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Guerra-García, Lina Marcela; Ferreira-Tinôco, Ilda de Fátima; Osorio-Saraz, Jairo Alexander; Osorio-Hernández, Robinson

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Thermal comfort in buildings for wet processing of coffee

Confort térmico en edificaciones para procesamiento húmedo de café

Conforto térmico em instalações para processamento úmido de café

Lina Marcela Guerra-García
Ilda de Fátima Ferreira-Tinôco
Universidade Federal de Viçosa. Viçosa (Brasil)
Departamento de Engenharia Agrícola

Jairo Alexander Osorio-Saraz
Universidad Nacional de Colombia. Medellín (Colombia)
Facultad de Ciencias Agrarias. Departamento de Ingeniería Agrícola

Robinson Osorio-Hernández
Universidad Nacional de Colombia. Bogotá (Colombia)
Facultad de Ingeniería. Departamento de Ingeniería Civil y Agrícola

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Lina Marcela Guerra-García
Architect, Universidad Nacional de Colombia, Medellín (Colombia).
PhD, MS in Agricultural Engineering—area of Rural Constructions and Bioclimatics, Universidad Federal de Viçosa (Brasil).
https://orcid.org/0000-0001-9115-9057
lmgg1220@gmail.com

Ilda de Fátima Ferreira-Tinôco
Agricultural Engineer, Universidad Federal de Lavras (Brasil).
PhD, MS in Agricultural Engineering—area of Rural Constructions and Bioclimatics, Universidad Federal de Lavras, Viçosa (Brasil).
https://orcid.org/0000-0002-4557-8071
iftinoco@ufv.br

Jairo Alexander Osorio-Saraz
Agricultural Engineer, Universidad Nacional de Colombia, Medellín (Colombia).
MS in Materials and Process Engineering, Universidad Nacional de Colombia, Medellín (Colombia)
Ph.D. in Agricultural Engineering—area of Rural Constructions and Bioclimatics, Universidad Federal de Viçosa (Brasil).
https://orcid.org/0000-0002-4358-3600
aosorio@unal.edu.co

Robinson Osorio-Hernández
Agricultural Engineer, Universidad Nacional de Colombia, Medellín (Colombia).
PhD, MS in Agricultural Engineering—area of Rural Constructions and Bioclimatics, Universidad Federal de Viçosa (Brasil).
https://orcid.org/orcid.org/0000-0002-8698-7234
rosorioh@unal.edu.co

Resumen

Este estudio tuvo como objetivo evaluar el confort térmico para trabajadores, en tres edificaciones de procesamiento húmedo de café en Colombia, utilizando el índice WBGT, y análisis de temperatura y humedad relativa a través de mapeo. Los límites recomendados del WBGT fueron excedidos en la actividad de abastecimiento de combustible de la secadora en la Edificación 3. Las tres edificaciones presentaron variabilidad higrotérmica espacial debida a la secadora de café, y a problemas con la ventilación, volumen de control y resistencia térmica de materiales en los edificios 2 y 3. Para favorecer la transferencia de calor de la secadora al ambiente exterior, y hacer más homogéneo el ambiente térmico de las edificaciones, se recomienda instalar puentes térmicos alrededor de esta zona, y para hacer más eficiente la evacuación de vapor y calor, aumentar el área de ventilación natural en las edificaciones 2 y 3, e instalar claraboyas de ventilación sobre la secadora.

Palabras clave: Arquitectura bioclimática; estrés térmico; evaluación posocupacional; índice WBGT (Wet Bulb Globe Thermometer); resistencia térmica; ventilación natural.

Abstract

This study aimed to assess thermal comfort for workers in three buildings for wet coffee processing in Colombia, using the WBGT index, and temperature and relative humidity analysis through mapping. The limits recommended by the WBGT index were exceeded during the activity of putting fuel in the dryer in Building 3. The three buildings presented spatial hygrothermal variability due to the coffee dryer, as well as problems with ventilation, volume control, and the thermal resistance of materials in Buildings 2 and 3. In order to favor heat transfer from the dryer to the outside environment, and to make the thermal environment of these buildings more homogeneous, it is recommended to install thermal bridges around this area, to make more efficient the evacuation of steam and heat, as well as to increase the natural ventilation area in Buildings 2 and 3, and install ventilation skylights over the dryer.

