Bioclimatic modeling for determining the minimum area of natural ventilation in buildings for the wet processing of coffee

Robinson Osorio-Hernandez [a], Iván Darío Aristizábal-Torres [b], Jairo Alexander Osorio-Saraz [b],
Ilda de Fátima Ferreira-Tinôco [c] & Lina Marcela Guerra-Garcia [c]

[a] Department of Civil and Agricultural Engineering, Universidad Nacional de Colombia, Bogotá, Colombia. rosorio0@unal.edu.co
[b] Department of Agricultural and Food Engineering, Universidad Nacional de Colombia, Medellín, Colombia. idaristi@unal.edu.co, aosorio@unal.edu.co
[c] Department of Agricultural Engineering, Universidade Federal de Viçosa, Viçosa, Brasil, iftinoco@ufv.br, lina.garcia@ufv.br

Abstract
This study aimed to find the minimum area of natural ventilation suitable for coffee processing wet facilities in Colombia that have mechanical drying inside, in order to preserve the quality of coffee through a bioclimatic environment conducive to biological safety, this study was made with the help of computational simulation in EnergyPlus™ program. It was found that as the drying capacity is increased, and therefore the power of the drying machines, temperature and internal humidity tend to increase. Furthermore an inverse linear correlation was found between the area of natural ventilation and variables temperature and relative humidity. Finally, it is found relationships between the minimum area of natural ventilation and the drying capacity, in order to obtain a suitable bioclimatic environment for preserving of coffee parchment.

Keywords: warm and humid environment; mechanical drying of coffee; biological risk; coffee storage; postharvest of coffee.

Modelamiento bioclimático para determinar el área mínima de ventilación natural para edificaciones de beneficio húmedo de café

Resumen
Este estudio tuvo como objetivo encontrar el área mínima de ventilación natural necesaria para instalaciones de beneficio húmedo de café con secado mecánico en su interior, con el fin de preservar la calidad de café a través de un ambiente bioclimático que propicie la inocuidad biológica, este estudio se realizó con ayuda de simulaciones computacionales en el programa EnergyPlus™. Se encontró que a medida que se incrementa la capacidad de secado, y por ende la potencia de las máquinas de secado, la temperatura y la humedad relativa interna tienden a aumentar. Por otra parte, se encontró una correlación lineal inversa entre el área de ventilación natural y las variables temperatura y humedad relativa. Por último, se encontraron relaciones de área mínima de ventilación natural con la capacidad de secado, con el fin de obtener un ambiente bioclimático adecuado para la preservación del café pergamino.

Palabras clave: ambiente cálido y húmedo; secado mecánico de café; riesgo biológico; almacenamiento de café; pos-cosecha de café.

1. Introduction

Coffee is one of the most popular beverages in the world, and has great economic and social importance [1,2]. In addition, global coffee consumption has also risen at an average annual rate of 1.9% over the past 50 years [3].

Coffee plants are grown in tropical and subtropical regions of Central and South America, Africa and South East Asia, mainly in regions with temperate and humid climates [4]. Latin America produces more than half the world's coffee, with Brazil and Colombia as the first and third highest producers, respectively [3].

High-quality coffee requires special care and handling from the pre-harvest phase, through harvest, to post-harvest. In these phases, several factors may cause changes that may affect the future drink. Producing coffees of better quality

means a good differential of product price and hence more profit for the producer [5]. Specifically, the post-harvest coffee process is one of the primary points for the preservation of coffee bean quality [6].

In regions like Colombia, Central America and Hawaii, Arabica coffees are processed via the wet method, where only mature coffee cherries are harvested and pulped to remove the exocarp and mesocarp. Subsequently, the thin mucilaginous layer surrounding the coffee seeds is removed either via a natural fermentation process or mechanically. Finally, the coffee beans are sun-dried or mechanically to a moisture content of 11–12% so as to achieve microbial stability [7-11].

