COB-2019-0697

ASSESSING THE INFLUENCE OF CONVECTIVE HEAT TRANSFER COEFFICIENT ON A HUMAN BODY EXERGY ANALYSIS

Thatiana Jéssica da Silva Ribeiro
Carlos Eduardo Keutenedjian Mady
State University of Campinas. 200 Mendeleyev Street - Cidade Universitaria, Campinas - SP, Brazil. ZIP code 13083-860
jessicathatiana@gmail.com, cekmady@fem.unicamp.br

Abstract. In this study, an assessment of the influence of the convective heat transfer coefficient on three methods of human body exergy analysis was performed. Four different correlations from the normative of thermal comfort were applied to the exergy analysis. Also, the effect of air velocity on the exergy analysis was analyzed. The results point out that, in general, the response to the change of convective heat transfer correlation presented the same effect at the exergy term related to the convection for all the exergy analysis methods. However, the impact on destroyed exergy rate differs especially for the method Shukuya et al. *(2010). The air velocity effect on the exergy analysis differs considerably for Prek and Butala (2010) exergy analysis method. Also, a good agreement between two of the correlations used to calculate convective heat transfer was observed for all three methods of exergy analysis.*

Keywords: Thermal Comfort, Exergy analysis, Human Body, Convective Heat Transfer Coefficient.

1. INTRODUCTION

Exergy analysis has been performed on human body thermal models in order to promote a better understanding of its functioning and to assess thermal comfort conditions. A first exergy analysis was performed by Batato *et al.* (1990). Other exergy analyses were also proposed by several authors, such as Prek and Butala (2010), Shukuya *et al.* (2010), Wu *et al.* (2013) and Mady *et al.* (2014).

A comparison of three exergy analysis methods, Prek and Butala (2010), Shukuya *et al.* (2010) and Mady *et al.* (2014) was presented at Ribeiro and Mady (2017). However, the main focus of this study is now to analyze a part of the exergy analysis that is related to the exergy associated to the convective heat transfer between the human body and the environment.

Hardy *et al.* (1938) analyzed the effect of forced air currents on heat transfer by convection and radiation on an energy basis. Hardy and DuBois (1938b) performed experimental procedures in order to develop a method to measure radiation and convection heat transfer, and further separate them by calculation of the radiation component according to the Stefan and Boltzmann equation. They stated that the radiation accounts for most of the energy transfer and the convection accounts for about 15% of the heat transfer for a quiet individual. However, if there is considerable air movement around the human body, this contribution increases. Hardy and DuBois (1938a) affirms that the convection is markedly increased by the slightest movement on any part of the human body. Within the temperature range analyzed on their study (22 to 35 °C), convection decreases as the temperature increases until it was zero at a temperature of 35 °C.

Many studies of thermal comfort use correlations from the normative American Society of Heating and Engineers (2005) to evaluate thermal comfort. Zhou *et al.* (2013) used Mitchell (1974) correlation in an experimental study of thermal comfort on outdoor and semi-outdoor environments in a humid subtropical climate city. Kurazumi *et al.* (2014) proposed a correlation to evaluate an average convective heat transfer coefficient for a human body seated. Nonetheless, no literature was found on the use and comparison of different correlations used in the calculation of the convective heat transfer in the scope of exergy analysis of the human body.

In this study, the correlations used to calculate the convective heat transfer coefficient are a part of the normative American Society of Heating and Engineers (2005). Four correlations are used: Mitchell (1974), Colin and Houdas (1967), Seppanen *et al.* (1972) and Nishi and Gagge (1970). The main parameters calculated with the exergy analysis are the exergy associated with convection and the destroyed exergy rate.

2. PROCEDURES

In this section, the human body thermal model used is described. Following, the three exergy analysis methods used in this study are briefly described emphasizing the terms related to the convection between the human body and

the environment. The exergy analysis methods are based on the following articles: Prek and Butala (2010), Shukuya *et al.* (2010) and Mady *et al.* (2014). Lastly, the correlations used to evaluate the convective heat transfer coefficient are described.

2.1 Human body thermal model

First, the same human thermal model used by Ribeiro and Mady (2017) is used in the current study. This model was developed by Ferreira and Yanagihara (2009) and comprises a computational routine in C++. The human body is represented by a set of 15 cylinders with an elliptical cross-sectional area. Each cylinder represents a part of the human body and has a combination of different tissues of the human body. Also, the human is considered to be naked.

2.2 Exergy analysis methods

The first exergy analysis method used in this study is shown on Prek and Butala (2010). In their original study, the human body was represented by two concentrical cylinders, the core, and the shell, following the two-node model as presented in Gagge *et al.* (1986). There were energy transfer between the core and the shell, and between the shell and the environment. Equation 1 presents the destroyed exergy rate for this method.

$$\Delta \dot{B}''_{dest} = \Delta \dot{B}''_{core-skin,K} + \Delta \dot{B}_{core-skin,blood} + \Delta \dot{B}''_{conv} + \Delta \dot{B}''_{rad} + \Delta \dot{B}''_{vap}$$
$$+ \Delta \dot{B}''_{a,mass} + \Delta \dot{B}''_{a,q} + \Delta \dot{B}''_{breathing} + \Delta \dot{B}''_{breathing,q} \tag{1}$$

As the goal of this study is the analysis of the impact of modifying the convective heat transfer coefficient on the exergy analysis, the term related to the convection process will be emphasized. Eq.(2) presents the exergy associated with convection.

$$\Delta \dot{B}''_{conv} = \dot{Q}''_{conv} \left(T_{clothing} - T_{air} - T_{air} \ln \left(\frac{T_{clothing}}{T_{air}} \right) \right) \tag{2}$$