Keywords: Bioclimatic architecture; thermal stress; post-occupation evaluation; WBGT (Wet Bulb Globe Thermometer) index; thermal resistance; natural ventilation.

Resumo

Este estudo tem como objetivo avaliar o conforto térmico para trabalhadores em três instalações de processamento úmido de café na Colômbia, utilizando o índice WBGT, a análise de temperatura e a umidade relativa através de mapeamento. Os limites recomendados do WBGT foram excedidos na atividade de abastecimento de combustível da secadora na Instalação 3. As três edificações apresentaram variabilidade higrotérmica espacial devidas à secadora de café e a problemas com ventilação, volume de controle e resistência térmica de materiais nos edifícios 2 e 3. Para favorecer a transferência de calor da secadora para o ambiente exterior e tornar mais homogêneo o ambiente térmico das edificações, recomenda-se instalar pontes térmicas ao redor dessa zona e, para tornar mais eficiente a evacuação de vapor e calor, aumentar a área de ventilação natural nas edificações 2 e 3, bem como instalar claraboias de ventilação sobre a secadora.

Palavras-chave: arquitetura bioclimática; estresse térmico; avaliação pós-ocupacional; índice WBGT (Wet Bulb Globe Thermometer); resistência térmica; ventilação natural.

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Introduction

Taking into account that Colombia and Brazil, two tropical countries in South America, are the main coffee producers of the continent (third and first world producers of coffee, respectively), and taking advantage of an existing agreement between the Federal University of Vicosa, Brazil (UFV), and the National University of Colombia (UNAL), this research sought to contribute to the study of bioclimatic architecture in the agro-industrial sector, considering all the negative effects that thermal stress can generate in workers as well as the scarcity of studies that analyze such conditions in agro-industrial buildings. In accordance with the above, this work aimed to evaluate thermal conditions inside three buildings for wet coffee post-harvest handling in Colombia, and their effect on the level of thermal stress in workers; to the effect, this study was carried out in collaboration between the UFV and the UNAL

Studies about environmental conditions suggest that the microclimate inside coffee processing buildings and storage units not only may affect the quality of coffee (Osorio *et al.*, 2015), but it can also influence the productivity of workers and the quality of their labor (Revueltas et al., 2015), as well as the concentration of people (Viloria *et al.*, 2016).

In Colombia, coffee processing is carried out in humid conditions (Lee et al., 2015), where water is used to pulp coffee cherries in order to remove the exocarp and mesocarp. Subsequently, the mucilaginous layer surrounding the seeds is removed through a natural fermentation or a mechanical process, then it is washed and a hydraulic classification is carried out to finalize with grain drying (Osorio et al., 2016; Osorio et al., 2019), which can be solar or mechanical; 70% of the coffee produced in Colombia is mechanically dried (Gonzalez et al., 2010). According to different studies, facilities of this type have dryers located in the same buildings where wet processes are performed, characterized by being closed, with some openings for ventilation (Osorio et al., 2015; Osorio et al., 2016).

In buildings for wet coffee processing in Colombia, with drying machines inside (Ciro Velásquez *et al*., 2011), heat and vapor emissions are generated, which can heat and moist said facilities when they cannot be transmitted to the outside (Osorio *et al*., 2016); this may jeopardize the workers' health and their productivity, as well as coffee quality (Oliveros *et al*., 2013). These unfavorable environmental conditions, combined with heavy physical work, such as those developed in these buildings, can produce thermal stress, resulting in the weakened general state of health, changes in psychosensory reactions, and fall in production (Lamberts *et al*., 2008).

According to Rivero (1986), there are several factors involved in the production of heat in human beings, such as sex, age, degree of acclimatization to the environment, but mainly any physical activity performed. The thermal overload varies from one activity to another, depending on the metabolic activity and physical effort involved in the work (Carvalho, 2011; Bitencourt *et al*., 2012; Todd & Valleron, 2015).

According to Iida (2005), temperature differences that occur in the same environment should not exceed 4 °C. In addition, environmental temperature that exceeds 30 °C increases the risk of damage to the worker's health.

In order to evaluate human performance in the workplace under conditions of exposure to heat, the Wet Bulb Globe Temperature (WBGT) index has been used as established by standards, such as Resolution 2400 of 1979 to establish some provisions on housing, hygiene, and safety in the workplace in Colombia (Ministerio de Trabajo y Seguridad Social de Colombia, 1979), the International Standard ISO 7243 (2017) to estimate the heat stress of workers (International Organization for Standardization, 2017), and the regulatory standard of the Ministry of Labor and Employment of Brazil—NR 15, Annex No. 3 (Ministério do Trabalho e Emprego, 2011).