In post-harvest treatment of coffee, the drying occupies one of the most important roles from an energetic effort point of view. If this process is badly performed, microorganism can grow on the coffee bean surface, exposing it to biochemical reactions that could affect sugar content [12]. The main problems in the taste of cup arise from poor drying and storage. Development of microorganisms is a factor in the environment that arises only when adverse storage conditions permit excessive moisture accumulation in the grain bulk or when grain is stored initially above the permissible safe moisture contents required for its preservation [13].

Microbial contamination can occur in the cherries and during harvesting, fermentation, drying and storage of the coffee beans [14]. Bacteria, yeasts and filamentous fungi have already been reported in the pulp and beans of coffee processed in Brazil, India, Hawaii, Congo, Argentina, Colombia, Costa Rica, Ethiopia and Mexico [14]. In terms of flavor and aroma of the beverage, filamentous fungi predominate at the end of the processing period and during storage, but also present a safety risk for the final product, due to the production of toxic secondary metabolites, the mycotoxins, which can be harmful to consumers at certain concentrations [15].

The bioclimatic conditions of the place where the parchment coffee is stored are very important. Fungi live and reproduce best between 70 and 80% relative humidity, whereas yeast and bacterial development require humidities higher than 85% in the intergranular air [16]. The biological risk is latent in facilities' wet processing of coffee; for example, according to [17], Aspergillus ochraceus (a leading producer of Ochratoxin A) was found in 70% of the facilities tested in Colombia, in the facilities' post-harvest coffee, solar dryers, coffee parchment and green coffee. This author argues that only when adequate conditions of humidity, temperature, time and unhygienic conditions occur, can these microorganisms proliferate.

On the other hand, temperatures above 50 °C can kill the seed of coffee and begin its process of decomposition. In the tropical zone, with relative humidity above 70% and temperatures higher than 27 °C, freshly harvested beans and processed grains can be attacked by insects common in storage [16].

Farmers, particularly to remote farmers, often keep store parchment or green-bean coffee for long periods before it can be transported to a sale point [18]. In the humid/rainy conditions, moisture can build up in stored beans, promoting fungi and bacteria development [16].

Approximately 70% of the volume of coffee that is produced in Colombia is dried mechanically [19]. This process usually generates a lot of steam and heat into the facilities where the coffee is dried. In the post-harvest coffee, the largest power consumption occurs in the mechanical drying process, with efficiency of 50% [20], The fact that machines are generating heat inside the agroindustrial buildings reinforces the importance of natural ventilation and its beneficial effect on the removal of water vapor [21] generated from the perspiration of the occupants and particularly the drying process, which can lead to biologically dangerous conditions for the preservation of quality coffee.

Natural ventilation is an effective method for improving indoor air quality and reducing energy consumption in buildings, especially when the indoor temperature is close to or higher than the temperature of the external environment [22-24]. The natural ventilation strategies design is often disregarded as there are no standards available to support designers in the design of natural ventilation openings [25].

A poor control and design of buildings for the wet processing of coffee can compromise product quality due to inadequate bioclimatic environments [26]. The bioclimatic approach of buildings in tropical warm and wet regions requires previous bioclimatic work, analyzing the envelope of building to limit the power contributions and to optimize the flow of air from natural ventilation [27].

Computational modeling of natural ventilation related to energy consumption and thermal comfort has been carried out using different methods: for example, fuzzy control algorithms have been used, combining indoor air quality that is acceptable to thermal comfort with good results [25], as well as computational fluid dynamics modeling (CFD) to analyze the flow field and turbulence [28]. Zonal and network models have also been used, in programs such as EnergyPlus[TM] [29].

[26] and [18] performed bioclimatic analysis for a parabolic solar dryer and wet mill of coffee facilities through simulations in the EnergyPlus[TM] program. These authors, were found that the greater the area of natural ventilation, is lower temperature and relative humidity inside these facilities, but in the no such relationship has been found, nor is there any recommendation for the minimum natural ventilation area necessary to maintain a suitable bioclimatic environment for different scales of coffee production.

