2.** Thermal habitability assessment proposal.

| **Thermal habitability scale** | |
|---|---|
| < 0.25 | Low thermal habitability |
| 0.25 < 0.50 | Medium thermal habitability |
| 0.50 < 0.75 | Moderate thermal habitability |
| 0.75 < 1.0 | High thermal habitability |

*Source: Compiled by author based on Duarte, 2013.*

The investigation was carried out in the town of El Grullo, which is located in the Sierra de Amula region of the State of Jalisco, Mexico, with a latitude of 19 ° 48'22.80 "N 104 ° 13'09.29" W, in the north shares borders with the municipality of Unión de Tula, Ejutla and El Limón; to the east with the municipalities of El Limón and Tuxcacuesco; to the south with the municipalities of Tuxcacuesco and Autlán de Navarro; to the west with the municipality of Autlán de Navarro and Unión de Tula (Secretaría de Medio Ambiente y Desarrollo Territorial SEMADET (2012).

**Figure 3**. Location of El Grullo, Jalisco.

*Source: Image obtained through Google Earth.*

This municipality is characterized by having semi-dry warm climate, although some months of the year, the conditions change to sub humid influenced by rainy weather. The average maximum temperature is 35°C. The minimum average of 11°C and the annual average temperature is 23.9°C with an annual average precipitation of 900 mm. It has an altitude of 876 meters above sea level and average relative humidity of 35% (Municipal Development Plan of El Grullo, 2012).

Two representative places of El Grullo, the Municipal Garden "Ramón Corona" and the Alameda Municipal, were surveyed. These places are exterior spaces of public coexistence and are located in the center of the city.


**Figures 4 and 5**. Aerial view of the Municipal Garden and Alameda.
*Source: Image obtained through Google Earth.*

In accordance with the bioclimatic diagnosis of the hours of comfort for the population of El Grullo and the analysis of the study areas, the survey was carried out with inhabitants of these outdoor public spaces in the municipal Garden and Municipal Alameda, between the ages of 12 and 60, without characteristics of cardiovascular origin diseases and/or neurological diseases, or pregnant or breast-feeding women.

During the warm period survey, a total of 538 inhabitant information cards and 98 thermal environment and urban context information cards were made. The design of the information card in the field of thermal preference was made in accordance with ISO 7933: 2004 (Thermal stress with estimated overload calculation) and ISO 10551: 1995 (Effect of the thermal environment with the use of subjective judgment).

The application of the information and additional data was collected in maximum 10 minutes. The surveyors' training was 48 hours before the beginning of the sampling and a test run was carried out. The dates in which the survey was carried out were from August 6$^{th}$-19$^{th}$ from 08:00 a.m. to 8:00 p.m. In the results section, the average records of the THI indicators for the warm period are presented. See table 7.

A deterministic method was used among the inhabitants of the public space who were within the age range of 12 to 60 years. If they were older, they were registered as a special group. For inhabitant information card, thermal environment data (dry bulb temperature, gray balloon temperature, relative humidity and wind speed) were recorded at the time of the application of the card. Thermal habitability data and space preference were obtained from the interviewee.

The measuring instruments (thermal stress meter, digital psychrometer and anemometer) were mounted on a wooden bracket at a height of 1.30 m from ground level and the data logger was located in a representative area, from 8:00 a.m. to 8:00 p.m. at a height of 1.30 m from ground level, following the World Meteorological Organization's recommendations (2014). They were placed in areas that were free of trees and buildings near the measuring point; however, the measuring instruments were placed 2 m away from the person at the time of the interview, in order to correctly estimate the thermal environment variables. See figures 6 and 7.

**Figures 6 and 7.** Application of inhabitant information card.
*Source: Compiled by author*

The recording of data of the thermal environment variables was every 15 minutes from 08:00 to 20:00 hours for the survey in the study areas. Every two hours the dry bulb temperature data was also recorded. Vertical, horizontal and public furniture surfaces, the anthropogenic heat generated by parked vehicles and the urban albedo of vertical, horizontal and public furniture areas were also registered with the same frequency. See figure 8.