There are few studies related to the effect of heat and/or humidity on agro-industrial workers (Herrera *et al*. 2015); for example, there are studies about sugar cane harvest workers (Roscani *et al*. 2017), workers of a corn-based food processing company (Herrera *et al*., 2015), workers in chicken sheds (Carvalho *et al*. 2014), and workers in the cold pork meat industry (Evangelista & Borges, 2015). Most bioclimatic studies and research have been carried out in urban areas, which is why at the moment there are no studies applying the WBGT index in buildings for post-harvest processing of coffee.

A bioclimatic design seeks to achieve high-level thermal comfort by adapting the geometry, orientation, and construction of the building to the climatic conditions of its surroundings, by means of elements and specific constructive solutions (Lamberts *et al*., 2014)

Methodology

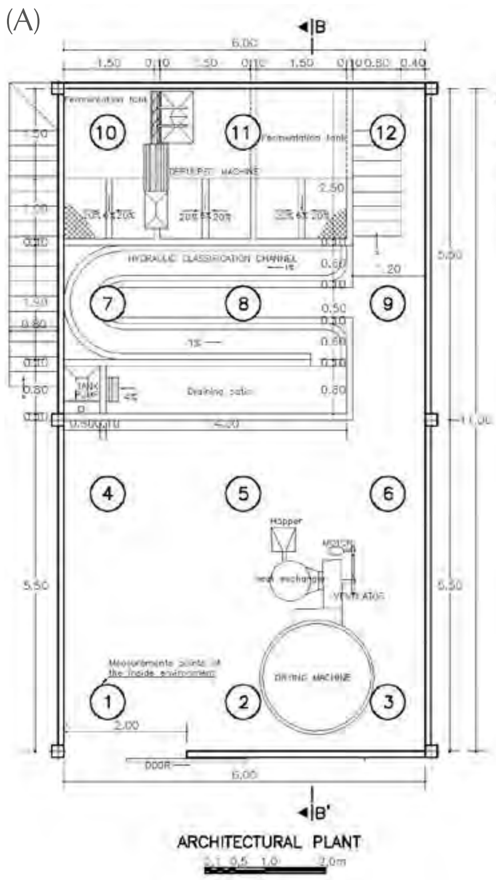
To carry out this study, three buildings for wet processing of coffee were selected, called Building 1, 2, and 3.

To make this selection, similar characteristics were considered, such as geographic and climatic conditions. All of them are close to the city of Medellín, Antioquia, Colombia (north of the city), and their exact locations are as follows: Building 1: city of Barbosa, N06° 24'47.64", W75° 20'47.08", 1508 m; Building 2: city of Bello, N06° 21'42.16", W75° 34'44.83 ", 1698 m; and Building 3: city of San Roque, N06° 29'22.79'', W75° 00'41.86", 1435 m, all with external average temperature between 20 and 22 °C (IDEAM, 2019). Other similar climatic characteristics that correspond to humid tropical climate (Af) according to the Köppen classification system (Kottek, 2006) were also considered, such as same production volume of 30 tons of parchment coffee per year (150 tons of coffee cherry per year, 1125 kg dry parchment coffee per day), mechanical drying, and maximum production period between October and November, which coincides with the second rainfall season in this region of Colombia (Oviedo & Torres, 2014).

Since harvest occurs in rainy seasons, the warmer period was not taken into account in this case, since there is no activity inside the facilities then. For this reason, only the main harvest period was analyzed, which shows a longer occupation time during the second harvest of the year.

