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Thermographic analysis and influence of colour on the temperature of building materials in a warm sub-humid climate

Análisis termográfico y la influencia del color en la temperatura de los materiales de construcción en un clima cálido subhúmedo

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Abstract

This work presents the results of the research carried out in the Bachelor of Architecture of the FEPZH; research that was also presented in the event of the 29th edition of the summer of science of the UASLP, and deals with the fluctuation in the balance of thermal comfort that can cause the color of the constructive elements; It analyses the oscillation and differences in the temperature of the different walls built with block of different thicknesses; 10cm, 12cm, 15cm, and 20cm; in order to obtain objective information to be able to recommend the range of colors for the sub-humid quality zone, such as Ciudad Valles, and thus support the decision making of urban planners and professionals who are dedicated to architectural design. In June 2023, the nine objects of study were built; walls with a surface area of one square meter, to which paints of different shades were applied, and subsequently the temperatures were recorded with the help of measuring equipment obtained thanks to the support of PRODEP.

Comfort, Temperature, Color walls

Resumen

Este trabajo presenta resultados de la investigación que se realiza en la Licenciatura de Arquitectura de la FEPZH, para el evento de la 29a edición del verano de la ciencia de la UASLP, y trata sobre el confort térmico generado por el color de los elementos constructivos; se analiza la oscilación y diferencias de la temperatura que originan los distintos colores aplicados en los muros construidos a base de block en distintos espesores; 10cm, 12cm, 15cm, y 20cm; con el fin de obtener información objetiva para poder recomendar la gama de colores para la zona calidad subhúmeda, como lo es Ciudad Valles, y así apoyar a la toma de decisiones de los urbanistas y profesionistas que se dedican al diseño arquitectónico. En el mes de junio del año 2023 se construyen los nueve objetos de estudio; muros de una superficie de un metro cuadrado; a los que se les aplican pinturas de distintas tonalidades y posteriormente se registran las temperaturas con ayuda de equipos de medición que se obtuvieron gracias al apoyo del PRODEP.

Confort, Temperatura, Muros de color

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Introduction

It is common to find manufactured environments that are worse than the natural environment. This contrasts with the role of architecture and urban planning to provide a corrected environment according to the individual's needs. New architecture and good urban planning must necessarily relate to man, architecture, and climate, achieving a conciliation between them (Álvarez, 2004).

Ciudad Valles, San Luis Potosí is located at the geographical coordinate 21°59′ 12″N 99°01′ 07″W, located at 85 masl on average, it has a warm sub-humid AW0 climate with a considerable relative humidity of 78% due to the influence of hydrology and the vegetation that abounds due to the proximity to the Sierra Madre Oriental, the average temperature is 24. 7°C; minimum of 6°C and maximum of 47°C according to SMN-CONAGUA information; and according to City newspapers; with maximums of up to 56°C with a thermal sensation of 60°C; wind speed is 6km/hr.

Color	Period	Hours	Recommendations
Red	May to September	11:00 to 19:00	Control of solar radiation, relative humidity and radiant temperature. Mechanical ventilation is required..
Orange	April	13:00 to15:00	Control of solar radiation and radiant temperature. Generate wind.
Yellow	March to November	24 hours	Decrease relative humidity, radiant temperature and daytime solar radiation.
Gray	Dicember to January	11:00 to 17:00	No intervention necessary as long as there are solar obstructions.
Gray	February	10:00 to 13:00	No intervention necessary as long as there are solar obstructions.
Blue	November, Dicember, January, and February	Before 10:00 and after 18:00	Decrease wind and increase radiant temperature.
Purple	January, February and Dicember	3:00 to 8:00	Increase radiant temperature.

Table 1 Bioclimatic recommendations for Ciudad Valles *(Zapata, 2021)*

As shown in table 1, Ciudad Valles has an unfavorable climate during most of the year and most of the hours of the day, so it is anticipated that a good thermal performance of the materials is necessary to cushion the climatic effects that affect the indoor environment of the dwellings and the outdoor urban spaces.