**Figure 8.** Record of thermal environment data and urban context
*Source: Compiled by author*

The instruments used were **digital psychrometer** (resolution factor: humidity 0.0 a 100.0%, air temperature (-20 to 50 °C) (-4.0 to 122.0 °F), infrared temperature (-20 to 450 °C) (-4 to 842 °F), accuracy factor: humidity (±3% HR) (10 to 90%), air temperature (±1°C) (±1.8°F), infrared temperature (±3% readings or ±3°C/6°F whichever is greater), **thermal stress meter** (resolution of (0.1°F/°C; 0.1% HR), **digital anemometer** (resolution: 0.1ms, 0.3km/h, 19ft/min, 0.2mph, 0.2Knots) and accuracy of (±5%), **data logger** (accuracy factor: humidity (0 to 20, 20 to 40, 40 to 60, 60 to 80 y 80 to 100%), temperature (-40 to -10 y +40 to +70 °C), dew point temperatura (25°C, 40 to 100 % HR), **weighing machine** and **flexometer.** See Figure 9.

**Figure 9.** Measurement Instruments.
*Source. Compiled by author.*

For the data analysis, multiple linear regression was performed with the meteorological variables and ordinal variables (sensation, preference, tolerance and thermal acceptance). Once this data was obtained, the Spearman correlation coefficient was used, since the coefficients of this type of existing linear correlation are the data that directly contribute to the Thermal Habitability Index (THI). The correlation matrix was calculated by using the statistical program SPSS for Windows.

## 3. Results and Discussion

Regarding the recording of meteorological variables of the Thermal Habitability Index (THI) for outdoor spaces, within the surveying of the inhabitants during the warm period the data was recorded by ranges, Dry Bulb Temperature (DBT), Relative Humidity (RH) and Wind Speed (WS).
Similarly, inhabitants responses were recorded in relation to Thermal Sensation (TS), Thermal Preference (TP), Thermal Tolerance (TT), Thermal Acceptance (TA) and Metabolic Activity Level (MAL). The process that was carried out to obtain the THI is explained, where 25 indicators of thermal environment (TE), inhabitant (H) and urban context (UC) were evaluated; of which 8 correspond to TA, 5 to H and 12 to UC.
In Figure 10, a difference of 9°C is observed in relation to the average maximums of DBT of

horizontal surfaces and the verticals; and a difference of 12 points with the average maximums and minimums of DBT. The average RH was recorded in the quartile 4.

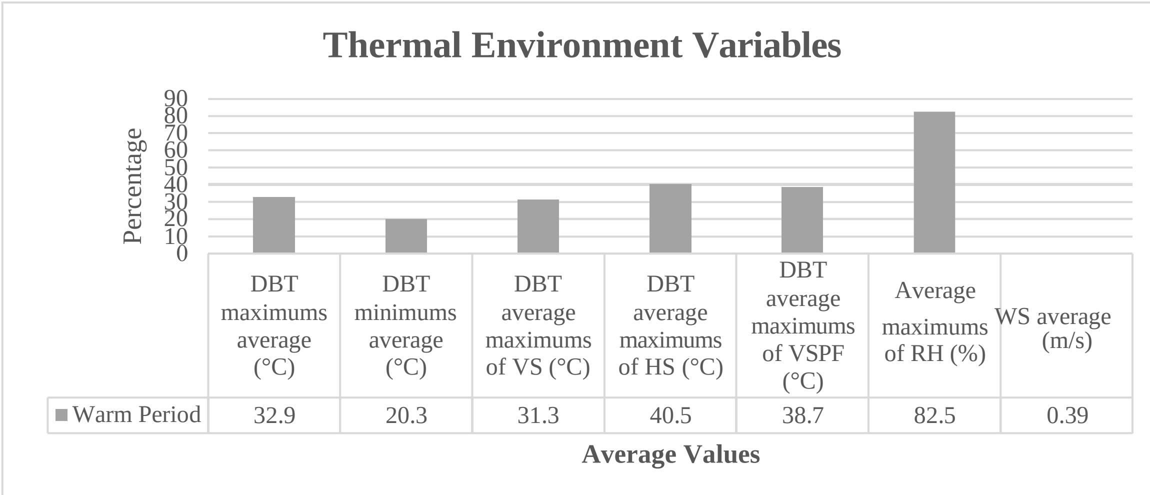


**Figure 10.** Comparative data of the Thermal Environment variables of the THI during the warm period.
*Source: Compiled by author.*

In the inhabitant category, the ordinal variable that can be seen with a marked difference from the others, was the thermal tolerance on thermal preference and thermal acceptance with a difference of 11 points. The metabolic activity level was recorded in the third quartile and the neutral temperature was 6 points above the average minimum DBT and 7 points below the average maximum DBT. See figure 11.