Figures 1(A), 2(A), and 3(A) show the architectural plans of Buildings 1, 2, and 3, respectively,

(A)



(B)

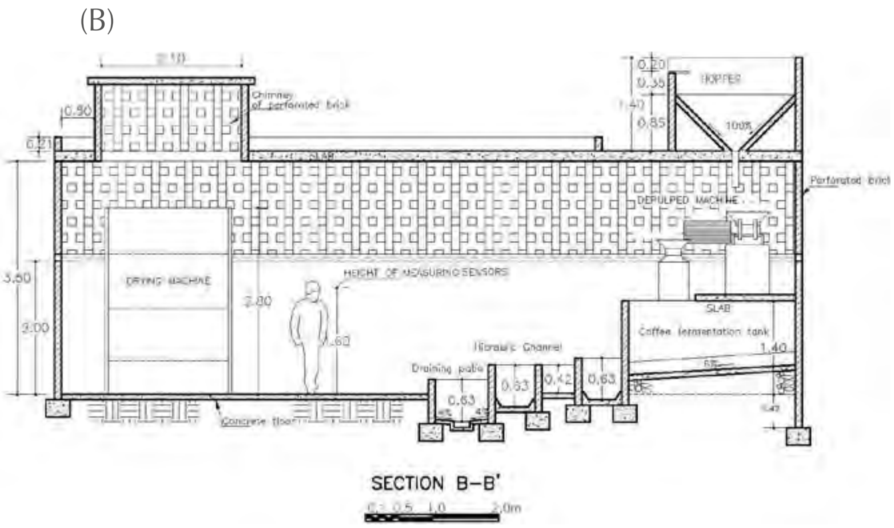


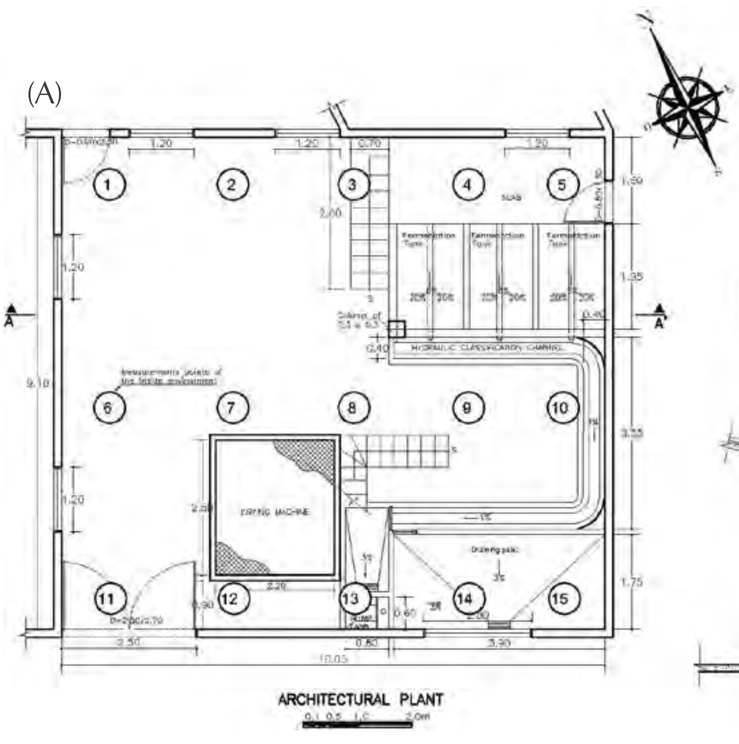
Figure 1. Building 1. (A) Distribution of measurement points (in circles) in the architectural plan; (B) Cross-section plan

Source: Authors.

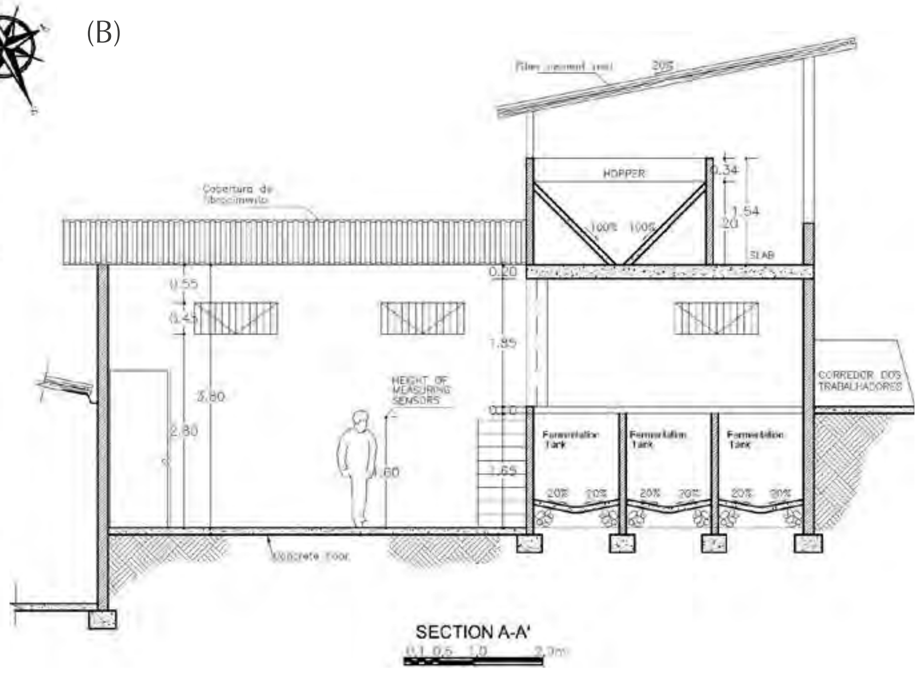
Figure 2. Building 2. (A) Distribution of measurement points (in circles) in the architectural plan; and (B) Cross-section plan