Taking into consideration facilities that varied in the size of production, and using the EnergyPlus[TM] program, this study aimed to find the minimum area of natural ventilation suitable for coffee processing wet facilities in Colombia that have mechanical drying inside, in order to preserve the quality of coffee through a bioclimatic environment conducive to biological safety.

2. Material and methods

This study was conducted taking into account the conditions of the coffee region of Antioquia, Colombia. For these simulations the climate file of its capital Medellin (at coordinates 6°14'41"N 75°34'29"W, altitude of 1500 m) – which has a climate representative of this coffee zone was used. The internal environment of the buildings was simulated for the month of November, during the main harvest of the year,
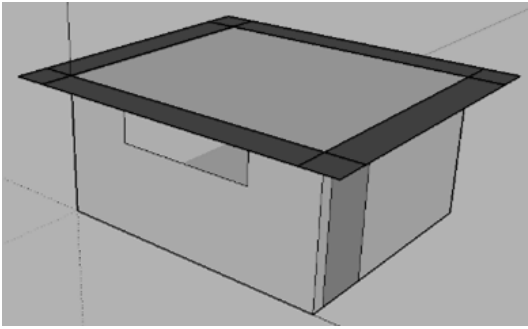
Figure 1. Simple geometry of the building.
Source: the authors.

Table 1.
Thermal properties of materials

Material	ρ (kg.m^{-3})	λ (W.m^{-1}.°K^{-1})	C_p (kJ.kg^{-1}.°K^{-1})
Brick	1800	1.05	0.92
Ceramics	1600	0.65	0.84
Concrete	2200	1.75	1.00
Fiber cement roofing	1600	0.65	0.84
Mortar	2000	1.15	1.00
Steel – Iron	7800	55.00	0.46

ρ: density, λ: thermal conductivity, C_p: specific heat.
Source: Adapted from [36].

which coincides with the second rainfall season in this part of Colombia [30].

Using the program EnergyPlus^{TM}, which is one of the most popular bioclimate simulation programs in the world [31], 118 computer simulations were performed for different sizes of production and different areas of ventilation, with mechanical drying inside with power (of heat exchanger) ranging from 26 kW to 1625 kW, and ventilation areas of 0 m^2 to 120 m^2, and with facilities with building volumes ranging from 28 m^3 to 3200 m^3. Data on drying power and volumes of buildings for wet coffee processing were provided by Comité de Cafeteros de Antioquia.

In engineering, all models are a simplified representation of reality, of complex physical or chemical phenomena in the world [32]. In this case, for the modeling, simple geometries of the buildings were assumed, orientation east–west, and drawn in the 3D geometries SketchUp® program, for each of the 118 different cases (Fig. 1).

For the thermal properties of the washing coffee, it was used equations 1 and 2 proposed by [33] for the specific heat (C_{pc}, J kg^{-1} °K^{-1}) and density of the coffee (ρ_C, kg m^{-3}). These properties are functions of the moisture content of the product on a dry basis (M_{db}, decimal dry basis).

$$C_{pc} = 1.3556 + 5.7859M_{db} \tag{1}$$

$$\rho_C = 365.884 + 2.7067M_{db} \tag{2}$$

To calculate the thermal properties of composite materials and the thickness and equivalent thermal resistance of the various construction materials [34], we used the simplified method of generating layers of materials [35].

Table 2.
Power of coffee processing equipment

Equipment	Power	Unit
Engine of mechanical dryer	0.37 – 45.52	kW
Machines of wet processing	0.37 – 44.76	kW
Lighting	10.00	W.m^{-2}
Mechanical dryer heat exchanger	26.00 – 1625.60	kW

Source: the authors.

For the calculation of the energy balance, it is necessary to calculate the heat generated within each building (heat generated by machines, lighting and human metabolism). Table 2 shows the power values of the machines and lighting.

It was assumed that the heat exchangers of the drying machines used coal (anthracite) as fuel, which, according to [20], has a consumption of 0.224 kg of coal per kg of dry parchment coffee, with a calorific value of 33440 kJ.kg^{-1}.