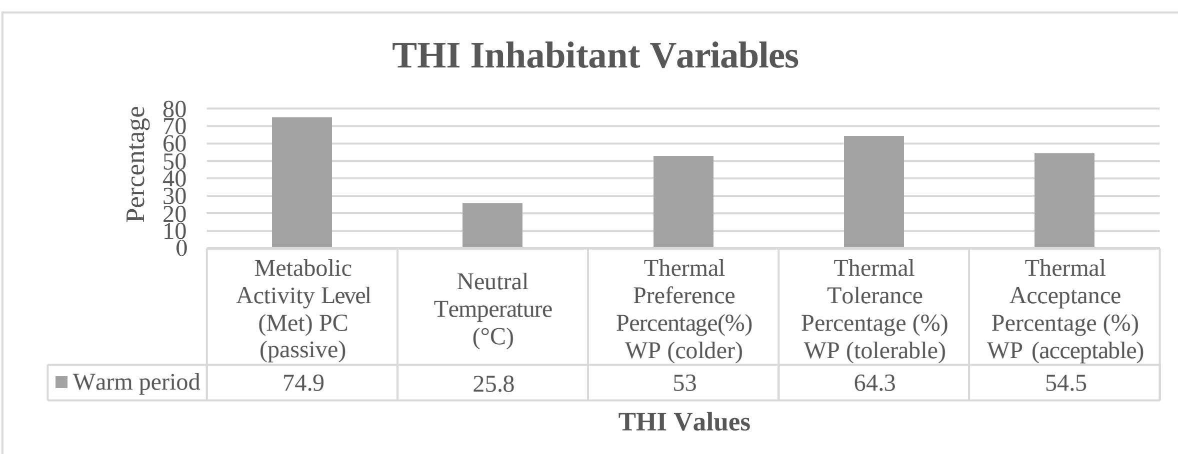


**Figure 11**. THI Inhabitant variable data during the warm period.
*Source: Compiled by author*

Figure 12 represents the average value of the road areas, walkways, pedestrian and non-motorized circulation of the public spaces analyzed. In both public spaces, the constructive material that predominates is hydraulic concrete for the area of roads and cobblestone for the walkways and pedestrian circulation areas.

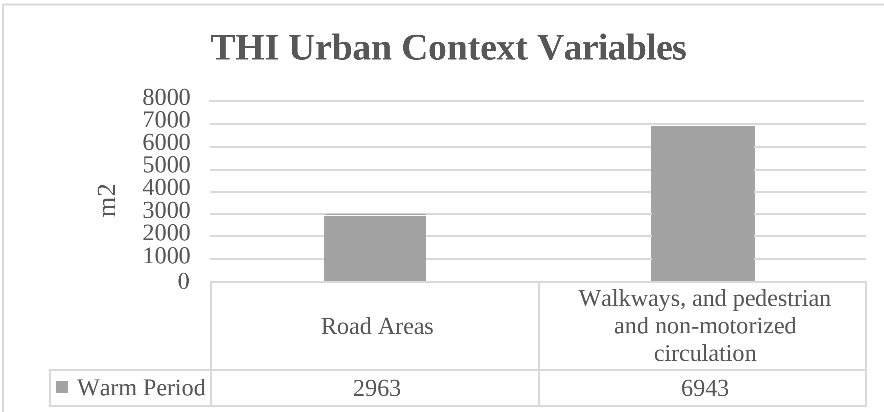


**Figure 12.** THI Urban Context Variables data during the warm period.
*Source: Compiled by author*

The average values of urban context variables that are part of the development of the THI are presented, displaying a difference of 2 and 3 points between the average public furniture areas, tree canopy and shadowed areas. In relation to the average building area and its height, there is a ratio of 1 to 12.