Source: Authors.

(A)



(B)



and the distribution of measurement points in the inside environment (in circles) of the three facilities for wet coffee processing. Figures 1(B), 2(B), and 3(B) show their cross-section plans.

Building 1 consists of one level of 6.0 m (W) x 11.0 m (L) x 3.50 m (H). Its walls are made of brick 0.15 m thick, at a height of 2 m, and there are perforated bricks for ventilation at 2 to 3.5 m, where they meet the slab that constitutes the roof, which has a thickness of 0.20 m, lightened with bricks. On the slab, there stands a kind of chimney on the dryer and the dry hopper. The concrete floors in sight, the lower part of the hydraulic classification channel, as well as the interior of the fermentation tanks have tile coating. There is a structure formed by columns and concrete beams (Figure 1).

Building 2 has two floors; most of the coffee processing is done on the first floor, while the reception of coffee cherry takes place on the second floor (in a hopper). The first floor is a plane of 9.10 m (W) x 10.05 m (L) x 3.60 m (H), with brick walls of

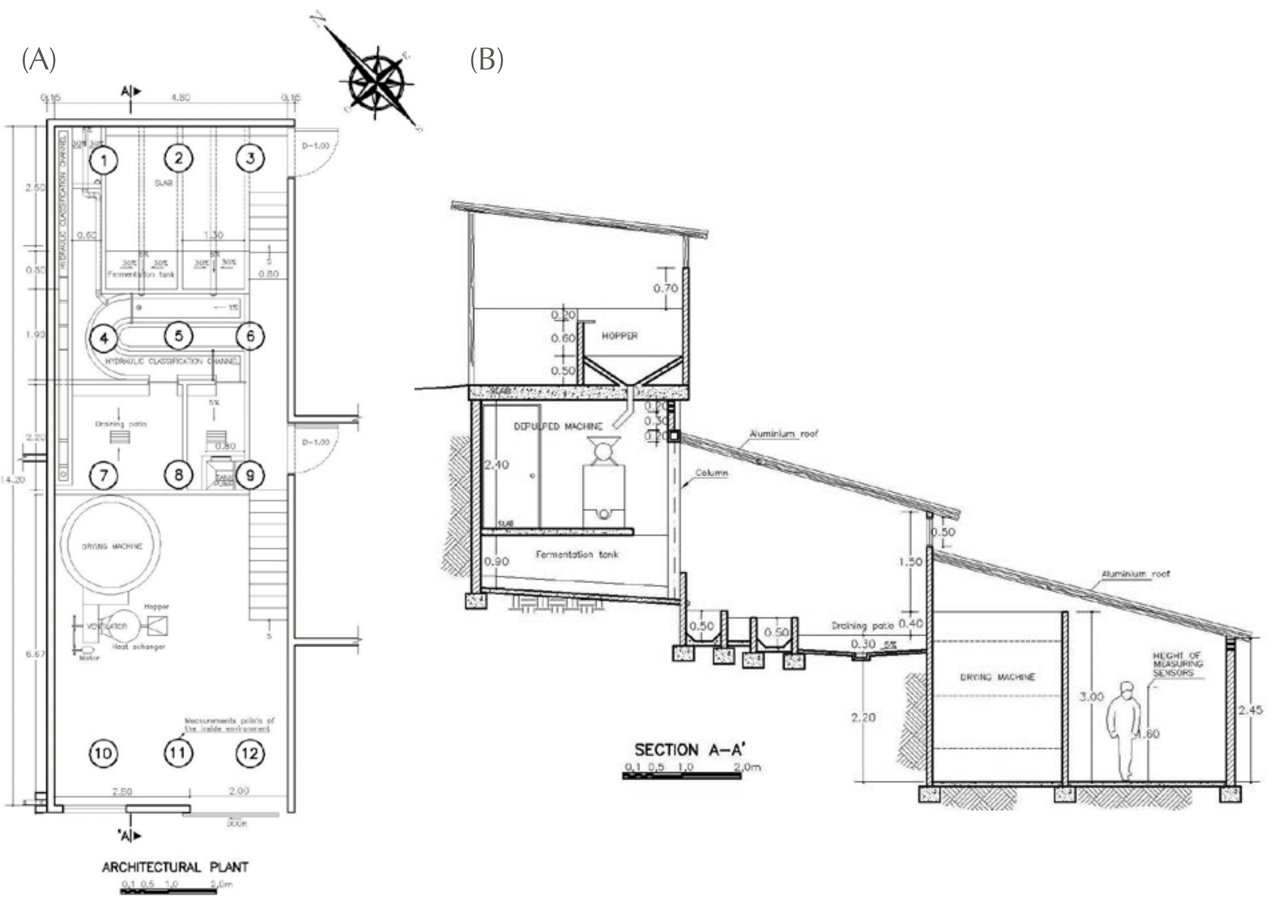


Figure 3. Building 3. (A) Distribution of measurement points (in circles) in the architectural plan; and (B) Cross-section plan.
Source: Authors.

0.15 m thick, with a layer of mortar at a height of 2 m inside. It has a lightweight slab roof with bricks that has a thickness of 0.20 m, at a height of 3.80 m, which covers a good part of the installation area. Part of the workers' house is built on this slab, and has an area dedicated to the dry hopper. The rest of the roof is a fiber cement roof, supported by a metal frame at a height of 3.50 m, of which a species of chimney stands out on the dryer. The floors have concrete lining, and tile floors in the lower part of the hydraulic classification channel and the fermentation tanks. The structure consists of columns and concrete beams to confine walls, and metal reinforcements to support the roof. Its openings for natural ventilation are composed of three doors and six windows (Figure 2).