From Eq.2 the term referred to as the energy transferred by this phenomenon ($\dot{Q}''_{conv}$) is evaluated as shown in Eq.3.

$$\dot{Q}''_{conv} = h_c f_{clothing} (T_{clothing} - T_{air}) \tag{3}$$

The second exergy analysis method used in this study is shown in Shukuya *et al.* (2010). They also used the denominated two-node human body thermal model, composed by the core and the shell described in Gagge *et al.* (1986). The destroyed exergy rate is shown on Eq.(4).

$$\dot{B}''_{dest} = (\dot{B}''_{met} + \dot{B}''_{air,inhaled} + \dot{B}''_{water,core} + \dot{B}''_{water,shell} + \dot{B}''_{rad,absorbed})$$
$$- (\dot{B}''_{stored} + \dot{B}''_{air,exhaled} + \dot{B}''_{sweat} + \dot{B}''_{rad,released} + \dot{B}''_{conv}) \tag{4}$$

In this study, two terms of Equation 4 were disregarded: the exergy associated with water generation within the shell due to metabolism ($\dot{B}''_{water,shell}$) and within the core ($\dot{B}''_{water,core}$) due to some inconsistencies that were approached in details on Ribeiro and Mady (2017). The exergy associated with the convection process between the skin and the environment on Shukuya *et al.* (2010) exergy analysis method is presented at Eq.(5)

$$\dot{B}''_{conv} = f_{clothing} h_{c,clothing} (T_{clothing} - T_{air}) \left(1 - \frac{T_0}{T_{clothing}} \right) \tag{5}$$

In this second analysis method, it is observed that the term within the last bracket shown in Eq.5 is analogous to a Carnot factor. A simple modification that was made in the present study was that, given that the human body is considered to be naked, the skin temperature was used instead of temperature in the clothing surface. Also, the coefficient $f_{clothing}$ was assumed to be equal to unity.

The third exergy analysis method was developed by Mady *et al.* (2014). It originally used the human body thermal model developed by Ferreira and Yanagihara (2009), at which the human body is represented by a combination of 15 cylinders. Equation 6 presents the destroyed exergy rate.

$$\dot{B}_{dest} = \left(\dot{B}_M - \frac{dB}{dt} \bigg|_{\Delta T} \right) - \dot{W} - (\dot{B}_r + \dot{B}_c + \dot{B}_e + \Delta \dot{B}_{breathing}) \tag{6}$$

The therm of exergy associated with the convective heat transfer at the skin is shown in Eq.(7).

$$\dot{B}_c = \dot{Q}_c \left(1 - \frac{T_{air}}{T_{skin}} \right) \tag{7}$$

In this latest analysis, the term related to the energy transfer is calculated as $\dot{Q}_c = A h_c (T_{clothing} - T_{air})$.Thus, it is possible to infer that Mady *et al.* (2014) evaluate the exergy associated with the convection process as an exergy due to a heat transfer by finite temperature difference.

2.3 Correlations of convective heat transfer coefficient

Many correlations that were proposed throughout time to calculate the convective heat transfer coefficient are present within the normative American Society of Heating and Engineers (2005). Originally, Ferreira and Yanagihara (2009) thermal model used a constant value of convective heat transfer coefficient for each member of the human body which is more detailed in Ferreira (2001). The first correlation used was Mitchel(1974). This correlation was proposed for conditions at which the individual is seated with air movement around its body. In this correlation, the convective heat transfer is affected by air velocity when it is higher than 0.2 m/s. For still air and air velocity lower than 0.2 m/s the constant value of 3.1 $W/(m^2K)$ is used. For air velocity between 0.2 and 4.0 m/s, the convective heat transfer is calculated by Eq.(8).

$$h_c = 8.3v_{air}^{0.6} \tag{8}$$

The second correlation is Colin and Houdas (1967). It was proposed for situations where the individual is reclined, also with moving air around its body. For still air and air velocity lower than 0.15 m/s, it uses the constant value of 5.1 $W/(m^2K)$. For velocity between 0.15 and 1.5 m/s, the convective heat transfer is calculated by Eq.(9).

$$h_c = 2.7 + 8.7v_{air}^{0.67} \tag{9}$$

The third correlation is Nishi and Gagge (1970). It should be used for individuals walking in a calm environment. Since the individual is walking, the velocity cannot be zero, thus it is valid for the range of air velocity between 0.5 and 2.0 m/s. The calculation of the convective heat transfer is shown in Eq.(10).

$$h_c = 8.6v_{air}^{0.53} \tag{10}$$

The last correlation was developed through the data presented at Seppanen *et al.* (1972). It is used for an individual standing with moving air around its body. For air velocity between 0 and 0.15 m/s, the constant value of 4.0 $W/(m^2K)$ is used. For velocity between 0.15 and 1.5 m/s, the calculation of the convective heat transfer is shown in Eq.(11).