For metabolic rate, the value of 423 W.person-1 was used in this study for the metabolic rate; according to [37], this value corresponds to heavy work activity and handling 50 kg sacks.

A statistical analysis was performed with a linear correlation matrix to observe the existence of a linear correlation between variables: drying capacity (kg of coffee parchment per day), building volume, natural ventilation area, mean temperature and mean relative humidity inside the facilities.

In addition, a mapping of the temperature and relative humidity variables related to the power drying machines and natural ventilation area was performed, applying the Kriging gridding method using the Surfer program. Finally, from the relationships drawn from these maps, a minimum area of natural ventilation was proposed to maintain the facilities with an adequate bioclimatic environment to preserve the quality of coffee.

3. Results and discussion

Table 3 shows the linear correlation matrix. It can be seen that there is a linear correlation between the capacity of the machines for drying coffee and the volume of the construction (building size), and the area of natural ventilation. This result is obvious, since the power of the machines, volume of the buildings and ventilation areas of actual installations were used.

Also, a direct linear correlation was observed between the internal temperature and capacity of the drying machines, and an inverse correlation between the capacity of the drying machines and the relative humidity inside the facilities. This is because, since the efficiency of these machines is 50% [20], this means that when the power increases, the thermal energy gain increases inside these buildings.

Table 3.
Matrix linear correlation

	CD	V	NVA	T	RH
CD	1.00	0.86	0.80	0.69	-0.43
V	0.86	1.00	0.74	-0.06	0.10
NVA	0.80	0.74	1.00	-0.92	-0.83
T	0.69	-0.06	-0.92	1.00	-0.46
RH	-0.43	0.10	-0.83	-0.46	1.00

CD: capacity of the machines for drying, V: volume, NVA: natural ventilation area, T: temperature, RH: relative humidity.
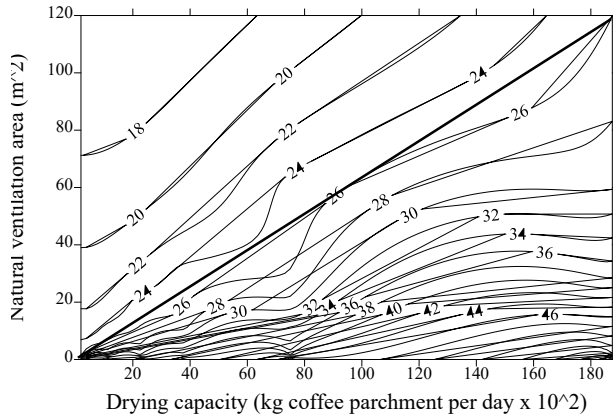Source: the authors.

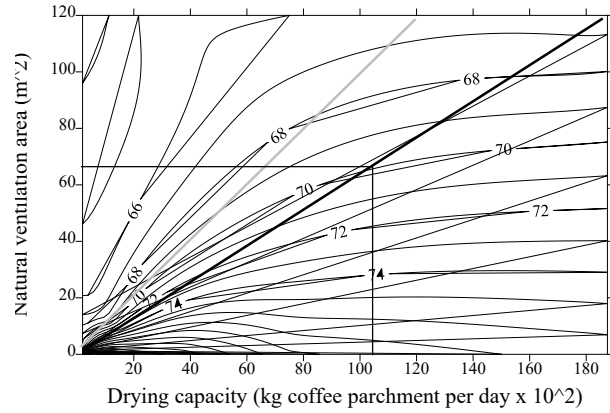Figure 2. Map of isolines of temperature.
Source: the authors.

Figure 3. Map of isolines of relative humidity.
Source: the authors

Furthermore, it is observed that the building volume didn't have a significant linear correlation with the variables temperature and relative humidity; however, the area of natural ventilation presented a strong inverse linear correlation with temperature and relative humidity variables. This fact suggests that as the area of natural ventilation is increased, the temperature and relative humidity decreases, because facilitates the transfer of heat and steam (produced by drying process) to the outside.