Thermal comfort in dwellings is the hydrothermal perception that people have of the interior of the spaces they inhabit. The definition of this term is inspired by the achievement of harmony between temperature and relative humidity. This concept implies that the people living in the dwellings perceive a neutral thermal sensation. In other words, the atmosphere they experience is neither hot nor cold. It is the perfect point for there to be a temperature balance without the need for people to sweat. Thermal comfort in dwellings is of vital importance because discomfort caused by inadequate temperature can affect people's health. However, it is not only used to evaluate the quality of the environment in a house, but also for spaces with other uses, such as outdoor spaces.

Color and temperature have a curious physical relationship and, as such, can be explained by science. This determines, for example, which colors absorb heat and which repel it. Thermal energy obeys the same conservation laws as light energy. This is the key that reveals the secrets of binomial color and temperature. If a given substance reflects most of the wavelengths of light, it will also reflect most of the thermal energy. Therefore, because of the visible nature of the light spectrum, colors that reflect most wavelengths of light tend to be cooler than those that reflect only a few wavelengths. In other words, colors that reflect more lighter repel more heat.

Heat is a form of energy that is spontaneously transferred between different areas of the body or from one body to another. Heat and temperature are different things, although they are closely related. Heat is the transfer of thermal energy from a body of higher temperature to a body of lower temperature. Temperature, on the other hand, is the physical quantity that measures the thermal state of a body and the kinetic energy of its molecules.

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Objective

In the present research, the objective is to record the temperature of the block walls over a period of three months, to analyze with the support of graphs produced in Excel, the oscillation and temperature differences that are generated on the surfaces of the construction elements due to the different colors; and with the support of the comfort ex application, the balance of thermal comfort of the person is calculated, by entering the different temperature values recorded. With this we intend to simulate the impact that the colors applied on the walls have on the thermal comfort of the person. The objects of study are nine walls built with blocks of different thicknesses; 10cm, 12cm, 15cm and 20cm, covered with vinyl paint in the following colors: white, cream, lime green, orange, blue, gray, brown, dark green and black.

Objectives

As particular objectives, in addition to carrying out a documentary analysis of the literature on the subject and integrating a photographic file, the specific objectives of the research are as follows: to construct the nine objects of study, record the temperatures of the walls, take pictures with the thermographic camera, and once the data is obtained, a database is created in Excel to organize it and obtain comparative graphs to analyze the results. In addition to Excel, the comfort ex application is used to calculate the thermal comfort balance by adjusting the temperature of the walls to identify the variation generated by each color.

Hypothesis

The hypothesis behind this research is that the colors used and the thickness of the block influence the sensation of thermal comfort in urban and architectural spaces, and particularly the temperature of the construction elements themselves. To date, there is no record of similar research for the warm subhumid zone, specifically in Ciudad Valles, San Luis Potosí, so that the temperature variation between different colors such as black and white can be up to 5ºC, and grey vs. white can be 3ºC.

This is according to previous activities and assumptions made by the research group formed by the students of the subject Sustainable Living Spaces, of the seventh semester of the Bachelor of Architecture of the FEPZH of the UASLP, also directed by the advisor of the present research.

Problematic

The strong sun exposure in the city, as well as the prolonged time of sun exposure, causes buildings to heat up and therefore creates uncomfortable environments for people in indoor and outdoor spaces, which reduces the quality of life in the city. This also causes people to avoid walking outdoors during the day, thus, businesses are also affected during the day. Ciudad Valles is gradually becoming a tourist city, therefore, it is important to provide comfortable urban spaces for people visiting the city.

The building regulations do not specify a relevant color range of urban spaces, or construction projects, therefore, many buildings use dark colors, which are believed to increase the air temperature in outdoor spaces. The regulation identifies the need to adapt buildings to the context, however, in most cases, it is interpreted only as giving the same architectural language to buildings in the same area; a visually similar design to neighboring buildings to make the urban area look homogeneous.

Justification

It is considered that this research helps to have objective evidence of temperature variations and excessive heating caused by the colors applied in the constructive elements such as walls; with which the specialized personnel in the different disciplines that deal with urban interventions, as well as the authorities in charge of updating construction regulations and generating urban improvement projects, will be convinced to add particular specifications such as the use of appropriate colors according to the climate of the region.