$$h_c = 14.8v_{air}^{0.69} \tag{11}$$

3. Results and Discussion

In the first section of this study, it was considered a scenario of still air. The exergy associated with the convection process was calculated in four different manners: using constant values of convective heat transfer coefficient for each human body member, as well as presented in Ferreira (2001); using the correlation of Mitchell (1974); using the correlation of Collin and Houdas (1967) and lastly using the correlation of Seppanen *et al.* (1972). The results are shown in Fig. 1 when the exergy analysis method of Mady *et al.* (2014) is used, in Fig. 2 (a) when the method of Prek and Butala (2010) is used and in Fig. 2 (b) when the method of Shukuya *et al.* (2010) is used.
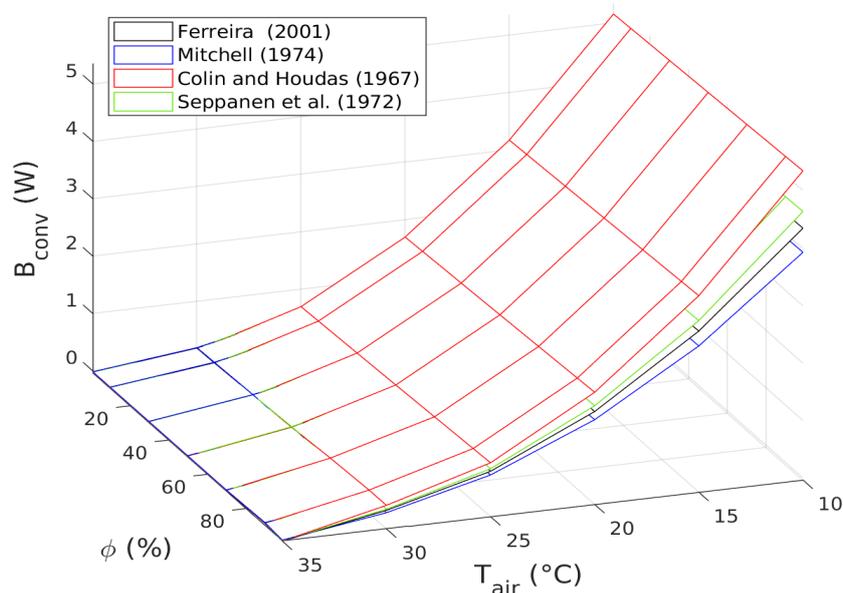

Figure 1: Exergy rate associated with convection using the method of Mady *et al.* (2014).
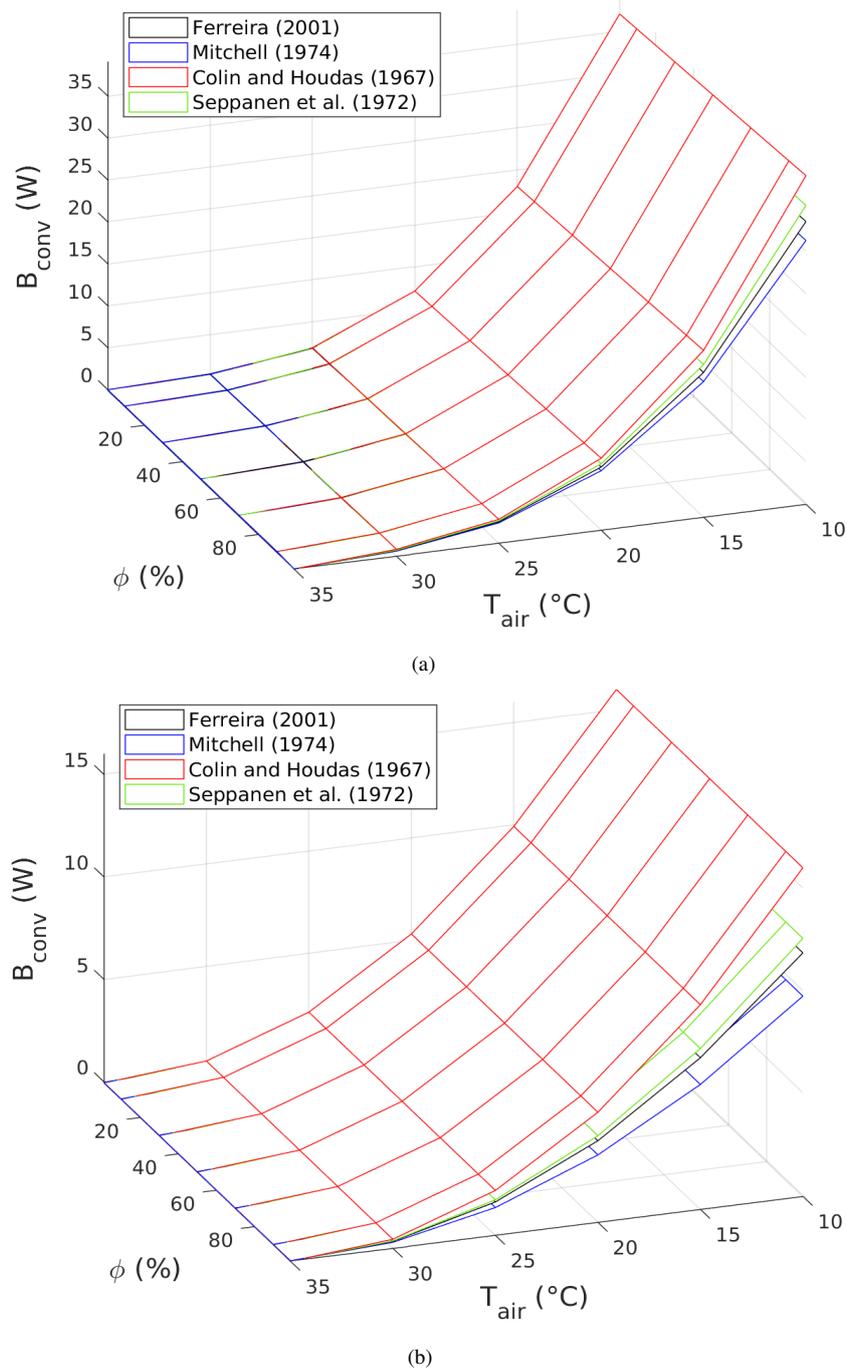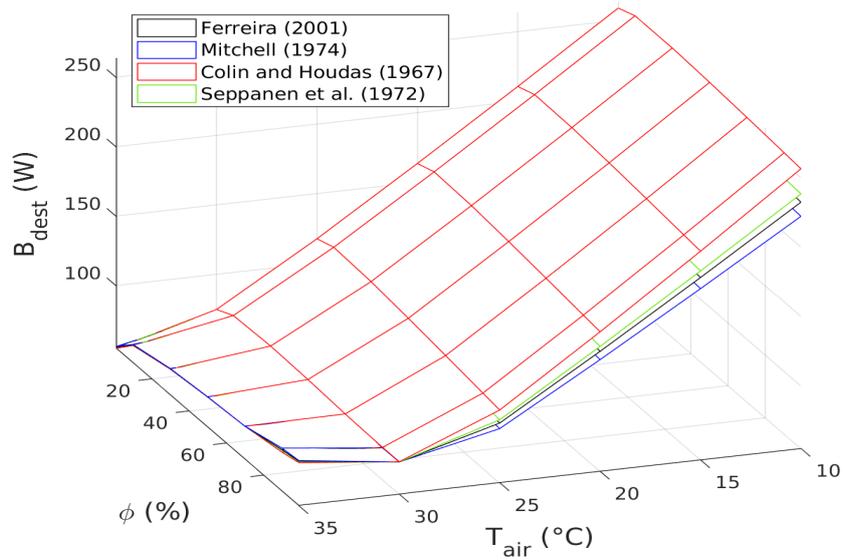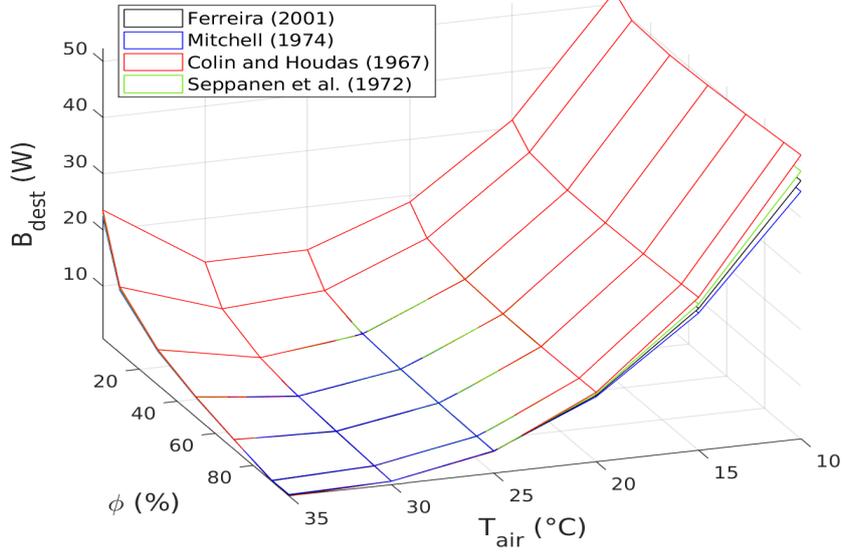
(a)