Building 3 has a rectangular plant of 5.10 m x 14.52 m, divided into three grades to adjust to the terrain slope in a staggered way, with roof heights of 2.40 m, 1.90 m and 2.45 m, in ascending order. It has brick walls of 0.15 m thick, covered with a mortar of 0.02 m thick and white tile. The roof is aluminum in the lower part and slab in the upper part, lightened with brick, with a thickness of 0.20 m; there is a dry hopper on this slab (Figure 3). The floors are concrete lined with ceramic tiles. It has openings that take advantage of the unevenness of the facility beyond the access door on the highest level and the gate of the lowest level. The structure consists of columns and concrete beams.

Data were experimentally collected (temperature, relative humidity, and WBGT) for three days in each building between October and November 2016, as follows:

- Building 1: 25, 26, and 27 of October 2016.
- Building 2: 1, 2, and 3 of November 2016.
- Building 3: 9, 10, and 11 of November 2016.

The thermal comfort assessment was carried out based on two aspects: mapping of the temperature and relative humidity present in the facilities, and the WBGT index, the latter according to Resolution 2400 of 1979, issued by the Ministry of Labor and Social Security of Colombia, and to NR 15 (Ministério do Trabalho e Emprego, 2011), for evaluation of the thermal environment of workers exposed to heat.

Mapping of the temperature and relative humidity

In the three buildings, dry-bulb temperature (Tdb) and wet-bulb temperature (Twb) were measured using a Delta OHM digital thermometer, model HD 32.1 (f) ($-40 \leq Tdb \leq 100\,°C$, $4 \leq Twb \leq 100\,°C$). These measurements were taken during working hours (from 7 am to 7 pm), measured at the level of the head of the worker (1.60 m, indicated in Figures 1(B), 2(B), and 3(B)), with intervals of one hour, in different points distributed in each building, as indicated in Figures 1(A), 2(A), and 3(A). By means of these data, the values of relative air humidity in each point were extracted with the help of a psychrometric chart.

Based on the average data of temperature and relative humidity at each point, a mapping was