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In addition to the above, it is considered that it is possible to improve the urban environment, because by buffering the climatic and environmental conditions of the region; outdoor spaces become more friendly areas for pedestrians and tourists, which can lead to greater social, pedestrian and of course commercial movement in the downtown area; likewise, it would improve the hygrothermal environment inside the family home by reducing the interior heat.

Approach

The research has a mixed approach, since we use measurement equipment, hard data, and thermal comfort, balance calculations with the help of software; with which it is possible to understand and describe the causes and consequences of the physical environmental factors in the context of the construction elements and of course on people's sensations.

Theoretical framework and Methodology

As a theoretical framework, the research is based on the studies and procedures of Ochoa de la Torre, Olgyay, Givoni and the research advisor; where from hard data it is possible to generate graphs and calculations where the physiological characteristics of the constructive, environmental, physical and subjective elements influence to determine the effects on the balance of thermal comfort of the person.

An example of this is the methodology used for the research study "Análisis de la evolución del confort en la vivienda en serie en Ciudad Valles, S.L.P." and the article "Comfort's evolution analysis of low-cost housing in Ciudad Valles, S.L. P" published in the year 2021, where the microclimatic variables within six social housing units are compiled during one year and then psychometric graphs are used to verify if the interior environments of the houses are comfortable or not. Based on this analysis, it is possible to show some of the climatic and constructive causes that provoke discomfort conditions.

Methodology

Bibliographic research is conducted, and the climatological normal of the city is verified to verify the climate of the region and especially the ambient temperature, which shows that the city is extremely hot. In June 2023, the objects of study were built with the help of the research group formed by the students of the sustainable living spaces course. These walls were made of 10 cm, 12 cm, 15 cm, and 20 cm thick cement blocks.

For the placement of the walls, a 25 cm deep trench was dug where a 20x25 cm cross-section concrete ditch was built, reinforced with stainless steel. Once the concrete had set, the block walls were placed on these ditches with the help of a hand level, a plumb line, and a mason's spoon. The mortar used for the block jointing was of a 1:3 ratio (one portion of cement to three portions of sand), and the thickness of the jointing was 1 cm. Once the mortar dries, the vinyl paint is applied to the walls. Once the elements are finished, they are painted with different shades of color.

Figure 1 Wall construction
Source: Own Elaboration

According to the research on thermal comfort in Ciudad Valles, it was decided to monitor the temperature of the walls at 9:00 h, 11:00 h, 13:00 h, 15:00 h and 17:00 h, since these hours cover the periods of the day when people feel the hottest in the city.

Figure 2 Coating 11:00h
Source: Own Elaboration

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The consultant organizes a training session on how to use the following measuring equipment: Milwaukee thermographic camera model 2257-20, which is used to take pictures in a range of colors ranging from blue to red, which indicate the temperature of the material in degrees Celsius; Steren infrared thermometers model HER-427 are used to measure the temperature of the surface of the walls in degrees Celsius; the pocket weather station Kestrel model 3500, is used to measure the air temperature in degrees Celsius, the percentage of relative humidity of the air %H. R., and also records wind speed in kilometers per hour or meters per second; and finally, Steren HER-408 lux meters are also used to measure light intensity in lux.

A database is designed with a format to record all measurements, so that when they are captured, the graphs are automatically generated. This is achieved with the help of training in the use of the Excel program.

After having organized the cabinet and research work, as well as having the walls built with the paint already dry, we proceeded to start the temperature measurements to record them and then capture them in the computer.

Figure 3 Measurements 9:00h
Source: Own Elaboration

With the luxmeters, the illumination is recorded to show that all the walls receive an average amount of light, therefore, they are in the same light conditions.

Figure 4 Example of luxmeter recordings
Source: Own Elaboration

Using the thermographic camera, temperature differences can be distinguished in a range of colors. This makes it possible to analyze oscillations and larger differences in wall temperature.

Figure 5 Example of images taken with a thermal imaging camera
Source: Own Elaboration

After having the record of the weeks, we now proceed to work on the application Confort - Ex; where the first exercises are done, which in this case were only six, since the intention is to continue and complement the research. The exercises consist of capturing microclimatic parameters of different environmental scenarios and modifying the temperature of the materials according to the records.

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The thermal comfort, balance calculated by the application shows if there are significant differences in the environment derived from the colors used in the objects of study.