(b)

Figure 2: Exergy rate associated with convection using methods of: (a) Prek and Butala (2010). (b) Shukuya *et al.* (2010).

It is observed that, for all the methods of exergy analysis used, the trend of the curve is the same. The higher value of exergy associated with convection is obtained when the correlation of Colin and Houdas (1967) is used, followed by Seppanen *et al.* (1972), constant values used in Ferreira (2001) and Mitchell (1974), respectively. Also, almost no difference among the correlations was found for higher temperatures. This occurs because, for higher temperatures, the temperature difference between then skin and the environment is reduced, thus, as the exergy is related to the temperature difference, it is also reduced. Then, as the temperature decreases some difference is observed. For Mady *et al.* (2014) and Shukuya *et al.* (2010) exergy analysis methods, the difference between the correlations begin to be observed for temperatures between 25 and 30 °C. Yet, for Prek and Butala (2010) method, the difference begins for temperature between 20 to 25 °C. This suggests that Prek and Butala (2010) method is more sensitive to changes in the convective heat transfer coefficient, which intrinsically reflects changes at human body position.
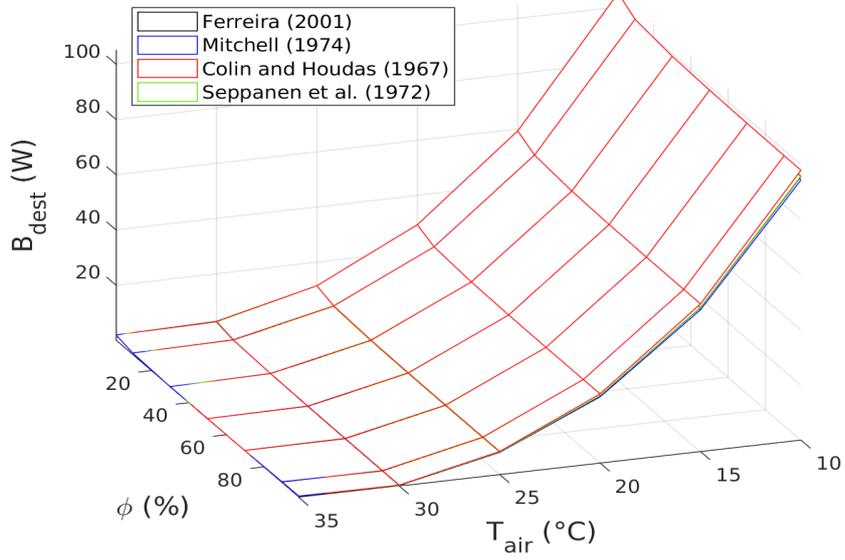
Still, in the scenario of stationary air, the destroyed exergy rate was calculated for each exergy analysis method and is shown in Fig. 3 from (a) to (c).