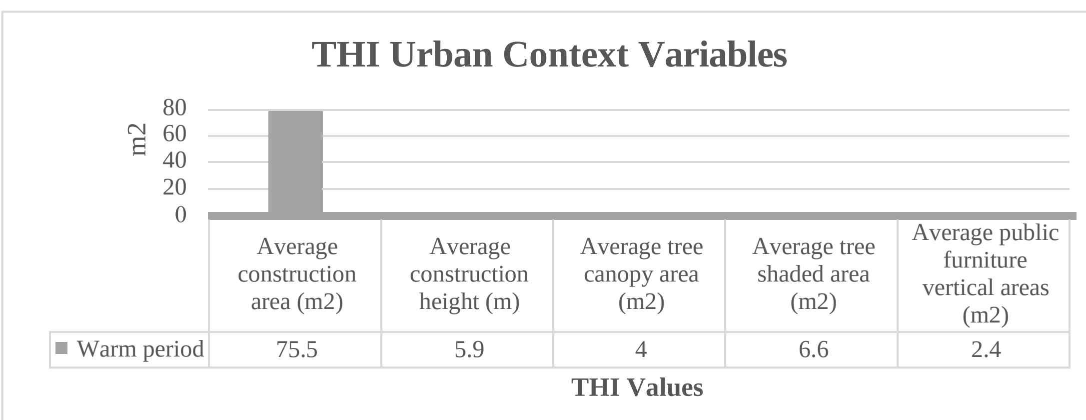


**Figure 13**. THI Urban Context variables data during the warm period.
*Source: Compiled by author.*

The average value of the solar permeability is shown, by means of the Photogrammetry method proposed by Santamaría and Sanz (2011), where it resulted on the scale of (average) for exterior interacting public spaces during the warm period. See figure 14.

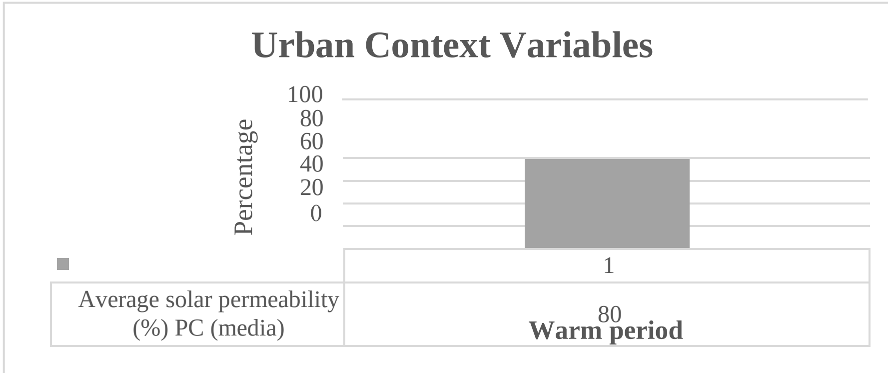


**Figure 14**. Urban Context variables data of the THI during the warm period.
*Source: Compiled by author.*

We obtained values of 0.6 and 11 tenths of difference between the average values of urban albedo (UA) of the analyzed areas and in relation to the anthropogenic heat (CA) generated by parked vehicles surrounding the public spaces. A difference of 1ºC was registered in relation with the estimated neutral temperature. See Figure 15.