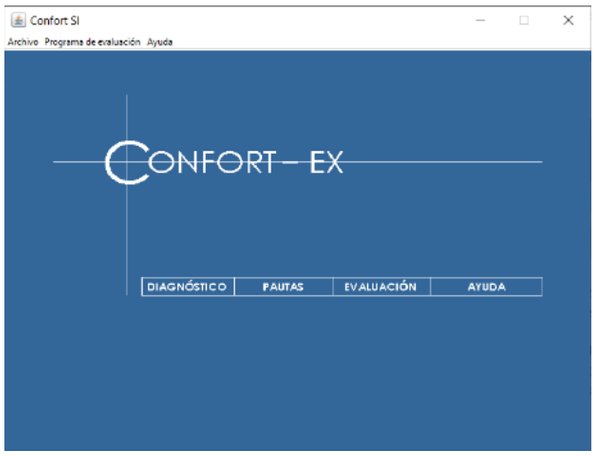


Figure 6 Comfort Ex application
Source: Own Elaboration

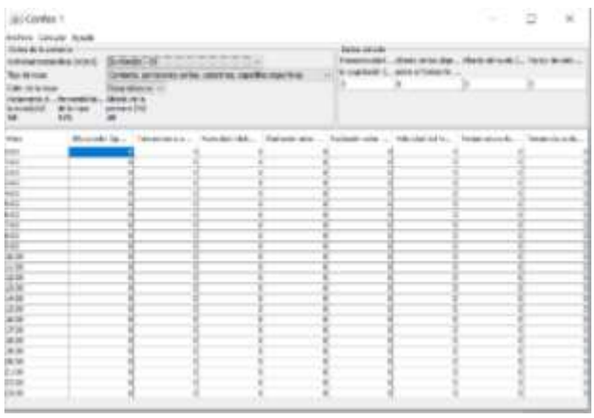
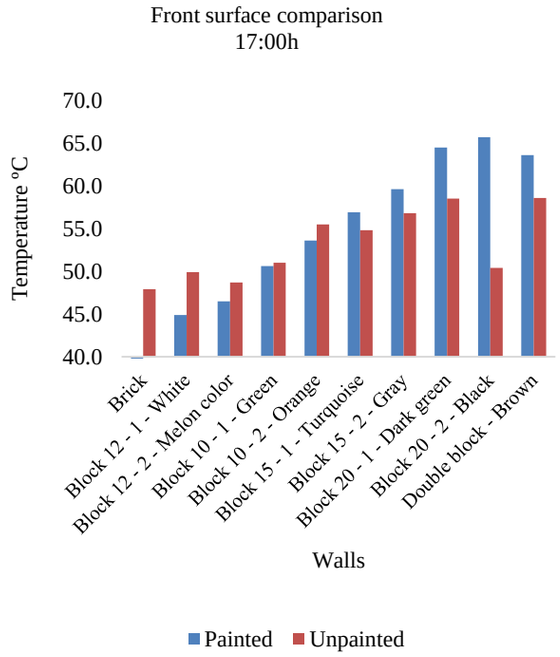


Figure 7 Comfort balance calculation interface
Source: Own Elaboration

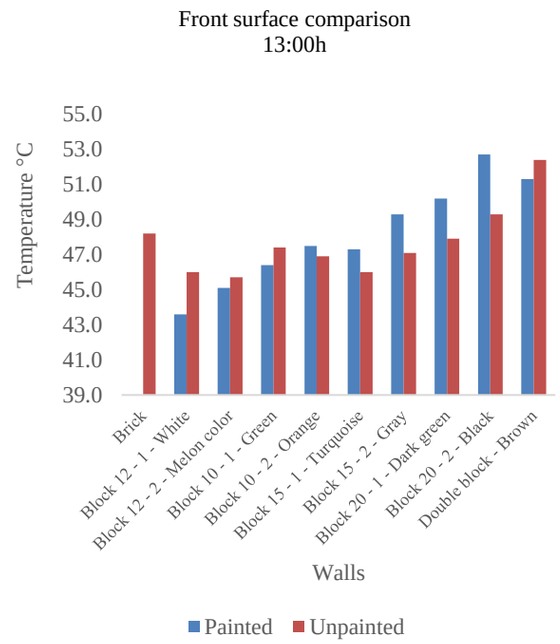
With the above, the first stage of the research is finished and the present document is elaborated.