Figure 3: Destroyed exergy rate using the methods of: (a) Mady *et al.* (2014). (b) Prek and Butala (2010). (c) Shukuya *et al.* (2010).

The same trend obeserved in Fig. 1 and Fig. 2 was observed at the evaluation of destroyed exergy rate, i.e. higher values were obtained when the correlation of Colin and Houdas (1967) was used and lower values when Mitchell (1974) correlation was used. For Mady *et al.* (2014) method, the influence of the convective heat transfer on destroyed exergy rate begins to be noted at a temperature around 30 °C and becomes more noticeable as the temperature gets lower. For Prek and Butala (2010) method, the influence of this parameter is observed for temperatures lower than 20 °C and for Shukuya *et al.* (2010) method the difference among the different correlations is almost none for all the range of temperature analyzed by this study. This indicates that in this latter exergy analysis method the convection does not play an important part in the destroyed exergy rate evaluation.

The second part of this study focused on the influence of air velocity variation in the same variables previously shown: exergy associated with convection and destroyed exergy rate. However, the case at which constant values of convective heat transfer coefficient was used in Ferreira thermal model is not shown given that it does not change with air velocity. Instead, an additional correlation is now shown, Nishi and Gagge (1970) correlation. In addition, for this part of the analysis, air relative humidity is fixed in 50 %.

It is also important to note that the correlations of Colin and Houdas (1967), Nishi and Gagge (1970) and Seppanen *et al.* (1972) are being used for this air velocity interval in an extrapolated form, since the upper air velocity limit at which the correlations are valid are in reality 2.0 m/s for the correlation of Nishi and Gagge (1970) and 1.5 m/s for correlations of Colin and Houdas (1967) and Seppanen *et al.* (1972). Figure 4, 5 and 6 displays the exergy associated with convection for all three methods of exergy analysis.
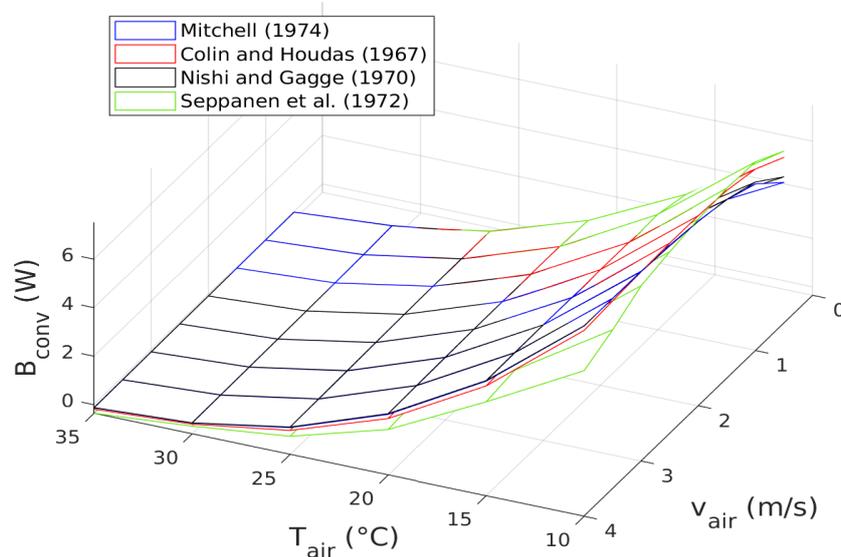

Figure 4: Exergy rate associated with convection using methods of Mady *et al.* (2014)
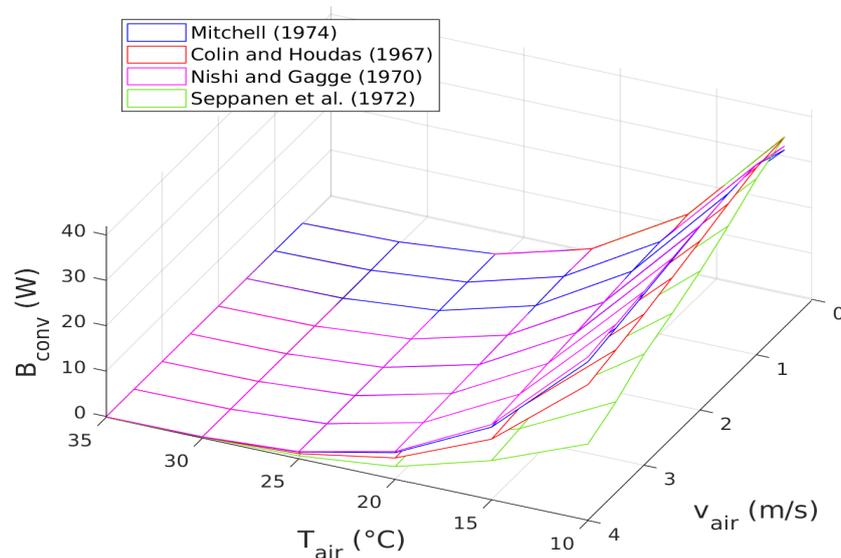