Fig. 2 shows a map of isolines of temperature (°C) within the wet coffee processing facilities, in function of drying capacity of machines, and area of natural ventilation. A pattern can be observed showing that when the drying capacity increases, so the internal temperature of these facilities increases; on the other hand, as the area of natural ventilation increases, so the internal temperature decreases. [18] found a similar result for a parabolic solar coffee dryer.

In Fig. 2 a straight diagonal line separating the lower internal temperatures at 27 °C can also be seen, which it is the limit for safekeeping grains from insect attack [16]. This line is defined by equation 3, and suggests the minimum area of natural ventilation in function of the drying capacity of the machines inside the coffee processing facilities.

$$NVA_m = 0.64DP/100 \tag{3}$$

Where:
NVA_m: Minimum area of natural ventilation (m^2).
DP: Drying capacity (kg of coffee parchment per day).

Fig. 3 shows a map of isolines of relative humidity (%) inside the coffee processing facilities in function to the drying capacity of the machines, and the area of natural ventilation. Similar to the temperature variable, a pattern can be observed, which shows that as the drying capacity increases, so too does the internal relative humidity of these facilities increase. On the other hand, the area of natural ventilation increases, so the internal relative humidity decreases. [18] found a similar result for a parabolic solar coffee dryer.

It can be observed in general that the facilities may be more prone to fungal attack when there is a relative humidity of between 70 and 80% [16]; this is consistent with the study of [17] and [38].

In Fig. 3, two straight diagonal lines can also be observed separating relative humidities greater than 70%, in order to maintain safety in the grains [16]: the black line is defined by equation 3, and its application range is to higher capacities of up to 10500 kg dry parchment coffee per day. For smaller capacities (gray line), the minimum area of natural ventilation is defined by equation 4.

$$NVA_m = 1.0DP/100 \tag{4}$$

With a higher drying capacity the slope of the isolines relative humidity within the facilities decreases, and this can be explained by the fact that although the increasing drying capacity of the machines increases the emission of water vapor, it also increases its addition of thermal energy, and so the temperature and pressure saturation vapor, and thus the relative humidity trends to decrease.

The dimensions of natural ventilation openings are very important, but so is its location [21]. Because within in buildings for wet processing of coffee is generated large amount of heat and steam, it is recommended to take advantage of dynamic and thermal ventilation, using air inlets located on the bottom of the building, and air outlets located on top of the facility, in order to direct the airflow [22] warm and steam laden outside of the building. It is recommended future studies in CFD in this regard.

4 Conclusions

In facilities used for the wet processing of coffee, with drying machines inside, as the capacity of such machines is increased, so the internal temperature and relative humidity tends to increase, due to the addition of heat and steam inside.

There is an inverse linear correlation between the natural ventilation area in facilities used for the wet processing of coffee with drying machines inside, and the temperature and relative humidity inside.

Facilities with little area of natural ventilation are more prone to attack by filamentous fungi and insects in grain storage.

It is possible, by using the capacity of the coffee drying machines, to calculate the required minimum area of natural ventilation to reduce the biohazard inside coffee processing facilities.

References

[1] López, M.F., Sistemas de lógica difusa en el proceso de secado de café en lecho fluidizado. Revista Ingeniería e Investigación, 25(3), pp. 84-91, 2005.

[2] López, M.F., Secado de café en lecho fluidizado. Revista Ingeniería e Investigación, 26(1), pp. 25-29, 2006.

[3] ICO. International Coffee Organization., Exporting countries: total production [Online]. 2016. Available at: http://www.ico.org/prices/po-production.pdf.