Results

When comparing the temperatures of the blocks without paint, it can be observed that the maximum difference is 6°C at 13:00 h, which is when the energy accumulates in the material, as shown in graph 1. Once the blocks are painted, it can be observed that the light colors in most of the hours lower the temperature of the walls up to 5°C, while the walls with medium and dark paint increase the temperature of the wall from 7°C to 15°C, as is the case of the black color, as shown in graph 2.



Graph 1 Temperature comparison July 13 17:00 h.
Source: Own Elaboration



Graph 2 Temperature comparison July 21 13:00 h.
Source: Own Elaboration

Regarding the highest temperatures of the walls, they are identified at 17:00 h as shown in graphs 3 and graphs 4, where it is shown that, due to the color, the walls have differences of up to 25ºC. Another thing that is detected is that the thickness of the block does influence the heating of the walls, to the surprise of the research team, the 20 cm block heats up more in the front part than the wall with a thickness of 10 centimeters; and when the temperature of the back part of the walls with similar temperatures is observed.

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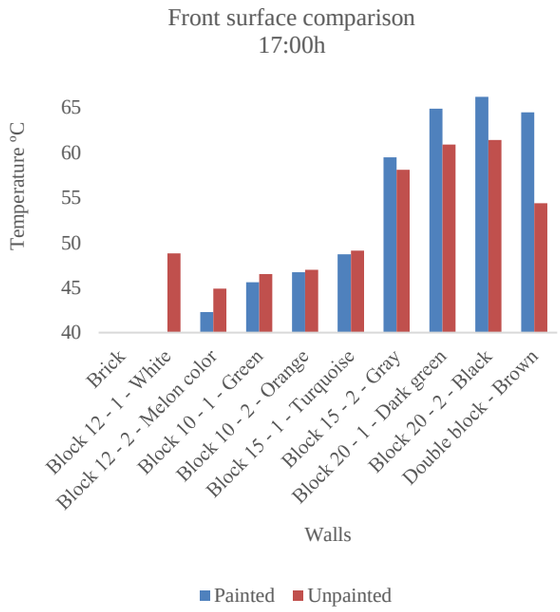
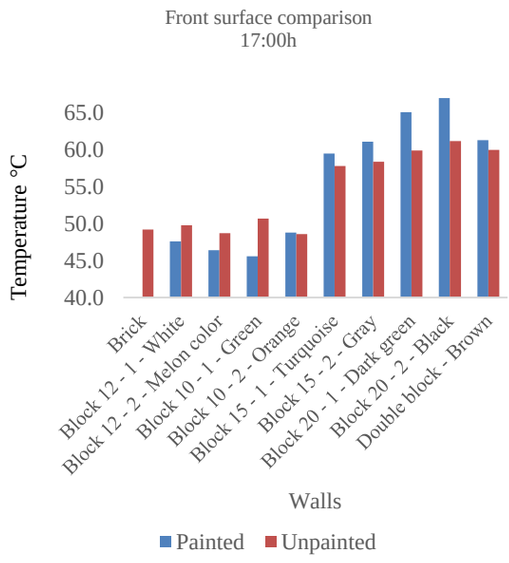
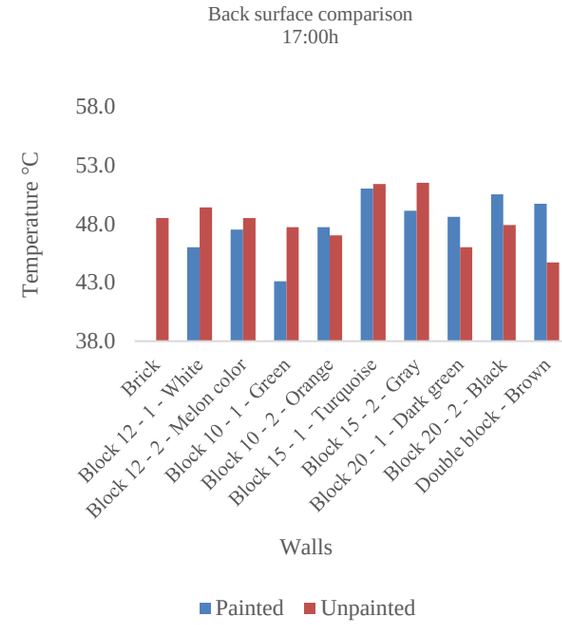
It can be seen that on average, the insulating capacity is better in the 10cm wall and in the 20cm thick wall, as can be compared in graphs 4 vs. graphs 5.