Figure 5: Exergy rate associated with convection using methods of Prek and Butala (2010)
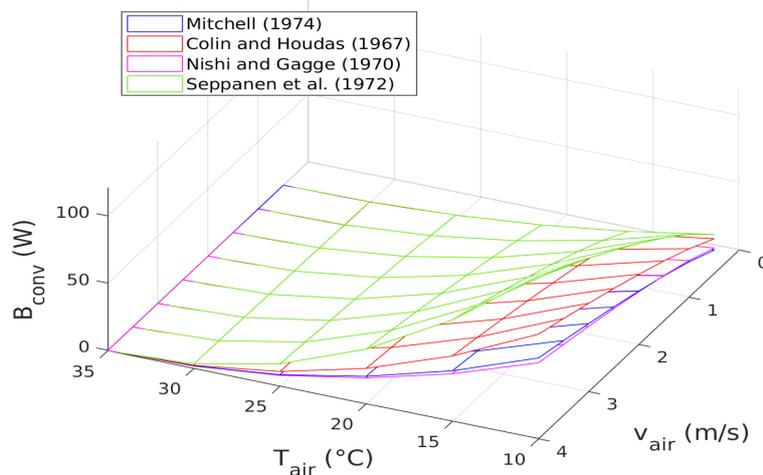
Figure 6: Exergy rate associated with convection using methods of Shukuya *et al.* (2010)

Observing Fig. 4 to Fig. 6, no similarity was found between the exergy analysis methods. Focusing on Fig.4, it is noted that when the exergy analysis method of Mady *et al.* (2014) is used even though some of the correlations were not developed for high air velocity values, there is a good agreement between the values of the exergy rate associated to the convection for velocity higher than 2.5 m/s for three of the correlations analyzed. Only the correlation of Seppanen *et al.* (1972) presents values with a significant difference. The largest difference between these values was found in the temperature of 10 °C and velocity of 4 m/s, when the correlation of Mitchell (1974) presents an exergy value of 7.5 W, whereas the correlation of Seppanen *et al.* (1972) presents 5.6 W. In general, for the interval of air velocity between 0.5 and 1.5 m/s, at which the application of all the correlations is recommended, it is verified that the increase of air velocity causes an increase in the convection exergy term. This agrees with what is pointed out in studies of Hardy *et al.* (1938).

Figure 5 shows that, in general, when the method of exergy analysis of Prek and Butala (2010) is used, the correlations for the convective coefficient calculation of Mitchell (1974) and Nishi and Gagge (1970) result in similar values of exergy rate associated to convection within the analyzed interval. As observed when the method of Mady *et al.* (2014) was used, the correlation of Seppanen *et al.* (1972) resulted in values slightly out of the trend. For the correlation of Mitchell (1974), Colin and Houdas (1967) and Nishi and Gagge (1970) it is observed that at an air velocity of about 1 m/s a behavioral change occurs. Between 0.5 and 1 m/s, the exergy rate associated with convection is higher when the convective heat transfer coefficient is calculated with the correlation of Colin and Houdas (1967), Nishi and Gagge (1970) and Mitchell (1974) respectively. However, this trend reverses to the rest of the velocity values within the analyzed range.

From Figure 6 it is noted that when using the exergy analysis method of Shukuya *et al.* (2010) a good agreement is observed between the exergy associated with convection calculated using the correlations of Mitchell (1974) and Nishi and Gagge (1970), which are valid for seated and reclined individuals respectively. An interesting trend observed exceptionally in this exergy analysis is that the values of exergy associated with convection are higher when the correlation of Seppanen *et al.* (1972), whereas in the other methods this correlation presented in general lower values.

Figure 7 and Figure 8 shows the destroyed exergy rate for all three methods of exergy analysis in the scenario of different air velocities.
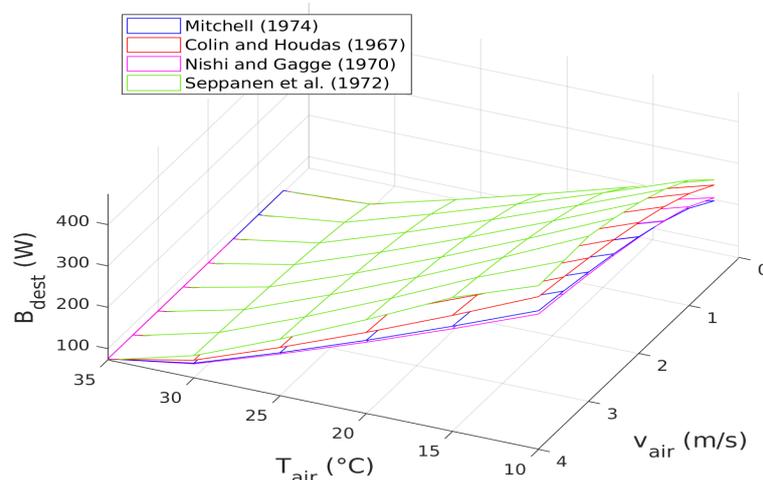