[4] Garcia, L., Posada, H. and Laderach, P., Recommendations for the regionalizing of coffee cultivation in Colombia: A methodological proposal based on agro-climatic indices. PLoS One, 9(12), pp. 1-22, 2014. DOI:10.1371/journal.pone.0113510

[5] Pereira, C., Chalfoun, M., Carvalho, R. and Savian, V., Multivariate analysis of sensory characteristics of coffee grains (Coffea Arabica L.) in the region of upper Paranaíba. Acta Sci. Agron., 32(4), pp. 635-641, 2010. DOI:10.4025/actasciagron.v32i4.4283

[6] Ribeiro, B., Mendonça, L., Dias, A., Assis, A. and Marques, C., Parâmetros qualitativos do café provenientes de diferentes processamentos na pós-colheita. Agrarian, 4(14), pp. 273-279, 2011.

[7] Borém, F.M., Ribeiro, D.M., Pereira, R.G.F.A., Rosa, S.D.V.F. and Morais, A.R., Qualidade do café submetido a diferentes temperaturas, fluxos de ar e períodos de pré-secagem. Coffee Sci., 1(1), pp. 55-65, 2007.

[8] Ciro, H.J., Abud, L.C. and Perez, L.R., Numerical simulation of thin layer coffee drying by control volumes. Dyna, 77(163), pp. 270-278, 2010.

[9] Ciro, H.J., Rodríguez, M.C. and Castaño, J.L.L., Secado de café en lecho fijo con intermitencia térmica y flujo de aire pulsado. Revista Facultad Nacional de Agronomia, 64(2), pp. 6247-6255, 2011.

[10] [10]Ghosh, P. and Venkatachalapathy, N., Processing and Drying of Coffee – A Review. Int. J. Eng. Res. Technol., 3(12), pp. 784-794, 2014.

[11] Wei, L., Wai, M., Curran, P., Yu, B. and Quan, S., Coffee fermentation and flavor – An intricate and delicate relationship. Food Chem., 185, pp. 182-191, 2015. DOI:10.1016/j.foodchem.2015.03.124

[12] Kleinwächter, M. and Selmar, D., Influence of drying on the content of sugars in wet processed green Arabica coffees. Food Chem., 119(2), pp. 500-504, 2010. DOI:10.1016/j.foodchem.2009.06.048

[13] Puerta, G.I., Riesgos para la calidad y la inocuidad del café en el secado. Cenicafé [En línea], 371, pp. 1-8, 2008. Disponible en: http://biblioteca.cenicafe.org/handle/10778/399

[14] Silva, C., Batista, L.R. and Schwan, R.F., Incidence and distribution of filamentous fungi during fermentation, drying and storage of coffee (Coffea Arabica L.) beans. Brazilian J. Microbiol., 39, pp. 521-526, 2008.

[15] Taniwaki, M.H., An update on ochratoxigenic fungi and ochratoxin A in coffee. Adv. food Mycol., 571, pp. 189-202, 2006. DOI: 10.1007/0-387-28391-9_12

[16] Navarro, S. and Noyes, R., The mechanics and physics of modern grain aeration management, PhD Thesis, 2001. (CRC PRESS, Ed.). DOI: 10.1017/CBO9781107415324.004

[17] Puerta, G.I, La humedad controlada del grano preserva la calidad del café. Cenicafé [En línea], 352, pp. 1-8, 2006. Disponible en: http://biblioteca.cenicafe.org/bitstream/10778/418/1/avt0352.pdf

[18] Osorio, R., Guerra, L.M., Tinôco, I.F.F., Martins, J.H., Souza, C.D.F. and Osorio, J.A., Simulation of the internal environment of a post-harvest installation and a solar dryer of coffee. Revista Brasileira de Engenharia Agrícola e Ambiental, 20(2), pp. 163-168, 2016. DOI:10.1590/1807-1929/agriambi.v20n2p163-168

[19] Gonzalez, C.A., Sanz, J.R. and Oliveros, C.E., Control de caudal y temperatura de aire en el secado mecánico de café. Cenicafe [En línea], 61(4), pp. 286-291, 2010. Disponible en: http://biblioteca.cenicafe.org/handle/10778/503

[20] Oliveros, C.E., Sanz, J.R., Ramirez, C.A. and Peñuela, A.E., Aprovechamiento eficiente de la energía en el secado mecánico del café. Cenicafe [En línea], 380, pp. 1-8, 2009. Disponible en: http://biblioteca.cenicafe.org/handle/10778/370

[21] Baêta, F.d.C. and Souza, C.d.F., Ambiência em edificações rurais: conforto animal. Ed. UFV, 2010.