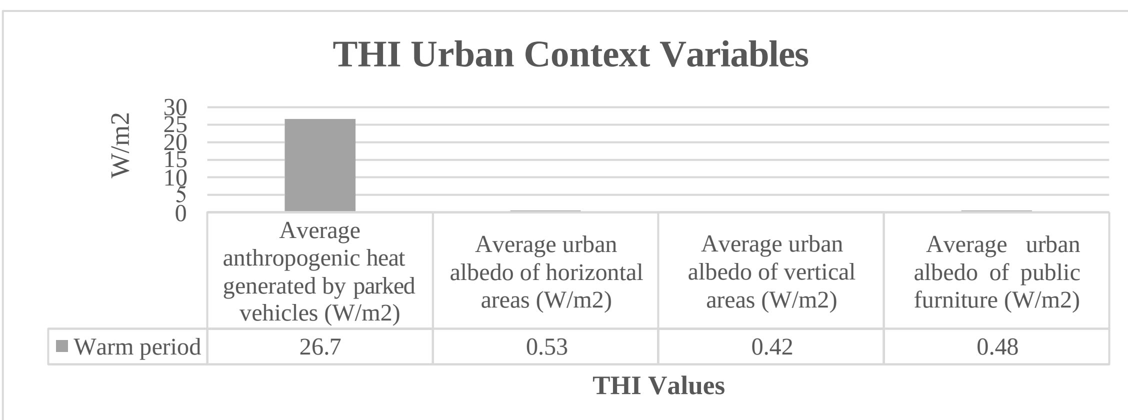


**Figure 15.** Data of Urban Context variables of the THI during the warm period.
*Source: Compiled by author.*

During the data analysis, due to the conditions of the investigation, it was determined to use the multiple linear regression between the meteorological variables of DBT, RH and WS, and the ordinal variables of TS, TP, TT and TA.

Once the multiple linear regression was obtained, we proceeded to associate thesevariables with the Spearman correlation, to identify the level of significance between each of them and obtain the degree of representativeness in order to present the THI result. In relation to the Spearman correlation, which allows an association between numerical variables or intervals with ordinal variables, the following data for the warm period is presented.

Table 3 refer to the degree of linear correlation between TS and thermal environment variables, where it can be appreciated that the WS has a perfect correlation with the ordinal variable.

**Table 3.** Spearman correlation between thermal environment variables and TS during the warm period.

| | | | Dry bulb temperature | Relative humidity | Wind Speed | Thermal sensation of the inhabitant |
|---|---|---|---|---|---|---|
| Spearman Rho | Dry bulb temperature | Correlation coefficient | 1,000 | -,463** | ,033 | ,397** |
| | | Next (bilateral) | . | ,000 | ,439 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Relative Humidity | Correlation coefficient | -,463** | 1,000 | -,087* | -,519** |
| | | Next (bilateral) | ,000 | . | ,044 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Wind speed | Correlation coefficient | ,033 | -,087* | 1,000 | -,002 |
| | | Next (bilateral) | ,439 | ,044 | . | ,961 |
| | | N | 538 | 538 | 538 | 538 |
| | Thermal sensation of the inhabitant | Correlation coefficient | ,397** | -,519** | -,002 | 1,000 |
| | | Next (bilateral) | ,000 | ,000 | ,961 | . |
| | | N | 538 | 538 | 538 | 538 |

*Source: Compiled by author.*

Regarding the TP, the DBT and RH variable do not present a degree of association, whereas the WS variable shows a weak association level in this category. See table 4.

**Table 4.** Spearman correlation between thermal environment variables and TP during the warm period.

| | | | Dry Bulb Temperature | Relative Humidity | Wind Speed | Inhabitant Thermal Preference |
|---|---|---|---|---|---|---|
| Spearman Rho | Dry Bulb Temperature | Correlation coefficient | 1,000 | -,463** | ,033 | -,294** |
| | | Next (bilateral) | . | ,000 | ,439 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Relative Humidity | Correlation coefficient | -,463** | 1,000 | -,087* | , 353** |
| | | Next (bilateral) | ,000 | . | ,044 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Wind Speed | Correlation coefficient | ,033 | -,087* | 1,000 | -,038 |
| | | Next (bilateral) | ,439 | ,044 | . | ,384 |
| | | N | 538 | 538 | 538 | 538 |
| | Inhabitant Thermal Preference | Correlation coefficient | -,294** | ,353** | -,038 | 1,000 |
| | | Next (bilateral) | ,000 | ,000 | ,384 | . |
| | | N | 538 | 538 | 538 | 538 |

*Source: Compiled by author.*

On the TT, both the DBT and the RH do not associate any deterministic value with the ordinal variable, unlike the WS that has a weak association level. See table 5.