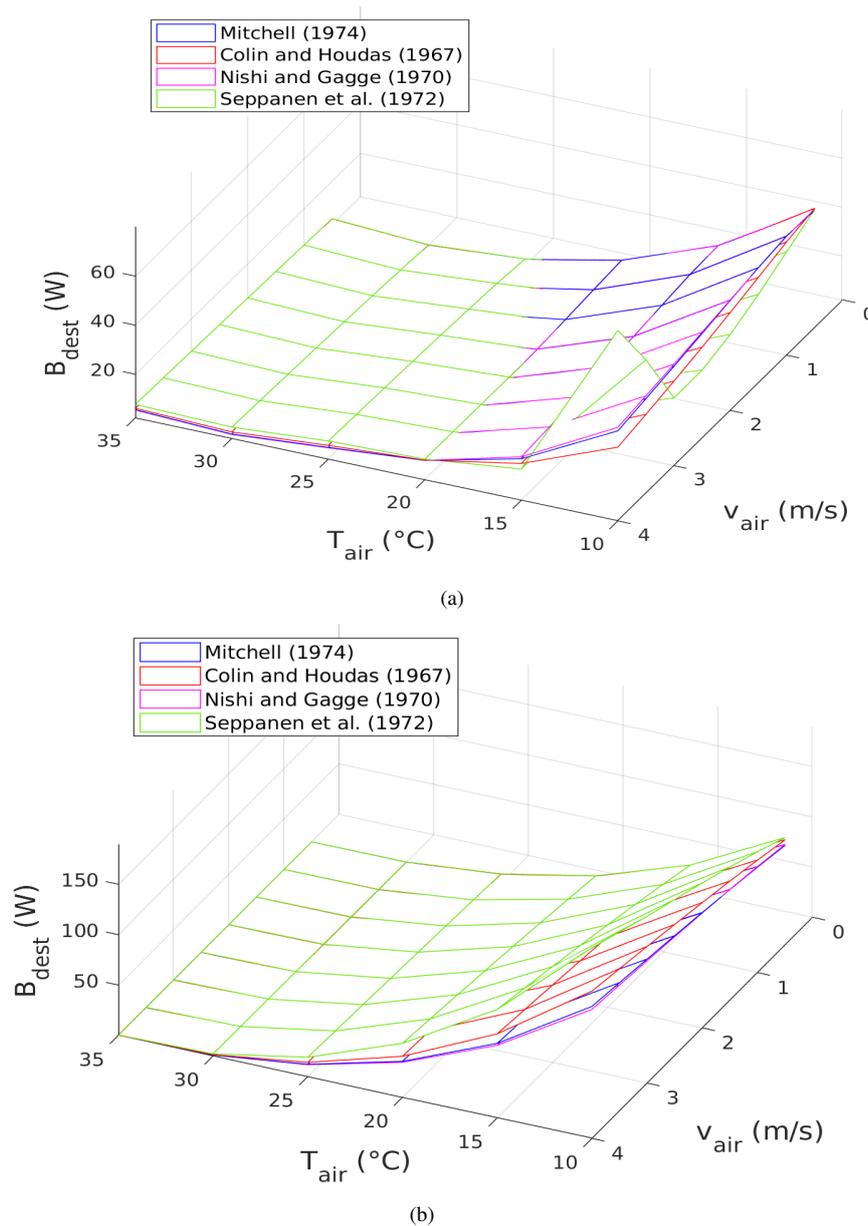Figure 7: Destroyed exergy rate using the method of Mady *et al.* (2014)

(a)

(b)

Figure 8: Destroyed exergy rate using the methods of: (a) Prek and Butala (2010). (b) Shukuya *et al.* (2010).

As well as observed in the previous analysis, for the exergy analysis method of Mady *et al.* (2014) a good agreement is found in the destroyed exergy rate between the cases at which the correlation of Mitchell (1974) and Nishi and Gagge (1970) are used, as presented on Fig. 7. The highest value of destroyed exergy rate is obtained when the correlation of Seppanen *et al.* (1972) is used. Besides, this correlation is more sensitive to velocity changes, followed by Colin and Houdas (1967), Nishi and Gagge (1970) and Mitchell (1974) correlations. For example, it is observed that when air velocity changes from 0.5 to 1.5 m/s an increase of 29% in the destroyed exergy rate occurs when using the correlation of Seppanen *et al.* (1972), while an increase of 20% is observed for Colin and Houdas (1967) and 13% is observed for both Nishi and Gagge (1970) and Mitchell (1974) correlations.

From Fig. 8 (a) it can be observed that, when the exergy analysis method Prek and Butala (2010) is used, the difference between the destroyed exergy rate obtained using all correlations increases as air velocity increases. Also, a good agreement between the correlations of Mitchell (1974) and Nishi and Gagge (1970) is observed. Moreover, points of very different destroyed exergy rate were obtained for temperature lower than 15 °C and air velocity higher than 3.5 m/s when the correlation of Seppanen *et al.* (1972) is used. However, these velocities are out of range recommended by American Society of Heating and Engineers (2005), thus it can be disregarded.

Lastly, from Fig. 8 (b) it is noted that, in the scenario at which the exergy analysis method of Shukuya *et al.* (2010) is used, besides the good agreement found between the destroyed exergy rate calculated using the correlation of Mitchell (1974) and Nishi and Gagge (1970), the curve of destroyed exergy rate follows the same trend observed in the evaluation of exergy associated with the convection process, whereas for the other two methods both curves presents completely

different behavior. Also, it can be inferred that air velocity impacts more the destroyed exergy rate when this method is used for the case at which Seppanen *et al.* (1972) correlation is used, followed by Colin and Houdas (1967), Nishi and Gagge (1970) and Mitchell (1974), respectively. For example, it is observed that when air velocity changes from 0.5 to 1.5 m/s an increase of 24% in the destroyed exergy rate occurs when using the correlation of Seppanen *et al.* (1972), while an increase of 13% is observed for Colin and Houdas (1967) and 10% is observed for both Nishi and Gagge (1970) and Mitchell (1974) correlations.

4. CONCLUDING REMARKS

In this study four correlations which are used to calculate convective transfer coefficient were applied to three different exergy analysis method in order to assess its influence on the exergy associated with convection and on the destroyed exergy rate. In addition, the influence of air velocity in the exergy analysis is also approached in this study.

From the first section of this study it was found that, for all three methods of exergy analysis, higher value of exergy associated with convection is obtained when the correlation of Colin and Houdas (1967) is used, followed by Seppanen *et al.* (1972), constant values used in Ferreira (2001) and Mitchell (1974), respectively. Also, almost no difference among the correlations was found for higher temperatures. The same trend was observed in the destroyed exergy rate, i.e. higher values were obtained when the correlation of Colin and Houdas (1967) was used and lower values when Mitchell (1974) was used. In the destroyed exergy rate evaluation, Shukuya *et al.* (2010) method differs from the other exergy analysis methods because the difference among the different correlations are almost none for all the range of temperature analyzed by this study. This indicates that convection does not play an important part in the destroyed exergy rate evaluation.