[22] Lomas, K., Architectural design of an advanced naturally ventilated building form. Energy and Building, 39(2), pp. 166-181, 2007. DOI: 10.1016/j.enbuild.2006.05.004

[23] Wang, Y., Zhao, F.Y., Kuckelkorn, J., Liu, D., Liu, J. and Zhang, J.L., Classroom energy efficiency and air environment with displacement natural ventilation in a passive public school building. Energy and Buildings, 70, pp. 258-270, 2014. DOI: 10.1016/j.enbuild.2013.11.071

[24] Aflaki, A., Mahyuddin, N., Al-Cheikh-Mahmoud, Z. and Baharum, M.R., A review on natural ventilation applications through building facade components and ventilation openings in tropical climates. Energy and Buildings, 101, pp. 153-162, 2015. DOI: 10.1016/j.enbuild.2015.04.033

[25] Schulze, T. and Eicker, U., Controlled natural ventilation for energy efficient buildings. Energy and Buildings, 56, pp. 221-232, 2013. DOI: 10.1016/j.enbuild.2012.07.044

[26] Osorio, R., Guerra, L.M., Tinôco, I.F.F., Osorio, J.A. and Aristizábal, I.D., Simulation of a thermal environment in two buildings for the wet processing of coffee. DYNA, 82(194), pp. 214-220, 2015. DOI:10.15446/dyna.v82n194.49526

[27] Bastide, A., Lauret, P., Garde, F. and Boyer, H., Building energy efficiency and thermal comfort in tropical climates. Presentation of a numerical approach for predicting the percentage of well-ventilated living spaces in buildings using natural ventilation. Energy and Buildings, 38(9), pp. 1093-1103, 2006. DOI: 10.1016/j.enbuild.2005.12.005

[28] Norton, T., Grant, J., Fallon, R. and Sun, D.W., Assessing the ventilation effectiveness of naturally ventilated livestock buildings under wind dominated conditions using computational fluid dynamics. Biosyst. Eng. [Online], 103(1), pp. 78-99, 2009. Available at: http://www.sciencedirect.com/science/article/pii/S1537511009000567

[29] Oropeza, I. and Ostergaard, P.A., The influence of an estimated energy saving due to natural ventilation on the Mexican energy system. Energy, 64, pp. 1080-1091, 2014. DOI: 10.1016/j.energy.2013.11.009

[30] Oviedo, N. and Torres, A., Atenuación hídrica y beneficios hidrológicos debido a la implementación de techos verdes ecoproductivos en zonas urbanas marginadas. Ingenieria y Univiversidad, 18(2), pp. 291-308, 2014.

[31] DoE, Energyplus engineering reference. Ref. to EnergyPlus Calc., 2012.

[32] Marlin, T.E., Process control: Designing processes and control systems for dynamic performance. New York: McGraw- Hill, 1996.

[33] Montoya, E.C., Oliveros, C.E. and Mejía, G., Optimización operacional del secador intermitente de flujos concurrentes para café pergamino. Cenicafé [En línea], 41(1), pp. 19-33, 1990. Disponible en: http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=ORTON.xis&method=post&formato=2&cantidad=1&expresion=mfn=044741

[34] [34]INMETRO, Qualidade e tecnologia, Ed., Anexo V - Portaria n.o 50 [Online], 2013. Available at: http://www.inmetro.gov.br/consumidor/produtosPBE/regulamentos/AnexoV.pdf

[35] LabEEE, Laboratório de Eficiencia Energetica. Florianópolis, Universidade Fedederal de Santa Catarina [Online], Available at: http//www. labeee. ufsc. br, 2015.