**Table 5.** Spearman correlation between thermal environment variables and TT during the warm period.

| | | | Dry Bulb Temperature | Relative Humidity | Wind Speed | Inhabitant Thermal Tolerance |
|---|---|---|---|---|---|---|
| Spearman Rho | Dry Bulb Temperature | Correlation coefficient | 1,000 | -,463** | ,033 | -,262** |
| | | Next (bilateral) | . | ,000 | ,439 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Relative Humidity | Correlation coefficient | -,463** | 1,000 | -,087* | , 267** |
| | | Next (bilateral) | ,000 | . | ,044 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Wind Speed | Correlation coefficient | ,033 | -,087* | 1,000 | ,049 |
| | | Next (bilateral) | ,439 | ,044 | . | ,259 |
| | | N | 538 | 538 | 538 | 538 |
| | Inhabitant Thermal Tolerance | Correlation coefficient | -,262** | ,267** | ,049 | 1,000 |
| | | Next (bilateral) | ,000 | ,000 | ,259 | . |
| | | N | 538 | 538 | 538 | 538 |

*Source: Compiled by author.*

Also, the TA does not have a degree of association with the variables of DBT and RH, however, the WS shows a weak level. See table 6.

Below (in table 7) is a comparative table of the THI indicators with theoretical data and recorded in the warm period field.

**Table 6.** Spearman correlation between thermal environment variables and TA during the warm period.

| | | | Dry Bulb Temperature | Relative Humidity | Wind Speed | Inhabitant termal acceptance |
|---|---|---|---|---|---|---|
| Spearman Rho | Dry Bulb Temperature | Correlation coefficient | 1,000 | -,463** | ,033 | -,294** |
| | | Next (bilateral) | . | ,000 | ,439 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Relative Humidity | Correlation coefficient | -,463** | 1,000 | -,087* | ,264** |
| | | Next (bilateral) | ,000 | . | ,044 | ,000 |
| | | N | 538 | 538 | 538 | 538 |
| | Wind Speed | Correlation coefficient | ,033 | -,087* | 1,000 | ,043 |
| | | Next (bilateral) | ,439 | ,044 | . | ,318 |
| | | N | 538 | 538 | 538 | 538 |
| | Inhabitant termal acceptance | Correlation coefficient | -,294** | ,264** | ,043 | 1,000 |
| | | Next (bilateral) | ,000 | ,000 | ,318 | . |
| | | N | 538 | 538 | 538 | 538 |

*Source: Compiled by author*

**Table 7.** Warm period comparative data.

| Indicator No. | Category | Indicator Name | Theoretical data | Data obtained in the field |
|---|---|---|---|---|
| 1 | Thermal Environment | Dry bulb temperature (DBT) average maximum during warm period | 32.0 °C | 32.9 °C |
| 2 | | Dry bulb temperature (DBT) average minimum during warm period | 21.0 °C | 20.3 °C |
| 3 | | Average dry bulb temperature (TBS) maximums of vertical surface (SV) during warm period | The use of a digital psychrometer to measure the infrared radiation of the vertical surface representative of the space and / or the recording and calculation of data with the use of the Heliodón program or similar method is suggested. | 31.3 °C |
| 4 | | Average dry bulb temperature ( DBT ) maximums of horizontal surfaces (HS) during warm period | “ | °C |
| 5 | | Average dry bulb temperature (DBT) maximums of vertical surfaces on public furniture (VSPF) during warm period | “ | °C |
| 6 | | Average maximums of relative humidity (RH) during warm period | 92.0 % | 82.5 % |
| 7 | | Wind speed (WS) average during warm period | 3.0 m/s | 0.39 m/s |
| 8 | | Average solar radiation on the horizontal plane (SPHP) during warm period | 7 W/m$^2$ | 8.5 W/m$^2$ |
| 9 | Inhabitant | Level of metabolic activity | Activity at rest: 58 a 87 W/m$^2$ | 58 a 87 W/m$^2$ |
| 10 | | Neutral temperature (NT) during warm period | A registration model of this item is presented according to current regulations based on the normal weather, Meteonorm program or similar method. Source: (ISO 10551). | 25.8 °C |