From the second part of this study, it was observed that no similarities were found between the methods of exergy analysis regarding the influence of air velocity on the evaluation of the variables forementioned. For the exergy analysis methods of Mady *et al.* (2014) and Shukuya *et al.* (2010) is was noted that for air velocity between 0.5 and 1.5 m/s the increase of air velocity causes an increase in the convection exergy term. This is in agreement with what is pointed out in studies of Hardy *et al.* (1938).

Also, an interesting trend observed in Shukuya *et al.* (2010) exergy analysis method: the values of exergy associated with convection are higher when the correlation of Seppanen *et al.* (1972) is used, whereas in the other methods this correlation resulted in lower values in general. Now, focusing on the destroyed exergy rate, it was noted a good agreement between the cases at which the correlations of Mitchell (1974) and Nishi and Gagge (1970) are used to evaluate the convective heat transfer for all three methods of exergy analysis. For the methods of Mady *et al.* (2014) and Shukuya *et al.* (2010), higher values of destroyed exergy rates were obtained using the correlation of Seppanen *et al.* (1972), while when using Prek and Butala (2010) this is true only for temperatures higher than 20 °C. Also, the results point out that the correlation of Seppanen *et al.* (1972) is more sensitive to changes in air velocity.

5. ACKNOWLEDGEMENTS

6. REFERENCES

American Society of Heating, R. and Engineers, A.C., 2005. *2005 ASHRAE Handbook: Fundamentals*. ASHRAE Handbook Fundamentals Systems-International Metric System. ASHRAE.

Batato, M., Borel, L., Deriaz, O. and Jequier, E., 1990. "Analyse exergétique théorique et expérimentale du corps humain". *Entropie: énergétique et dynamique des systèmes complexes : la revue internationale des sciences et techniques enénergétique, génie chimique, génie biologique*, Vol. 153/154, p. 1.

Colin, J. and Houdas, Y., 1967. "Experimental determination of coefficient of heat exchanges by convection of human body." *Journal of Applied Physiology*, Vol. 22, No. 1, pp. 31–38.

Ferreira, M. and Yanagihara, J., 2009. "A transient three-dimensional heat transfer model of the human body". Vol. 36, pp. 718–724.

Ferreira, M., 2001. *Um modelo do sistema térmico do corpo humano*. Ph.D. thesis, Escola Politécnica da Universidade de São Paulo.

Gagge, A., Fobelets, A. and Berglund, L., 1986. *A standard predictive index of human response to the thermal environment*, Vol. 92:2B.

Hardy, J.D. and DuBois, E.F., 1938a. "Basal metabolism, radiation, convection and vaporization at temperatures of 22 to 35°c." *Journal of Nutrition*, Vol. 15, pp. 477–497.

Hardy, J.D. and DuBois, E.F., 1938b. "The technic of measuring radiation and convection." *Journal of Nutrition*, Vol. 15, pp. 461–475.

Hardy, J.D., Milhorat, A.T. and DuBois, E.F., 1938. "The effect of forced air currents and clothing on radiation and

convection.” *Journal of Nutrition*, Vol. 15, pp. 583–505.

Kurazumi, Y., Rezgals, L. and Melikov, A.K., 2014. “Convective heat transfer coefficients of the human body under forced convection from ceiling”. *Journal of Ergonomics*, Vol. 4, No. 1.

Mady, C.E.K., Ferreira, M.S., Yanagihara, J.I. and de Oliveira, S., 2014. “Human body exergy analysis and the assessment of thermal comfort conditions”. *International Journal of Heat and Mass Transfer*, Vol. 77, pp. 577–584.

Mitchell, D., 1974. “4 - convective heat transfer from man and other animals”. In J. Monteith and L. Mount, eds., *Heat Loss from Animals and Man*, Butterworth-Heinemann, pp. 59 – 76.

Nishi, Y. and Gagge, A.P., 1970. “Direct evaluation of convective heat transfer coefficient by naphthalene sublimation”. *Journal of Applied Physiology*, Vol. 29, No. 6, pp. 830–838.

Prek, M. and Butala, V., 2010. “Principles of exergy analysis of human heat and mass exchange with the indoor environment”. Vol. 53, pp. 5806–5814.

Ribeiro, T.J.S. and Mady, C.E.K., 2017. “A first comparison of different exergy analysis applied to the human body to assess thermal comfort conditions”. In *Procceedings of the 24th ABCM International Congress of Mechanical Engineering - COBEM 2017*. Curitiba, Brazil.

Seppanen, O., Mcnall, P.E., Munson, D.M. and Sprague, C.H., 1972. “Thermal insulating values for typical indoor clothing ensembles”. In *ASHRAE Transactions, Volume 78, Part 1, New Orleans, LA*. New Orleans, USA.

Shukuya, M., Saito, M., Isawa, K., Iwamatsu, T. and Asada, H., 2010. “Human-body exergy balance and thermal comfort”. *Working Repoprt of IEA ECBS Annex*, Vol. 49.

Wu, X., Zhao, J., Olesen, B. and Fang, L., 2013. “A novel human body exergy consumption formula to determine indoor thermal conditions for optimal human performance in office buildings”. Vol. 56, pp. 48 – 55.

Zhou, Z., Chen, H., Deng, Q. and Mochida, A., 2013. “A field study of thermal comfort in outdoor and semi-outdoor environments in a humid subtropical climate city”. *Journal of Asian Architecture and Building Engineering*, Vol. 12, pp. 73–79. doi:10.3130/jaabe.12.73.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.