Graph 3 Front temperature comparison 15 July 17:00h
Source: Own Elaboration



Graph 4 Front temperature comparison 21 July 17:00h
Source: Own Elaboration



Graph 5 Back temperature comparison 21 July 17:00h
Source: Own Elaboration

When calculating the thermal comfort balance in the comfort ex application, it is observed that the color does influence the results, but in a relatively small percentage compared to the influence on the temperature of the objects. We speculate that this is since the radiation generated by a block element does not have a significant distance range, so it is inferred that its contribution to the feeling of comfort in the environment is rather long term. This can be verified by approaching the walls to determine the approximate distance at which the sensation of heat is appreciated, which ranges between 30 cm and 40 cm. Therefore, as soon as we move away from the wall, the radiation is no longer felt.

Hours	Absorbed radiation W/m2	Energy balance W/m2
00:00	◦	◦
01:00	◦	◦
02:00	◦	◦
03:00	◦	◦
04:00	◦	◦
05:00	◦	◦
06:00	◦	◦
07:00	◦	◦
08:00	◦	◦
09:00	288.69	-5.42
10:00	◦	◦
11:00	306.77	68.75
12:00	◦	◦
13:00	323.58	182.35
14:00	◦	◦
15:00	381.65	188.46
16:00	◦	◦
17:00	441.02	187.76
18:00	◦	◦

Figure 8 Comfort balance 001, Black color
Source: Own Elaboration

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Hours	Absorbed radiation	Energy balance W/m2
00:00	º	º
01:00	º	º
02:00	º	º
03:00	º	º
04:00	º	º
05:00	º	º
06:00	º	º
07:00	º	º
08:00	º	º
09:00	291.09	-3.02
10:00	º	º
11:00	308.42	70.41
12:00	º	º
13:00	329.61	187.82
14:00	º	º
15:00	388.61	195.42
16:00	º	º
17:00	421.85	168.6
18:00	º	º

Figure 9 Comfort balance 001, White color
Source: Own Elaboration

Hours	Absorbed radiation W/m2	Energy balance W/m2
00:00	º	º
01:00	º	º
02:00	º	º
03:00	º	º
04:00	º	º
05:00	º	º
06:00	º	º
07:00	º	º
08:00	º	º
09:00	291.09	-3.02
10:00	º	º
11:00	311.83	73.81
12:00	º	º
13:00	331.89	190.67
14:00	º	º
15:00	393.86	200.67
16:00	º	º
17:00	428.29	175.04
18:00	º	º

Figure 10 Comfort balance 001, Gray color
Source: Own Elaboration

Thanks

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Conclusions

After the time invested in the bibliographic studies, it can be affirmed that there is no research on the impact of color on the temperature of the walls in the hot subhumid zone, specifically in Ciudad Valles, San Luis Potosi. In the same way, little evidence of research on thermal comfort in interior and exterior spaces in the city is detected when it is considered that it is necessary because the city has an extremely hot climate.

The difference in block thickness does contribute to the time in which the material cools down or heats up; the color difference has more impact on the surface temperature of the material than on the thermal comfort balance of the person, however, it is important to express the assumption that a black urban area can generate a lot of radiant heat that in the end will be transmitted to the air temperature and could generate hot environments for the pedestrian.

It is particularly important to continue this type of research, since they are interesting and with them it is possible to verify and advise home users about the oscillation and maximum differences that the temperature of their walls can present with a specific color, because to date the work team had no exact idea of the differences. It is well known that light colors vs. dark colors are cooler, but it was not known by how many degrees Celsius. The experience, the learning and the results were generated in an objective way, thanks to the application of measuring equipment and the application of calculation software; which was another thing that the team did not know: the fact of creating a link between the measured parameters, in relation to the subjective information about the people to calculate the thermal comfort balance.

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