| | | | | | |
|---|---|---|---|---|---|
| 11 | | Percentage of Thermal Preference (TP) during warm period | | A prototype questionnaire for Thermal Habitability Index (THI) based on ISO 10551: 1995, which can be applied at any place or similar method, was carried out. | 53% (colder) |
| 12 | | Percentage of Thermal Tolerance (TT) during warm period | | “ | 64.3% (tolerable) |
| 13 | | Percentage of Thermal Acceptance (TA) during warm period | | “ | 54.5% (aceptable) |
| 14 | Urban Context | Urban footprint | Road areas | The use of a tape measure, laser distance meter and / or the application of Google Maps as an auxiliary method or similar method is suggested. | 3044 $m^2$ |
| 15 | | | Walkways, pedestrian and non-motorized circulation area | “ | 6835 $m^2$ |
| 16 | | | Average anthropogenic heat (AH) generated by vehicles parked during warm period | Calculation in W / m² with Heliodón program based on regulations in force on the site or similar method. | 26.7 $W/m^2$ |
| 17 | | | Urban albedo (UA) average of horizontal areas during warm period | “ | 28.2 $W/m^2$ |
| 18 | | Profile | Average building area | The use of a tape measure, laser distance meter and / or the application of Google Maps as an auxiliary method or similar method is suggested. | 44.4 $m^2$ |
| 19 | | | Average building height | “ | 4.7 m |
| 20 | | | Average urban albedo (UA) of vertical areas during warm period | Calculation in W / m² with Heliodón program based on regulations in force on the site or similar method. | 23.7 $W/m^2$ |
| 21 | | Vegetation | Average tree canopy area | The use of a tape measure, laser distance meter and / or the application of Google Maps as an auxiliary method or similar method is suggested. | 4.4 $m^2$ |
| 22 | | | Average tree shaded area during warm period | “ | 7.0 $m^2$ |
| 23 | | | Average solar permeability (SP) during warm period | A solar permeability measurement model is developed based on literature and regulations in force at the site or similar method. | Media |
| 24 | | Public furniture | Average urban albedo (UA) on public furniture during warm period | Calculation in W / m² with Heliodón program based on regulations in force on the site or similar method. | 26.8 $W/m^2$ |
| 25 | | | Average vertical areas on public furniture | The use of a tape measure, laser distance meter and / or the application of Google Maps as an auxiliary method or similar method is suggested. | 2.4 $m^2$ |

*Source: Compiled by author*

## 4. Conclusions

Based on the results, it is determined that the development of the THI contributes to the relationship and adaptation between man and his environment, and is referred to the integration which results from the ability to satisfy human needs and their expectations of development and interaction in an exterior public space. On the other hand, the thermal comfort sensation can be affected by the level of activity that a person performs, as well as their level of clothing depending on the environmental characteristics. Nevertheless, this is of interest not only when it is about evaluating a situation, but when the intention is to modify a thermal environment.

It is concluded that the Comfort Formula (COMFA) Brown and Gillespie (1995), with adjustments made and needs of the study, was a benchmark in the development of THI in outdoor public living spaces due to the characteristics of the method and its interrelation of meteorological variables, of the inhabitant and urban context.

The generalized application of the method is evident in its inclusion as part of the regulations related to the thermal environment evaluation. According to values obtained from the Spearman correlation, the thermal environment variables for the development of the index, were found to be the most influential and linear association, due to the effect on the estimate of the inhabitants level of sensation (0.020 r2), preference ( 0.038 r2), tolerance (0.049 r2) and thermal acceptance (0.043 r2), r2 *which means coefficient of determination*, as well as the variables of urban context, had greater incidence in the preference and thermal acceptance of the inhabitants surveyed by 2 and 3 points respectively , in relation to the sensation and thermal tolerance for the warm period.

According to the data analysis with the Spearman correlation, the wind speed (WS) variable had greater bilateral association with the ordinal variables.

The conclusions that are derived from the research work presented, link the topics discussed, which are the thermal environment, habitability and urban planning, the confluence and analysis of each of its parts was what allowed the Index to develop of Thermal Habitability for outdoor public living spaces. The indicators proposed to obtain the THI, permit the evaluation of the performance levels and parameters that link the strategies of progress and improvement for exterior public coexistence spaces with the index that is obtained and for the desired purposes. This way, it is recommended that this index be taken advantage of, despite the characteristics of outdoor spaces and weather conditions of the application site.

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