[36] ABNT, NBR 15220-2., Desempenho térmico de edificações-Parte 2: Métodos de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator de calor solar de elementos e componentes de edificações, 2003.

[37] ASHRAE., Fundamentals. Am. Soc. Heating, Refrig. Air Cond. Eng. Atlanta [Online], 111, 2001. Available at: http://shop.iccsafe.org/media/wysiwyg/material/8950P203-toc.pdf

[38] Gamboa, M.Á., Presence of aspergillus and other fungal symbionts in coffee beans from colombia. Acta Biológica Colombiana, 17(1), pp. 39-50, 2012.

R. Osorio-Hernandez, received the BSc. Eng in Agricultural Engineering in 2006 from the Universidad Nacional de Colombia - Medellin, the MSc. degree in 2012, and the PhD degree in Agricultural Engineering from the Universidade Federal de Viçosa – Brazil. From 2006 to 2010, and from 2012 to 2014, he worked for the National Federation Coffee Growers of Colombia, in Medellin, within the area of Post-harvest and Quality of Coffee, at the same time, from 2007 to 2010, 2012, 2013 and 2017, he worked for the Universidad Nacional de Colombia - Medellín, as occasional professor of electrotechnics, rural constructions, and bioclimatic for animals and plants. His research areas include: bioclimatic simulation and energy of rural buildings, postharvest coffee, and energy in agriculture. Currently he works in the Universidad Nacional de Colombia - Bogotá, as assistant professor in the Department of Civil and Agricultural Engineering.
ORCID: 0000-0002-8698-7234

I.D. Aristizábal-Torres, BSc. Eng. in Agricultural Engineering in 1995 from Universidad Nacional de Colombia - Medellin, PhD in Agricultural Mechanization and Technology from the Universidad Politécnica de Valencia- Spain in 2006. Associate professor at the Universidad Nacional de Colombia - Medellin in the Department of Agricultural and Food Engineering at the Faculty of Agricultural Sciences. Coordinator research group Agricultural Engineering (2012- current). Work areas; agricultural mechanization, agro-industrial processes and properties of agricultural products (fruits and grains).
ORCID: 0000-0003-1913-6832

J.A. Osorio-Saraz, received the BSc. Eng in Agricultural Engineering in 1998 from the Universidad Nacional de Colombia - Medellin, is Sp in Environmental Legislation in 2001 from the Universidad de Medellin, MSc. degree in Materials Engineering in 2006 from the Universidad Nacional de Colombia – Medellin, PhD. degree in Agricultural Engineering in 2010, from the Universidade Federal de Viçosa – Brazil. Since 2003 Dr. Osorio is professor at the Universidad Nacional de Colombia - Medellin, teaching and rural constructions, bamboo constructions, computational modeling for livestock housing, air quality and animal welfare.
ORCID: 0000-0002-4358-3600

I.F. Ferreira-Tinôco, has a BSc. in Agricultural Engineer in 1980, the MSc. degree in Agricultural Engineer in 1988, both achieved at the Federal University of Lavras – Brazil, and PhD degree in Animal Sciences from the Federal University of Minas Gerais - Brazil in 1996. She is a full professor at the Department of Agricultural Engineering of Federal University of Viçosa. Her research areas are design of rural structures and evaporative cooling systems, thermal confort for animals, air quality and animal welfare.
ORCID: 0000-0002-4557-8071

L.M. Guerra-Garcia, received the BSc. in Architecture in 2004 at the Universidad Nacional de Colombia - Medellin, the MSc. degree in 2012 and PhD degree in 2018 in Agricultural Engineering in rural constructions and ambience area from the Universidade Federal de Viçosa – Brazil. From 2004 to 2009, she worked in different companies in design and / or construction of social housing, commercial buildings, religious and agricultural use. In 2014, 2016 and 2017 she worked for the Universidad Nacional de Colombia - Medellín, as an occasional teacher rural constructions and bioclimatic. Her research interests include: bioclimatic simulation and energy of buildings, rural architecture and rural constructions and ambience.
ORCID: 0000-0001-9115-9057